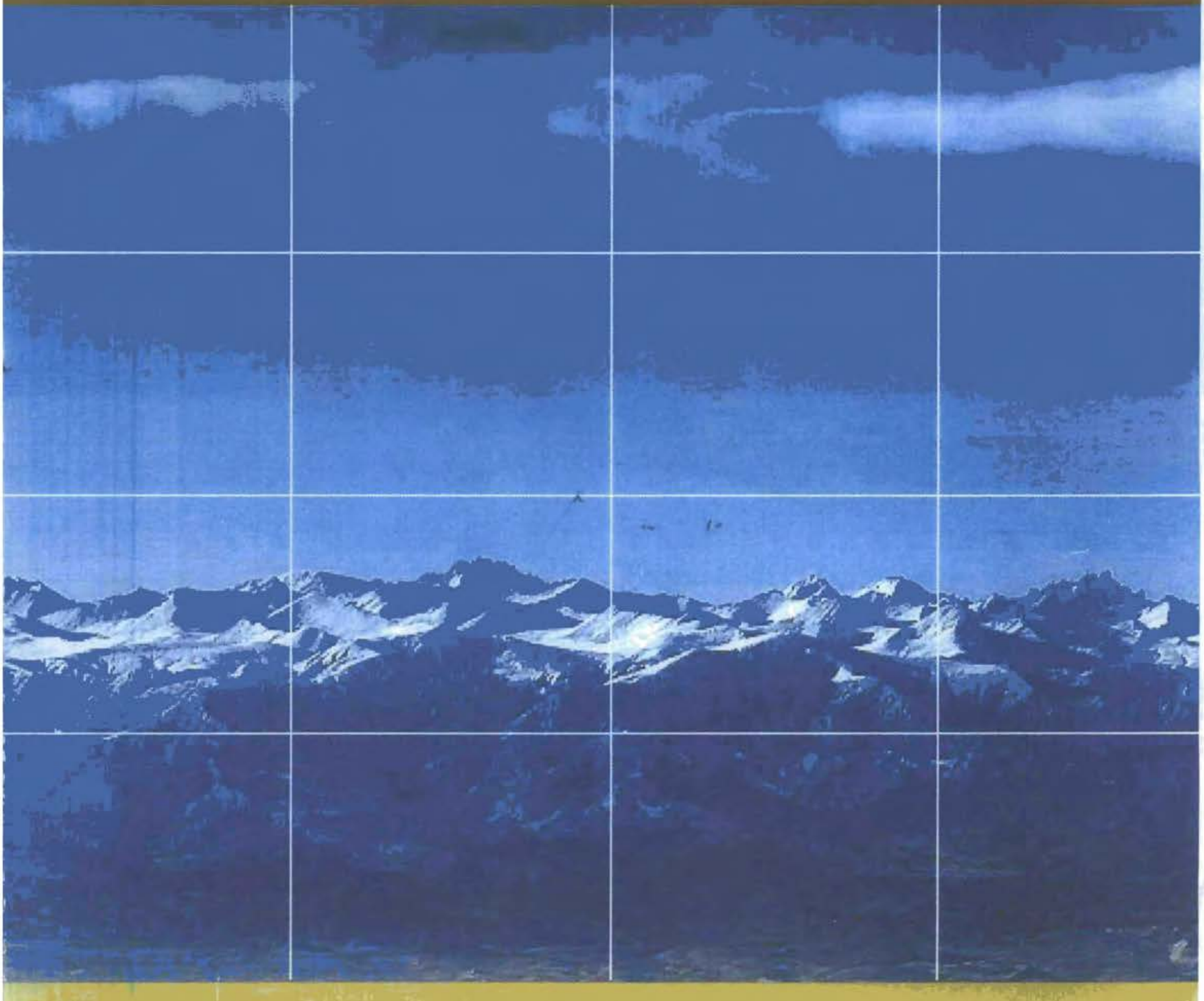
Montreal Protocol on Substances that Deplete the Ozone Layer



2006 Report of the Methyl Bromide Technical Options Committee (MBTOC)

2006 Assessment

United Nations Environment Programme

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MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

2006 REPORT OF THE METHYL BROMIDE TECHNICAL OPTIONS COMMITTEE

2006 Assessment

Montreal Protocol on Substances that Deplete the Ozone Layer

United Nations Environment Programme (UNEP)
2006 Report of the Methyl Bromide Technical Options Committee

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TECHNICAL OPTIONS COMMITTEE

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Glossary of Acronyms

1,3-D	1,3-dichloropropene
CUE	Critical Use Exemption
CUN	Critical Use Nomination
EC	European Commission
EPA	Environmental Protection Agency
EPPO	European Plant Protection Organisation
IPM	Integrated Pest Management
LPBF	Low Permeability Barrier Film
MB	Methyl bromide
MBTOC	Methyl Bromide Technical Options Committee
MITC	Methyl isothiocyanate
MOP	Meeting of the Parties
MS	Metham sodium
Pic	Chloropicrin
QPS	Quarantine and Pre-shipment
SF	Sulfuryl fluoride
TEAP	Technology and Economics Assessment Panel
US	United States of America
VIF	Virtually Impermeable Film

Chapter

1

Executive Summary

The Methyl Bromide Technical Options Committee

The Methyl Bromide Technical Options Committee (MBTOC) was established by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to methyl bromide (MB). This Committee, in particular, addresses the technical feasibility of chemical and non-chemical alternatives for the current uses of MB, apart from its use as a chemical feedstock.

MBTOC reports to the Technology and Economic Assessment Panel (TEAP), which advises the Parties on scientific, technical and economic matters related to the control of ozone depleting substances and their alternatives. MBTOC members have expertise in the uses of MB and its alternatives. At December 2006 MBTOC had 39 members; 14 (36%) from developing and 25 (64%) from developed countries and coming from 10 Article 5 and 12 non-Article 5 countries.

Mandate and Report Structure

Under Decision XV/53(2) taken at the Fifteenth Meeting of the Parties to the Protocol in 2003, the Parties requested the Assessment Panels to update their 2002 reports in 2006 and submit them to the Secretariat by 31 December 2006 for consideration by the Open-ended Working Group and by the Nineteenth Meeting of the Parties to the Montreal Protocol, in 2007.

This MBTOC 2006 Assessment reports on advances since 2002 in the technical and economic feasibility of alternatives to replace methyl bromide and, in particular, on commercial adoption of alternatives and potential alternative treatments to MB as a soil fumigant and as a fumigant of durable commodities and structures; and approved and potential alternatives for quarantine and pre-shipment (QPS) treatments, including treatments for perishables. It also shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of MB to the atmosphere, and strategies to reduce those emissions.

In addition, the report describes critical uses of MB that have been approved by the Parties for 2005 onwards and on economic issues influencing MB phase-out.

Information is provided on results of alternatives implemented in Article 5 countries through investment projects, sustainability of alternatives, constraints to adoption and other topics relating to MB phase-out in Article 5 countries.

General Features of Methyl Bromide

MB is a fumigant that has been used commercially for more than 60 years to control pests. Targets have included various fungi, bacteria, soil-borne viruses, insects, mites, nematodes and rodents. It also has sufficient toxicity to manage many weeds and seeds in soils. MB is used mostly for soil fumigation; a lesser amount is used for disinfestation of food processing buildings, durable commodities and other miscellaneous uses. MB also has well-established uses for quarantine and pre-shipment treatment of a diverse range of pests and diseases on many commodities in trade, including timber, wooden packaging and some perishables (fruit and vegetables).

MB has features that make it a versatile material with a wide range of potential applications. In particular, it is a gas that is quite penetrative and usually effective over a broad range of temperatures. Its action is usually sufficiently fast and it airs rapidly enough from treated systems to cause relatively little disruption to commerce or crop production.

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Control schedules leading to phase-out were agreed in 1995 and 1997. There are a number of concerns apart from ozone depletion that have also led countries to impose severe restrictions on MB use. These concerns include residues in food, toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and its derived bromide ion are also concerns.

Methyl Bromide Control Measures

The control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, were for phase out by 1 January 2005 in non-Article 5 countries and for Parties operating under Article 5 of the Protocol (developing countries) a 20% cut in production and consumption, based on the average in 1995-98, from 1 January 2005 and phase out by 1 January 2015.

The Protocol provides exemptions under Article 2H for the amounts of MB used for QPS purposes and for those uses deemed to meet the criteria for 'critical uses' for non-QPS purposes. The Parties may seek the latter after the scheduled phaseout date, either 2005 for non-Article 5 countries or 2015 for Article 5 countries

Production and Consumption Trends

Information relating to production and consumption of MB was compiled primarily from the database on ODS consumption and production of the Ozone Secretariat as available at the end of November 2006, including data from Accounting Framework Reports. Some countries have revised or corrected their historical consumption data at certain times, and in consequence official figures and baselines have changed. At the time of writing this report, almost all Parties had submitted data for 2005, and the database on MB consumption is much more complete than in the past. In the few cases where data gaps exist, data from the previous year were assumed to apply to MB production or consumption. All tonnages are given in metric tonnes in this report.

In 2005, global production for the MB uses controlled under the Protocol was about 18,140 metric tonnes, which represented 27% of the 1991 reported production data (66,430 tonnes). More than 90% of production occurs in non-Article 5 countries. MB production in Article 5 countries for controlled uses peaked in 2000 at 2,397 tonnes, falling to 39% of the baseline, 538 metric tonnes, in 2005 (aggregate baseline for all Article 5 regions is 1,375 tonnes, i.e. average of 1995-98 production). At least one Article 5 Party and two non-Article 5 Parties have recently ceased production.

Global consumption of MB for controlled uses was reported to be about 64,420 metric tonnes in 1991 and remained above 60,000 tonnes until 1998. Global consumption was estimated at 45,520 tonnes in 2000, falling to about 20,752 tonnes in 2005. The reduction in consumption of MB for soil fumigation has been the major contributor to the overall reduction in global consumption of MB because many non-Article 5 countries have achieved phase-out or substantial reductions in most sectors.

Historically in non-Article 5 regions about 91% of MB was used for pre-plant and about 9% for stored products and structures. The official aggregate baseline for non-Article 5 countries was about 56,083 tonnes in 1991. By 2003, this consumption had been reduced to about 14,504 tonnes, representing 26% of the baseline. The Meetings of the Parties approved CUEs totalling 16,050 tonnes for 2005, but at national level less than 13,808 tonnes was authorised. In 2005, MB consumption (production + imports) was reduced to about 11,468 tonnes in non-Article 5 Parties for critical use exemptions, accounting for about 20% of the total non-Article 5 baseline. The Meetings of the Parties have granted CUEs of 13,418 tonnes for 2006 and 9,161 tonnes for 2007, although lower quantities have been authorised at national level. The MOP has to date approved 5,884 tonnes in the first round for 2008 (about 3 additional Parties are expected to request CUEs in the second round for 2008).

The Article 5 consumption aggregate baseline is about 15,680 tonnes (average of 1995-98), with peak consumption of more than 18,100 tonnes in 1998. Recently, total Article 5 consumption was reduced from 75% of the baseline in 2003 to 67% of baseline in 2004 (about 10,520 tonnes) and 59% of the baseline in 2005 (about 9,285 tonnes). A MBTOC survey of ozone offices and national experts in 2006 provided information on the breakdown of MB uses in major MB-consuming countries. In 2005, an estimated 87% was used for soil and 13% for commodities/structures, not including QPS in Article 5 regions.

Consumption trends at national level

In 1991 the USA, European Community and Japan used more than 90% of the MB consumed in non-Article 5 countries. In 2005 the MB consumption (for CUEs) in these three Parties was 28%, 12% and 10% of their respective baselines In 2007 the approved or licensed consumption for CUEs was reduced to 17%, 3% and 10% of the respective baselines.

Most Article 5 parties achieved the national freeze level in 2002. Of 144 Article 5 (1) countries that are Parties to the Montreal Protocol, only 11 did not achieve compliance with the freeze target, and together needed to phase out a total of 440 tonnes. In 2005, 94% of Article 5 parties (136 out of 144) achieved the 20% reduction step by the required date; and in many cases they achieved this several years earlier than required by the Protocol. Only 8 Parties did not comply with the 20% reduction step in 2005; they needed to phase out a combined total of about 740 tonnes to get back into compliance. Over 80% of Article 5 parties (115 of 144 parties) reduced their national MB consumption to less than 50% of national baseline in 2005. 88% of Article 5 parties (127 parties) reported national MB consumption between zero and 16.6 tonnes (10 ODP-tonnes) in 2005. 67% of Article 5 parties (96 parties) reported zero MB consumption in 2005.

Alternatives to Methyl Bromide

Definition of an alternative

Following the guidance provided in Annex 1 of 16 MOP report, MBTOC defines 'alternatives' as any practices or treatments that can be used in place of methyl bromide. 'Existing alternatives' are those alternatives in present or past use in some regions. 'Potential alternatives' are those in the process of investigation or development.
MBTOC assumed that an alternative demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex.

Additionally, it was recognised that regulatory requirements, or other specific constraints may make an alternative unavailable in a specific country or region. When evaluating CUNs, MBTOC takes account of the specific circumstances. Decision IX/6 1(a)(ii) refers to alternatives that are 'acceptable from the standpoint of environment and health'. MBTOC has consistently interpreted this to mean alternatives that are registered or allowed by the relevant regulatory authorities in individual CUN regions.

Areas where MBTOC did not identify alternatives

MBTOC was able to identify alternatives for about 95% of controlled uses in 2005; situations where no alternatives have been identified amount to about 1,200 tonnes of MB. However these figures may be influenced by local regulatory restrictions on the alternatives for the remaining uses. Technically effective alternatives have not yet been identified by MBTOC for the following controlled uses of MB:

- For pre-plant uses: ginseng replant, elimination of broomrape and certain nursery plants and orchard replant situations in some situations
- For post-harvest: stabilization of high-moisture fresh dates, fresh market chestnuts, cheese in storage, immovable museum artefacts (especially when attacked by fungi) and cured pork products in storage.

At this time, technically feasible alternatives have also been identified for many QPS applications, but there are many, diverse QPS uses where such alternatives are not at present available.

Further research or development, including refinement and extension of existing techniques is needed to address these areas.

Availability and registration of alternatives

MBTOC considers that technical alternatives exist for almost all remaining controlled uses of MB (including those seeking critical use exemptions). Regulatory or economic barriers exist that limit the implementation of several key alternatives and this is affecting the ability to completely phaseout methyl bromide in several non-Article 5 countries.

Of the total of about 13,800 tonnes authorised or licensed for Critical Use Exemptions in 2005, MBTOC considers that technical alternatives are more difficult to adopt in certain pre-plant sectors (i.e. certain types of strawberry nurseries, some orchard replant industries and control of branched broomrape in certain locations) representing about 1136 tonnes of MB use. MBTOC recognises that economic constraints, regulatory issues and the period of time to uptake alternatives affect the rate of phase out for these remaining uses.

Impact of Registration on Availability of Alternatives

Significant effort has been undertaken by many Parties to transfer, register and implement alternatives and to optimise their use. While an alternative may be technically appropriate as an MB replacement for a given situation, it may not be available in practice. Lack of registration may still be a constraint in some countries, affecting the availability of certain types of alternatives. In many countries, any product or sometimes even a process, which claims to kill pests, must be registered. Overall, the registration and approval process is often costly and protracted, with the outcome uncertain from the point of view of the potential registrants. In addition, the market size for a particular MB application may be too small to justify the commercial risk and investment involved.

Additional registration issues arise where treatments will be used on food commodities or where treatments used in food processing buildings might transfer residues to food because the residues must also be registered in importing countries. However, some countries have registered some alternatives in recent years and some large MB-volume consuming countries are in the process of registering additional alternatives and/or publishing maximum residue levels for the residues of some alternatives in foods.

It should be noted that chemical fumigant alternatives in general, like MB, have issues related to their long-term suitability for use. In both the EC and US, MB and most other fumigants are involved in a rigorous review that could affect future regulations over their use. MBTOC has been informed that the US government has received a petition to stay (i.e. remove regulatory approval) the pesticide tolerances for Sulfuryl fluoride (SF). Sulfuryl fluoride is a recently approved, methyl bromide alternative for several post-harvest applications. A stay or other action that removes the pesticide tolerance for SF would increase significantly pressure to revert to MB in structural and commodity fumigation.

Thus, consideration of the long-term sustainability of treatments adopted as alternatives to MB is most important; both chemical and non-chemical alternatives should be adopted for the short to medium term, developing sustainable IPM or non-chemical approaches for the longer term.

Critical use exemptions

Under Article 2H of the Montreal Protocol the production and consumption of methyl bromide was scheduled to be phased out in Parties not operating under Article 5 of the Protocol, by 1 January 2005, except for QPS and feedstock uses. However, the Parties agreed to a provision enabling further temporary exemptions for those uses of methyl bromide that qualify as 'critical'. Decision IX/6 of the Protocol lays down the criteria that such uses need to meet in order to be granted an exemption. The procedures for applying for and evaluating CUEs are described in the Handbook of Critical Use

Exemptions and in the TEAP Reports on Critical Use Nominations.
This Assessment Report analyses the sectors or categories still exempted as CUEs in non-Article 5 countries, constraints to adoption of alternatives in these categories and areas where future efforts might be concentrated in order to achieve total phase-out of MB.

Alternatives for Soil Treatments

The reduction in consumption of MB for soil fumigation has been the major contributor to the overall reduction in global consumption of MB with amounts used falling 85% from about 57,400 tonnes in 1992 to approximately 21,790 tonnes in 2005, 13,776 in non-Article 5 regions and about 8,014 in Article 5. Authorised or licensed soil uses in non-Article 5 countries fell to approximately 7,750 tonnes in 2007.

Since the 2002 MBTOC Report, clearer trends have developed in the adoption of alternatives to replace MB as a pre-plant soil fumigant. These include alternatives that either provide broad-spectrum control of pests, diseases and weeds (e.g. chemicals and their combinations, steam and solarisation) or cultural practices including the use of soilless substrates, resistant varieties and grafting which avoid the need for MB.

The main crops for which MB is still being used in some non-Article 5 countries are; cucurbits (melons and cucumbers), peppers, eggplants, tomatoes, perennial fruit and vine crops (particularly replant), strawberry fruit and nurseries for the production of propagation material for forests, and strawberries and ornamentals (cut flowers and bulbs). Remaining usage of MB in Article 5 countries follows very similar trends with some additional crops such as bananas, some brassicas and ginseng.

A recent review by MBTOC of over 160 international studies identified a large number of alternatives for strawberry fruit and tomato crops many of which are useful alternatives for other cropping systems.

Many sectors that were formerly heavily reliant on MB have adopted alternatives and as a result the use of MB has been substantially reduced or eliminated. The major adopted MB alternatives include:

- Fumigants and other chemical pesticides applied alone or as mixtures. 1,3-dichloropropene (1,3-D) and chloropicrin (Pic) (especially as 1,3-D/Pic formulations) are the most common fumigant alternatives adopted, followed by chloropicrin, metham sodium (MNa) and dazomet used alone. Combinations of 1,3-D, Pic, metham and dazomet, with or without Low Permeability Barrier Films

(LPBF) or additional herbicides and fungicides, or other non-chemical alternatives have been shown to be as effective as MB in many research trials and in commercial practice. In some cases additional adaptation is needed to improve application methods at local level.

- Solarisation, alone or combined with biofumigation or low doses of fumigants, has gained wider adoption as a MB alternative in areas with sunny climates and where it suits the cropping season and the pest and disease complex.
- Steaming has been adopted for high value crops grown in protected agriculture e.g. greenhouses, particularly when quick turn around times are required or where fumigant use is impractical.
- Soilless culture is a rapidly expanding cropping practice worldwide, primarily for protected agriculture, which has offset the need for MB, especially in some floricultural crops, vegetables and seedling production. In particular, flotation systems, based on soilless substrates and hydroponics, have replaced the majority of the MB for tobacco seedling production worldwide. The adoption of this technique is currently expanding into vegetable production and some ornamentals.
- Grafting, resistant rootstocks and resistant varieties are commonly used practices to control soilborne diseases in vegetables, particularly tomatoes, cucurbits, peppers and eggplants. They are commonly adopted as part of an integrated pest control system, or combined with an alternative fumigant, and have led to the reduction or complete replacement of MB use.

Potential in-kind alternatives including methyl iodide, sodium azide and cyanogen (also sometimes referred to as ethane dinitrile or EDN), have demonstrated results as effective as MB in research trials in some cropping systems where MB is currently used. Methyl iodide is being used under permit in at least two countries and full registration is pending in these countries.

Formulation changes and more adequate application methods have improved the effectiveness of several alternatives (Pic 1,3-D/Pic, metham and others) and wider adoption has occurred where these improved methods are available. In many instances, the adoption of alternatives has involved a change in cropping practice, i.e. slightly longer plant back times and a greater awareness of soil conditions which improve the efficiency of alternatives. Modification to application machinery, sometimes with economic implications. Some sectors that were formerly heavily reliant on methyl bromide have completely switched to chemical alternatives combined with improved crop rotation practices (e.g. tomato and pepper production).

The combination of chemical and non-chemical control methods has also been recognized as an effective strategy to overcome problems due to the narrow spectrum of activity of some single control methods. Soil solarisation and grafting vegetable crops onto resistant rootstocks for instance has proven to be a valuable non-chemical alternative. Similarly the efficacy of grafted plants can be greatly enhanced by combining it with biofumigation, green manures, and chemicals such as MITC generators, 1,3-D and non- fumigant nematicides. Combinations of fumigant alternatives (1,3-D/Pic, MNa/Pic) with LPBF or relevant herbicides have been shown to be effective for nutsedge (*Cyperus spp.*), which is the key target pest for several CUNs. In the more difficult nursery and replant industries where high levels of disease control are required to meet quality standards (e.g. certification requirements), several alternatives are also showing promise for control of pathogens.

MBTOC estimates that reductions from the 1991 consumption baseline by the end of 2006 in non-Article 5 Parties for soil fumigation will have resulted from the use of alternative fumigants and chemical treatments (60%); transitional strategies (about 15% of the reduction), and use of soilless systems (10%). Other measures, steaming and solarisation, account for less than 5% of the present reduction in use, though they are important as alternatives in some particular situations.

Projects in Article 5 countries have shown that a similar range of alternatives to those in non-Article 5 countries can be successfully adopted. Costs and different resource availability can lead to preference for different alternatives in Article 5 compared to non-Article 5 countries. There are a few specific MB uses in Article 5 countries where research is needed to identify or demonstrate suitable alternatives; these include post harvest stabilisation of high moisture dates.

Crop specific strategies implemented both in non-Article 5 and Article 5 regions are discussed in detail in the 2006 Assessment Report. These include alternatives used for the major crops using MB in specific climates, soil types and locations, as well as combinations of alternatives, application methods and others.

Alternatives for Treatment of Post-Harvest Uses: Food Processing Structures and Durable Commodities (non-QPS)

Food processing structures that currently use methyl bromide include flour mills, bakeries and other food production and storage facilities. These structures are fumigated to control stored product (food) pests. Additionally, historical or museum structures are fumigated to destroy wood boring pests and fungi. Previous structural uses for transport vehicles, where not a QPS application, have been virtually eliminated. These were routinely treated with MB to control stored product or wood destroying insects, rodents and other pests.

Durables are commodities with low moisture content that, in the absence of pest attack, can be safely stored for long periods. The remaining durable commodities fumigated with MB in some non-QPS applications include milled rice, various dried fruits nuts, beans cocoa beans, rice fresh market chestnuts, dry cure ham and cheese in storage houses.

At this time, technically feasible alternatives have been tested and have shown efficacy for almost all durable and structural treatments currently treated with methyl bromide. MBTOC has not identified available and technically effective alternatives for high-moisture fresh dates, fresh market chestnuts against chestnut weevils, cheese in storage against cheese mites, immovable museum artefacts (especially when attacked by fungi), and cured pork products in storage.

There are, however, a number of constraints to the replacement of the remaining MB uses for durables and structures. These include cost differentials versus MB, treatment logistics (availability of appropriate chambers and other factors), market logistics (since phosphine, a principal alternative requires a longer treatment time), regulatory and registration requirements.

For 2005, MBTOC estimated that approximately 33% of the global fumigant usage of MB was for the disinfestation of durable commodities and about 3.9% was used for structures. These estimates included both non-QPS and QPS uses. The proportion of use on durables and structures has risen since 2002, with falling consumption for soils and rising use on wood and.wooden packaging. Presently, based on CUEs granted by the Parties to the Montreal Protocol for use in 2007, approximately 2% of non-QPS MB is used in non-Article 5 countries for the control of pests in durable commodities (182.45 tonnes) and 6.2% in structures (573.61 tonnes). There has been considerable adoption of a wide variety of alternatives by durable commodities sector since 2002. The lower rate of adoption of alternatives for structural uses has been primarily as a result of issues with registration, logistics and efficacy, and cost concerns.

The main alternatives to the disinfestation of flour mills and food processing premises are sulfuryl fluoride (including combinations of SF and heat) and heat (as full site or spot heat treatments). Some pest control operators report that full control of structural pests in some food processing situations can be obtained without full site fumigation through a more vigorous application of IPM approaches. Other pest control operators report success using a combination of heat, phosphine and carbon dioxide. Phosphine fumigation of commodities has expanded.

Sulfuryl fluoride

Sulfuryl fluoride is sufficiently registered in the US to allow virtually all mills and food processing facilities to test, adapt and consider adoption as an alternative to methyl bromide. Additionally, registration coverage for mills in Canada and for numerous milling and food processing applications in EC countries allows adoption on empty structures. The difficulty is that in some cases, emptying a mill to the extent required by regulators for SF fumigations is considered to be unworkable or impracticable with food production logistics. Some EC countries recently allowed the expansion of SF use through publication of maximum residue limits (MRLs) for fluorine residues in food.

Although preparation for fumigation should include the emptying of mill equipment prior to fumigation, the publication of MRLs will decrease difficulty with the definition of 'empty' and will assist adoption of SF by those mills with attached silos. New research testing SF effectiveness for treatment of durable commodities that are currently subject of critical use nominations may further expand its use.

A registrant for SF is working to expand maximum residue levels (MRL) for fluorine and registration to expand the use of sulfuryl fluoride. The use of sulfuryl fluoride for mills and food processing facilities producing foods for export may be affected by upcoming decisions concerning the maximum residue levels for fluorine residues in the foods. More widespread adoption of fluorine MRLs in processed foods may increase adoption, but legal challenges to in the US intended to reduce fluorine levels in foods may reduce adoption.

In many cases, initial efficacy problems have been resolved through additional experience. In other situations, particularly larger mills with complex design and/or mills in cooler climates, a combination process with heat has been used (temperature at or slightly above 26°C). In this method, pest kill efficacy has been very high and fumigant costs have been minimized. This approach requires careful adaptation on an individual mill basis by knowledgeable and experienced fumigators.

Heat treatments

Since 2002, considerable research and commercial phase-in trials of heat treatment in mills and other food processing have taken place. Some food processing facilities through diligent adaptation and investment have been able to achieve reliable pest control by using either full-site or spot heat treatments. Heat treatments must always be combined with IPM since sanitation is critical to the success of heat treatments. Several manufacturers of mobile heat treatment equipment have advanced with systems designed for flour mills and food processing facilities. New equipment has simplified heat treatments, made them more reliable and controllable. Depending on the circumstances, full-site heat treatment may be considerably more costly than fumigations with methyl bromide. However, some corporations prefer the convenience, greater relative safety (compared to fumigants) and environmental sensitivity of full site or spot heat treatments. Costs of heat treatment, length of time required, problems in reliability, especially in larger mills or large horizontal structures and concerns about heat equipment or temperature distribution damaging mill equipment or structure, are given as reasons that limit the use of heat as an MB alternative. To ensure success, heat treatments require as much planning, care in implementation and evaluation as do chemical fumigations.
Heat treatments for commodities are an active development area, and although there is considerable laboratory research data, more work is needed to know how to adapt research to actual treatments of commercial quantities of commodities.

Phosphine

The use of phosphine, which was already in widespread use before phase out, has increased in the treatment of dried commodities and in the treatment of warehouses holding non-food commodities (such as tobacco warehouses). Fast generating forms of phosphine (cylinderized gas, phosphine generators or faster acting formulations), spurred greater use of this fumigant since these forms were more easily controlled and since they reduced fumigation time. The use of these newly marketed forms of an older fumigant has been largely responsible for a considerable reduction in use of methyl bromide for commodities. Yet, in this commodity sector, MB continues to be requested when a fast treatment immediately before marketing is required.

Other Processes

Controlled atmosphere conditions are in commercial use for a wide variety of durable commodities and also for museum artefacts and building components where the conditions can be maintained sufficiently long. Many techniques have been developed to change and hold the atmosphere in numerous product adaptations. Grains and cereals are held in controlled atmospheres in silos, bubbles and bag stacks. Artefacts are treated in bubbles and chambers and under tarps. Commercial service providers use large, versatile chambers. Controlled atmosphere treatment usually requires more time than fumigation, but the lengthy hold times also deter re-infestation.

Vacuum, in flexible enclosures has been further commercialised since MBTOC's last assessment with more testing and availability of the enclosures. Vacuum enclosure is a viable treatment for disinfesting those durable commodities that can withstand the physical pressures created by the vacuum system. The system can be applied to a wide range of situations from small on-farm stores to large storage premises.

Other fumigants

Contact insecticides, in widespread use as grain protectants in some EU countries, are under regulatory pressure and may no longer be available for those uses in the near future. On the other hand, improvements in the techniques used for older volatile compounds may increase their effective use as part of IPM strategies.

Several other fumigants with apparent potential to replace MB in particular circumstances are at various stages of investigation, with registration being sought. Propylene oxide is registered to treat several dried food commodities in the US and new formulas have been released to improve its utility. The US nut processors have gained greater experience with propylene oxide since it was approved for control of bacterial contaminants and that experience may translate into expanded use in the dried fruit and nut category. Carbonyl sulphide and cyanogen are at advanced stages of investigation with registration being sought in Australia. Australia recently registered ethyl formate for dried commodities following research that showed good effectiveness in packaged food protection. It is now being tested for disinfestation of fresh chestnuts in France and Japan.

Alternatives to Methyl bromide for Quarantine and Pre-shipment Applications *(perishables, durable commodities and structures)*

For quarantine and pre-shipment purposes, MB fumigation is currently often a preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities.

Commodities may carry pests and diseases that can be a threat to agriculture, health and the environment. Quarantine pests, detected in a country or region previously free of them, can result in considerable cost caused by restriction of exports, eradication measures and implementation of disinfestation treatments.

Quarantine pests of concern are numerous and include insects, mites, snails, nematodes, vertebrate pests and fungi. Although QPS uses are usually for commodities in trade, recently, some Parties have identified some methyl bromide soils uses as being quarantine uses.

Usually quarantine treatments are only approved on a pest and product specific basis, and following bilateral negotiations. This process helps ensure safety against the incursion of harmful pests, but also often requires years to complete. For this and other reasons, replacing methyl bromide quarantine treatments is expected to be a long term proposition. Many non-MB quarantine treatments are, however, published in quarantine regulations, but they are often not used.

Article 2H exempts MB used for QPS treatments from phaseout. The European Community is one of the few Parties that has placed conditions additional to those under the Protocol on MB consumed for QPS, including a cap on the amount that can be used and further reporting requirements. Japan has mandated application of coloured labels to the cylinders to differentiate MB used for QPS or non-QPS. A survey of QPS use by Parties was carried out in 2004 by a consultant commissioned by the European Community, to provide a basis for response to Decision XI/13(4). Decision XVI/10(4) requested Parties that had not already submitted data to provide best available data on QPS uses and associated quantities. Data from these two sources was integrated to give an overview of QPS. Use of 6,893 tonnes was reported, being about 65% of reported annual QPS consumption (10,601 metric tonnes) in the 2002-2004 period.

Data was not received for 16 of the 70 Parties reporting non-zero consumption of QPS methyl bromide. Five of the 16 Parties with reported annual consumption for QPS purposes exceeding 100 metric tonnes annually did not report use or use details. In several cases, the quantity of methyl bromide reported as used for QPS purposes in a year differed substantially (> +/-30%) from consumption for that year reported to the Ozone Secretariat.

The seven categories with the highest QPS usage cover 96% of the total QPS methyl bromide reported with sufficient detail for analysis. The major use categories were soil (preplant 29%), grains (24%), wood, including sawn timber (16%), fresh fruit and vegetables (14%), wooden packing materials (6.4%), logs (4.0%) and dried foodstuffs (3.0%). The use of QPS methyl bromide for treatment of whole logs and timber appears underrepresented. Independent estimates of the volume of methyl bromide required to treat East Asian and Russian trade in logs suggest that QPS methyl bromide use for this use exceed 4,000 tonnes.

Reported production of methyl bromide for QPS purposes rose from 10,660 tonnes in 2004 to 13,815 tonnes in 2005, with the increase attributable largely to the widespread implementation of the ISPM-15 standard for treatment of wooden packaging materials.

Non-MB QPS treatments

Quarantine treatments are designed, tested and negotiated bilaterally on an individual product and treatment basis. The treatments must both kill pests and maintain product quality, both difficult hurdles. The pest-kill requirement hurdle is set particularly high; generally it must be demonstrated that the treatment kills over 99.9968% of the quarantine pests that might be present. Allowed treatments are found in the quarantine inspection manuals for the importing country, and these are usually available electronically.

For perishables, there are various approved treatments, depending on product and situation, including heat (as dry heat, steam, vapour heat or hot dipping), cold (sometimes combined with modified atmosphere), modified and controlled atmospheres, alternative fumigants, physical removal, chemical dips and irradiation. ISPM-15 standard for wooden packaging material specifies a heat treatment as an alternative to methyl bromide. Some export timber is treated with alternative fumigants and processes to methyl bromide, including phosphine in transit.

Alternatives to methyl bromide for Preshipment treatment of grains and similar commodities are the same as for these commodities in storage, but economic and logistic issues may restrict their use, notably the need for rapid treatment of large volumes of product under conditions at ports where storage and handling capacities may be very limited. Alternative fumigants are under development and registration, which may provide adequate speed of treatment. However, several countries specify use of methyl bromide as the only acceptable QPS treatment of imported grain from specified exporters.

Overall, there are technically effective and approved treatments available for more than half current QPS treatments by volume of methyl bromide consumed, but many individual QPS uses do not have proven, acceptable alternatives at this time. There is scope for minimising emissions from those QPS uses of methyl bromide that lack alternatives through deployment of recapture technology.

Rate of Adoption of Alternatives

Generally, time is required to allow the relevant industry to transition to available effective alternatives once these are identified. Since the critical use process commenced in 2005, most industries show a reduction in nominated quantity requested from that of the preceding year, reflecting progressive adoption of alternatives; while others have the same or similar quantities of MB nominated. Some CUNs show comparatively slow rates of adoption.

When reviewing technical information on alternatives and their commercial adoption by Parties previously using MB in similar sectors to those where CUNs had been sought, it was found that in most instances the adoption rates varied between 10 and 25% per year. This includes Article 5 countries that have adopted alternatives through investment projects, where the rate of adoption is on average between 20 and 25% per year.
Difficulties for MBTOC occurred where in some sectors, even though a number of technical alternatives have been proven worldwide (e.g. tomatoes, some vegetables and strawberry fruit in particular) and many countries have been able to transition to alternatives, either voluntarily or by licensing, several countries have reported slow adoption rates for these sectors.

Analysis of the data indicates that by the end of 2006, 95% reduction of MB use or complete phase out of MB has occurred for tomato crops in Australia, Japan, New Zealand, Portugal, Spain, Greece, Belgium, and the UK; in strawberry fruit in Australia, Belgium, Greece, Japan, Portugal and Spain; and in peppers or eggplants in Australia, Greece, Israel, Japan, Malta, New Zealand, Spain and the UK. Reductions in the range of 35–42% have been made in the US and Israeli strawberry fruit and tomato industries and the US tomato industry since 1998. Israel has found transition more difficult in these sectors mainly because some formulations of alternatives are not registered and restrictions on the use of a key alternative, chloropicrin exist; also because of the occurrence of specific pests (*Verticillium dahliae* race 2, *Orobanche* spp.). Regulatory restrictions in the US have also limited uptake of a leading alternative, 1,3-D.

Many examples of successful phase-out or significant use reduction are available from Article 5 countries e.g. the tobacco sectors in Brazil and Argentina, the flower sector in Costa Rica, Uganda and Kenya, the vegetable and strawberry sectors in Lebanon, the horticulture sector in Morocco, Uruguay and Peru and others.

On the other hand, some countries have not been able to follow the adoption rates achieved in other countries, even if they were able to reduce MB in the years leading to phase-out. In some cases, technical trials have shown that Parties could achieve faster phase out than the Party had indicated was possible.

Progress in Phasing-out MB in Article 5 Countries

Progress in phasing-out MB in Article 5 countries has been achieved mainly through MLF investment (or phase-out) projects. Alternatives chosen generally follow those identified as successful through demonstration projects carried out in the same country or in regions with similar circumstances. Projects in Article 5 countries have shown that a similar range of alternatives to those in non-Article 5 countries can be successfully adopted. Costs and different resource availability may lead to preference for different alternatives in Article 5 compared to non-Article 5 countries.

The projects showed that for all locations and all crops or situations tested, except stabilisation of high-moisture fresh dates, one or more of the alternatives proved comparable to MB in their effectiveness in the control of pests and diseases targeted in the projects in these Article 5 countries.
By December 2006 the Multilateral Fund (MLF) had approved a total of 324 MB projects in more than 72 countries. This included 43 demonstration projects for evaluating and customising alternatives, 79 MB investment projects for phasing-out MB and 202 other projects for information exchange, awareness raising, policy development and project preparation. Further MB phaseout activities have been funded directly by Article 5 countries and/or agricultural producers, bilateral assistance and the Global Environment Facility.

In the 72 countries implementing full phaseout projects, MB was scheduled to be reduced at an average annual rate of about 22.5% per year, in a total of 4.4 years on average (range 3-6 years). This includes countries that are small, medium and large MB consumers.

The fact that MB cannot generally be replaced by one in-kind alternative has become clear through both demonstration and investment projects. This implies that growers and other stakeholders need to change their approach to production and may even have to make important changes in process management. This relates mostly to IPM but also time management, as alternatives often require longer exposure times than MB. Reluctance to management change is often the major reason for resistance to adoption of alternatives, even over economic matters.

Results obtained from projects to date indicate that particular attention needs to be paid to appropriate, effective application methods. Adapting the alternatives to the specific cropping environment and local conditions is essential to success. Strong emphasis on awareness raising activities, information transfer and training, not only within one country and sector but also with other projects, regions and sectors still appears most important. Ways to promote such horizontal experience-sharing could include for example developing an electronic network, organizing technical seminars, building a database with service and input suppliers all over the world and promoting field visits of technical teams and others.

More than 90% of all Article 5 countries complied with the freeze of 2002 and the 20% reduction of 2005. However, a small number of countries have experienced difficulties. A recent study conducted by the MLF found several common reasons to explain cases of non-compliance or significant delays, such as,

- Political and economic transformation processes;
- Recent ratification of the Montreal Protocol (after 2000) and/or its Amendments;
- Project implementation delays;
- Weaknesses of the National Ozone Unit (e.g. frequent staff changes; communication difficulties within the Environment Ministry and/or with other ministries);
- Low baseline due to exceptional circumstances (war, economic recession, insufficient data collection);
- Delayed approval and implementation of MB-related legislation;
- Reluctance of stakeholders to actively cooperate in the MB phase-out process or insufficient involvement of key sectors or stakeholders since the onset of the projects;
- Expansion of the main sector using MB after the baseline years.

Although a need to build up confidence on the use of certain alternatives or methods as well as further adjustment and trials were evident in some cases, lack of technically feasible alternatives was not found to be a cause of non-compliance. Some countries have opted for a revised schedule of MB reductions in projects that will be easier to achieve under their particular circumstances.

Economic Criteria

The purpose of the economics chapter is to survey the existing literature to provide an overview of economic information relating to alternatives as a guide to what is known about the economic impact of the MB phase-out. A review of the existing literature shows that there are three main economic criteria that have been used to determine economic outcomes from adoption of alternatives to MB. These include;

- Articles that report only the changed (increased) costs of using methyl bromide alternatives;
- Articles that use some form of partial budgeting technique to assess the impact of the use of methyl bromide alternatives on the revenues and costs of a particular application, i.e. on the net financial position of firms (mostly farmers in pre-harvest applications). In these cases the current use of methyl bromide (in terms of application methods and application rates, etc.) is used as the norm from which deviations are measured;
- Articles that report the impact of the use of methyl bromide alternatives on the sector (e.g. California strawberries, cut flowers in Spain) as a whole.

The variation in the means of assessing economics highlights the fact that little research has been done to increase understanding of the actual impacts of the methyl bromide phase-out. The existing literature is narrow in the sense that it relates primarily to the USA and a narrow range of methyl bromide uses. Economic data is available in some Article 5 countries that are implementing MLF projects but the MBTOC economic group did not assess these data.

TEAP/MBTOC have been asked to assess the economic feasibility of Critical Use Nominations. However, although Decision Ex. I/4 lays out the general scope of work for Parties and TEAP, guidance concerning economic feasibility benchmarks is lacking.

Emissions from Methyl Bromide Use and Their Reduction

Emissions from fumigation operations occur mainly through leakage and permeation during treatment (inadvertent emissions) and from venting at the end of a treatment (intentional emissions). Some additional emissions may occur after venting as a result of slow desorption of gas from treated materials (e.g. soils, commodities, materials in treated structures). A proportion of methyl bromide reacts to produce nonvolatile materials. This makes it inappropriate to equate consumption or usage directly with emissions.

Estimates of the proportion of MB used that is released into the atmosphere vary widely because of: differences in usage pattern; the condition and nature of the fumigated materials; the degree of gastightness; and local environmental conditions Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 46 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 59 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 75%, or 27,601 metric tonnes based on estimated use of 36,866 tonnes in 2005.

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering and condition; period of time that a surface covering is present; soil conditions during fumigation; MB injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest effect on emissions.

Studies under field conditions in diverse regions, together with the large scale adoption of Low Permeability Barrier Films (LPBF) in Europe, have confirmed that such films allow for conventional MB dosage rates to be reduced. Typically equivalent effectiveness is achieved with 25 –50% less methyl bromide dosage applied under LPBF compared with normal polyethylene containment films. There is a need for growers to obtain confidence in new sealing methods and new films when adopting such films for the first time.

The use of low permeability barrier films (VIF or equivalent) is compulsory in the European Union (EC Regulation 2037/2000). In other regions LPBF films are considered technically feasible for bed fumigation. However, in the State of California in the US a regulation currently prevents implementation of VIF with MB (California Code of Regulations Title 3 Section 6450(e). This regulation resulted from concerns of possible worker exposure to MB when the film is removed or when seedlings are planted due to altered flux rates of MB.

For QPS treatments, Decisions VII/5(c) and XI/13(7) urge Parties to minimize use and emissions of methyl bromide through containment and recovery and recycling methodologies to the extent possible. There has been limited research into the development of recovery and recycling systems for MB. There are now several examples of recovery equipment in current commercial use. All these units use are based on absorption of used methyl bromide on activated carbon. Some are designed for recycling of the recaptured methyl bromide while others include a destruction step to eliminate the sorbed methyl bromide, thus minimising emissions. Adoption of these systems has been driven by considerations other than ozone layer protection, e.g. occupational safety issues or local air quality. The equipment is not is widespread use. In the absence of regulations, companies reported they would not invest in the systems, because their competitors (who had not made the investment) would then have a cost advantage.

Chapter

2

Introduction to the Assessment

2.1 Methyl Bromide

Methyl bromide (MB) is a fumigant that has been used commercially since the 1930's (Anon, 1994). It has been used to control a wide spectrum of pests including fungi, bacteria, soil-borne viruses, insects, mites, nematodes and rodents and weeds or weed seeds. In 2005, most MB was used for soil fumigation, a lesser amount for disinfestation of durable and perishable commodities, while a minor amount was used for disinfestation of buildings, ships and aircraft. MB has well- established uses for quarantine and pre-shipment treatment of a diverse range of pests and diseases on many commodities in trade, including timber and wooden packaging.

MB has features that make it a versatile material with a wide range of potential applications. In particular, it is a gas that is quite penetrative and usually effective over a broad range of temperatures. Its action is usually sufficiently fast and it airs rapidly enough from treated systems to cause relatively little disruption to commerce or crop production.

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Additional control schedules leading to phase-out (with specific exceptions) were agreed in 1995 and 1997. A number of concerns over methyl bromide apart from ozone depletion have also led countries to impose severe restrictions on its use. These concerns include residues in food, toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and its derived bromide ion are also concerns.

2.1.1. MB uses identified in Articles of the Protocol

MB is classified as a "controlled substance" under the Montreal Protocol (Article 1 and Annex E). The Articles of the Protocol refer to about four main categories of MB uses, and each is subject to different legal requirements. Table 2.1 lists the four categories, and indicates those for which information is provided in this MBTOC report.

Two of the categories - the non-QPS fumigant uses and laboratory and analytical (L&A) uses - are subject to the phase-out schedules under Articles 2 and 5, with authorised Critical Use Exemptions. The phase-out schedules are summarized in Table 2.2 below. The other two categories of MB uses – QPS and feedstock used in industrial processes – are not subject to phase-out schedules but are subject to reporting requirements under the Protocol.

This report focuses primarily on the non-QPS and QPS fumigant uses. Feedstock is mentioned in this report only when discussing statistics on global MB production for all uses in Chapter 3. Laboratory and Analytical (L&A) uses are also included in general statistics on MB production in Chapter 3 but no breakdown is available. L&A uses are not discussed in MBTOC reports because they are assessed in the reports of the Chemical Technical Options Committee (CTOC).

Table 2.1. Classification of MB uses under the Montreal Protocol, indicating relevant sections in this Assessment report

MB uses	Status under the Montreal Protocol	Information in MBTOC Assessment
Non-QPS fumigant uses	Subject to production and consumption phase-out schedules of Articles 2 and 5, trade and licensing controls of Article 4, and data reporting requirements of Article 7. Critical Use Exemptions can be authorised by the MOP for specific uses that meet the criteria in Decision IX/6 and other relevant decisions	Chapters 1-8 and 10
QPS fumigant uses	Exempted from reduction and phase-out schedules. Subject to Article 7 data reporting requirements	Chapter 9 and several sections in chapter 3
Laboratory and analytical uses	Subject to production and consumption phase-out schedules of Articles 2 and 5 except for the specific Critical Use Exemptions under Decision XVIII/15. Subject to data reporting under Annex II of the Sixth Meeting of the Parties	L&A uses are covered in CTOC reports. Chapter 3 statistics on MB production include L&A, but no breakdown is available
Feedstock used in the manufacture of other chemicals	Exempted from phase-out schedule under Article 1. Subject to Article 7 data reporting requirements	Chapter 3 statistics on MB production

2.2 MBTOC Mandate

The Methyl Bromide Technical Options Committee (MBTOC) was established in 1992 by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to MB. MBTOC, in particular, addresses the technical and economic feasibility of chemical and non-chemical alternatives for controlled uses of MB. Additionally, from 2003, MBTOC has had the task of evaluating Critical Use Nominations submitted by non- Article 5 Parties to the Montreal Protocol and providing draft recommendations, for consideration by the Technology and Economic Assessment Panel (TEAP) and the Parties.

MBTOC is a subsidiary body of TEAP, the Panel that advises the Parties on scientific, technical and economic matters related to ozone depleting substances and their alternatives. MBTOC members have expertise in the uses of MB and alternatives to MB.

Information contained in MBTOC's reports contributes to the Parties' deliberations on appropriate controls for MB and on Critical Use Exemptions. Parties review MBTOC and TEAP's recommendations and may accept, reject of modify these recommendations when taking decisions on CUE requests.

Table 2.2. Phase-out schedules agreed at the Ninth Meeting of the Parties in 1997

Year	Non-Article 5 countries	Article 5 countries
1991	Consumption/ production baseline	
1995	Freeze	
1995-98 average		Consumption/ production baseline
1999	25% reduction	
2001	50% reduction	
2002		Freeze
2003	70% reduction	Review of reductions
2005	Phaseout with provision for CUEs	20% reduction
2015		Phaseout with provision for CUEs

Critical and emergency uses may be permitted after phaseout if they meet agreed criteria.
Quarantine and pre-shipment (QPS) uses and feedstock are exempt from reductions and phaseout.
Decisions encouraging advanced phaseout:

- Countries may take more stringent measures than those required by the schedules (Article 2 of the Montreal Protocol).
- In applying the QPS exemption, all countries are urged to refrain from use of MB and to use non-ozone-depleting techniques wherever possible (Decisions VII/5 and XI/13).
- A number of developing and industrialised countries signed Declarations in 1992, 1993, 1995, 1997, 2003 and 2004 stating their determination to phase out MB as soon as possible.

Source: UNEP, Ozone Secretariat

2.3 Committee Process and Composition

At December 2006 MBTOC had 39 members; 14 (36%) from Article 5 and 25 (64%) from non-Article 5 countries. These members come from 10 Article 5 and 12 non-Article 5 countries. Representation from diverse geographic regions of the world promotes balanced review and documentation of alternatives to MB, based on the wide-ranging expertise of Committee members. Most Article 5 MBTOC members and many non- Article 5 members were nominated by their governments.

In accordance with the terms of reference of TEAP and TOCs, MBTOC members participate in a personal capacity as experts and do not function as representatives of governments, industries, non-government organisations (NGOs) or others (Annex V of the report of the Eighth Meeting of the Parties). Members of MBTOC contribute substantial amounts of work in their own time. For construction of this Assessment report, MBTOC met formally in Dubrovnik (2006) and Yokohama (2006). To produce each chapter as efficiently as possible, MBTOC members were divided into sub-committees and topics affecting all chapters were discussed and agreed by the entire committee. Assessment structure and contents were agreed during the formal meetings. The Assessment was finalised by email, to produce a consensus document of the Committee.

MBTOC members and sub-committee chairs for the working groups within the MBTOC 2006 Assessment Report are listed in Appendix 1. The subcommittee chairs acted as coordinators and lead authors for the main chapters of this Assessment.

2.4 UNEP Assessments

The first interim assessment on MB for the Protocol was completed in 1992. A full assessment of the alternatives to MB was completed in 1994 and reported to the Parties in 1995 (MBTOC, 1995) as a result of Decisions taken at the fourth Meeting of the Parties to the Montreal Protocol held in 1992. The second MBTOC Assessment was presented to Parties in 1998 (MBTOC, 1998) and the third in 2002 (MBTOC, 2002). MBTOC progress reports on advances in alternatives to methyl bromide and other issues related to methyl bromide were included in annual TEAP reports to the Parties (1999; 2000; 2001; 2002; 2003; 2004; 2005 a, b; 2006 a, b). An index to methyl bromide alternatives discussed in TEAP and MBTOC reports can be found at http://ozone.unep.org/teap/Reports/MBTOC/index.asp .

Under Decision XV/53(2) taken at the Fifteenth Meeting of the Parties to the Protocol in 2003, the Parties requested the Assessment Panels to update their 2002 reports in 2006 and submit them to the Secretariat by 31 December 2006 for consideration by the Open-ended Working Group and by the Nineteenth Meeting of the Parties to the Montreal Protocol, in 2007. This MBTOC 2006 Assessment reports provides an update on advances since 2002.

2.5 Definition of an Alternative

In this report, , following guidance given in Annex 1 of 16 MOP report, MBTOC defined 'alternatives' as:

> *' any practice or treatment that can be used in place of methyl bromide. 'Existing alternatives' are those alternatives in present or past use in some regions. 'Potential alternatives' are those in the process of investigation or development.*
> *MBTOC assumed that an alternative demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex.*

This definition of 'alternatives' is consistent with that used in previous Assessments.

MBTOC is not required in its terms of reference to conduct economic studies on MB and alternatives. Additionally, it was recognised that regulatory requirements, environmental issues and social constraints may make an alternative unavailable in a specific country or region. MBTOC did not omit alternatives from consideration on such grounds in this Assessment report, although MBTOC reports on CUNs do fully consider the availability or lack of availability in specific locations.

2.6 Report Structure

Chapter 3: Methyl bromide production, consumption and progress in phase-out provides statistics on MB production, consumption and major uses from 1991 to the present day. The chapter has been written in five major parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third describes consumption in non-Article 5 countries, the fourth describes consumption in Article 5 countries, and the final part describes the trends in MB fumigant uses by crop or sector.

Chapter 4: Reducing Methyl Bromide Emissions discusses:

- Inadvertent and intentional MB emissions.
- Emissions estimated from soil, perishable and durable commodities and structural treatments.
- Containment techniques.
- Developments in MB recovery and recycling systems.

Chapter 5: Alternatives to Methyl Bromide for Soil Treatment covers a range of alternatives for this currently major MB-use area. Discussion includes:

- Commercial alternatives available at a large scale:
- Chemical and non chemical alternatives
- Combined alternatives
- Emerging chemical technologies
- Effective technologies for small scale farms
- Crop specific strategies
- Adoption of alternatives in Article 5 and non-Article 5 regions

Chapter 6: Alternatives for Treatment of Post-Harvest Commodities, Food Processing Facilities and Other Structures, Wood Products and Other Durables includes discussion on:

- Alternative fumigants such as phosphine and sulfuryl fluoride
- Heat treatments
- IPM approach combining several different measures,
- Physical and vacuum technologies.
- Contact insecticides and aerosols for persistent protection against re-infestation.

Chapter 7: Factors that have assisted with MB phase-out discusses Multilateral Fund (MLF) projects carried out by Article 5 countries. It identifies the main types and objectives of MLF projects, and major technologies being implemented. It discusses lessons learned and barriers to the adoption of alternatives. The chapter outlines other factors that have contributed to MB phase-out, such as voluntary efforts of growers and others undertaken in both Article 5 and non-Article 5 regions..

Chapter 8: Economic Issues Relating to Methyl Bromide Phase-out discusses economic issues influencing adoption of alternatives to MB, in response to Decision Ex.I/4. The chapter outlines the main Decisions of the Parties relating to assessments of the economic feasibility of alternatives in critical use nominations. It covers a good number of peer- reviewed publications on this topic and identifies the main categories and economic approaches used by different authors to date. It shows that further investigation would be needed to provide a better understanding of the economic impacts of the methyl bromide phase-out, in particular in countries outside of the USA (especially in Article 5 countries) and for a wider range of methyl bromide uses.

Chapter 9: Quarantine and Pre-shipment covers MB and alternative treatments for Quarantine and Pre-shipment (QPS) of durable and perishable commodities, including discussion of :

- Existing MB treatments.
- Approved alternative treatments.
- Situations where MBTOC did not identify alternatives.

Chapter10: Case studies on MB alternatives in commercial use contains 26 case studies from nearly 20 countries describing applications of MB alternative technology in various circumstances, covering:

- Fruit and vegetable production (including cucurbits, tomatoes strawberries and others).
- Ornamentals
- Tobacco
- Postharvest applications.

In past Assessments (1998 and 2002), the case studies were focused on describing alternatives and methods that were already in use in some countries or sectors. In the 2006 Assessment case studies aim to show progress made in MB phase-out and adoption of alternatives in different industries or sectors, in one same country or region, in different situations and cropping systems, both in Article 5 and non-Article 5 Parties. Case studies have thus been grouped by region and not by crop as in past reports.

The *Appendix* contains:

- List of MBTOC members and their contact details and disclosure of interest statements.

2.7 References

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Chapter

3

Methyl bromide production, consumption and progress in phase-out

3.1. Introduction

This chapter provides statistics on MB production, consumption and major uses from 1991 to the present day. The chapter has been written in five major parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third describes consumption in Non-Article 5 countries, the fourth describes consumption in Article 5 countries, and the final part describes the trends in MB fumigant uses by crop or sector.

Most of the data in this chapter, and all of the consumption statistics, refer to non-QPS fumigant uses, which have been the major MB use. The non-QPS fumigant uses are sometimes referred to as controlled uses or controlled production/consumption in this chapter, to distinguish them from other MB uses which do not have phase-out schedules under the Protocol, namely QPS and feedstock used in industrial processes. (The status of the various MB uses under the Protocol is summarised in Table 2.1 in chapter 2). Statistics on QPS are provided in several sections below (3.3.2 and 3.7.2-3.7.3). However, feedstock is mentioned in this chapter only when discussing statistics on global MB production for all uses in section 3.3.2. There are no statistics available on laboratory and analytical (L&A) uses of MB, although L&A uses lie within the general statistics on production and consumption. L&A uses are discussed in the reports of the Chemicals Technical Options Committee.

3.2. Overview of Major Trends

This section provides a brief overview of major trends in production and consumption. More detailed descriptions and data sources are provided in the remaining sections of this chapter.

3.2.1 Overview of global production statistics

Production of MB for uses controlled by the Montreal Protocol was reported to total about 66,430 tonnes in 1991, falling to about 18,140 tonnes in 2005, which represented 27% of the 1991 level. Further reductions have been made since 2005.

Production of MB for all purposes, including quarantine, pre-shipment and chemical feedstock, was estimated to be approximately 75,000 tonnes in 1991, and was reduced to 37,923 tonnes in 2005. In 2005 more than 36% (13,815 tonnes) was produced for QPS, 16% for feedstock and unaccounted uses, and about 48% for controlled uses (about 18,140 tonnes).

In 2000, 14 facilities in 8 countries produced MB, and by 2006 this was reduced to 8 facilities in 4 countries. More than 90% of MB production occurs in non-Article 5 countries (Israel, Japan and US).

3.2.2. Overview of global consumption statistics

Consumption of MB for uses controlled by the Protocol was reported to total about 64,418 tonnes in 1991. Consumption fell to 20,752 tonnes in 2005 or 32% of the 1991 level. Consumption in 2005 was in fact 29% of the global official baseline of 71,764 tonnes (the baseline year was 1991 in non-Article 5 countries and the average of 1995-8 in Article 5 countries).

Parties have continued to make substantial reductions since 2005, and global consumption in 2007 is expected to be approximately 13,500 tonnes or about 19% of the global baseline based on recent trends.

3.2.3 Trends in Non-Article 5 countries

The observed trends in non-Article 5 countries are summarised below. Further details and data sources are described in the remainder of this chapter.

In 2005 the situation for controlled MB uses in non-Article 5 countries was as follows:

- MB production was 27% of the 1991 baseline; this included production for export to Article 5 parties;
- MB consumption was 20% of the 1991 baseline;

From 1 January 2005 consumption was permitted only for Critical Use Exemptions (CUEs) in non-Article 5 parties. The trends observed in CUEs in the period 2005-2007 were as follows:

- About 18,704 tonnes MB were nominated in CUNs for 2005, and the MOP authorised 16,050 tonnes; however less than 13,808 tonnes of CUEs were authorised or licensed at national level. Reported consumption (production + imports) was 11,468 tonnes for CUEs in 2005;
- For 2007, 10,678 tonnes were nominated in CUNs, the MOP authorised 9,161 tonnes, and national authorisation procedures reduced this to less than 8,473 tonnes. Authorised consumption (production + imports) is less than 6,538 tonnes for CUEs in 2007;
- The number of individual CUEs was reduced from about 134 in 2005 to about 64 in 2007;
- The nominated tonnage of CUNs was reduced by 43% from 2005 to 2007;

- The tonnage of CUE 'use categories' authorised by the MOP was also reduced by 43% in this period;
- The tonnage of consumption (production + imports) authorised by the MOP was reduced by 47% from 2005 to 2007;
- National CUE tonnage in 2007 is showing a downward trend in all countries with the exception of Israel.

3.2.4 Summary of trends in Article 5 countries

In 2005 the situation for controlled MB uses in Article 5 countries was as follows:-

- MB production was 39% of the 1995-98 baseline;
- MB consumption was 59% of the 1995-98 baseline;
- 80% of Article 5 countries consumed less than 50% of their national baseline in 2005;
- Of the 95 countries that have used MB, 47 (50%) reached zero consumption by 2005;
- Latin American countries phased out 24% of the regional baseline;
- African countries phased out 42% of the regional baseline;
- Asian countries phased out 53% of the regional baseline;
- Eastern European Article 5 countries phased out 94% of the regional baseline;
- National consumption greater than 500 tonnes remained in only six countries in 2005; three in Latin America, two in Africa and one in Asia.

Status with respect to compliance in 2005:-

- The vast majority of Article 5 countries achieved the freeze in consumption in 2002
- 136 (94%) of 144 countries complied with the 20% reduction step in 2005; only 8 countries did not comply;
- 87% of countries achieved the 20% reduction step earlier than the scheduled date of 2005.

In 2005 the situation in the 14 Article 5 countries that have historically consumed the largest volumes of MB (600 - 3,500 tonnes per annum) was as follows:-

- The top 14 countries phased out on average 34% of their national baselines;
- These 14 countries eliminated a combined total of 11,373 tonnes of MB, reducing consumption to 41% of their historical peak level of consumption;
- They eliminated consumption of 7,238 tonnes in the 4-year period from 2001 to 2005.

These statistics indicate that the majority of countries have made very substantial reductions in MB consumption. The remainder of this chapter provides more details and analysis of the trends summarised above.

3.3. Methyl Bromide Production and Supply

MB is normally supplied and transported as a liquid in pressurised steel cylinders or cans, because it is a gas at normal atmospheric pressure. Typically the cylinders range in size from 10 kg to 200 kg capacity, although MB is also stored in much larger pressurised containers of more than 100 tonnes capacity. In some countries it is also supplied in disposable canisters of approximately 1 lb or 0.5 kg, however MB fumigation using disposable canisters is banned in the European Union (EC Regulation 2037/2000 Article 16(4)) and in a number of Article 5 countries (e.g. Chile, Kenya, Morocco, South Africa). At present, cans are used in Japan and many developing countries.

3.3.1. Global production for all purposes

The information on MB production in this section has been compiled primarily from the Ozone Secretariat data available at the end of November 2006. The Ozone Secretariat database is compiled from the ODS data reports submitted by Parties under Article 7. For historical data, information from the Methyl Bromide Global Coalition and previous MBTOC reports were also used. All tonnes stated in this chapter are metric tonnes.

Table 3.1 below shows the trends in global production, as reported to the Ozone Secretariat by Parties, for the years in which data is available (1991 and 1995-2005). The table also shows MBTOC estimates of the allocation of total MB production for fumigant and feedstock in earlier years, based on estimates published in previous MBTOC reports and Ozone Secretariat data. The predominant use of MB is as a fumigant (a pesticide product), which is used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in specific high-value crops, and for the control of insects and rodents in certain types of commodities and structures.

Table 3.1. Reported MB production for all purposes, 1984-2005 (metric tonnes).

Year	Fumigant Non-QPS & QPS		Chemical feedstock		Total production [a]	
	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties
1984	41,575		3,997		45,572	
1985	43,766		4,507		48,273	
1986	46,451		4,004		50,455	
1987	52,980		2,710		55,690	
1988	56,806		3,804		60,610	
1989	60,074		2,496		62,570	
1990	62,206		3,693		65,899	
1991	73,602	69,995 [b]	3,610	3,610	77,212	73,605 [b]
1992	72,967		2,658		75,625	
1993	71,157		3,000		74,157	
1994	71,009		3,612		74,621	
1995		65,284		4,754		70,038
1996		67,979		3,104		71,082
1997		69,760		3,829		73,589
1998		70,875		4,448		75,323
1999		61,517		4,453		65,970

	Fumigant Non-QPS & QPS		Chemical feedstock		Total production [a]	
2000		56,533		13,132		69,665
2001		45,134		3,190		48,324
2002		40,236		4,331		44,567
2003		36,565		6,759		43,324
2004		35,970		8,012		43,982
2005		32,909		5,014		37,923

a. Total production includes laboratory and analytical (L&A) uses; however no statistics are available on L&A specifically.

b. The reported total for 1991 does not include the production that occurred in Ukraine.

Sources: data estimates from MBTOC 2002 Assessment report and Ozone Secretariat data available for 1991 and 1995–2005.

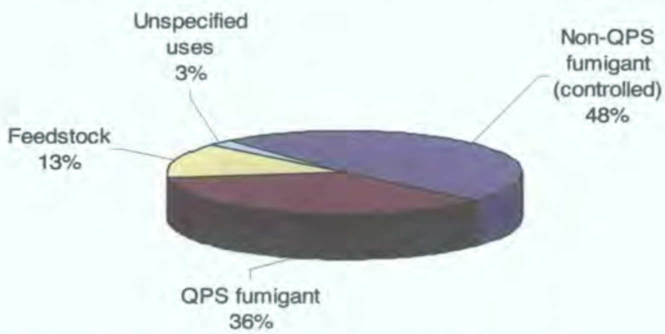
Table 3.2 shows the intended purposes of the total MB that was produced in 2005. The predominant use of MB is as a fumigant (a pesticide product), which is used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in specific high-value crops, and for the control of insects and rodents in certain types of commodities and structures. About 48% of total production was intended for controlled uses, i.e. for non-QPS fumigant, non-exempted L&A uses, while 50% was intended for uses that are not controlled under the Protocol, i.e. for QPS fumigant uses and feedstock. 36% of the total production in 2005 was intended for QPS.

Table 3.2. MB production in 2005, by intended purpose as reported by producers.

Intended purpose	Reported MB production in 2005	
	Metric tonnes	%
Fumigant non-QPS	18,141	48%
Sub-total of uses controlled by the MP	**18,141**	**48%**
Fumigant for QPS	13,815	36%
Feedstock	5,014	13%
Sub-total of uses not controlled by MP	**18,829**	**50%**
Unspecified	952	2%
Total - all uses, controlled and not controlled	**37,923**	**100%**

Source: Database of Ozone Secretariat in November 2006.

Figure 3.1. MB production in 2005, by intended purpose as reported by producers.



Source: Database of Ozone Secretariat in November 2006.

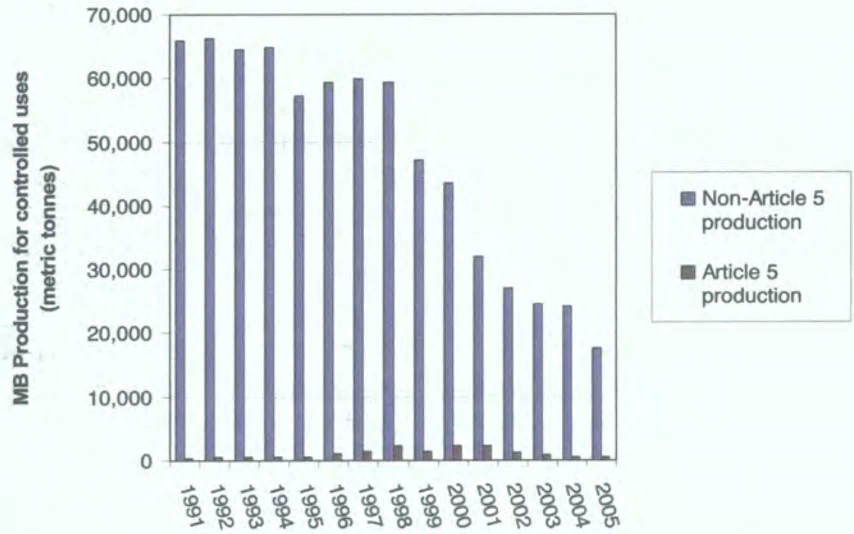
3.3.2. Global production for controlled uses

In 2005 the global MB production for controlled uses (primarily non-QPS fumigant uses) was about 18,140 metric tonnes, which indicates a reduction of 73% since the 1991 reported production level of about 66,430 tonnes (excluding QPS and feedstock).
The total for 1991 can be expected to be adjusted when further information becomes available. Data on MB production in Ukraine for controlled uses is not yet available in the Ozone Secretariat database, however Ukraine has recently compiled statistics. A recent MBTOC analysis of 1991 production data also indicated that some MB produced for QPS appears to have been included in the non-QPS data. Only three producer countries reported production for QPS in 1991 in the Ozone Secretariat database while industry data indicates that about four produced MB for QPS around that time (MBGC, 1994).

Figure 3.2 below illustrates the fact that MB production has occurred primarily in non-Article 5 parties, and that significant reductions have occurred since the 1990's. MB production for controlled uses in non-Article 5 countries fell from 66,002 tonnes in 1991 (official baseline) to 17,603 tonnes in 2005. Non-Article 5 production was 37% of the baseline in 2004 and 27% in 2005; this included production for export to Article 5 countries.

Figure 3.2 shows that Article 5 countries have also reduced their production for controlled uses from a peak of 2,397 tonnes in 2000 to about 538 tonnes in 2005. MB production in Article 5 regions fell from 70% of the baseline in 2003 to 39% in 2005 (the official baseline is 1,374 tonnes, the average of 1995-1998).

Figure 3.2. Reported MB production in non-Article 5 and Article 5 regions for controlled uses, excluding QPS and feedstock, 1991 - 2005 (metric tonnes).



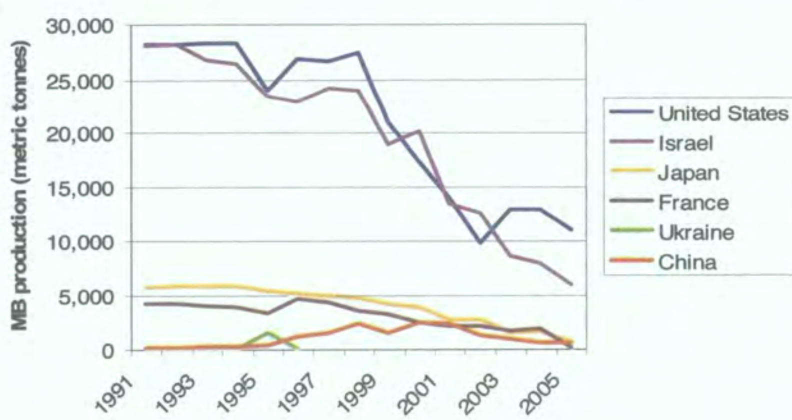
Source: Data for 1991 and 1995-2005 were taken from the database of Ozone Secretariat of November 2006. Data for 1992-94 were estimated from Table 3.1 of MBTOC's Assessment Report (2002).

3.3.3 Major producer countries

Figure 3.3 below indicates the trends in reported MB production for controlled uses in 1991-2005 for the six countries that have produced MB in volumes greater than 1000 tonnes per annum. Most countries have shown a downward trend in recent years, with the exception of the US where production increased in 2003.
Israel and the US remain the major producers, accounting for 33% and 61% respectively, of global production for controlled uses. Together, the US and Israel accounted for 93% of production for controlled uses in 2005.

Figure 3.3. Reported MB production for controlled uses, 1991-2005.

Countries that have produced >1000 tonnes MB per annum



Source: Database of Ozone Secretariat of November 2006.

3.3.4. Production facilities

In 2000, 14 facilities in 8 countries produced MB for controlled and/or uncontrolled uses, and by 2006 this was reduced to 8 facilities in 4 countries, as indicated in Table 3.3 below.

In 1995 four Article 5 countries produced MB (China, India, Korea DPR and Romania). Since 2005 only one Article 5 country (China) has produced MB. Korea DPR ceased production in 1996, India ceased production in 2003, and Romania closed its MB production facilities in 2004 (Ozone Secretariat data; Pak Chun Il, 1999, *pers. comm.*; S.K. Mukerjee, 2006, *pers. comm.;* R. Morohoi, 2007, *pers. comm.*)

In 1995 five non-Article 5 countries produced MB (France, Israel, Japan, Ukraine and the US). Three of these countries produced MB in 2006 (Israel, Japan and US). Ukraine has not produced MB since 2002 and its production facilities are currently inoperable; France did not produce any MB in 2006 (V. Tsirkunov, 2006, *pers. comm.*; European Commission, 2007, *pers. comm.*).

Table 3.3. Companies that produced methyl bromide in 2000 and 2006, for all purposes. Y – production. N – no production

Country	MB manufacturers	2000	2006
China	Lianyungang Seawater Chemical First Plant and Lianyungang Dead Sea Bromine Co. Ltd, Jiangsu Province.	Y	Y
	Linhai Jianxin Chemical Co Ltd, Zhejiang.	Y	Y
	Changui Chemical Plant, Shandung.	Y	Y
France	Albemarle, formerly Elf Atochem, Port de Bouc	Y	N
India	M/S Tata Chemicals Ltd, Mithapore, Gujurat State	Y	N
Israel	Dead Sea Bromine Group (company of ICL-Industrial Products), Beer Sheva	Y	Y
Japan	Teijin Chemicals Ltd, Mihara, Hiroshima Prefecture.	Y	N
	Nippoh Chemicals Co Ltd, Isumi, Chiba Prefecture.	Y	N
	Dohkai Chemical Industry Co. Ltd (Asahi Glass SITec Co.Ltd), Kitakyushu, Fukuoka Prefecture.	Y	N
	Sanko Chemical Industry Co. Ltd, Samukawa, Kanagawa Prefecture.	Y	Y
	Chemicrea Co Ltd, Chiba, Chiba Prefecture.	Y	Y
	Ikeda Kogyo Co. Ltd, Kitakyushu, Fukuoka Prefecture.	N	Y [a]
Romania	SC Sinteza SA, Oradea	Y	N
Ukraine	Saki Chemical Plant, Saki, Crimea	Y	N
US	Chemtura Inc., formerly Great Lakes Chemical Corp., Arkansas	Y	Y

a. Manufacture was transferred to Ikeda Kogyo Co. Ltd. from other companies.
Source: information provided by national experts.

3.4 Trends in Global MB Consumption

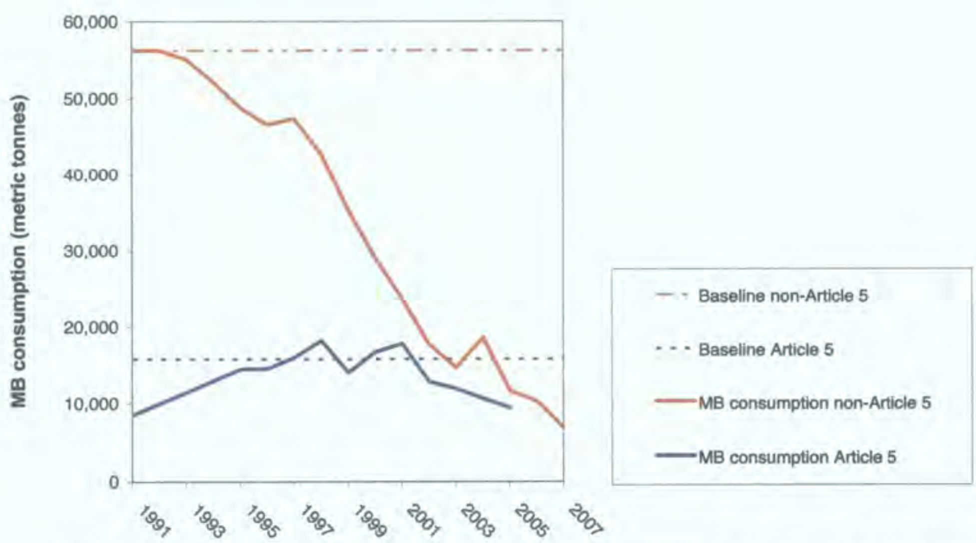
The data on MB consumption are taken from the Ozone Secretariat database of November 2006, which comprises national data reported by Parties under Article 7. Consumption refers only to controlled uses of MB.

3.4.1. Global consumption for controlled uses

On the basis of Ozone Secretariat data, global consumption of MB for controlled uses (i.e. fumigant uses, excluding QPS) was estimated to be about 64,418 tonnes in 1991. However the 1991 reported data did not include Ukraine's consumption data and may have included some QPS tonnage in error, so these figures may be adjusted when further information becomes available. Consumption for controlled uses remained above 60,000 tonnes until 1998. Global consumption was about 45,520 tonnes in 2000, falling to about 26,324 tonnes in 2003 and 20,752 tonnes in 2005.

Figure 3.4 illustrates and compares the trends in MB consumption in Article 5 and non-Article 5 countries. Consumption started at a considerably higher level in the Non-Article 5 group - around 56,083 tonnes in 1991 – falling to 11,468 tonnes in 2005 (20% of the official baseline). In Article 5 countries consumption started at less than 8,340 tonnes in 1991, increased to more than 18,100 tonnes and then fell back to 9,285 tonnes in 2005 (59% of the official baseline of about 15,680 tonnes). In 2007 the non-Article 5 consumption fell further, to less than 6,560 tonnes authorised or licensed for consumption for CUEs, which is less than 12% of the baseline. Extrapolation of consumption in 2002-2005 indicates that consumption of approximately 7,000 tonnes can be expected in Article 5 countries in 2007 if recent trends continue. Article 5 countries accounted for 13% of global consumption in 1991, but this proportion increased to 45% in 2005 because consumption has fallen substantially in Non-Article 5 regions.

Figure 3.4. Baselines and trends in MB consumption in Non-Article 5 and Article 5 regions, 1991 – 2007 (metric tonnes).



Sources: Database of Ozone Secretariat of November 2006. Non-Article 5 data for 2006-7 is the MB consumption authorised for CUEs by MOP Decisions or licensed by parties.

3.4.2. Global consumption by geographical region

An analysis of Ozone Secretariat data revealed that at the end of 2005, global consumption of MB was reduced by 71% with respect to the global aggregate baseline, as shown in Table 3.4 below. The geographical regions that have made the greatest reductions in consumption in the period 1991-2005 were Europe (88% reduction), Asia & Pacific (75% reduction) and North America (72% reduction). Latin America made the smallest reduction (24%) in this period.

Table 3.4. Global consumption by geographic region, 2005 (metric tonnes).

Region	Regional baseline [a]	2005 consumption	% reduction 1991-2005	Number of Parties
Africa	4,470	2,605	42	52
Latin America & Caribbean	6,388	4,837	24	33
Asia & Pacific [b]	14,304	3,592	75	56
Europe [c]	20,873	2,410	88	46
North America [d]	25,729	7,309	72	2
TOTAL	**71,764**	**20,752**	**71**	**189**

a. Aggregate regional baselines as provided in the database of Ozone Secretariat of November 2006, compiled from 1991 consumption in non-Article 5 countries and 1995-1998 average in Article 5 countries.

b. The relatively high baseline in this region arises from the historical consumption in Japan and Israel.

c. The European region comprises Western Europe, Eastern Europe and Scandinavia.

d. The North American region comprises US and Canada.

Source: Database of Ozone Secretariat of November 2006.

3.4.3. Number of countries using MB

MB has been consumed for controlled uses by 135 out of the 188 countries that have reported data to the Ozone Secretariat since 1990. Many of these MB user countries (56% or 75 of 135) no longer consume MB. Table 3.5 below summarises the number of current and former MB user countries in Article 5 and non-Article 5 regions.

Table 3.5. Number of MB user countries (current and former) and countries that have not used MB, comparison of Article 5 and Non-Article 5 regions.

Status of MB consumption	Number of countries		
	Non-Article 5 in 2007	Article 5 in 2005	Total
Current MB users: Parties consuming MB	12 (27%)	48 (33%)	60 (32%)
Former MB users: Parties that used MB in past but now have zero consumption [ab]	28 (64%)	47 (33%)	75 (40%)
Non-users: Parties that have not consumed MB since 1990 [b]	4 (9%)	49 (34%)	53 (28%)
Total	**44 (100%)**	**144 (100%)**	**188 (100%)**

a. MB consumption reported in database of Ozone Secretariat in November 2006 in the case of Article 5 parties, and authorised or licensed CUE data in the case of non-Article 5 parties.

b. Excluding QPS.

3.5. Trends in MB Consumption in Non-Article 5 Countries

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat data available at the end of November 2006, which is based on the ODS data reports submitted by Parties under Article 7 of the Protocol. Some countries have revised or corrected their historical consumption data on occasion, and in consequence the reported figures and baselines have changed slightly in each MBTOC review of MB consumption. At the time of making this analysis all but one non-Article 5 parties had submitted consumption data for 2005. (This party's consumption has been zero since 1997 so this particular data gap is not expected to have any impact on the data in this section.) Consumption data relating to 2006 and 2007 was compiled from the CUE consumption authorised by MOP Decisions (Decisions XVI/2, Ex.II/1, XVII/9 and XVIII/13) and the national authorisation/licensing documents of individual parties.

It should be noted that, under the Protocol, consumption is calculated as MB production plus MB imports minus exports, minus QPS, minus feedstock. Consumption thus represents the national supply of MB (from new production or imports) for uses that are controlled by the Protocol, i.e. non-QPS fumigant uses. Consumption data does not include QPS.

3.5.1. Total non-Article 5 consumption

Non-Article 5 consumption was about 56,083 tonnes in 1991. It has fallen to less than 6,560 tonnes consumption licensed or authorised for CUEs in 2007, which is less than 12% of the baseline level. Figure 3.4 in section 3.4.1 above illustrates the trend in total MB consumption in Non-Article 5 countries in the period from 1991 to 2007.

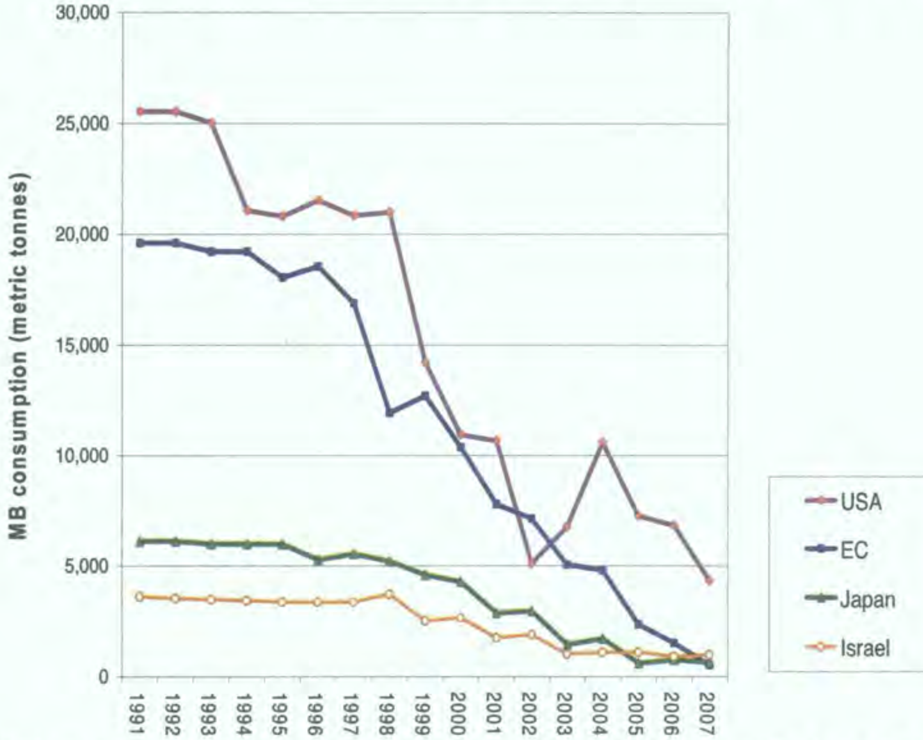
3.5.2. National consumption trends in major consumer countries

In 1991 the US, EC, Japan and Israel together used 97% of the MB consumed in non-Article 5 parties. Figure 3.5 below shows the trends in national MB consumption in these four parties. The US was the highest consumer for much of the period from 1991 to 2007, and its consumption has fluctuated more than that of other countries. US consumption increased after 2002, then fell to pre-2002 levels in 2007.

In 2004, US consumption appeared to increase to 10,589 tonnes (41% of baseline), however this occurred primarily because 3,310 tonnes scheduled for export to Article 5 countries were not shipped before 31 December of that year and this consignment was counted as part of the official national consumption. If this amount were to be deducted, the US consumption in 2004 would have been approximately 7,280 tonnes.

Consumption in the EC, the second-highest consumer, has shown a steadier downward trend since 1999, falling to a low level of authorised consumption in 2007.

Figure 3.5. National MB consumption in US, EC, Japan and Israel, 1991 – 2007.



Source: Database of Ozone Secretariat in November 2006, reports of the Meetings of the Parties to the Montreal Protocol, and national licensing and authorisation documents relating to consumption.

3.5.3. National consumption as percentage of national baseline

In 2005 the MB consumption in the US, EC and Japan was 28%, 12% and 10% of their respective national baselines. And in 2007 the authorised or licensed consumption (for CUEs) was reduced to about 17%, 3% and 10% of national baselines in the US, EC and Japan, respectively.

Table 3.6 summarises the trends in MB consumption (imports/production) as a percentage of national baselines from 2003 to 2007, showing the total for all non-Article 5 countries (final row of Table 3.6) and in countries that have had CUEs. Although most countries requesting CUEs consumed MB at a similar percentage of baseline in 2003 (mainly in the range of 23 – 29% of national baseline), the subsequent trends in MB consumption have varied greatly from party to party. In 2004, the year before the scheduled phase-out, consumption increased in five countries as indicated in Table 3.6. Similar peaks have been observed in Article 5 countries immediately before a compliance date, as observed in section 3.6.2. The observed increase was temporary in all but two non-Article 5 countries. In 2007 the authorised consumption (imports/production) for CUEs was in the range of 0 – 27% of national baselines, with an average of less than 12%. MB consumption for CUEs in 2007 is trending downwards in all parties with the exception of Israel, as seen in Table 3.6.

Table 3.6. National consumption (imports/production) as percentage of national baseline, 2003-2007.

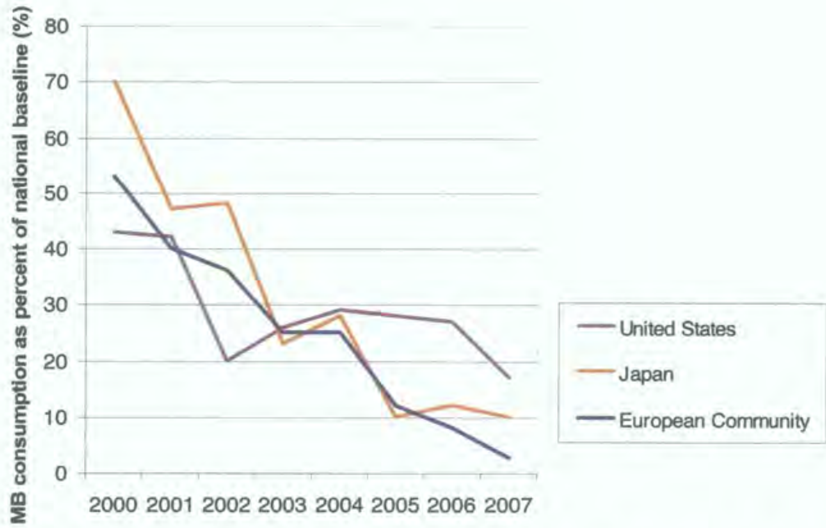
Party	MB imports/production as percentage of baseline (metric tonnes)				
	Reported by party			Authorised by MOP or national authorities[a]	
	2003	2004	2005	2006	2007
Australia	26% (181)	29% (205)	16% (116)	9% (63) [b]	7% (49)
Canada	29% (58)	29% (58)	27% (54)	27% (54)	26% (53)
European Community	25% (4,921)	25% (4,789)	12% (2,341) [c]	8% (1,509) [b]	3% (519) [bc]
Israel	28% (992)	30% (1,071)	30% (1,072)	25% (880)	27% (967)
Japan	23% (1,430)	28% (1,698)	10% (595)	12% (741)	10% (636)
New Zealand	15% (21)	13% (17)	22% (30)	30% (41)	14% (18)
Switzerland	24% (11)	29% (12)	10% (4)	4% (2)	0% (0)
United States	26% (6,755)	[29%] [7,279] [d]	28% (7,255)	27% (6,822) [b]	17% (4,316) [b]
All non-Article 5 countries	**26% (14,504)**	**27% (15,131)[d]**	**20% (11,468)**	**<18% (<10,112)**	**<12% (<6,558)** [b]

Source: Database of Ozone Secretariat in November, 2006, reports of Meetings of the Parties, and national authorisation of consumption relating to CUEs.

a. Imports/ production authorised by MOP Decisions, except where indicated as b.
b. Consumption authorised by national authorities
c. The members of the European Community for which the MOP authorised CUEs in 2005 were Belgium, France, Germany, Greece, Ireland, Italy, Latvia, Malta, Netherlands, Poland, Portugal, Spain, and the United Kingdom (13 countries). The EC authorised CUEs for 2007 in France, Italy, Netherlands, Poland, Spain and UK (6 countries).
d. Total consumption (production + imports) in US in 2004 was 10,589 t. However, the indicated percentage of baseline (29%) was calculated after deduction of 3310 t that was produced for export to Article 5 countries but was not exported prior to 31 December 2004 (UNEP/OzL.Pro/ImpCom/35/10).

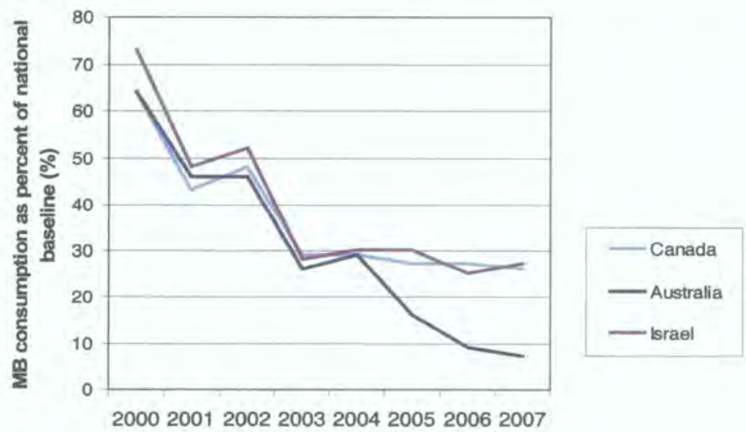
The graphs in Figures 3.6 and 3.7 below also provide an illustration of these trends over a slightly longer period of time (2000-2007). Figure 3.6 illustrates the national consumption (imports/ production) as a percentage of national baseline in the Non-Article 5 parties which have baselines greater than 6,000 tonnes, while Figure 3.7 illustrates trends in parties which have baselines in the range of 200 – 6,000 tonnes (in fact, they have baselines from 200 to 3,600 tonnes; there are no countries at the higher end of this particular range).

Figure 3.6. National MB consumption as percentage of national baseline (%) in Non-Article 5 parties that have baselines greater than 6000 tonnes, 2000-2007.



Source: Database of Ozone Secretariat in November 2006. The data for 2006-7 is MB consumption authorised for CUEs by MOP Decisions or licensed by parties.
The US data for 2004 excludes 3,310 tonnes consumption that was scheduled for export to Article 5 countries but not shipped before December 2004.

Figure 3.7. National MB consumption as percentage of national baseline (%) in Non-Article 5 parties that have baselines of 200 – 3,600 tonnes, 2000-2007.



Source: Database of Ozone Secretariat in November 2006. Data for 2006-7 is MB consumption authorised for CUEs by MOP Decisions or licensed by parties.

3.5.4. Number of countries consuming MB

About 90% of non-Article 5 countries, i.e. 40 of the total of 44 countries, have consumed MB for uses controlled by the Protocol. Of these, 73% (28 of 40) no longer consume MB (as shown in Table 3.5 in section 3.4.3 above). It should be noted that consumption data does not include QPS.

A total of 20 countries requested CUEs in 2005/6. In 2007 this number fell to 12 countries, a reduction of 40%. The member countries of the European Community provide an illustration of the changing patterns of MB use. In the past, 26 of the 27 current countries of the European Community consumed MB for uses controlled by the Protocol. In 2005, 10 of these countries still consumed MB for CUEs. By 2007, only 6 EC countries remained as MB consumers.

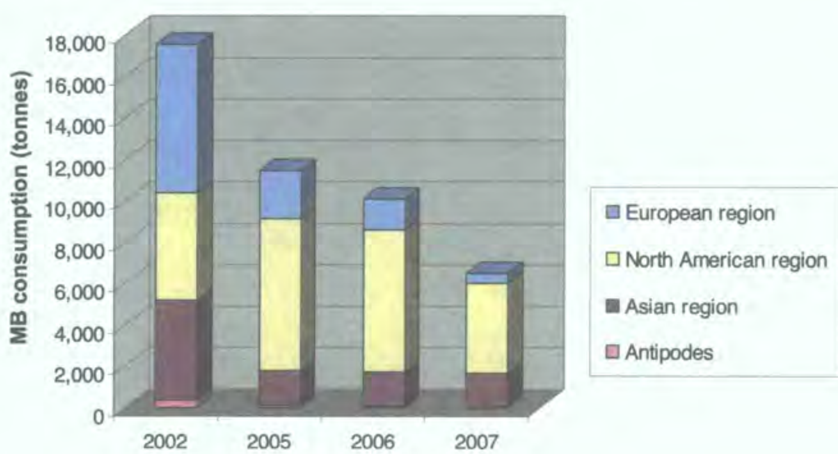
3.5.5. Consumption by geographical region

The proportions of consumption changed substantially in non-Article 5 geographical regions between 2002 and 2006, as indicated in Figures 3.8 below.

There was a proportional shift to North America (comprising the United States and Canada), which accounted for about 30% (5,181 tonnes) of total non-Article 5 consumption in 2002 and about 67% (4,369 tonnes) of total non-Article 5 authorised consumption in 2007.

The European region's consumption changed from 41% (7,188 tonnes) of total non-Article 5 consumption in 2002 to less than 3% (about 500 tonnes) of the total non-Article 5 consumption authorised in 2007.

Figure 3.8. MB consumption in non-Article 5 countries by geographic region, 2002 - 2007 (metric tonnes).



Source: Database of Ozone Secretariat in November 2006.

3.5.6. Trends in critical use exemptions

This section describes the recent trends in Critical Use Exemptions in non-Article 5 parties. In addition to the quantities authorised for CUE consumption (production + imports), which were described in some sections above, this section analyses the quantities authorised for CUE uses (called 'critical use categories' in MOP Decisions) which may imply the use of some stocks. The MOP Decisions on CUEs used in this analysis were Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

3.5.6.1. Total tonnage of critical use exemptions

Critical use exemptions (CUEs) were granted to some non-Article 5 countries for continued use in specific sectors and circumstances after the scheduled phase-out date of 1 January, 2005. Table 3.7 below summarises the trends in the total tonnage of CUEs from the initial quantity nominated, approval by MOP Decisions, and authorisation by national authorities for 2005 to 2008 that had occurred as of December 2006.

For the year 2005, for example, Table 3.7 indicates that the amount of MB eventually used for critical uses in 2005 was significantly smaller than the amount originally nominated and authorised by MOP Decisions, as follows:-

- Non-Article 5 parties submitted critical use nominations amounting to 18,704 tonnes for 2005
- MOP Decisions authorised 16,050 tonnes
- National authorities authorised less than 13,808 tonnes
- And finally the Accounting Frameworks submitted by parties reported that 11,545 tonnes MB were "used" for critical uses in 2005
- This was 72% of the quantity that was authorised by MOP decisions for that year.

Analysis of the trends in total CUE tonnes from 2005 to 2007 indicates the following (calculated on data in Table 3.7):-

- The total nominated tonnage of CUNs was reduced by 43% from 2005 to 2007;
- The tonnage of CUE 'use categories' authorised by the MOP was reduced by 43%;
- The tonnage of CUE 'use categories' authorised by national authorities was reduced by 39% from 2005 to 2007;
- The tonnage of consumption (new production and imports) for CUEs authorised by the MOP was reduced by 47% from 2005 to 2007.

Table 3.7. Trend in total tonnage of critical use exemptions authorised 2005-2008.

Phase in procedure	2005	2006	2007	2008 1st round
Nominations submitted to the MOP	18,704	15,615	10,678	7,098
CUE 'use categories' authorised by MOP Decisions	16,050	13,418	9,161	5,884
CUE 'use categories' authorised by Parties	< 13,808	< 11,396	< 8,473	n.d.
MB "used" for CUEs reported in parties' Accounting Frameworks (production + imports plus stocks used)	11,545	To be reported in 2007	To be reported in 2008	To be reported in 2009
Production + imports authorised by MOP Decisions	14,132	12,993	7,561	5,123
Production + imports authorised by Parties	<14,301	<10,112	<6,560	
Production + imports (consumption) reported to Ozone Secretariat by Party	11,468	To be reported in 2007	To be reported in 2008	To be reported in 2009

Data compiled from TEAP/MBTOC reports, Decisions of MP meetings, national authorisations relating to CUEs, and Accounting Framework reports submitted to the Ozone Secretariat.

3.5.6.2. Trends in critical use exemptions in major Parties

Figure 3.9 below provides an illustration of the reductions that have occurred in the CUEs requested and authorised by the US from one year to the next year (moving from left to right) and within each single year (moving from the back to the front of the chart). The following data illustrate the reductions that occurred in the US in 2005.

US CUE uses in 2005:-

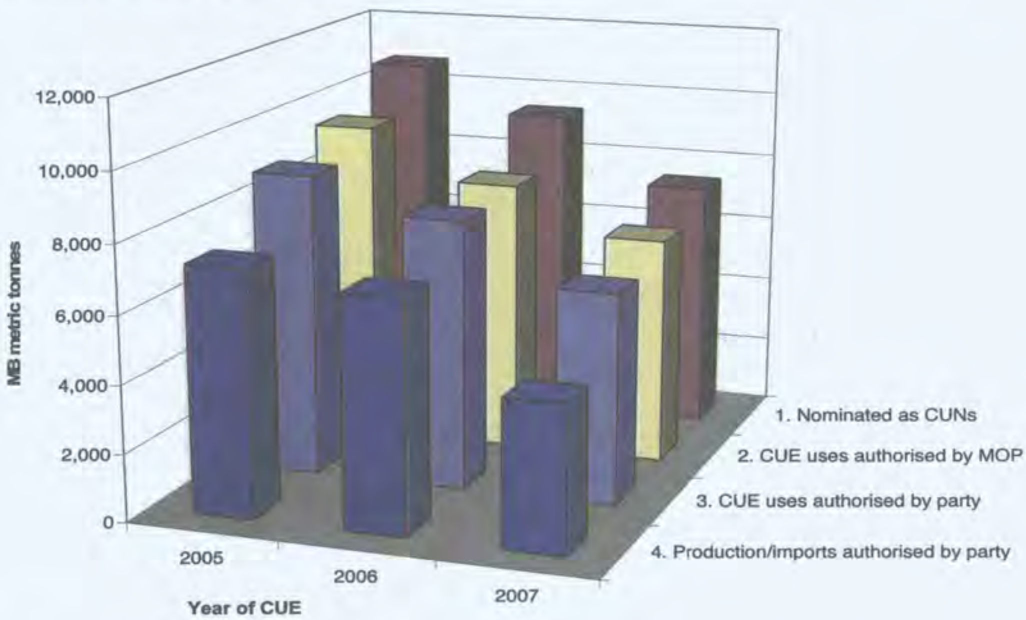
- A total of 10,754 tonnes was nominated by the US in critical use nominations, CUNs (illustrated by purple column in Figure 3.9);
- 9,553 tonnes CUE uses in 2005 were authorised by MOP Decisions (cream column);
- 8,942 tonnes CUE uses were authorised by the US (pale blue column).

US CUE consumption (imports/production) in2005:-

- 7,659 tonnes consumption was authorised by MOP Decisions;
- The US reported consumption of 7,255 tonnes for CUEs in 2005 (shown as dark blue column in Figure 3.9). Consumption was lower than authorised use because some stocks were used in the US.
- In 2006 a similar series of reductions was observed in CUEs in the US as illustrated in Figure 3.9, with the result that the CUE uses authorised by the US

(7,957 tonnes) were 85% of the amount nominated. Similar reductions occurred in 2007.

Figure 3.9. Trends in CUEs in the United States (total tonnes) during various phases of the CUE process, 2005-2007.



KEY:- 1. Tonnes nominated as CUNs (purple);
2. CUEs authorised by MOP Decisions (cream);
3. CUEs authorised by the party (pale blue);
4. production + imports authorised by the party (dark blue).

Data compiled from MBTOC reports, Decisions of MP meetings, consumption database of Ozone Secretariat in November 2006, US Federal Register.

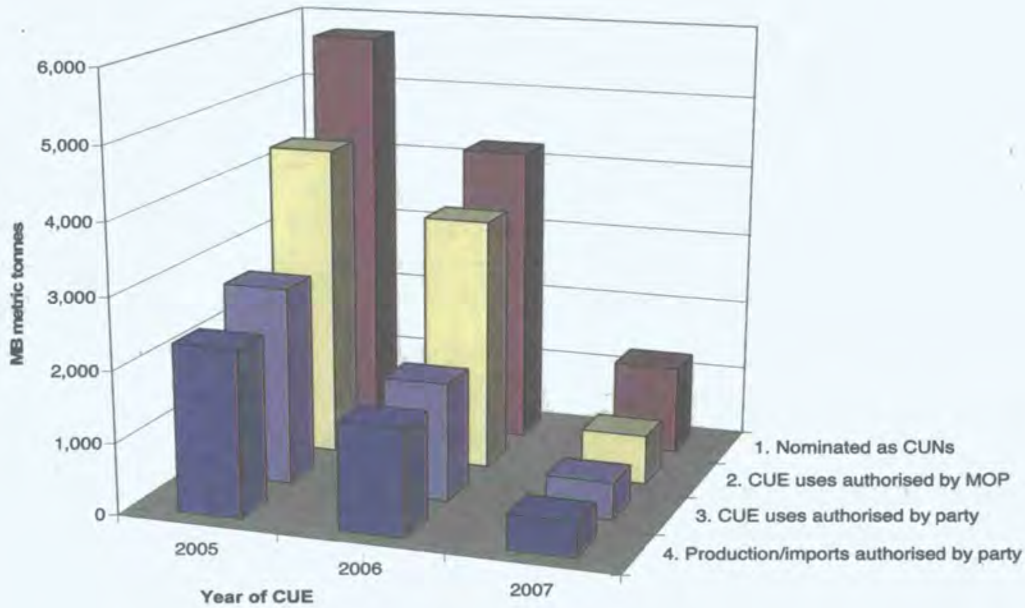
EC CUE uses in 2005:

- A total of 5,754 tonnes was nominated by the EC in critical use nominations (illustrated by purple column in Figure 3.10);
- 4,393 tonnes was authorised for 2005 by MOP Decisions (cream column);
- 2,777 tonnes was authorised by the EC and member countries during the licensing phase (pale blue column) following a second review of the availability and technical and economic feasibility of alternatives, and taking account of developments since the CUNs were submitted (European Commission, 2006ab);
- 2,530 tonnes was used for CUEs by the EC, including stocks, as reported in the Accounting Framework;
- In 57 of the 76 individual CUE sectors in the EC, the agricultural industry used less MB than the quantity that was authorised for each sector.
- In total, the EC used only 44% of the quantity that was originally nominated in CUNs for 2005

EC CUE consumption (production + imports) in 2005:

- 4,393 tonnes consumption for CUEs was authorised by MOP Decisions;
- 2,341 tonnes was finally consumed (produced/imported) for CUEs in 2005 (illustrated by dark blue column in Figure 3.10);

Figure 3.10. Trends in CUEs in the European Community (total tonnes) during the various phases of the CUE process, 2005-2007.



KEY:- 1. Tonnes nominated as CUNs (purple); 2. CUEs authorised by MOP Decisions (cream); 3. CUEs authorised by the party (pale blue); 4. production + imports authorised by the party (dark blue).
Data compiled from MBTOC reports, Decisions of MP meetings, consumption database of Ozone Secretariat in November 2006, and EC Decisions relating to CUEs

Figure 3.10 provides an illustration of the series of reductions that occurred in the CUEs in the European Community from year to year (moving from left to right) and within each year (moving from back to front of chart). The following data illustrates the reductions that occurred in the EC's CUEs of 2005.

In 2006 a similar series of reductions was observed in the EC CUEs as illustrated in Figure 3.10, with the result that the tonnage authorised (1,654 tonnes) by the EC and member countries was 39% of the amount nominated. For 2007 the EC and member countries authorised only 519 tonnes. This represents 19% of the quantity that was finally authorised for 2005.

3.5.6.3. Number of critical use exemptions

Table 3.8 provides an overview of the number of individual CUEs authorised by MOP Decisions for the years 2005-2008. The data for 2008 are incomplete. The total number decreased from about 134 CUEs in 2005 to 80 CUEs in 2007, a reduction of 40% in the number authorised by the MOP. However, some parties conducted a second review of alternatives during the licensing phase and as a result the number was further reduced. The EC and member countries, for example, authorised about 76 CUEs in 2005 and 19 CUEs for 2007. This reduced the total for all countries in 2007 to 64 individual CUEs, a reduction of 52% in the number authorised from 2005 to 2007. To date, 28 CUEs have been authorised by the MOP for 2008 and a further 18 have been nominated, giving a potential total of 46 individual CUEs in 2008.

Table 3.8. Number of critical use exemptions authorised by MOP, 2005-2008.

Party	Number of CUEs authorised by MOP Decisions (brackets indicate number authorised by party at licensing phase)			
	2005	**2006**	**2007**	**2008**
Australia	7	5	3	3
Canada	3	3	5	2 + [1][a]
EC	77 (76)	86 (46)	35 (19)	[6][a]
Israel	12	11	12	[11][a]
Japan	13	8	7	7
New Zealand	2	2	2	0
Switzerland	1	1	0	0
US	19	17	16	16
Total	**134 (133)**	**133 (93)**	**80 (64)**	**46 authorised + nominated**

a. Submitted as CUN in January 2007; subject to MOP authorisation during 2007

3.5.7. Assessment of progress in MB phase-out in non-Article 5 countries

The trend indicators analysed above lead to the conclusion that substantial progress has been made in phasing out methyl bromide in non-Article 5 countries. The trends can be summarised as follows for the controlled uses of MB.

Status and progress achieved in 2005:-

- 73% of the non-Article 5 production baseline has been phased out;
- 80% of the non-Article 5 consumption baseline has been phased out in 2005.

Trends in CUEs in the period from 2005 to 2007:-

- The nominated tonnage of CUNs was reduced by 43% in 2005-2007;
- The tonnage of CUE 'use categories' authorised by the MOP was reduced by 43%;
- The tonnage of CUE 'use categories' authorised by national authorities was reduced by 39% from 2005 to 2007;
- The tonnage of new production + imports (consumption) for CUEs authorised by the MOP was reduced by 47% from 2005 to 2007;
- The number of individual CUEs was reduced from 134 in 2005 to about 65 in 2007;
- CUEs in 2007 show a downward trend in all parties with the exception of Israel.

Regional analyses provided the following results (the information relating to authorised consumption in 2007 was taken from the consumption for CUEs authorised by the MOP and national competent authorities):-

- Australia phased-out 84% of its national baseline in 2005 and is scheduled to phase-out 93% of national baseline in 2007;
- European countries phased-out 88% of the regional consumption baseline in 2005 and are scheduled to phase-out 98% of the regional baseline in 2007;

- Israel phased-out 70% of its national baseline in 2005 and is scheduled to phase-out 73% of national baseline in 2007;
- Japan phased-out about 90% of its national baseline in 2005 and is scheduled to phase-out 90% of national baseline in 2007;
- New Zealand phase-out 78% of its national baseline in 2005 and is scheduled to phase-out 86% of national baseline in 2007;
- The US phased-out 72% of its national baseline in 2005 and is scheduled to phase-out 83% of baseline in 2007.

3.6 MB Consumption Trends in Article 5 Countries

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat database available at the end of November 2006. Some countries have revised or corrected their historical consumption data on occasion, and in consequence the reported figures and baselines change slightly in each MBTOC report. At the time of making this analysis all but six Article 5 parties had submitted national consumption data for 2005. The database relating to MB consumption is much more complete than in the past.

3.6.1. Total consumption

Figure 3.4 in section 3.4.1 above illustrated the trend in total MB consumption in Article 5 countries for the period between 1991 and 2005. The official Article 5 baseline was about 15,680 tonnes (average of 1995-98). Total MB consumption peaked at more than 18,100 tonnes in 1998. Recently, the total Article 5 consumption fell from 75% of the baseline in 2003 to 59% of baseline in 2005 (about 9,285 tonnes). Many Article 5 countries have implemented MLF projects with the aim of reducing MB consumption, and have carried out other activities to promote the adoption of alternatives, as described in chapter 7. These activities have led to the very substantial MB reductions observed in Article 5 countries in recent years.

3.6.2. Consumption trends by geographic region

Figure 3.11 below illustrates the trends in MB consumption in the major Article 5 regions. All of the regions started at a relatively low level of consumption in 1991, and most regions increased consumption until 1998 or later. However by 2005, consumption in Asia, Africa and European Article 5 regions had fallen back below the low level consumed in 1991 in those regions. But in contrast to the other regions, consumption in Latin America remained 84% higher than its 1991 consumption. Two agricultural sectors stand out in this region as large consumers: melon production in Central America and cut flowers production in countries such as Ecuador and Brazil. In contrast the MB reductions achieved in other agricultural sectors such as tobacco and vegetables have been very substantial in Latin America.

Figure 3.11. Article 5 consumption by geographic region, 1991-2005

Source: Database of Ozone Secretariat in November 2006.

This figure also shows that substantial peaks often occurred before the compliance years, at the end of the baseline period in 1998, and immediately before the freeze in 2001. These peaks were generally followed by significant troughs indicating that there has been a tendency to import more MB than needed when a compliance date approached.

The Asia and Pacific region reduced consumption from a peak of 5,025 tonnes in 2000 to about 1,780 tonnes in 2005 (a reduction of 65%). Africa reduced consumption from a peak of 5,931 tonnes in 2001 to about 2,605 tonnes in 2005 (a reduction of 56%). Eastern Europe made the greatest percentage reduction, from a peak of 1,245 tonnes in 1996 to 64 tonnes in 2005 (a reduction of 95%). Latin America's consumption peaked at 7,030 tonnes in 1998, and was reduced to 4,837 tonnes in 2005 (a reduction of 31%), as illustrated in Figure 3.11 above.

Figure 3.12 illustrates the proportional changes that occurred among the regions from 2002 to 2005. In 2002, the consumption was highest in Latin America at 37% of the Article 5 total, followed by Asia at 31%, Africa at 27%, and Eastern Europe at 5%. By 2005, the relative consumption was proportionately higher in Latin America at 52% of the total, followed by Africa at 28%, Asia at 19% and Eastern Europe at only 1% of the total reported in Article 5 regions. This is a substantial change from the proportions of 2002. The shift was mainly due to continued large use of MB in the melon sector in several countries in Central America (MLF, 2006; Implementation Committee, 2006)

Figure 3.12. Relative MB consumption (by region) in Article 5 countries in 2002 c.f. 2005.

2002 (12,711 tonnes) **2005 (9,285 tonnes)**

Regions in this figure correspond to the regions of UNEP's ozone networks.
Source: Database of Ozone Secretariat in November 2006.

Table 3.9 summarises the status of consumption with respect to regional baselines of 1995-98 in the major Article 5 regions in 2005. Regions reduced their consumption by 24 – 90% compared to the regional baselines:

Table 3.9. MB consumption by Article 5 regions in 2005.

Region	2005 consumption	Regional baseline	% reduction	Number of Parties
Latin America	4,837	6,388	24	33
Africa	2,605	4,470	42	52
Asia	1,779	3,751	53	49
Eastern Europe	64	1,072	90	10
TOTAL	**9,285**	**15,681**	**41**	**144**

Source: Database of Ozone Secretariat in November 2006.

3.6.3. National consumption as percentage of national baseline

Most Article 5 countries have achieved considerable MB reductions at national level. With respect to compliance, the vast majority of Article 5 countries achieved the MP freeze as scheduled in 2002. By 2003, 82% of Article 5 Parties (117 out of 142 Parties) had achieved the 20% reduction step earlier than the scheduled date of 2005, as indicated in Table 3.10. In 2003 only 25 Parties needed to take action to meet the 20% reduction step of 2005. The consumption data reported for 2005 indicates that only 8 parties failed to comply:- 3 countries in Latin America, 3 countries in Africa, 1 country in the Pacific and one CEIT country. By 2005 95% (or 136 of a total of 144) Article 5 parties achieved compliance with the 20% reduction step; and many countries achieved this several years earlier than required.

In fact, many Article 5 countries have achieved MB reductions far greater than those required by the Protocol schedule. In 2005, 80% of Article 5 countries (115 countries) had reduced national MB consumption to less than 50% of national Baseline, as indicated in Table 3.10. A number of Article 5 countries have implemented measures to promote and maintain MB phaseout; further information can be found in Chapter 7.

Table 3.10. National MB consumption compared to national baselines in Article 5 countries.

Status of national MB consumption	Number of Article 5 countries		
	2003	2004	2005
MB consumption was 0% of national baseline	87	91	96
MB consumption was >0% - 50% of national baseline	19	22	19
MB consumption was 50 – 80% of national baseline	11	10	21
MB consumption was more than 80% of national baseline	25	19	8 [a]
Total	142	144	144

a. Ecuador, Fiji, Guatemala, Honduras, Libya, Tunisia, Turkmenistan, Uganda.
Source: Database of Ozone Secretariat in November 2006.

3.6.4. Number of countries consuming MB

As in other sections, this analysis of MB consumption covers controlled uses only, which means that QPS uses are excluded. Forty-nine Article 5 parties (34%) have never used MB or reported zero MB consumption since 1990, as summarised in Table 3.11 below. The total number of Article 5 parties that have consumed MB (currently or in the past) is 95, which is 66% of the total 144 Article 5 parties. Of these 95 MB-user countries, 47 (50%) have phased out MB, and 48 remained as consumers in 2005 as shown in Table 3.11.

This indicates that many Article 5 countries have made substantial progress by completing their national phase-out of MB consumption. In total, 67% of Article 5 countries did not use MB in 2005. Note that this analysis refers only to the controlled uses of MB, and that some of these countries may still use MB for QPS.

A regional comparison reveals that Eastern European Article 5 countries have made the greatest progress in ceasing consumption (67% of countries that used MB), followed by Africa (50%), Latin America (48%) and Asia (45% of countries).

Table 3.11. Number of Article 5 countries that are MB consumers (current and former) by region, in 2005 (excluding QPS).

National MB consumption status [a]	Number of countries, by region				
	Africa	Asia Pacific	Latin America [b]	Eastern Europe	Total
Current MB users: countries using MB in 2005	15	16	14	3	48 (33%)
Former MB users: countries that used MB in past and have zero consumption in 2005	15	13	13	6	47 (33%)
Sub-total: Current users and former MB users	**30**	**29**	**27**	**9**	**95** (66%)
Non-users: countries that have not consumed MB since 1990 [c]	22	20	6	1	49 (34%)
Total	**52**	**49**	**33**	**10**	**144** (100%)

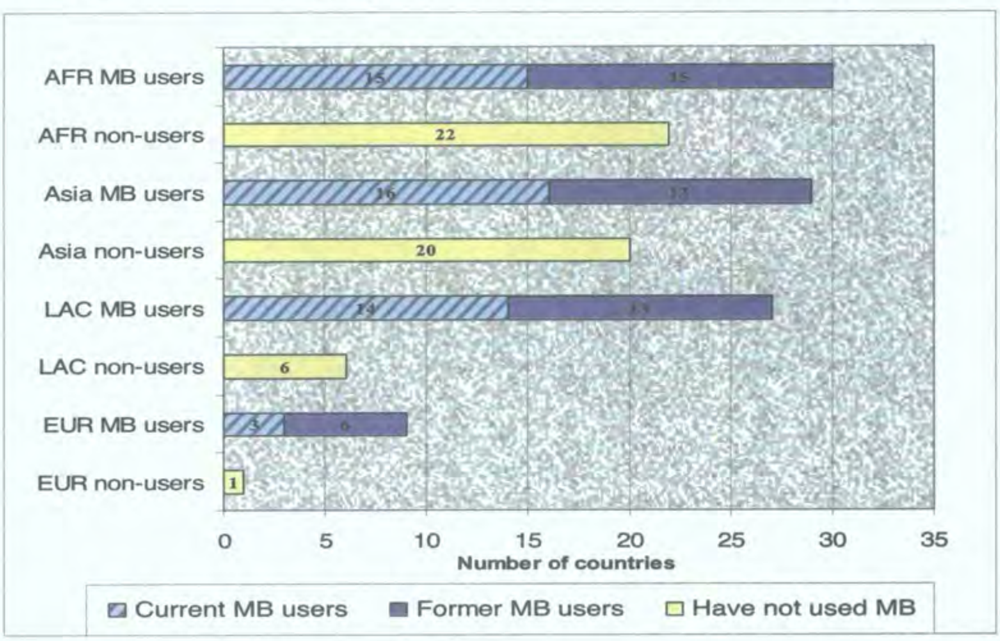
a. MB consumption reported in database of Ozone Secretariat in November 2006.
b. Latin American and Caribbean region.
c. Parties that have not reported any MB consumption in the period 1991-2005, excluding QPS.

Figure 3.13 provides a graphic illustration of Table 3.11, showing the status of MB users (current and former) and non-users in each Article 5 region in 2005, excluding QPS. In the African region, for example, 15 countries currently use MB (hashed bar), 15 countries consumed MB in the past but no longer consumed MB in 2005 (dark bar), and 22 countries have not used MB (pale bar). This means that 15 (50%) of the 30 countries that have used MB in Africa phased it out by 2005.

Similarly in Asia, 16 countries used MB in 2005 (hashed bar), 13 past users no longer consumed MB (dark bar) and 20 countries have not used MB (pale bar). This means that 13 (45%) of the 29 countries that have used MB in Asia had phased it out by 2005.

The picture is similar in the region of Latin America and the Caribbean where 13 (48%) of the 27 countries that have used MB in LAC no longer consume MB.

Figure 3.13. Number of Article 5 countries that are MB consumers (current and former) and non-users, by region, in 2005 (controlled MB uses only).



Source: Database of Ozone Secretariat in November 2006.

Some countries may currently use MB for QPS, which is not shown in this chart, because QPS is not included in official consumption. Countries that have reported zero MB consumption for controlled uses since 1990 are defined as countries that have not used MB.

3.6.5. Small, medium and large consumers

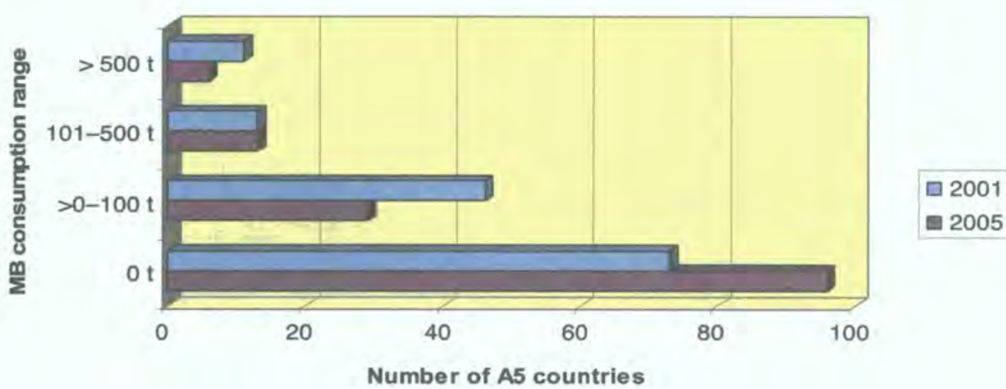
Table 3.12 shows the diversity of MB consumption patterns in Article 5 countries. In 2005 the distribution of small, medium and large consumers was as follows:- 87% of Article 5 countries consumed 0-100 tonnes, while 9% consumed 101-500 tonnes, and only 4% consumed more than 500 tonnes. The number of large consumers (>500 tonnes) has decreased from 11 countries in 2001 to 6 countries in 2005.

Table 3.12. Number of small, medium and large consumer countries, 2001 vs 2005.

MB consumption per country	Number of Article 5 countries	
	2001	2005
0 tonnes	73	96
Small: > 0 – 100 tonnes	46	29
Medium: 101 – 500 tonnes	13	13
Large: > 500 tonnes	11	6
Total number of countries	143	144

The data in Table 3.12 is graphically illustrated in Figure 3.14 and compares the number of large, medium and small consumer countries in 2001 (pale bars) and 2005 (dark bars). It shows that a number of Article 5 countries changed from being small consumers (consuming up to 100 tonnes) to non-consumers (consuming 0 tonnes MB), and some large consumers became medium sized consumers in this 4-year period.

Figure 3.14. Number of small, medium and large consumer countries, 2001 compared to 2005.



Source: Database of Ozone Secretariat in November 2006.

3.6.6. Major consumer countries

In the past, 14 Article 5 parties have consumed more than 500 tonnes MB per annum; these countries are listed in Table 3.13 below. By 2005, only six countries remained as large MB consumers (>500 tonnes per annum), together accounting for 58% of the total Article 5 consumption in 2005. All but one of these countries has implemented MLF projects (refer to chapter 6 for information about MLF projects). The exception is South Africa, which is currently preparing a GEF project.

The data in Table 3.13 shows the significant progress has been achieved by most of the large MB consumer countries. Collectively, they reduced MB from a total of 15,087 tonnes in 2001 to about 7,849 tonnes in 2005, almost halving their combined MB consumption in this 4-year period. By 2005 they had eliminated a total of about 11,373 tonnes of MB since their peak level of consumption in the past.

In 2005 these 14 countries reduced national MB consumption to an average of 66% of national baseline. However, three of the countries did not achieve the compliance step of 20% reduction in 2005; in these three cases the national consumption increased substantially after the baseline period, primarily in the melon sector (Guatemala and Honduras) and cut flowers (Ecuador).

Table 3.13. National MB consumption trends in the 14 Article 5 countries which have consumed >500 tonnes per annum, 2005.

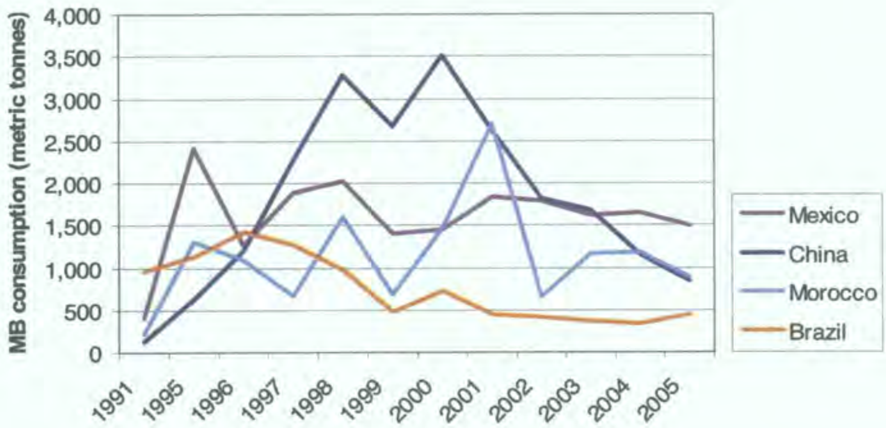
Country [a]	MB consumption (metric tonnes)			2005 consumpt-ion as % of peak year	2005 consumpt-ion as % of Base	MLF project [c]
	in peak year [b]	2001	2005			
China	3,501	2,613	841	24%	46%	Y
Morocco	2,702	2,702	875	32%	75%	Y
Mexico	2,397	1,834	1,485	62%	79%	Y
Brazil	1,408	429	433	31%	37%	Y
Zimbabwe	1,365	907	259	19%	28%	Y
Guatemala	1,311	1,311	871	66%	130%	Y
South Africa	1,007	994	794	79%	79%	N [d]
Turkey	964	379	48	5%	6%	Y
Honduras	852	852	526	62%	122%	Y
Argentina	841	598	475	56%	69%	Y
Thailand	784	485	243	31%	80%	Y
Costa Rica	757	650	430	57%	75%	Y
Egypt	717	717	314	44%	79%	Y
Ecuador	616	616	255	41%	230%	Y
Total of 14 countries	**19,222**	**15,087**	**7,849**	**41% average**	**66% average**	

a. Countries which have consumed more than 500 metric tonnes per annum in database of Ozone Secretariat in November 2006.
b. Maximum national MB consumption in the past
c. Y – country is implementing a MLF project. N – country is not implementing a MLF project.
d. South Africa was not considered eligible for MLF projects, and is preparing a GEF project with the World Bank..

Figure 3.15 below illustrates the trends in consumption in the four countries that have consumed the largest volumes of MB, in the range of 1,400 – 3,500 tonnes per annum historically (China, Brazil, Mexico and Morocco).

Consumption in Mexico and Brazil peaked in the 1990's, while consumption in China and Morocco peaked in the early 2000's. China has made the greatest progress in reducing MB, eliminating 2,660 tonnes in the period from 2000 to 2005. Morocco has also made substantial progress in recent years. Brazil reduced its consumption significantly during the 1990s. In 2005, consumption in the three largest consuming countries showed a downward trend, while consumption in Brazil showed an upward trend, as illustrated in Figure 3.15.

Figure 3.15. Trends in MB consumption in four Article 5 Parties that have consumed the largest volume of MB (>1400 tonnes per annum), 1991 – 2005.



Source: Database of Ozone Secretariat in November 2006.

3.6.7. Assessment of progress in phase-out in Article 5 countries

The trends and indicators analysed above lead to the conclusion that Article 5 countries have achieved substantial progress in reducing and phasing out MB, as illustrated by the following summary of the situation in 2005:-

- Many Article 5 countries have implemented MLF projects and other activities that have led to MB reductions;
- 61% of the Article 5 production baseline has been phased out;
- 41% of the Article 5 consumption baseline has been phased out;
- 80% of countries consumed less than 50% of their national baseline in 2005;
- Of the 95 countries that have used MB, 47 (50%) reached zero consumption by 2005;
- Latin American countries phased out 24% of the regional baseline and 31% of their peak level of consumption (7,030 tonnes);
- African countries phased out 42% of the regional baseline and 56% of their peak level of consumption (5,931 tonnes);
- Asian countries phased out 53% of the regional baseline and 65% of their peak level of consumption (5,025 tonnes);
- Eastern European Article 5 countries phased out 94% of the regional baseline and 95% of their peak consumption (1,245 tonnes);
- Large consumption (>500 tonnes) remains in only six countries; three in Latin America, two in Africa and one in Asia.

Article 5 consumption with respect to compliance:-

- The vast majority of Article 5 countries achieved the freeze in consumption in 2002;
- 94% or 136 of 144 countries complied with the 20% reduction step in 2005; only 8 countries did not comply;

- 87% of countries achieved the 20% reduction step earlier than the scheduled date of 2005.

Status in 2005 of the 14 Article 5 countries that have historically consumed the largest volumes of MB (600 - 3,500 tonnes per annum):-

- The top 14 countries phased out on average 34% of their national baselines;
- These 14 countries eliminated a combined total of 11,373 tonnes of MB since their peak level of consumption;
- They eliminated consumption of 7,238 tonnes in the 4-year period from 2001 to 2005.

Most Article 5 countries have achieved considerable MB reductions at national level, as illustrated by the following information. Further details are provided in Chapter 7.

3.7. Methyl Bromide Use by Sector

The data reported in this section was compiled from several sources. MBTOC estimated the relative proportion of MB use in the soil and postharvest sectors in non-Article 5 countries by examining CUEs that have been authorised by the MOP Decisions and, where available, by national authorisation or licensing procedures.

MBTOC also carried out a survey of Article 5 ozone offices and national experts in countries that reported consumption larger than 30 tonnes of MB in 2005. The survey sample covered about 90% of the Article 5 MB consumption for non-QPS purposes in 2005. Most Article 5 countries that use MB are implementing MLF projects and have carried out national surveys to identify MB uses. As a result the quality of information on MB uses in Article 5 countries is now more reliable than it was in the past. However, some countries were able to provide only estimates rather than national survey data, so the MBTOC survey results in this chapter should be regarded as estimates rather than precise data.

3.7.1. Global overview of fumigant uses

MB has been used commercially as a fumigant since the 1930's (MBGC, 1994). It is a highly versatile product, used in many different applications. MB is mainly used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in high-value crops, and to a lesser extent for the control of insects and rodents in structures, transport and commodities.

The diverse uses of MB as a fumigant can be categorised as shown in Table 3.14. The main categories are soil, durables commodities and structures.

Table 3.14. Main types of MB fumigation.

In soil:	• as a preplant treatment to control soil borne pests (nematodes, fungi and insects) and weeds of high-value crops such as cut flowers, tomatoes, strawberry fruit, cucurbits (melon, cucumber, squash), peppers and eggplant.
	• as a treatment to control 'replant disease' in some vines, deciduous fruit trees or nut trees;
	• as a treatment of seed beds principally against fungi for production of a wide range of seedlings, notably tobacco and some vegetables;
	• as a treatment to control soilborne pests in the production of pest-free propagation stock, e.g. strawberry runners, nursery propagation materials, which in some cases need to meet certification requirements;
In durables:	• as a treatment to control quarantine pests in import-export commodities or restrict damage caused by cosmopolitan insect pests in stored products such as cereal grains, dried fruit, nuts, cocoa beans, coffee beans, dried herbs, spices, also cultural artefacts and museum items;
	• as an import-export treatment to control quarantine pests and in some cases fungal pests in durable commodities such as logs, timber and wooden pallets, artefacts and other products;
In perishables:	• as an import-export treatment to control quarantine insects, other pests and mites in some types of fresh fruit, vegetables, tubers and cut flowers in export or import trade;
In "semi-perishables"	• as a treatment to control cosmopolitan or quarantine insects, to prevent fermentation or inhibit sprouting and fungal development in products that have high (>25% wb) or very high (>90%) moisture contents, for example high moisture dates and fresh chestnuts, and also some stored vegetables, e.g. yams, and ginger;
In structures and transport:	• as a treatment to control insects and rodents in flour mills, pasta mills, food processing facilities and other buildings;
	• as a treatment to control cosmopolitan or quarantine insect pest and rodents in ships and freight containers, either empty or containing durable cargo.

3.7.2 QPS and non-QPS uses

The categories shown above in Table 3.14 can also be divided into two major groups:-

1. Quarantine and pre-shipment (QPS) uses, which were estimated to account for about 38% of MB fumigant use in 2005. These uses are not subject to Protocol reduction schedules. QPS uses include wooden pallets, durable commodities in the import/export trade, transport and some perishable commodities. Further information on QPS is provided in section 3.7.3 and chapter 9.

2. Non-QPS uses, which were estimated to account for approximately 63% of MB fumigant usage in 2005. These uses are controlled under the Protocol in the sense that they are subject to phase-out schedules. Non-QPS uses include soil fumigation, structures (mills and food processing) durable stored products, semi-perishables and some transport. Further information is provided in section 3.7.4 – 3.7.8.

Reliable data is not available for the tonnage used for QPS, however the reported production for QPS purposes was 13,815 tonnes in 2005, and has been used as an estimate of 2005 actual use for QPS in order to estimate the global breakdown of MB fumigant use in 2005, as shown in Table 3.15 below. The non-QPS tonnage was calculated on the basis of the tonnage of CUE uses authorised by the MOP and by parties during the licensing phase and the results of the MBTOC survey of MB uses in Article 5 countries. Using this data, MBTOC estimated that approximately 38% of global use was for QPS (13,815 tonnes), while approximately 63% may have been used for non-QPS. The latter comprised an estimated 56% for soil fumigation and about 7% for postharvest (durable commodities and structures) as indicated in Table 3.15.

Table 3.15. Estimated use of MB for QPS and non-QPS in 2005.

Major sectors	**Estimated MB use in 2005**	
	metric tonnes	**%**
QPS	13,815	37%
Non-QPS comprising:-	23,050	63%
Soil	20,646	56%
Durables	978	3%
Structures	1,426	4%
Total QPS & non-QPS	**36,866**	**100%**

Sources: Reported MB production for QPS in database of Ozone Secretariat of November 2006, CUE uses authorised by MOP Decisions and by parties during licensing, and MBTOC survey of MB uses in Article 5 countries carried out in 2006.

3.7.3. Quarantine and pre-shipment

In 2005 the reported MB production for QPS was 13,815 tonnes. This represents about 36% of total production and an estimated 38% of MB fumigant use in 2005. Overall, the total quantity of MB used for QPS purposes is currently higher in non-Article 5 regions than in Article 5 regions. Two Parties, USA and Japan, used in excess of 1,000 metric tonnes of methyl bromide for QPS purposes in 2004 (USA, 4,115 tonnes; Japan, 1,240 tonnes) (TEAP 2006a). In some individual Article 5 countries the proportion of MB used for QPS is 25% - 100% of national use. In non-Article 5countries that have ceased MB consumption for controlled purposes, QPS now represents all (100%) of national MB use.

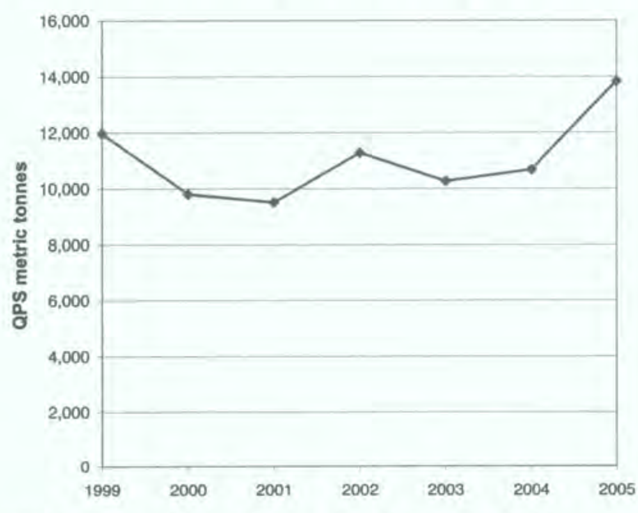
The Ozone Secretariat data indicated that 11,950 tonnes of MB production in 1999 was intended for QPS. When the figures were estimated on the basis of use data in 2000, the estimated range for QPS consumption was 10,600 - 12,300, accounting for about 19 - 22% of global consumption at that time. Thus the production-based and consumption-based estimates were in good agreement, given the uncertainties involved in both estimates.

In the 1990's and early 2000's the use of QPS was reduced substantially in certain countries, as the following examples illustrate:-

- Japan reduced its use of MB for QPS from 2,703 tonnes in 1994 to 1,480 tonnes in 2001 (45% reduction) and 1,165 tonnes in 2005 (57% reduction in total);
- Israel reported QPS of 853 tonnes in 1997 and 319 tonnes in 2000 (62% reduction);
- Mexico reported QPS of 1,252 tonnes in 1997 and 359 tonnes in 2000 (71% reduction).

Global annual production of MB for QPS purposes showed a downward trend from 1999 to 2001 but increased slightly in 2002 and showed a sharp increase in 2005 (Figure 3.16 below) coincident with the widespread implementation of ISPM 15.

Figure 3.16. Trend in reported global production of MB for QPS, 1999-2005



Source: Database of Ozone Secretariat of November 2006.

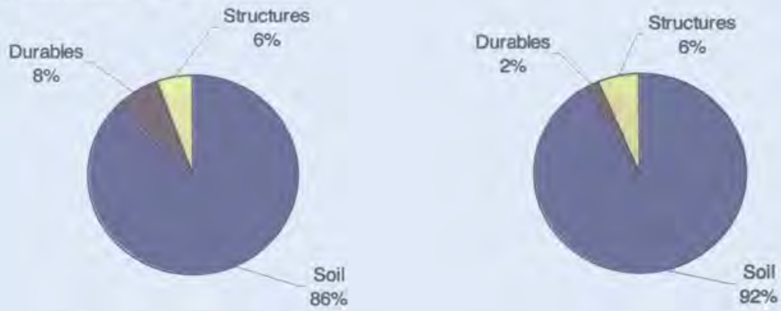
The increase in 2005 represented a 31% increase over the average reported production for QPS from 1999 to 2004. The use of MB for QPS has recently increased in a number of countries as a result of ISPM 15 'Guidelines for Regulating Wood Packaging Material in International Trade' (IPPC, 2002) which came into force in various countries over the period 2004 - 2006 (DAFF, 2007).

A further increase can be expected in QPS production for 2006/7 with further implementation of ISPM 15 using methyl bromide. This international phytosanitary standard covers wood packaging materials, such as pallets, dunnage and crates, made of unprocessed raw wood that may provide a pathway for spreading or introducing injurious forest pests. The standard recognises both heat treatment and MB fumigation as effective control measures.

3.7.4. Non-QPS sectors

MBTOC has estimated that the total non-QPS use can currently be allocated to major sectors as follows: approximately 90% for soil fumigation, about 6% for structures and about 4% for durables in 2005. In non-Article 5 countries the estimated proportions in 2005 were approximately 92% for soil uses, about 6% for structures and about 2% for durables as illustrated in Figure 3.17. The results of the MBTOC survey indicated that Article 5 countries in 2005 used approximately 87% of MB for soil fumigation, 6% for structures and about 8% for durable commodities, excluding QPS, as illustrated in Figure 3.17 below.

Figure 3.17. Estimates of global methyl bromide fumigant use by major sector, 2005, excluding QPS.



Article 5 countries **Non-Article 5 countries**

Sources: Estimates derived from database of Ozone Secretariat in November 2006, MBTOC Survey of MB uses in Article 5 countries in 2005 and CUEs authorised by MOP Decisions and authorised by national authorities.

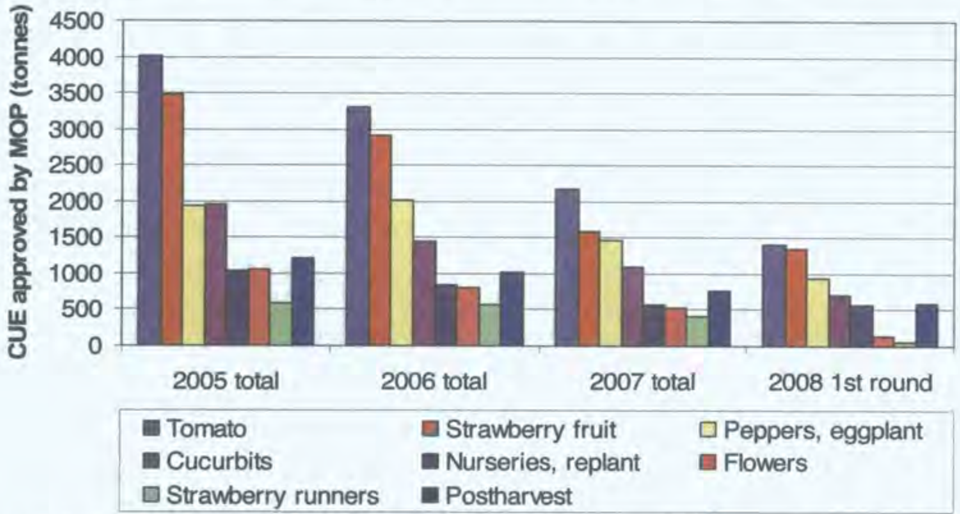
3.7.5. Non-QPS uses in non-Article 5 countries

The remaining controlled uses of MB in non-Article 5 countries are presently allowed as critical use exemptions only. CUEs have been authorised by the Meetings of the Parties for the following crops in specific circumstances: tomatoes, strawberry fruit, peppers, eggplant, cucurbits, ornamentals (cut flowers and bulbs), orchard replant, nurseries, strawberry runners, and several miscellaneous crops.

The postharvest uses of MB comprise specific circumstances in food processing structures such as flour mills, pasta mills, bakeries and other food production and storage facilities, immovable museum artefacts, durable commodities such as dried fruits, nuts, cocoa beans, rice, and other products such as cheese in storage, cured pork products in storage and fresh market chestnuts.

Figure 3.18 illustrates the trends in the CUE tonnage authorised by MOP Decisions for individual major crops and postharvest uses, from 2005 to the first round of 2008. (Some parties made further reductions in the CUE tonnages during the licensing procedures, but these reductions are not taken into account in Figure 3.17.) Substantial reductions in the MOP-authorised tonnage can be seen for all crops in the period from 2005 to 2007. The data for 2008 are not yet complete, but indicate a continued downward trend for all crops and uses except nurseries and replant.

Figure 3.18. Major uses of MB CUEs authorised by MOP, 2005–2008.



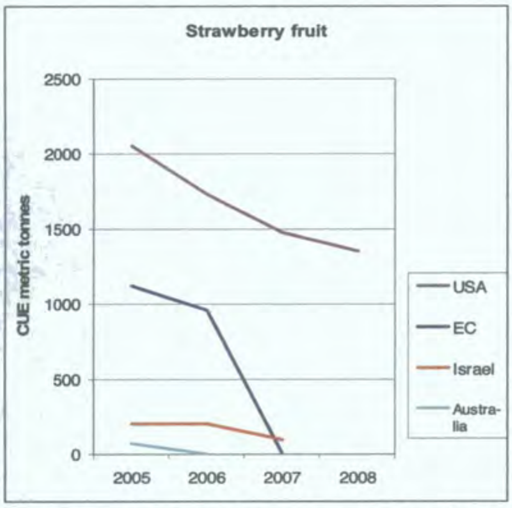
Source: Authorised lists of CUEs in Decisions published in the reports of the meetings of the Parties to the Montreal Protocol 2004-2006.

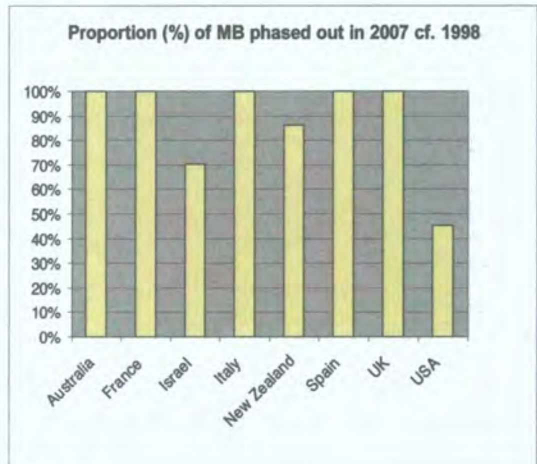
The chart indicates metric tonnes authorised for CUEs by MOP Decisions. Some parties made further tonnage reductions (not shown in this chart) during the licensing procedures.

3.7.6. Major soil uses in non-Article 5 countries

This section examines the trends in the soil uses for major crops in the period 2005-2008. In Figure 3.19, below, the left-hand chart shows the quantity of MB authorised by MOP Decisions for strawberry fruit CUEs in individual parties. (Further reductions in CUEs were made by some parties at the licensing phase but these reductions are not shown in the Figures in this section). The number of countries using CUEs for strawberry fruit was 8 in 2005 and only 3 in 2007 (Israel, New Zealand and US). The total CUE tonnage authorised by MOP Decisions for strawberry fruit was reduced by 55% from 2005 to 2007. Additional reductions were also made at national level during the licensing phase, but are not shown in these graphs. The chart on the right side of Figure 3.18 shows some of the countries that used MB for strawberry fruit in 1998, and the percentage of MB that was phased-out in strawberry fruit in these countries in 2007.

Figure 3.19. Left: Strawberry fruit CUE tonnes authorised by MOP, 2005-2008. Right: percentage of MB phased-out in strawberry fruit, by party, 2007 c.f. 1998.



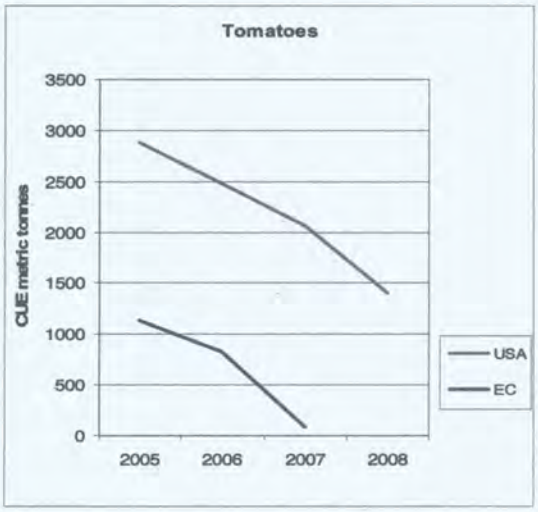


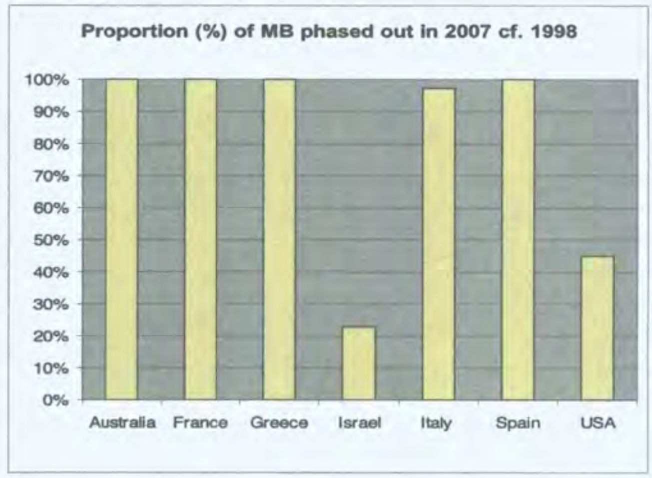
EC countries included are France, Italy, Spain and the UK.

Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol, and 1998 data of historical MB use from critical use nomination documents.

Figure 3.20 shows similar data for tomato CUEs authorised by MOP Decisions. The total CUE tonnage authorised by the MOP for tomato was reduced by 46% from 2005 to 2007. Additional reductions were also made a national level during the licensing phase, but are not shown in these graphs. The number of countries that had a CUE for tomato was 5 in 2005, and 3 in 2007 (Italy, Israel and US). The chart on the right side of Figure 3.19 shows some of the countries that used MB for tomato production in 1998, and the percentage of MB that was phased-out in tomato in these countries in 2007.

Figure 3.20. Left: Tomato CUE tonnes authorised by the MOP, 2005-2008. Right: Percentage of MB phased-out in tomato, by party, 2007 c.f. 1998.

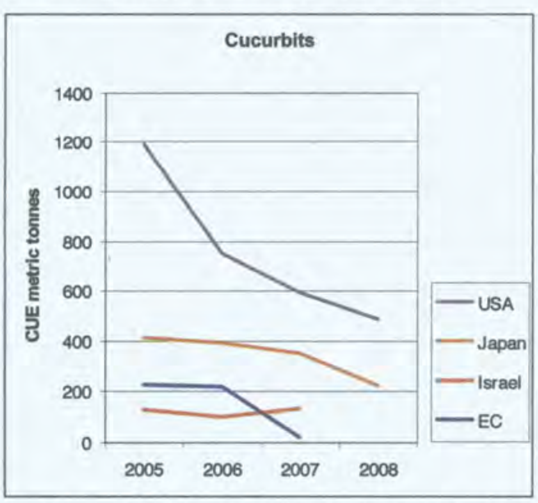


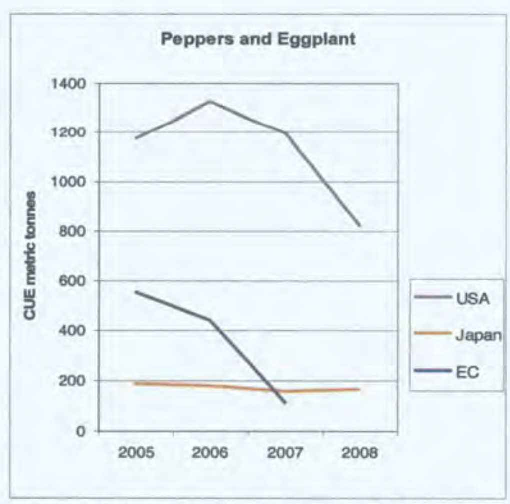


The EC countries were Belgium, France, Greece and Italy.
Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol, and 1998 data of historical MB use from critical use nomination documents.

Figures 3.21 and 3.22 provide a series of charts illustrating the trends in the CUE tonnage authorised by MOP Decisions for other individual crops in 2005-2008, namely cucurbits, peppers and eggplant, ornamentals (cut flowers and bulbs) and orchard replant.

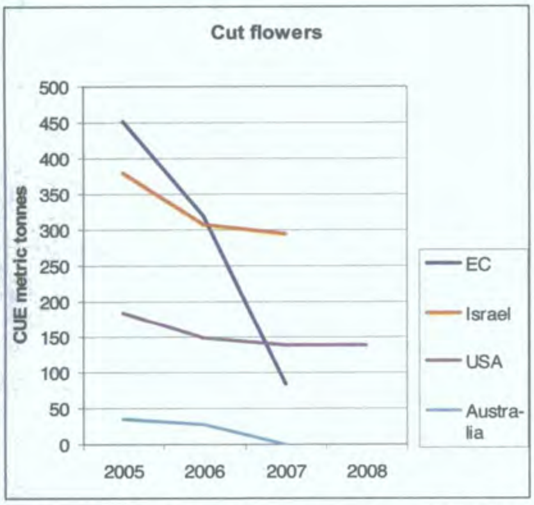
Figure 3.21. Cucurbits (Left), peppers and eggplant (Right) CUE tonnes authorised by MOP, 2005-2008.

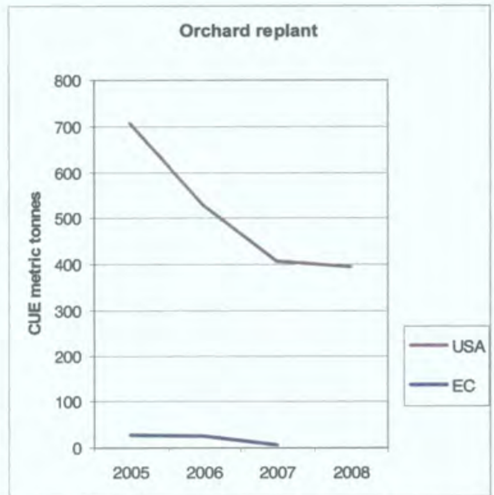




Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol.

Figure 3.22. Cut flowers (Left), orchard replant (Right) CUE tonnes authorised by MOP, 2005-2008.



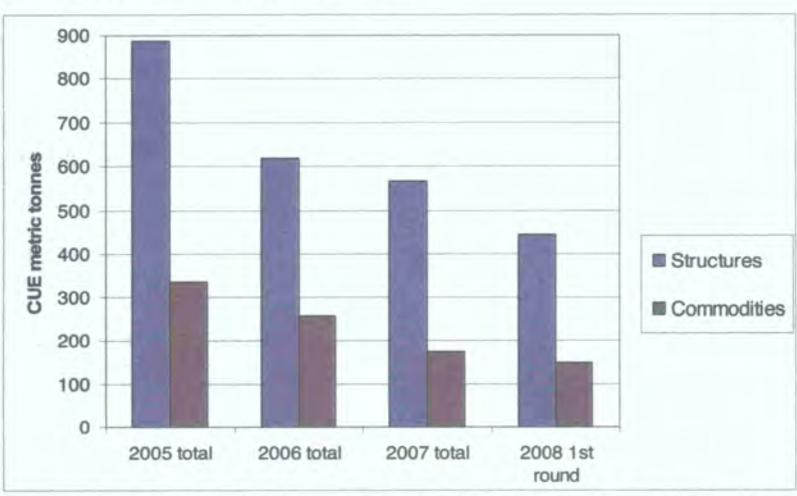


Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol.

3.7.7. Postharvest uses in non-Article 5 countries

Postharvest uses can be divided into structures and commodities. Structures comprised more than 70% of the postharvest CUE tonnage authorised in 2005 to 2007.

Figure 3.23. CUE tonnes for postharvest commodities and structures authorised by MOP Decisions for 2005-2008.



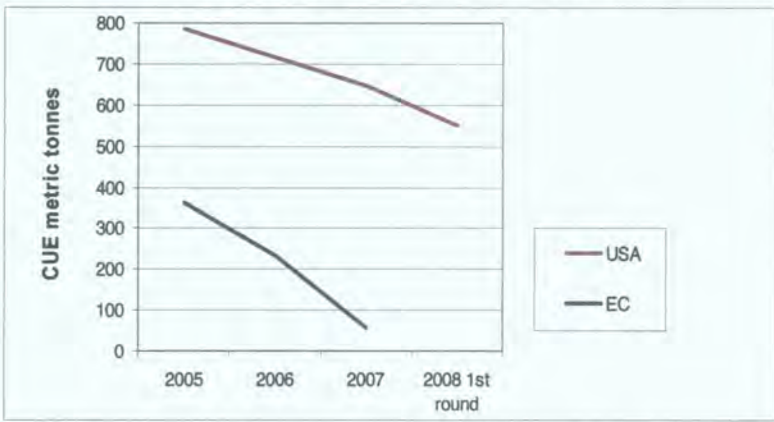
Source: Compiled from MOP Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

Figure 3.23 above illustrates the trends in the CUE tonnes authorised by MOP Decisions (Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13) for structures and for commodities for 2005 to 2008. The data for 2008 may not be complete because there may be further CUNs submitted for that year.

Further, Figure 3.23 shows that both sectors have demonstrated significant reductions; the quantity of MB for structures was reduced by 36%, while the quantity for commodities was reduced by 48% in 2005-2007.

In 2005/6, 16 countries had postharvest CUEs, while in 2007 there were 11 countries. Figure 3.24 below illustrates the trends in CUE tonnes authorised by MOP Decisions (listed above) for structures and commodities combined for parties with CUEs greater than 350 tonnes in this sector.

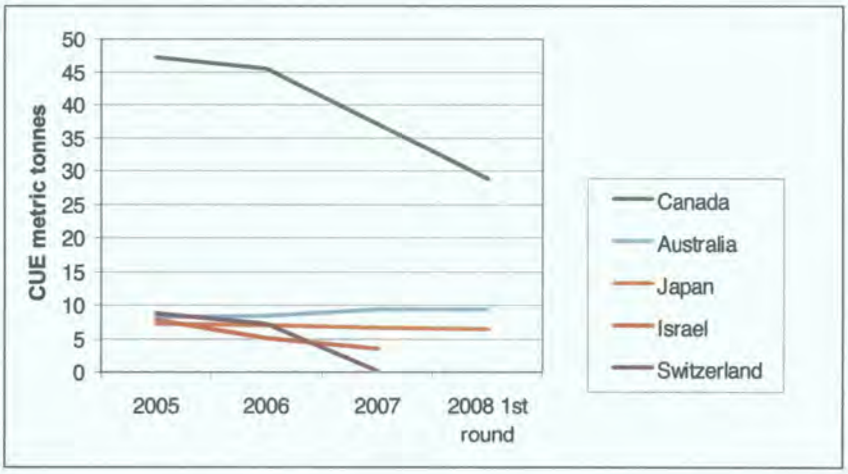
Figure 3.24. Trend in postharvest CUE tonnes authorised by MOP Decisions for parties with CUEs greater than 350 tonnes MB in this sector, 2005-2008.



The EC countries having CUEs in 2005 were Belgium, France, Germany, Greece, Italy, the Netherlands, Poland and the UK.
Source: Compiled from MOP Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

Figure 3.25 illustrates trends in parties with smaller postharvest CUEs. Postharvest CUEs have shown a marked downward trend in the US, EC and Switzerland, and slight downward trend in Japan and Israel. In contrast, CUEs in Australia have increased in this period.

Figure 3.25. Trend in postharvest CUE tonnes authorised by MOP Decisions for parties with CUEs less than 50 tonnes MB in this sector, 2005-2008.



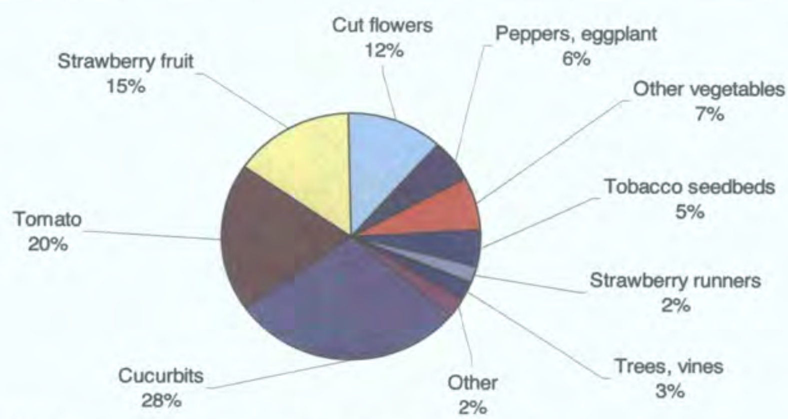
Source: Compiled from MOP Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

3.7.8. Major non-QPS uses in Article 5 countries

This section provides an overview of major non-QPS uses in Article 5 countries. The recent MBTOC survey carried out in 2006, as described in section 3.2.1, identified the major MB uses in 2005 as follows:- approximately 87% was used for soil fumigation (i.e. for treatment of soil before planting crops), approximately 8% for durable commodities and about 6% for structures (excluding QPS). These survey results should be regarded as estimates rather than precise data.

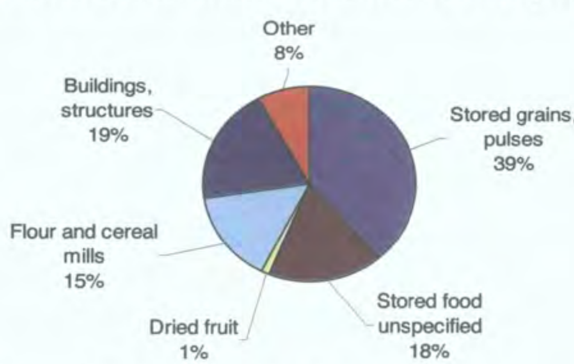
Figure 3.26 presents the survey results for the soil sector in Article 5 countries, indicating that the major crops using MB in 2005 were cucurbits (i.e. melon, cucumber and similar crops) (29%), followed by tomatoes (20%) strawberry fruit (15%), cut flowers (12%) peppers and eggplant (6%), tobacco seedbeds (5%), fruit and forest tress and vines (3%), strawberry runners (2%) and others (8%). A previous MBTOC survey identified the largest Article 5 uses in 2002 to be tomato (23%), cucurbits (20%), tobacco seedbeds (20%), strawberry (15%) and cut flowers (9%). This indicates that substantial reductions have been made in tobacco seedbeds, while use has increased for cucurbits relative to other crops.

Figure 3.26. Soil sector survey results: major crops using MB in Article 5 countries in 2005.



Source: MBTOC survey of MB uses in Article 5 countries, 2005

Figure 3.27. Postharvest sector survey results: major MB uses for durable products and structures in Article 5 countries in 2005 (excluding QPS uses).



Source: MBTOC survey of MB uses in Article 5 countries, 2005

Figure 3.27 presents the MBTOC survey results for the postharvest sector in Article 5 regions in 2005. The results indicate that the major uses were stored grains and dried fruit (about 40%), buildings and structures including mills (about 34%), stored food 18%, and other uses 8%. A previous MBTOC survey in 2002 estimated that about 79% was used for stored grains, other stored products (8%), food facilities/buildings/empty warehouses and transport (2-3%), artefacts (2%), stored timber (1%) and other or unidentified uses (7-8%), according to the survey responses at that time. These results indicate that substantial reductions have been made in MB use for stored grains in Article 5 regions, while the percentage use for buildings and structures appears to have increased. However, it should be noted that the survey results are estimates and do not provide precise data.

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Chapter

4

Reducing methyl bromide emissions

4.1 Introduction

Methyl bromide is a gas at normal ambient temperatures (boiling point: 4°C). During a fumigation some of the gas becomes sorbed on the treated materials and components thereof. Treated materials in 2006 include soils; various commodities such as cereal grains, timber and wooden packaging materials; and structures such as flour mills. Some of the sorbed material remains unchanged and will air off at the end of the treatment, but a portion of the sorbed material is converted into nonvolatile residues. Except for this portion, all the methyl bromide applied during a fumigation will eventually be emitted to the atmosphere, unless special measures are taken.

The phase out of MB under the Montreal Protocol has emphasised protecting the ozone layer from the destructive effects of MB through a schedule of progressive reductions in production and consumption of MB. The Parties have taken several explicit decisions calling for steps to minimise emissions of MB where there are exemptions from this phaseout – Critical Use Exemptions (Decision IX/6) and exemptions for QPS use (Article 2H). Decision IX/6 states in part that critical uses should be permitted only if "all technically and economically feasible steps have been taken to minimise the critical use and any associated emission of MB". Decision Ex.II/1 also mentions emission minimisation techniques, requesting Parties "…to ensure, wherever MB is authorised for critical-use exemptions, the use of emission minimisation techniques such as virtually impermeable films, barrier film technologies, deep shank injection and/or other techniques that promote environmental protection, whenever technically and economically feasible." Decisions VII/5(c) and XI/13(7) that urge Parties to adopt MB recovery and to minimise emissions for QPS MB treatments, where technically and economically feasible. There is opportunity for Article 5 countries to adopt emission control technologies during progress towards full phase-out of MB, where such technologies also reduce quantity of MB needed for a particular use or treatment, as is usually the case..

This chapter makes a best estimate of the level of emissions for the uses of MB as at 2005, the first year of full phaseout of MB for fumigation in non-Article 5 countries (with exemptions for Critical Uses and QPS). It also updates on new developments in reducing emissions of MB, particularly the use of barrier films and reduced dosages for soils, and the potential for recapture, recycling and destruction for commodity and structural treatments.

During any fumigation operation there are three distinct sources or opportunities for MB to be emitted to the atmosphere:

i. By leakage during the actual fumigation treatment.
ii. During discharge of the excess non reacted MB gas during venting of the fumigated space immediately after fumigation of commodities or structures or removal of the plastic sheets after soil fumigation
iii. Following treatment when the treated soil, commodity or structure slowly emits any adsorbed MB over a number of days or weeks.

The first and to some extent the third situation can be controlled or reduced by better containment of the fumigation site (Section 9.3 (soil treatments) and 9.6 (commodities)). Leakage in these instances is undesirable from the fumigation perspective as it reduces the effectiveness of the treatment as well as having worker safety and local air quality implications.

The second situation can be controlled by a reduction in MB dosage applied or by recapture of the MB (recovery) followed by recycling, reclamation or by destruction (Sections 4.8 and 4.9). For most fumigation operations, venting following fumigation results in the largest potential discharge (emission) to the atmosphere.
Section 4.2 estimates the global amount of MB emitted from current uses; Section 4.3 considers opportunities for reducing MB application rates and finally Section 4.9 discusses constraints to their implementation.

4.2 MB Emissions from Current Uses for Soil, Commodities and Structures

4.2.1 Total emissions of methyl bromide from fumigations

All the MB applied in a fumigation will be released to the atmosphere excepting that which reacts irreversibly with treated materials (e.g. soil components, commodities or structural materials) or which is recaptured and destroyed. Since there is insignificant use of recapture and destruction at this time (<100 tonnes was destroyed in 2005) to influence significantly global emissions, the only 'sink' within the MB fumigation process is a reaction to give inorganic, nonvolatile bromide ion.

There is remarkably little firm quantitative field data available on this production of bromide ion or other measures of loss of MB from particular systems. For the purposes of this report, as in previous Assessments, MBTOC has relied on some particular data for specific situations and estimates provided by MBTOC members. Minor adjustments have been made to these factors since they were first used in the 1994 MBTOC Assessment Report. Ranges of estimates are given. These are used to encompass both the true variability to be expected with different sites, techniques and situations and also the range of opinions expressed by experts within MBTOC. An approximation of the quantity of MB lost to the atmosphere has been made by integrating this information over the total usage of MB (Table 4.1.) Supporting calculations for some of the emission levels used in these calculations are given in previous MBTOC Assessments (MBTOC 1994;1998).
Table 4.1 includes estimates for emissions from five types of application to soils. The variation given in two of these is wide and reflects the range of data available to MBTOC experts. It is not possible to provide a weighting of figures within these

ranges to give a precise average emission as the distribution of emissions over the global range of practices cannot be estimated because of lack of data. However, it may well be that the true value differs from the average value of the range quoted.

The overall usage figures given in Table 4.1 are derived from a combination of reported 2005 global production for QPS, usage in 2005 in Article 5(1) countries estimated by MBTOC survey (Chapter 3, Section *3.7.6*) and 2005 use in non-Article 5(1) countries as authorised for CUE purposes (Chapter 3, Section *3.7.5*). The usage figures for the individual sectors are based on tonnages estimated from these data sources. Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 46 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 59 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 75%, or 27,601 tonnes based on estimated use of 36,866 tonnes in 2005.

The mean estimated emissions in 2005 are substantially less than when MBTOC last carried out this estimation previously using 2000 year estimates (Fig. 4.1.). There have been substantial reductions in usage for soil fumigations, counterbalanced to some extent by increases in fumigation of timber and wood packaging materials treated as a requirement to meet Quarantine and Preshipment requirements. It appears that the usage on perishables was overestimated in previous MBTOC Assessments.

Table 4.1. Estimated global usage of MB and emissions to atmosphere for different categories of fumigation by major use category, including QPS use.

Type of fumigation and commodity/use	**Estimated usage**		**Estimated emissions**	
	tonnes	%	Tones	% (*a*)
Enclosed space - durables				
Grains, dried fruit, other dry foodstuffs.	4,005	10.8	2,043 – 3,565	51 - 89
Timber and wooden packaging	8,244	22	7,255	88
Subtotal - durables	*12,249*	*33*	*9,298 – 10,820*	*76 – 88*
Enclosed space – structures	1,426	3.9	1,190 – 1,372	90 – 98
Enclosed space – perishables	1,400	3.8	1,283 – 1,397	85 – 98
Soil fumigation				
Soil injection, shallow with PE tarp or 'hot gas'	17,504	47	7,001–16,103	40 – 92
Soil injection – deep without tarp	706	1.9	565	80
Small cans – with PE tarp	2,479	6.7	1,983– 2,280	80 – 92
Soil treatment, with LPBF(*b*)	1,102	3.0	386 – 959	35 – 87
Subtotal - soil fumigation	*21,790*	*59*	*9,935 – 19,907*	*46 – 91*
Total estimated fumigant use	**36,866**	**100**	**21,706 – 33,496**	**59 – 91**
Best estimate over all categories			27,601	75 (*c*)

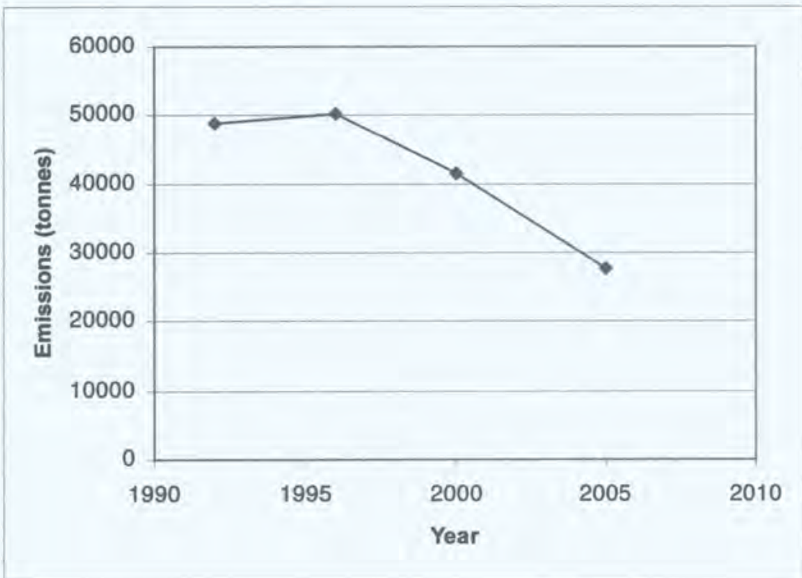
a For original sources of estimates, see MBTOC (1995;1998; 2002)

b Fluxes of MB through LPBF tarps are very low, but loss can occur after lifting the tarp. This is very dependent on the duration of tarping and the soil type and conditions (Yates, 2005; Fraser *et al.*, 2006). Experimentally, very low emissions can be obtained (e.g. 6%, Yates, 2005).

c MBTOC recognises that the true value of emissions may differ from this best estimate.

Calculations based on QPS production data, authorised CUE use and MBTOC survey of Article 5(1) consumption and use, excluding feedstock. Reported use of stocks included. No allowance for unreported use.

Figure 4.1 Weighted mean estimated emissions of methyl bromide from fumigations, including QPS. Data for 1992, 1996 and 2000 from MBTOC Assessment Reports of 1994, 1998 and 2002.



4.2.2 Methyl bromide reaction and measurement

A proportion of any applied dosage of MB reacts with the treated material. Treated materials include soil, grain, fruit or the associated structures and packing materials. The end product of this reaction is typically non-volatile bromide ion and various methylated products. These have not been identified as ozone depleters. The proportion of non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere. The proportion emitted is found by difference. This 'mass balance' approach is typically used to estimate quantities of MB released to atmosphere from a treatment. It gives a conservative estimate and is simple to use as bromide ion tends to be easily detected and quantified. An allowance must be made for natural bromide ion already present prior to treatment.

An alternative approach is to observe the quantities emitted directly. This is experimentally difficult as it relies on quantification of a number of fluxes of gas and may miss some important ones. The approach tends to underestimate the emissions, but is often used in soil fumigation studies.

The proportion of applied MB converted to fixed residues and thus not released to the atmosphere, varies widely with the particular treatment situation. It is influenced, *inter alia*, by the degree of gastightness (sealing, permeability of the enclosure) and the temperature, moisture content and reactivity of the treated material (e.g. soil, commodity). With soil fumigation, the mode of application is also a major factor since it influences the contact time between the MB and substrate and thus the opportunity for varying degrees of reaction and dispersion within the soil before loss from the system.

4.3 Emission Reduction through Better Containment

Improving the gastightness of a fumigation treatment can provide three potential pathways for reducing the emission of MB. These are:

i) by limiting the release to the atmosphere of any MB leaking during the treatment,
ii) by allowing lower initial MB dosages or MB top-ups to be applied, and
iii) by prolonging the effective fumigation period allowing increased opportunity for breakdown of MB on the commodity, structure or substrate.

4.3.1 Soil fumigation

It is generally understood, that MB emissions to the atmosphere from soil fumigation can come from any of three major sources:

i) MB emitted through plastic sheets during fumigation;
ii) MB lost from edges during fumigation; and
iii) MB emerging from soil after lifting the sheets after fumigation.

The total emitted is unlikely to be 100% of that applied because of breakdown of applied MB in the soil. Degradation is due to reaction with soil organic matter and some mineral constituents as well as other reaction pathways such as hydrolysis (De Heer *et al.,* 1983). It is estimated that in practice emission ranges from is 40-92% from the standard polyethylene (PE) and 35 - 87% for barrier films (Table 4.1). Under experimental conditions with full tarping, not strip treatment, and extended exposure periods, emissions can be reduced to as little as 6% of applied MB (Yates, 2005).

4.3.2 Use of barrier films and other plastic covers to reduce emissions

Studies under field conditions in a number of regions (Table 4.2), together with the large scale adoption of barrier films in Europe (e.g. VIF), support the use of these films as a means to reduce MB dosage rates and emissions. Controlled studies have also shown substantial reductions in MB emissions (Wang, 1997; Yates, 2005; Fraser *et al.,* 2006). Summaries of earlier studies were presented in the 1998 and 2002 MBTOC Assessment Reports, Table 4.2. shows the relative efficacies of trials conducted on a range of crops with different types of barrier films compared to the standard polyethylene films. These results confirm that barrier films allow for substantial reductions in dosage of MB applied. Recent studies have shown that barrier films can almost completely reduce the flux of MB though films (Yates, 2005). Fraser *et al.* (2006) stated that a VIF barrier film and a semipermeable barrier film (metallised with aluminium) were 6 to 9 times more effective in blocking MB flux to the atmosphere.

Table 4.2 shows that typically equivalent effectiveness is achieved with 25 –50% less MB dosage applied under the LPBF films compared with normal polyethylene fumigation films. Recent advances in the cost and technical performance of barrier films, especially metallised polyethylene films have reduced cost and extended their suitability for use with MB and also some of the alternatives. Previous difficulties with sealing and gluing barrier films are no longer seen as a technical barrier to implementation of barrier films as new application technologies (i.e. glues, polyethylene edges and perforated films) have solved earlier problems, such as encountered by Fennimore *et al.* (2006) at least for some products.

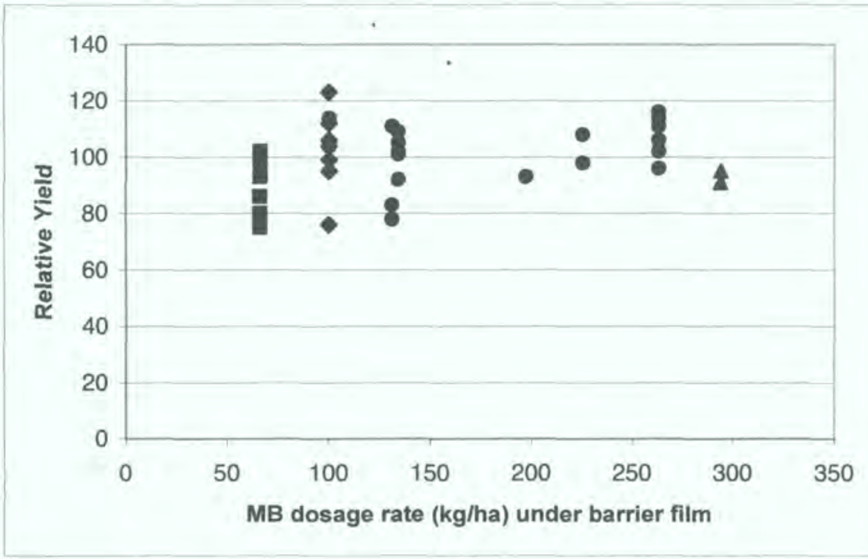
The use of low permeability barrier films (VIF or equivalent) has been compulsory in the member states of the European Union (EC Regulation 2037/2000) since 2000. In most other regions LPBF films are considered technically feasible. The State of California in the US, however, has a regulation which prevents implementation of VIF (California Code of Regulations Title 3 Section 6450(e)). It was implemented because of concerns over possible worker exposure due to altered flux rates of MB when the film is removed or when seedlings are planted. The regulation is under review at the time of writing this report.

Table 4.2. Relative effectiveness of MB/Pic formulations applied in combination with low permeability barrier films compared to the commercial standard MB/Pic formulation applied under standard low density polyethylene films (from MBTOC 2006).

Country	Region	Commodity	Brand or Type of Barrier Film	Untreated	Methyl Bromide/Chloropicrin Mixtures (Product rate per treated area)													Notes	Reference
					Std film		Barrier Film - Relative yield compared to standard polyethylene												
				Yield	MB/Pic Formuln.	Product Rate	Not Spec	98:2	98:2	67:33	67:33	67:33	67:33	67:33	67:33	50:50	33:67		
						kg/ha	300	400	300	98	196	200	294	336	392	200	200		
MB Dosage rate (g/m2)								392	294	66	131	134	197	225	263	100	66		
Spain	Vinderos	Strawb. Runner	VIF – Not Spec	74	50:50	400											93	Fusarium, Phytophthora, Pythium, Rhizoctonia and Verticillium	De Cal *et al.* 2004
	Navalmanzano			78	50:50	400											80		
Spain	Vinderos	Strawb. Runner	VIF - Not Spec	68	50:50	400										114	102	Fusarium, Cladosporium, Rhizoctonia	Melgarejo *et al.* 2003
	Navalmanzano			34	50:50	400										76	75		
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec		50:50	400											97	2003 results	Lopez-Aranda *et al.* 2003
	Malvinas				50:50	400											99		
Spain	Valencia	Strawb. Fruit	VIF - Not Spec	59	Not Spec	600	94											1998 Fusarium At 10cm & 30cm	Bartual *et al.* 2002
				53	Not Spec	600	93											1999 results	
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec	80	67:33	400										112		Meloidogyne and weeds (unspec.)	Lopez-Aranda *et al.* 2001a
	Tariquejo			54	67:33	400										106			
Spain	Moguer/Cartaya	Strawb. Runner	VIF - Not Spec		50:50	392										99		Inoculum not specified	Lopez-Aranda *et al.* 2001b
Spain	Cabeza, Nav.	Strawb. Runner	VIF - Not Spec	74	67:33	400						105, 92						1998 Two sites	Melgarejo *et al.* 2001
	Arevalo, Nav.			84	50:50	400										104, 104		1999 results, nurseries	
	Vinaderos, Nav.			49	50:50	400										95, 123		2000 results, nurseries	
Spain	Huelva	Strawb. Fruit	VIF - Not Spec	82	67:33	400						101						1997-1998 Inoc.unspecified	Lopez-Aranda *et al.* 2000
				72	67:33	400						102						1998-1999 Inoc. Unspecified	
				68	67:33	400						109						1999-2000 Inoc. Unspecified	

Spain	Moncada	Strawb. Fruit	VIF - Not Spec	60	98:2	600			95									1998 No major pathogens but Fusarium buried 10cm&30cm.	Cebolla *et al.* 1999
				54	98:2	600			91										
France	Douville	Strawb. Fruit	VIF - Not Spec	65	Not Spec	800		99										Inoculum not specified	Fritsch 1998
NZ	Havelock North	Strawb. Fruit	VIF - Not Spec	83	67:33	500								98				Phytophthora present	Horner 1999
USA	Florida	Pepper	VIF Plastopil	69	67:33	392					78							Nutgrass	Gilreath *et al.* 2005
			VIF Plastopil	69	67:33	392				99								Present	
			VIF Vikase	69	67:33	392					83								
			VIF Vikase	69	67:33	392				86									
USA	Florida	Strawb Fruit, Cantaloupe	Barrier - Pliant, Metallised		98:2 67:33	Trials on 18 Commercial Farms between 2000-2004; no increase in disease or weeds when rates reduced up to 50% under VIF wrt. Polyethylene												Nutgrass and pathogens present	Noling and Gilreath 2004
USA	California	Strawb. Fruit	VIF - Not Spec	72	67:33	336								108				Inoculum not specified	Ajwa *et al.* 2004
				80	67:33	392									96				
USA	Florida	Tomato	VIF - Not Spec	31	67:33	392					111		93		114			Nutgrass and rootknot nematodes	Hamill *et al.* 2004
USA	California	Strawb. Fruit	VIF - Not Spec	75	67:33	392									106			Watsonville, high pathogen pressure	Ajwa *et al.* 2003
				83	67:33	392									111				
				65	67:33	392									102				
USA	Florida	Tomato	VIF - Not Spec		67:33	392	"No significant reduction in yield"												Noling *et al.* 2001
USA	California	Strawb. Fruit	VIF - Not Spec	45	67:33	364									116				Duniway *et al.* 1998
Unweighted averages (relative % yield)				66			94	99	93	93		102		103	108	104	91		

Figure 4.2. Relative yield of crops (strawberries, tomatoes, peppers, cantaloupes) grown under barrier films with different MB/Pic formulations compared to the standard commercial treatment using standard polyethylene from trials between 1998 and 2004



▲MB/Pic 98:2; ● MB/Pic 67:33; ♦ MB/Pic 50:50; ■ MB/Pic 33:67. Data from Table 4.2..

4.3.3 Correct application of barrier films to reduce emissions

Barrier films consists of either 1) multi-layer laminates with outer layers of low density polyethylene and a barrier layer of polyamide or ethylene vinyl alcohol, or 2) a mixture of these materials, often called an "alloy" or 3) two layer, metallised polyethylene films. Barrier films reduce MB emissions from soil fumigation by keeping the MB in the soil to allow for degradation (Yates *et al.* 1998) when:

- The entire field is covered with VIF film;
- All film strip over-laps are well glued and sealed;
- The VIF film edges are sealed (buried under soil);
- The MB is injected deeply in the soil;
- The film is kept on the field, completely sealed, for 10 to 20 days; and
- The soil temperature, moisture and organic matter content are optimal - medium temperatures, moist soil, and high organic matter.

Barrier films are less effective at reducing MB emissions from soil fumigation (Rice *et al.*, 1996; Thomas, 1998; Wang *et al.*, 1999) when:

- Only part of the field is covered with VIF;
- Any of the film strip over-laps become unglued or are otherwise unsealed;
- Any of the film edges anywhere around the field become unsealed;
- The film seal is broken before 10 to 20 days have passed; and
- Soil temperature, moisture, organic matter are in any way sub-optimal (hot, soil dry or very wet with little organic matter).

Studies have shown that, with traditionally laid plastic films, most unreacted MB either passed through the films or was emitted from the edges of the film (Yates, 2005). In general fumigation films remain in place for 5 to 7 days and with standard films this ensures maximum effectiveness of the applied dose. With barrier films, even though lower doses of MB are used, longer periods of tarping may be required to ensure complete degradation of MB dosage applied and to effectively reduce MB emissions and avoid off gassing.

4.3.4 Adjustments of dosage rates in MB/Pic formulations to reduce emissions

One key strategy to reduce MB dosage and therefore relative emissions has been the adoption of MB:Pic formulations with lower concentrations of MB (e.g. MB:Pic 50:50, 30:70 or less). These formulations are considered to be equally as effective in controlling soilborne pathogens as formulations containing higher quantities of MB (e.g. 98:2, 67:33) (e. g. Porter *et al.*, 1997; Melgarejo *et al.*, 2001; Lopez-Aranda *et al.*, 2003). Formulations containing high proportions of chloropicrin in mixtures with MB have been adopted widely by non-Article 5 countries to meet Montreal Protocol restrictions where such formulations are registered or otherwise permitted. Their use can be achieved with similar application machinery which allows co-injection of MB and chloropicrin or by use of premixed formulations. Consistent performance has been demonstrated with both barrier (Table 4.2.) and non barrier films. Fig 4.2. demonstrates the reduction in dosage rates achievable with barrier films compared to standard fumigation films

4.3.5 Other cultural management methods to reduce emissions

Irrespective of what surface barrier is used to contain MB during soil fumigation, there are a number of key factors which affect emissions of MB during soil fumigation. Recent reports (Yates, 2005; 2006) have shown that manipulation of many other factors can reduce emissions of applied MB, but the extent to which these factors are practiced by industry is unreported.

They concluded that emissions can be reduced by improving containment of the MB gas and by increasing degradation time, however natural soil degradation is insufficient to reduce fumigant emissions to the atmosphere. Methods to improve containment included barrier films as discussed above, but also improvements in cultural factors of the cropping system including soil management, e.g. strip verses broadacre treatment, increased containment time, addition of sulphur containing fertilizers, increasing organic matter, soil water content, soil compaction and surface sealing with water.

4.3.5.1 Soil characteristics

Studies of MB degradation in various soil types have shown that soil type greatly affects degradation, depending upon the time the MB is held in the soil. High organic matter and soil water content and increasing bulk densities are major factors which assist reduction in emissions (Gan *et al.*, 1997; Thomas, 1998; Yates, 2005).

4.3.5.2 Fumigation period

Tarps left on soil for longer periods increase the resident time MB is in the soil, thereby decreasing emissions. Wang *et al.* (1997a) demonstrated that emissions were reduced from 64% with PE tarps to 37.5% with VIF over a 5 day exposure, and from 56.4% to <3% respectively for a 10 day exposure with a sandy loam soil.

4.3.5.3 Irrigation, organic amendments and fertilisers

MB emissions can be reduced if the air filled porosity of the soil is reduced by increasing the water content. The presence of water increases the hydrolysis of MB to bromine ions.

Irrigation reduces the variability in the distribution of MB in the soil, thus achieving a more reliable fumigation result (Wang *et al.*, 1997a).

In laboratory and field studies Yates, (2005, 2006) reported that the use of ammonium thiosulphate fertilizer added to the surface of soil could reduce emissions from 60 to less than 10%, and irrigation and surface sealing with water were an inexpensive way to reduce emissions.

The above results supported earlier work that addition of nitrogen fertilisers and organic amendments enhance degradation of MB. Lime, ammonia fertiliser and ammonia oxidation bacteria also increased the degradation rate of MB in soil (Ou *et al.*, 1997; Gan *et al.*, 1997). These products have been shown to enhance degradation of MB. However, further research is required to identify their use for emission reduction.

4.3.5.4 Soil surface structure

A light rolling (pressing) of soil immediately after shank application closes furrows and seals the soil surface. This decreases direct emission from the injection points (channelling) within the first 24 hours after application and may assist reduction of total emissions (Anon 1997). Yates (2005) showed that surface compaction could reduce emissions from 90 to 64% of the applied MB.

4.3.5.5 Depth of injection

Emissions of MB can be reduced by injecting the material deep into the soil. The extent of the reduction depends upon soil conditions. For example, in field and laboratory studies, increasing the depth of injection from roughly 25 to 60 cm resulted in a 40% decrease in emissions under tarped conditions (Yates *et al.*, 1996). In laboratory studies, it was shown that increasing injection depth delays the occurrence of maximum volatilisation flux and also decreases cumulative emissions (Gan *et al.*, 1997; Yates, 2005). The deeper the MB is injected the lower the emissions. Deeper shank injections increased the path distance, thus increasing the residence time for degradation (Wang *et al.*, 1997ab) and minimising emissions.

4.3.5.6 Broadacre vs. strip

Strip fumigation (bed fumigation) can reduce the amount of MB applied by 20-40% as only the crop rows are treated rather than the entire field. This technique is common in many vegetable crops and most strawberry crops outside California. However, the 'edge effect' predominates and losses of MB from the edge of the bed tends to offset some of the advantages of strip fumigation with regard to emission reduction.

4.3.6 Regulatory practices to reduce MB emissions from soil

There are a number of practices in use in various parts of the world that result in reduced MB emissions from soil treatments, including:

- Limiting the frequency of MB fumigation by requiring intervals of 12–60 months between treatments. Alternative treatment methods could be implemented in the intervening period such as IPM, steam, solarisation, alternative fumigants and predatory fungi treatments. Reductions of 17–50% are feasible by implementing a reduction in fumigation frequency (refer to Table 8.1 in Anon. 1997). Reductions of >75% are feasible when other methods of pest control are used in combination.

- Use of MB only when pests are shown to be present at potentially damaging levels. In the UK, diagnostic tests are available for *Verticillium dahliae, Pythium* spp. and *Plasmodiophora brassicae* and diagnostic tests are being developed for the *Rhizoctonia solani* fungi; in New Zealand, indirect tests have been adopted for monitoring replant diseases using old season root stock and soil and comparing against a healthy standard; nematodes and pathogens are monitored in the USA; in South Africa proof of diseases is needed in order to use MB in orchards.
- Imposing permit systems which could ensure that only technically necessary fumigation would be carried out (e.g. The Netherlands in 1981, Belgium 2005). The criteria for permits could be proof of: (a) disease present and (b) that other pest control options have been examined. An organisational structure is needed to support this.
- Reducing doses by combining MB with other treatments in addition to LPBFs, e.g. solarisation or biological controls (see Chapter 5 - 'Alternatives to Methyl Bromide for Soil Treatments').
- Adjusting pesticide controls. For instance, Italy in 1994 reduced the maximum dosage to 60 g m^{-2} and in 1998 Spain introduced a maximum rate of 40 g m^{-2} and 20 g m^{-2} when used in combination with LPBFs. Anon (1997) indicated substantial emission reductions if pesticide authorities reduced permitted MB doses (usually 50–60%).
- Regulating the users of MB to contractors only and licence and train operators responsible for fumigation.
- Where possible, shifting practices from 'hot gas' methods using high concentrations of MB to soil injection that uses mixtures of MB/chloropicrin at lower MB concentrations, or substitute other chemical and non chemical treatments.

4.4 Structural and Commodity Fumigation

Post-harvest disinfestation of commodities using MB is performed either in fixed-wall structures such as fumigation chambers, or under gastight tarpaulins.
Controlled conditions allow manipulation of the key fumigation parameters: dosage, temperature and time. Greater control is potentially more achievable in an enclosed structure than in relatively uncontrolled field situations. The dosage can be reduced by increasing either the temperature or the time, or both, providing the commodity is able to tolerate the conditions. Forced air circulation allows reduction of the dosage through reducing the range of dosages experienced within the enclosure and thus reducing the need for high dosage rates.

Developing high temperature schedules, with or without longer fumigation durations, could also reduce MB use providing the marketability, including food safety of the produce is acceptable. Improving the gastightness of fumigation facilities will minimise leakage of MB into the atmosphere. Simple test criteria have long been available to the industry for determining the gastightness of chambers (Bond, 1984) and these are part of the mandatory fumigation requirements for export of many perishable commodities.

More accurate measuring equipment to weigh MB will minimise excessive use of MB. This equipment could also be attached to equipment used for fumigation from small cylinders (e.g. 5 kg). A system for decanting weighed dosages of MB from stock cylinders to small receivers for precise dosing of enclosures has recently been developed.

A combination of gases, e.g. MB with carbon dioxide and phosphine, allows a reduction in MB. The mixture is less phytotoxic to cut flowers and ornamentals than MB or phosphine alone and has the same insecticidal activity. Reduced emissions can also be achieved by using reduced MB dosages in combination with carbon dioxide and/or heat. The MAKR™ system (Sansone, 1994) is an alternative treatment that combines MB and carbon dioxide to reduce MB dosage from 24–36 g m^{-3} to 8 g m^{-3}. By adding 10% carbon dioxide, the amount of MB required is reduced by 50–66%. The carbon dioxide is heated, expanded and introduced into a structure with MB. The effects of carbon dioxide are twofold: it provides more efficient dispersion of MB into all parts of the structure; and increases the toxicity of the MB, perhaps by increasing the respiration rate of insects, reducing the amount of MB needed to eradicate the infestation.

Mixing MB with other gases such as pure phosphine may also allow a significant reduction in MB concentration. For example, effects of MB, phosphine and a mixture of MB and phosphine were tested on satsuma mandarins (*Citrus reticulate*). No injury was observed on fruit at 48 g m^{-3} of MB for 2 hours at 15, 20 and 25°C and mixtures of 14 g m^{-3} of MB and 3 g m^{-3} of phosphine for 3 hours at 20°C (Akagawa *et al.,* 1997). However, waxed fruit were damaged when fumigated with the mixture. This research demonstrates that half the dose of MB could be feasible compared to the use of MB alone.

4.5 Fumigant Recapture

4.5.1 Efficiencies and potential quantities of MB available for recapture

For maximum 'recapturable' MB from a fumigation, losses within and from the system must be minimised. During any fumigation operation there four distinct opportunities for MB to be lost or emitted to the atmosphere:

i. By leakage during the actual fumigation treatment.
ii. During venting of the fumigation space immediately after fumigation or removal of the cover sheets where a deliberate discharge to the atmosphere takes place.
iii. Following treatment when the treated commodity or structure slowly emits any sorbed MB.
iv. By reaction when sorbed MB is converted irreversibly to nonvolatile products

Situation (i) and, to some extent, (iii) can be controlled or reduced by better containment of the fumigation site. Leakage in these instances is undesirable from the fumigation perspective as it reduces the effectiveness of the treatment as well as having worker safety implications. A proportion of any applied MB reacts with material within the fumigation enclosure. The product of this reaction is typically non-volatile bromide ion and various methylated products.

These have not been identified as ozone depleters. The proportion of added non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere, provided an allowance is made for natural or added bromide ion already present prior to treatment. Only the remaining MB is available for recapture and/or destruction.

The proportion of applied MB converted to fixed residues, and thus not released to the atmosphere, varies widely with the particular treatment situation and treated material. It is influenced, *inter alia*, by the mass of material within the enclosure (the filling ratio) and its temperature and moisture content, and the exposure time. Longer exposure periods, higher temperatures, higher moisture contents and greater mass of material all lead to lower potential recapturable MB.

MB may be temporarily and reversibly lost from the gas space within the fumigation enclosure through physical sorption on or in materials in the enclosure. This includes dissolving in fats and oils, surface adsorption and capillary condensation. In a fumigation it typically takes a few hours to approach equilibrium for this reversible sorption. Subsequent to the intentional exposure to the fumigant, the sorbed MB may volatilise from the treated commodity quite slowly, sometimes taking several days to reach low levels of emission. The rate of sorption and desorption is strongly dependent on the materials treated, their state and their dimensions.

There is remarkably little firm quantitative field data available on the production of bromide ion or other measures of loss of MB from particular systems that could be used to estimate the maximum total quantity of MB available from fumigations. The general overall potential for recovery from enclosed space fumigation, such as almost all QPS treatments, can be estimated from the total emissions expected. Table 4.3 gives such emissions for some QPS situations. These figures include sorbed MB.

Table 4.3. Estimated emissions of MB to atmosphere for different categories of enclosed space QPS fumigation.

Type of fumigation and commodity/use	Estimated emissions
	%
Enclosed space – durables	
Grains, nuts, dried fruit etc.	51 - 89
Timber, pallets, wooden packaging	88
Enclosed space – structures	90 – 98
Enclosed space – perishables	85 – 98

Extracted from Table 4.1.

As an approximation, most postharvest and structural fumigations have at least 85% of the applied dosage present at the end of the fumigation as MB in some form, including that lost by leakage. Fumigations of oily and high protein materials, such as nuts or oilseeds, may have 50% or even less available. The proportion of this theoretical limit that can actually be recaptured depends mainly on leakage from the enclosure during the fumigation.

TEAP (2002b) estimated that about 86% of the applied MB used in commodity and structural (space) fumigations remained as unreacted MB in some form at the end of the fumigation exposure period. This figure of 86% implies an average loss by reaction of 14% of applied dosage. In practice some leakage is inevitable and the time required for total desorption may be excessive. On the basis that 15% (8% loss from leakage, 6% residual material and other inefficiencies) of the originally applied material is lost from the system under best practice, TEAP (2002b) estimated that 70% of applied material could be recovered from structure, commodity and QPS fumigations. The actual figure achievable in practice will vary substantially from this average figure according to the particular situation.

Since the material that reacts irreversibly with the commodity or structures does not contribute to emissions, and the reversibly sorbed material will eventually be released and is thus potentially recapturable, the only losses from the system relate to leakage and ventilation losses. With these less than 10% per day from well sealed systems (see below), there is theoretical potential for reduction of MB emissions of more than 90% of the quantity applied through adoption of recapture and efficient containment. Almost all QPS treatments are carried out under conditions that could potentially lead to a reduction in over 90% of applied dosage being emitted to atmosphere, though this would need adoption of substantially improved containment compared with much current practice.

On the basis of 70% recapturable MB, about 9,000 metric tonnes of MB emissions from the 2005 worldwide production of about 13,000 tonnes of MB for QPS purposes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment (TEAP 2002b).

Worldwide many fumigations are conducted in poorly sealed enclosures, leading to high rates of leakage and gas loss. It is not uncommon to find <10% of applied MB present after a 24 h exposure, particularly with structural fumigations. For maximum potential for recapture, many fumigation enclosures would need substantially improved sealing to restrict leakage to a low level. Banks and Annis (1984) estimated loss rates of as low as 5 to 10% per day were achievable in most structures with appropriate sealing.

In good fumigation practice, such as specified by AQIS (2006), there is a residual gas level present after a fumigation. Table 4.4 gives the residual gas levels expected at various times.

Table 4.4. Minimum concentrations of methyl bromide remaining at various times for quarantine fumigations (AQIS 2006).

Time after dosing (h)	Minimum % concentration remaining
0.5	75
1	70
2	60
4	50
12	35
24	30

These values are aimed at achieving effective kill under practical quarantine conditions. They are not specifically targeted at achieving minimum emissions (losses by leakage) during fumigation. They provide a guide to what is typically achieved in good current commercial practice. With better sealing levels, relative MB concentrations remaining, even at long exposures, can be substantially improved. The figures underlie the need to minimise exposure periods if it is desirable to achieve maximum potential for recapture.

These minima represent minimum recapturable MB. They do not take into account desorbable MB. This may be as much as 50% of applied dosage with sorptive materials. Treatments of perishables are typically for less than 4 hours, but timber and durables may be exposed for 24 h or longer, to allow for full distribution and penetration of the fumigant.

Recent modifications (IPPC 2006) to the ISPM 15 standard for treatment of solid wooden packaging materials in export trade have set an increased retention of 50 % of the initial standard dosage at the end of an extended fumigation period (24h) (Table 4.5.) If this standard were typically met in practice, as is possible with good sealing and process, the potential for recapture would be increased compared with the earlier version of the standard. In practice, some fumigators are adding extra MB at the start of the ISPM15 fumigations to compensate for high leakage so that specified minimum concentrations at the end of the exposure are met. This process uses additional MB and reduces the proportion of MB added that is in practice available for recapture.

Table 4.5. ISPM 15 standard for treatment of solid wood packaging material. Dosage rates and final concentrations specified in the modification of the standard endorsed in April 2006 (IPPC 2006).

Temperature	Dosage (g/m3)	Minimum concentration (g/m3) at 24h:	% retention at 24 h
21°C or above	48	24	50
16°C or above	56	28	50
10°C or above	64	32	50

4.6 Efficiency of Recapture

The efficiency of recapture/destruction can be described in several ways. For dilute MB sources, the same general concepts may be applied as for dilute CFC sources. These are the overall Destruction Efficiency (DE), the Recovery and Destruction Efficiency (RDE) and the Destruction and Removal Efficiency (DRE). Decision XVII/11 specifically requests information on DRE. These various measures of efficiency of destruction, and thus ozone protection, are defined (TEAP 2002, a, b; 2005, a, b) thus:

- Destruction Efficiency (DE) is determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical that is released in stack gases, fly ash, scrubber water, bottom ash, and any other system residues and expressing that difference as a percentage of the mass of the chemical fed into the system.
- Destruction and Removal Efficiency (DRE) has traditionally been determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical alone that is released in stack gases, and expressing that difference as a percentage of the mass of that chemical fed into the system.
- Recovery and Destruction Efficiency (RDE) is given by the quantity of the chemical destroyed in the destruction system as a percentage of that present in situ prior to the start of the destruction system. This measure includes losses in segregation, decommissioning, mechanical recovery and incineration or other destruction process.

With specific regard to MB from fumigation, the DRE is a measure of the recapture/destruction process itself, while the DE is a measure of the complete process. It includes losses from leakage and reaction on the commodity, as well as inefficiencies in removing the substance (MB) from the fumigation enclosure for input to the recapture/destruction system.

Efficiency of destruction (DE) of MB from a fumigation can be expressed thus:

$$DE = R1 * 100 / M1 = (M1 - L - R2 - R3 - R4) * 100 / M1,$$

where M1 is the initial charge of MB introduced into the system, R1 is the gas quantity retained by the recapture or destruction system, L is the quantity lost during the fumigation by leakage or reaction, R2 is the residual free gas left in the enclosure after extraction of MB into the recapture system, R3 is the remaining sorbed gas, and R4 the quantity of MB transiting the recapture/destruction system or lost by leaks in the system.
In practice, it may be better to measure efficiency of recapture on the basis of recapture of the gas present at the end of the fumigation, without allowance for leakage during the fumigation or loss by reaction. The latter is not recoverable and is, effectively, destroyed.

Thus the net efficiency of recapture (DRE) becomes:

$$DRE = R1 * 100 / M2 = (M2 - R2 - R3 - R4) * 100 / M2,$$

where M2 is the total gas left in the fumigated system at start of recapture.

In practice, M1 and R2 are easy to measure and R1 can be estimated by analysis. M2 can be approximated from the remaining free space concentration in the fumigated enclosure at start of recapture. L and R4 are difficult to measure directly, but are not required for direct estimates of efficiency.

4.7 Commercial and Developmental Processes for MB Recapture, Destruction or Recovery

A number of techniques have been proposed or investigated for their potential to recapture MB after fumigation operations. In some cases the recaptured MB is recovered in liquid or gaseous form, but usually the MB is subsequently destroyed or released by further processing after recapture. Versions of all the approaches given below are, or have been, in some commercial use.

In addition to the processes below, use of bacteria that oxidise methyl halides, including MB, has been suggested for decomposition of MB (Miller *et al.* 1999; 2003). The system is likely to be impractical for elimination of large quantities of MB (> a few kilos), though may have potential for removal of trace quantities. The bacteria may also be useful and possibly naturally present in landfills where MB-containing materials may be dumped.

4.7.1 Sorption on activated carbon

Activated carbon can adsorb relatively large amounts of MB. MB capacities vary with carbon type, conditions and tolerance for quantities of fumigant transiting through the system. Capacities of up to 30% by weight are said to be achievable at low temperatures (10C) (Snyder and Leesch, 2001), but in practice maximum loadings are likely to be around 5 – 10%. Sorption is temperature dependent, with less MB sorbed at higher temperatures. The sorption is exothermic (Leesch *et al.*, 2000). At low loadings, almost complete and rapid removal of MB from an air stream is easily achievable. Publications on carbon for MB recapture do not typically specify the type of carbon used. It appears that carbon derived from coconut husk is typically used. This is a microporous carbon that is widely used for removal of organic contaminants from air streams. It had the highest capacity of the three types of carbon tested by Leesch *et al.* (2000). Leesch *et al.* (2000) and Snyder and Leesch (2001) give mathematical descriptions of MB loading as a function of temperature and moisture content of the carbon.

Although there has been much research into the potential use of activated carbon with MB, there are only a few commercial fumigation installations worldwide which have or have had activated carbon beds installed specifically to recapture MB.

Recapture units in commercial operation with carbon beds for MB recapture are summarised in Table 4.6. In addition to the units described in Table 4.6, a further system has recently completed proving trials and is available for commercial use. Details are not available for the two units installed in the Los Angeles port area designed principally for recapture of MB from fumigations of cotton. Since MB is easily released from a carbon-based absorption system, all these units have potential for recycling of the captured MB. There are several constraints to actual reuse of captured MB from fumigations (see Section 4.9). Only one of the systems given in Table 4.6, that in Szczecin, actually reuses the MB captured. The others are designed with destruction of the recaptured fumigant.

Nordiko (Nordiko 2006, TEAP 2006) have developed an efficient system for recapture of fumigant MB on activated charcoal, followed by destruction with aqueous sodium thiosulphate solution. This system is in commercial use at several Australian sites. Typical efficiencies (TEAP 2006) of destruction (DRE) for the Nordiko system are claimed to be high (>99.8%), with overall efficiencies (DE) of about 70%for the applications described in TEAP (2006).

Table 4.6. Operating efficiencies and costs per kg of methyl bromide destroyed for some commercial carbon-based recapture systems.

System	Location	DRE (%)	DE (%)	Cost ($US/kg destroyed)	Projected cost ($US/kg destroyed)	Data source
Nordiko, Chamber for timber treatment	Raymond Terr., NSW, Australia	>99.9	71-77	21-24	11-12	TEAP 2006
Nordiko, clip on unit for containers	Prospect, Tasmania, Australia	>99.9	61-69	28-30	15-17	TEAP 2006
Nordiko sustem, for general fumigation under Tarp	Tasmania, Australia (mobile unit)	>99.8	58-75	5.8-7.6	3.2-4.2	TEAP 2006
Twelve chamber unit for general cargos	Rotterdam, Netherlands	>99.9	60-72	17	11 (2)	EcO_2 (pers. com.)
Ruvoma treatment chamber for strawberry runners	Aalsmeer, Netherlands	>99.9	50-60	17	27	EcO_2 (pers. com.)
Chambers for coffee and cocoa bean treatment	Szczecin Swinoujscie, Poland	(1)	n/a	n/a	n/a	Kozakiewicz (pers. com.)
MBECP, CHAMBERS	Dallas/Fort Worth and Bush International Airports, Texas; Well-Pict Berries, Watsonville, California, USA	95	94	31.84	-	TEAP 2006

(1) about two-thirds of the applied methyl bromide is recovered.
(2) The complex is designed for >20 years lifetime.
n/a = not available

The Polish installation (J. Kozakiewicz, pers. com.) is equipped with a carbon bed with hot air regeneration of the absorption bed. The released gas is reused as a fumigant on new batches of commodity, typically imported cocoa beans, with losses made up by addition of new MB. About two-thirds of the original charge of MB is recovered for reuse.

In the Desclean system (Spruyt *et al.*, 2006; E. Williame pers. com.), at an advanced stage of development in Belgium, MB fumigant is recaptured on a cooled carbon bed held in a transportable cartridge. The MB can be released for reuse by heating the carbon bed. The carbon beds can be stored at low temperatures to retain absorbed MB until it is required. The low temperature storage reduces the decomposition of the stored MB on the carbon beds. The process recovers more than 80% of the MB applied to an empty shipping container.

MBTOC (1995) reported that there were five 30 m^3 chambers in the Netherlands (one transportable) each with a 70 kg filter of activated carbon. Fumigation at 30 g m^{-3} was carried out and a 40 - 50% recovery of applied MB was achieved. The activated carbon lasted for 40 fumigation cycles and the spent carbon containing the adsorbed MB was incinerated in a special incineration facility. There was also a 30 m^3 chamber in Thailand fitted with a 72 kg bed of activated carbon. The chamber was used for fumigating asparagus and green okra exported to Japan. The system was capable of reducing MB concentrations in the vented gas to 5 ppm v/v within 30 minutes. The fully charged activated carbon was disposed of in a sanitary landfill.

An activated carbon system was developed by Rentokil, UK for use with their fumigation bubble, a well sealed plastic tent enclosure used for fumigation of small quantities of material. The 10 kg activated carbon bed held up to 1.5 kg MB. Regeneration of the activated carbon was achieved by blowing hot air through the bed, resulting in direct emission of the desorbed MB to the atmosphere. It was designed only to prevent emissions that might endanger people in the immediate vicinity of the fumigation operation not as a means of elimination of MB emissions.

Very large activated carbon beds containing tonnage quantities of carbon would be required for the fumigation of large structures or enclosures such as mills or grain silos. Large scale pilot studies (Smith, 1992) have demonstrated technical feasibility of the process, including recovery of the sorbed MB, with up to 95% of recaptured gas available for reuse. In Mannheim, Germany, a large, new flour mill, 35,000 m^3 volume, was equipped with a prototype carbon-based recapture system (Stankiewicz and Schreiner, 1993; MBTOC 1998). The system was transportable. In commissioning operations (September 1994), 1.26 tonnes of MB was applied to the mill. At the end of the fumigation 0.565 tonnes remained in the mill, the rest presumably being lost by leakage. Of this, 0.325 tonnes was recaptured and 0.180 tonnes eventually reclaimed for reuse. The recycling process was too slow for normal mill operation. Removal of the MB from the carbon was achieved by a combined temperature/pressure swing system. Electrothermal desorption was investigated as an alternative.

A process developed in the USA uses activated carbon to capture MB followed by thermal destruction (Knapp *et al.*, 1998; Leesch *et al.*, 2000). A small commercial unit is in operation at Dallas/Fort Worth airport capturing MB from quarantine operations (McAllister and Knapp, 1999; TEAP, 2006) and a larger unit in operation at a commercial berry fruit exporter's site in Watsonville, California (Knapp, 2001; TEAP, 2006). Both plants reduce the MB concentration in the fumigation chambers down to a level of 500 ppm, about 2 g m^{-3}

MB, before venting the remainder. Once each plant has processed sufficient MB to fully load the activated carbon beds, they are shipped to Pennsylvania to be incinerated. Efficiencies (DRE) of destruction of MB for both plants are around 95% (TEAP, 2006)

Two plants associated with quarantine fumigation facilities in the Los Angeles port area in USA are equipped with carbon bed absorption systems to prevent MB discharge into the local environment to meet local air quality regulations. Both these facilities treat a diverse range of commodities, including export cotton, using vacuum fumigation. Cotton is typically treated at a high dosage rate (144 g m^{-3} MB), making reclamation a feasible process. The plants were commissioned in 1993 and 1996.

One site uses a system based on a condensation/activated carbon process to recover MB from cotton fumigation for reuse. It has been in use since December 1993. The facility has two vacuum chambers that were retrofitted with a recovery/recycle plant. At the completion of each fumigation operation, the remaining MB is diluted by the addition of air from a single air wash. This diluted mixture is then drawn through vessels where liquid nitrogen cools and condenses most of the MB. The remaining MB and air is passed through an activated carbon bed where most of the remaining MB is adsorbed. Periodically the activated carbon bed is isolated and undergoes a pressure swing desorption to recover the MB for reuse. The plant is designed to recover 98% of the MB available for capture. The fumigation plant, with its condensation and activated carbon recovery system, is reported to meet the strict local air quality requirements. Access to the plant is restricted and no data have been supplied to determine either the level of recovery (emission reduction) or of recycling. It should be noted that very few fumigation chambers used for QPS are designed to operate at the vacuum levels used at this particular site. The capital cost and operating costs are not available, nor are figures for the effectiveness of operation.

The other Los Angeles recovery plant was installed in late 1996 at another cotton fumigation site. It uses ozone (see Section *4.7.5.2*) to destroy the MB in the discharge and air washes from a vacuum chamber. Activated carbon is used to scrub any residual traces of MB from the discharge air stream. Results from two monitored trials indicated that more than 90% of MB used in each treatment was destroyed. The destruction plant is large and has a significant electrical power requirement for the ozone lamps and the blowers. No data are available to determine the impact of the technologies on the cost of the fumigation operation. It is understood that the capital cost of both Los Angeles recovery plants was in excess of US$0.5 million each (MBTOC, 1998).

4.7.2 Sorption on zeolites

Zeolites are a special type of silica-containing material, which has a porous structure that make them valuable as adsorbents and catalysts. They are found naturally and can also be manufactured to precise specifications, such as very narrow pore size distribution tolerances, for specific applications. Developers of zeolite systems hoped to avoid potential problems of contamination of recovered MB with other volatile compounds by utilising the selective sorption that is conferred by a particular pore size range. Zeolites are more expensive than activated carbon. They can have moderate sorptive capacity, a few % by weight, and are particularly suited to removal of low concentrations of MB.

Pilot scale demonstration trials have been carried out to demonstrate the technical feasibility of the technique. These were conducted in Washington, USA, at a large facility packing and fumigating cherries for export. Recovery of MB in excess of 90% was achieved (Nagji and Veljovic, 1994). A similar, but smaller, recovery plant was installed and successfully commissioned at a fumigation facility in Chile. Recoveries of more than 94% of the MB from the fumigation chamber and recycling rates of 87% were achieved. Neither plant is now operational.

The Port of San Diego Authority in 1995 installed a full size prototype plant based on adsorption of zeolite to reduce MB emissions from a 2,100 m^3 quarantine chamber. The system suffered from corrosion problems, not directly associated with the zeolite, and was not adopted.

The process of MB capture on zeolite has been demonstrated on diverse operations such as fumigation of an empty ship hold (Fields and Jones, 1999), shipping containers and a lumber warehouse (Weightman, 1999). Data from the ship hold trials indicate that the process is capable of capturing up to 90% of the applied MB (Fields and Jones, 1999). In an improved version of the process, direct on-site recycling was not attempted. The captured MB was recovered from the zeolite bed and refined in an off-line step (Willis, 1998). This change significantly reduces the complexity of operation of the recovery plant.

To MBTOC's knowledge, there are no MB fumigant scrubbing systems working on zeolite currently in commercial operation.

4.7.3 Recondensation

Because of the low MB concentration in vented gases from fumigations, typically <25 g m^{-3} and its low boiling point/high vapour pressure, recondensation has generally been considered too complex and expensive for recovery of MB. However, it may be appropriate where high concentrations (>120 g m^{-3}) of MB are applied, such as for fumigation against Giant African Snail, some treatments against fungi and some timber fumigations. Recondensation is used in USA to recover MB where it is in a highly concentrated form in the vent gas lines and other equipment associated with decanting fumigant at a bulk handling facility into smaller cylinders for commercial use.

Recondensation is, or was, in use at one facility at the port of Los Angeles, USA. This unusual facility has two vacuum chambers, retrofitted with a recovery/recycling plant. At the time of fitting the system, the facility was for fumigating export cotton. A very high rate of MB, 144 g m^{-3}, was used in this treatment, making recondensation feasible. At the completion of each vacuum fumigation operation, the remaining MB is diluted by the addition of air from a single air wash. This diluted mixture is then drawn through vessels where liquid nitrogen cools and condenses most of the MB. Residual MB is removed on activated carbon. Details are not available for the relative quantities of MB condensed to that subsequently removed by sorption on the charcoal.

4.7.4 Fumigant transfer

At sites where there are multiple vacuum chambers treating large quantities of commodities there is the opportunity to reduce the amount of MB being emitted to the atmosphere by direct transfer of the MB that would otherwise be vented at the end of a fumigation treatment to an adjacent chamber where a treatment is about to commence. There is no intermediate concentration or storage step. This process needs equipment for accurate and rapid measurement of MB concentrations to be available so that the 'topping up' dosage can be calculated to compensate for MB lost through sorption into the commodity and through reactive breakdown. This technique is used at a fumigation facility in the Ivory Coast (Dosso, 1998).

Transfer of residual fumigant in atmospheric pressure facilities is likely to be an inefficient process, with substantial losses associated with transfer inefficiencies from gas mixing and incomplete flushing. Under good conditions about 60% of residual gas might be transferred.

4.7.5 Direct destruction systems

4.7.5.1 Combustion

Research was also carried out in Japan in the 1970s into a direct combustion method and a catalytic cracking method for destroying MB in the vent gas stream from chamber fumigations (Anon., 1976a). Large pilot plants were built to test the techniques, but neither method proceeded to full size installation. The processes were effective at reducing the concentration in vent gas streams down to ppm levels but were not further developed because of the high cost, their unsuitability for stack fumigations (i.e. not transportable), concerns about the use of direct heat when MB can (under very restricted conditions) form an explosive mixture with air and the difficulties of handling the products of destruction (HBr and Br_2).

Catalytic decomposition of MB has been investigated in Japan. Promising results from using new Mn/Cu zeolites indicate that satisfactory levels of destruction can be obtained at quite low temperatures, about 300° C. Trial machines equipped with alumina/precious metal based catalysis for combustion of halogens have been developed in Japan. Although this machine required neutralization using alkali in process, it could decompose MB at lower temperature (ca. 350°C). However, production of such machines for commercial use has been interrupted due to poor demand at present(Nippon Shokubai 2002).

Belmonte *et al.* (2001) patent mixing alkyl halides with a combustible fluid and then oxidising the mixture catalytically.

4.7.5.2 Reaction with ozone

A recovery plant was installed in late 1996 at a cotton fumigation facility at the port of Los Angeles, USA. This facility carries our other fumigations including QPS ones at this time. It uses ozone to destroy the MB in the discharge and air washes the vacuum fumigation chambers. Activated carbon is used to scrub any residual traces of MB from the discharge air stream that have not reacted with the ozone. The system appears to be unique. It was installed to meet strict local air quality requirements.

4.7.5.3 Reaction with nucleophiles (direct reaction)

MB reacts with nucleopliles to produce bromide ion and methylated products. Typical reactive nucleophiles include activated oxygen, sulphur and nitrogen. The reaction occurs when MB reacts with many constituents of foodstuffs and other natural products, giving rise to the bromide residues typically produced in MB fumigations.

Several different nucleophiles have been used on an experimental and pilot scale to recapture and decompose MB after fumigations. MB can be destroyed by reaction with ammonium thiosulphate (Gan *et al.*, 1998), through reaction with one of the sulphur atoms in the thiosulphate. In a US patent, Joyce *et al.*, (2004), propose a scrubber system based on reaction with aqueous thiosulphate, with or without an immiscible organic solvent present to assist trapping the MB. Data in TEAP (2006) and a recent press release (Value Recovery Inc., 2005) suggests that the development is still at prototype stage and destruction (DRE) is about 86% of incoming MB.to the scrubber.

Reaction with aqueous thiosulphate forms the basis of destruction of the MB recaptured on carbon in the Nordiko system (TEAP, 2006).

Amines have been used in several systems, though apparently not at present used commercially. Research was carried out in the 1970s into a technique of liquid scrubbing to remove MB from fumigation operations (Anon., 1976b). The process was developed and tested on timber fumigation under stacks and consisted of equipment to circulate MB and air from the fumigation enclosure through a tank of aqueous monoethanolamine (50%) and back to the fumigation tent. The process achieved 70% reduction in MB concentrations in about 1 hour. The size of the necessary equipment for full scale operation and the difficulties of handling the contaminated liquid material prevented its further commercial development. Ethanolamine was also used in a scrubber developed for removing MB from an exhaust stream from a demethylation process (non-fumigant) (Hettenbach *et al.*, 2002).

A system based on organic amines and alkali for removing residual MB from fumigated freight containers in Russia has been described (Rozvaga and Bakhishev, 1982). Mordkovich *et al.*, (1985) have described a technique using aqueous sodium sulphite as a neutraliser and a mixture of ethylene diamine and sodium carbonate as an adsorbent. Granular and a sheet products, containing a mixture of activated carbon and amines have been developed for use in adsorbing the residual MB that is slowly emitted after a fumigation treatment (Kawakami and Soma, 1995). No information is available on whether these systems achieved commercial use.

4.7.6 Destruction following recapture

4.7.6.1 Combustion

MB has a history of use as a fire extinguisher, discontinued many years ago because of its toxicity. However within narrow limits, 11.5 – 12.5% v/v, it is combustible and explosive when mixed in air at room temperature, when ignited by a high energy spark. The Approved Destruction Technologies given in Annex II to the meeting report of 15MOP, for destruction of halons, such as combustion in cement kilns, can presumably also destroy MB, itself actually a halon, provided toxicity issues can be managed appropriately. This provides a potential method of destruction of impure MB recaptured and then stripped from its sorbent or for stocks of MB surplus to requirements.

It is reported that MB, previously captured on activated carbon or zeolite, can be decomposed in a reactor at 400 – 500 °C with quicklime giving inorganic salts as products (Yahata *et al.*, 2001). A bench scale apparatus has been described that gave MB concentration reductions of 99.99%.

Combustion is used to destroy MB-loaded carbon subsequent to its use in recapture in several systems (see Section *4.7.5.1*)

4.7.6.2 Reaction with nucleophiles following recapture

Recovery and destruction systems are now being sold (Nordiko, 2006) based on MB capture from fumigation operations using activated carbon followed by destruction of the MB and regeneration of the activated carbon using thiosulphate. Once the beds are fully loaded, they are removed and treated by immersion in sodium thiosulphate. The activated carbon beds are prepared for reuse by rinsing and drying in air at <60 C. No off-site or further processing of the spent carbon is required.

MB is not very stable on fresh, activated coconut carbon. At 40°C./21% m.c., it has a half-life of 11h as observed by Gan *et al.* (1995). Gan *et al.* measured kinetics of this hydrolysis under various conditions and attributed the instability to basic impurities in the charcoal. The Desclean recapture (see Section *4.7.1*) system includes a cooling step that allows the hydrolysis of the recaptured MB sorbed on carbon to be minimised, thus maximising the available material for recycling.

4.7.6.3 Landfill

Landfill sites provide highly active decomposition environments. They are capable of slowly decomposing even relatively inert materials, chemically similar to MB, such as CFCs (Altamar *et al.*, 2004). Loaded carbon from some systems is disposed of in landfill sites. Presumably the MB in these carbons will decompose slowly through direct hydrolysis (Gan *et al.*, 1995)reaction with organic materials containing active nucleophiles and possibly through bacterial action such as of the type described by Hancock *et al.* (1998).

4.7.7 Removal of methyl bromide from carbon or zeolite for reuse or disposal.

Recycling processes have the potential to provide a means of reducing total emissions from a range of fumigation operations, and making MB available for uses where MB alternatives are more difficult to implement. Despite the attractiveness of the concept, practical considerations have resulted in destruction systems coupled with use of newly manufactured MB being favoured over recycling.

There are several technical options available for the removal of MB from loaded carbon that yield MB in a form for reuse or condensation for reclamation or recycling. Hot air, steam heating and pressure swing systems have been used. It is technically possible to recycle MB adsorbed on activated carbon by heating the carbon, by passing hot air or steam over it, or by altering the pressure (temperature and pressure swing adsorption). In the hot air system, circulating air strips the MB from the activated carbon. Potentially, the mixture can then be reintroduced into the fumigation chamber. The MB is reclaimed as a high concentration mixture in air, but some topping up will be necessary to compensate for system losses so as to achieve a satisfactory fumigation concentration. Pilot scale studies have demonstrated the technical feasibility of such a process (Smith, 1992) with up to 95% of the recoverable MB being available for direct reuse. Fire risk needs to be managed with hot air systems as the carbon is quite combustible. Use of nitrogen for purging has been suggested.

Electrothermal processes look particularly attractive technically as a means of producing a concentrated MB stream from loaded carbon. A laboratory demonstration of this process is reported in Snyder and Leesch (2001). The newly developed activated carbon fibre cloth (Sullivan *et al.*, 2004) may be more suited (less hazardous) to MB sorption than normal granular carbon. The material can easily be regenerated electrothermally.

MB is relatively easily removed from zeolite by hot air stripping, giving a sufficiently concentrated MB air mixture to permit condensation of the recovered MB for recycling (Willis, 1998) or direct reuse as a fumigant.

An issue with any process aimed at recycling MB is whether the recovered MB is sufficiently pure to be able to be reused as 'pure MB' to comply with the specifications for established quarantine and other fumigations and also whether it can meet the labelling requirements of individual countries to be used as a fumigant. There have been concerns about the purity of recycled MB and, in particular, whether there will be build-up of other gas phase impurities with multiple recovery cycles that may be of concern for the treated products. In the USA and Canada, the original suppliers of the MB have said that they do not regard recovered MB as their product. It is thus effectively 'unlabelled' and requires reregistration before use. In some other countries (e.g. Poland) the MB recovered from carbon absorbant is apparently acceptable for reuse.

Developers of recycling technology have also encountered technical difficulties in designing equipment to perform the recycling step within the time constraints placed on commercial fumigation operations. An alternative approach, adopted by developers of the (now discontinued) zeolite technology, is to transport loaded sorbant to a central facility for reclamation and recycling. Critical aspects of this technique include regulatory implications associated with the transportation and storage of toxic materials and environmental impact (truck fuel, energy use) of transporting equipment containing the loaded beds saturated with MB over some distance to the reprocessing plant. Similar considerations apply to transport of loaded carbon beds to a central destruction point.

4.8 Economics of Recycling and Destruction

There is very little published data on the economics of recapture and destruction/recycling, apart from general statements that the costs can be substantial. Also it is said that the cost of producing a kilo of recycled MB is likely to be much higher than the supply cost of a kilo of newly manufactured MB.

TEAP (2006) gives costs per kilo of MB recaptured and destroyed for some commercial systems. Costs are strongly situation-dependent and subject to economies of scale. With widespread use, costs of recapture and destruction given in TEAP (2006) were projected to be in the range $US 3.2 – 17.0 per kg MB recaptured and destroyed. Current (2006) prices of MB to typical end users exceed $US 15.0 per kg.

Statements on costs of recapture and reuse need to be viewed against a background of rising MB costs with increasing scarcity and regulation, possible production of cheaper recapture systems with widespread and routine use, and regulatory requirements where emission control for MB from fumigations may be part of "the cost of doing business". These regulatory controls could be local air quality and OH&S requirements in addition to any measures required for ozone layer protection.

At present MB prices, reclamation of MB for reuse may be difficult to justify solely on economic grounds, though it may be in future with constrained MB availability and improvements in recapture technologies.

During the development of one carbon-based system it was proposed that users instead of purchasing recovery systems, would be able to buy MB at a higher price that would include the cost of MB recovery, transport and disposal.

Given that the cheapest option, if permitted, will be venting residual MB to atmosphere after a fumigation, and that there are inefficiencies and constraints on the quantity and quality of material that can be recaptured, it remains unlikely that recapture/recycling will be adopted purely on economic grounds. A further consideration, favouring destruction and new supply, is the uncertainties on the suitability and possible additional costs of reclamation to appropriate standards of recycled material.

Economics will tend to favour destruction over recycling in situations where new MB continue to be easily obtained for QPS purposes and destruction technologies are relatively cheap, including allowance for disposal of products of the destruction system. There may be a special case where recycled, 'used' MB can be made available for uncontrolled uses that otherwise would be forced to use non-ODS technologies and have a particular desire to use MB.

4.9 Drivers and Constraints for Adoption of Recapture

Despite Decisions VII/5(c) and XI/13(7) that urge Parties to adopt MB recovery and to minimise emissions for QPS MB treatments, there are no installations known to MBTOC that have been commissioned prior to 2005 specifically for ozone-layer protection. However there are increasing numbers of installations (see Section 4.7), based on active carbon systems that are designed to recapture MB after well-contained commodity treatments.

These units are being attached to MB fumigations in port areas and other urban environments to scrub emissions from fumigations to comply with local regulations for toxic gas emissions, air and environmental quality and worker safety. Some most recent installations may have been at least partly driven by the need to reduce ozone-depleting emissions.

Most of the recovery technologies mentioned above are complex in nature. In many cases, they are likely to be a significant part of the total cost of a new fumigation facility or to contribute significant capital cost or hire costs to apparatus associated with mobile treatment units. Most have significant running costs compared with costs of treatments
Because of the extra costs associated with recapture, it is unlikely there will be substantial adoption by private industry without some incentives or regulatory intervention. Adoption in the absence of such measures or other requirements, such as local air quality specifications, will place early adopters at a competitive disadvantage compared with those that chose not to adopt recapture.

The technologies are unlikely to become widely used to assist ozone layer protection without further international and national economic and regulatory drivers. One possible way forward might be the obtaining of approved destruction process status, as set out in Annex II of the 15MOP, for one or more MB recapture and destruction technologies. The performance data (TEAP, 2006) supplied in response to Decision XVII/11, at least for activated carbon-based systems, may be a sufficient basis for this approval.

An issue with any process aimed at recycling MB is whether the recovered MB is sufficiently pure to be able to be reused as 'pure MB' to comply with the specifications for established quarantine schedules and whether it can meet the labelling requirements of individual countries to be sold as MB for any permitted use.

Developers of recycling technology have encountered technical difficulties in designing equipment to perform the recycling step within the time constraints placed on commercial fumigation operations. An alternative approach, adopted by developers of the (now discontinued) zeolite technology, is to transport loaded sorbant to a central facility for reclamation and recycling. Critical aspects of this technique include regulatory implications associated with the transportation and storage of toxic materials and environmental impact (truck fuel, energy use) of transporting equipment containing the loaded beds saturated with MB over some distance to the reprocessing plant. Similar considerations apply to transport of loaded carbon beds to a central destruction point.

Recapture and recycling processes have the potential to provide a means of reducing emissions from a range of fumigation operations, and making MB supplies available as a transitional measure for uses where MB alternatives are most difficult to implement.

4.10 Containment

The aim of containment in the use of MB for the fumigation of structures is to enable reduced dosages to be effective and to reduce emissions to the atmosphere. Containment alone would not normally be considered as a viable possibility to reduce emissions to the atmosphere without effective recovery technology. However, improved containment and monitoring may in fact be considered as a strategy for reducing emissions from structures while maintaining efficacy.

Containment and emission reduction strategies for structures involve: leakage control; extending the fumigation period, while ensuring adequate *ct*-products are achieved; and pressure testing. This aspect of fumigation can be enhanced by improved monitoring of fumigant concentrations and adjusting dosages where they are excessive.

4.11 Emission Reduction through Modification of Treatment Schedules

MBTOC has suggested previously that Parties encourage their regulatory authorities to review their current treatment schedule requirements and confirming that only the minimum amount of MB needed to control pests including QPS pests, are required. A dosage reduction may be appropriate where better containment can be achieved. As an example, cut flowers from Israel consist of many different species, each with differs in tolerance to MB and each with a range of pests of quarantine concern to overseas markets. The MB dosage could be reduced by 2-2.5 times compared to previous schedules, while at the same time avoiding phytotoxicity and controlling three of the main quarantine pests (Kostyukovsky *et al.,* 1998).

However, efforts at dosage-reduction may be negated by other research that continues to increase the dependency on MB. For example, research is still being commissioned in a number of countries to develop MB-based treatments for export crops that will continue to add to the amount of MB consumed for quarantine and pre-shipment treatments.

4.12 References

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Chapter

5

Alternatives to Methyl Bromide for Soils Uses

5.1 Introduction

The 2002 MBTOC Assessment report identified a wide range of methods that were either available, under development, or had some potential to replace or reduce the need for MB treatments of soils. Since 2002, several chemical alternatives, and to a lesser extent non-chemical alternatives, have been accepted widely as commercial alternatives to MB fumigation. Many agricultural sectors have fully adopted these alternatives in a wide range of cropping practices and no longer submit nominations to continue use of MB under critical use provisions of the Montreal Protocol. The fact that MB cannot generally be replaced by one in-kind alternative has been re-confirmed in non-Article 5 and Article 5 regions. This implies that growers and other stakeholders need to change their approach to crop production, which often involves new skills, training and change in time management. Management change is often a major barrier to adoption of alternatives, often more so than economic issues.

This update to our previous reports focuses primarily on the methodologies that have been adopted by significant numbers of users. However, we also describe soil treatments that are effective for managing soilborne pests but may be limited to specific areas by availability of active ingredients, by climatic factors, by cultural practices, by regulations and by economics. Lastly, we briefly detail some emerging technologies that in the future may be available for reducing crop losses originating from soils and substrates. A number of excellent review articles have been published on alternatives to MB use (Duniway 2002; Gullino *et al.* 2003; Martin 2003; Schneider *et al.* 2003; Loumakis 2004; Hannah *et al.* 2005; Rosskopf *et al.* 2005; Santos *et al.* 2006; Chellemi and Mirusso, 2006) and a meta-analysis of over 200 international studies (Porter *et al.* 2006b) compared the relative performance of many chemical and non chemical alternatives used either alone and in combination. The Proceedings of several key symposia and conferences have excellent papers presented which cover the key alternatives to MB (www.mbao.org , http://ec.europa.eu/environment/ozone/lisbon_conference.htm , Vanachter, 2005).

In response to Decision XVI/5, which provided financial support to MBTOC for expert assistance with the assessment of the critical-use nominations, a statistical analysis or meta-analysis study was conducted to analyse MB alternatives for pre-plant fumigation (Porter *et al.* 2006b). This report provides Parties with a technical overview of results from current published research. It provides the statistical best estimate of the relative effectiveness of the major chemical alternatives to MB as determined by analysis of information across a large number of studies in different regions and under different pathogen pressures. Effectiveness was assessed by comparing relative yield of the alternative to the respective MB/ chloropicrin (MB/Pic) treatment. The study took account of both registered and unregistered products and concentrated on two major crops traditionally using MB and for which CUEs have been requested, strawberry fruit and tomatoes. Comparisons were made to peppers, melons, other cucurbits and eggplants where possible. Much of the information for tomatoes (i.e. effect on target pathogens and weeds) was relevant to the outcomes for these other crops. The statistical analysis also includes a detailed assessment of the effect of alternatives for nutsedge under different pressures and the influence of low permeability barrier films across a range of regions and crops.

Analyses from strawberry fruit trials showed that a large number of alternatives used alone or in various combinations had mean estimated yields which were within 5% of the estimated yield of the standard MB treatment (MB/Pic 67:33). Of these, a number of alternatives and MB/Pic formulations (50:50, 30:70) led to results that were similar to MB/Pic 67:33. These included PicEC (chloropicrin), TC35EC (1,3-dichloropropene/ chloropicrin), TC35 and TC35ECMNa (TC35 EC combined with metham sodium) and MI60 (Methyl iodide/chloropicrin), which is undergoing review for registration in several countries.

Analyses from tomato trials also showed that a range of alternative treatments used alone or in various combinations had mean estimated yields which were within 5% of the estimated yield of the standard MB treatment (MB/Pic 67:33). While some of these treatments contained pebulate, a herbicide that is not commercially registered anymore, most treatments did not contain this particular product. Several treatments, PicMNa (chloropicrin combined with metham sodium), 1,3D/Pic in combination with a range of herbicides and MI60 (methyl iodide/chloropicrin) (not registered), provided results similar to MB/Pic 67:33.

5.2 Methyl Bromide Application for Pre-plant Soil Uses

In order to develop appropriate alternatives to MB, it is important to understand how MB is applied and distributed through soils.

MB is a volatile gas at temperature above 4°C which when pressurised exists as a liquid for storage in cans before fumigation. It can be applied by either mechanised injection or manual application as a hot gas or as cold gas from cans.

5.2.1 Mechanical Injection

The main method of application in non Article 5 countries has been the use of mechanised injection rigs, which apply MB at depths of 15 to 30 cm in soil (called 'shallow injection'), followed immediately by tarps applied in strips or broad acre to seal in the fumigant. This is the principal method still used for large scale treatment for critical use applications for the USA, several European countries, Canada, Israel, New Zealand and Australia. This use also occurs in Article 5 countries, such as South Africa, and is being increasingly used in Mexico, Chile, and other countries. The process is either carried out as a broad-acre fumigation where one sheet is glued to the previous one, or under strips of plastic with both edges of the strips buried by the machinery during application to soil. Strip fumigation occurs before many strawberry fruit crops and some vegetable crops (tomatoes, peppers, cucurbits) with strips generally ranging from 0.8 – 1.8 m wide.

A variety of mixtures of MB and chloropicrin are used in this type of fumigation. Until recently the predominant mixture used was 98% MB containing 2% chloropicrin. The chloropicrin was added as a warning agent, not as an active ingredient. With restriction of supplies of MB under the Montreal Protocol there is now a much increased use of formulations of MB with high concentrations of chloropicrin, for example MB/Pic 67:33; 70:30 or 50:50, with the chloropicrin being used as an active agent, mainly for the control of fungi. High concentrations of chloropicrin are in use particularly in non-Article 5 countries, but formulations like these are slowly becoming available in some Article 5 countries.

A second injection method for MB is called 'deep injection' (approximately 80 cm depth) where in this case MB is applied without covering the area with plastic sheets. Deep injection of MB is carried out mainly prior to planting and replanting in deciduous orchards, vineyards and other plantations, mainly in the USA.

5.2.2 Manual application

MB can also be applied manually using simple equipment and application methods. This can be either by prevapourising the gas in a 'hot gas' method or using directly from a punctured can as a cold gas. This involves treating soils, which have been pre-tarped with plastic sheets. This method especially suits small-scale areas or enclosed spaces where machinery is difficult to operate. The main manual method is the so-called 'hot gas' method where liquid MB from cylinders under pressure is vaporised in a heat exchanger and then dispersed under plastic covers over the top of the soil. As MB is a heavy gas it permeates into soil to give control of pathogens and weeds.

Worldwide, this is the principal method of application in Article 5 countries and the predominant method used for fumigating soil in greenhouses (glass and plastic houses). In many Article 5 countries, this method is also widely used for outdoor fumigation. When applied manually, MB is often supplied as a mixture containing 2% chloropicrin, added as a warning agent in many instances to comply with national safety regulations.

The cold gas method is the easiest but can be most inefficient of the methods discussed to apply MB. Parties have reported that this method has been eliminated in most non- Article 5 countries as it was considered dangerous and is only registered in very few Article 5 countries. In fact, fumigation using methyl bromide from disposable cans is banned in a number of countries (e.g. European Union, under paragraph 4 of Article 16 in Regulation (EC) No 2037/2000, South Africa, Chile, Kenya, Morocco). Despite this, cans are still used in several countries because they provide small land holders with an easy application method and the ability to apply targeted amounts of methyl bromide to small areas where injection machinery may be difficult to use in these circumstances. During this method, small steel cans of less than 1 kg capacity are placed beneath thick plastic sheets and then punctured with a specialised device to release the gas into soil. This must be done carefully so as not to damage the plastic barrier and increase risk to the user from MB.

Methyl Bromide can also be applied through drip irrigation lines. The main advantage of applying fumigants via drip irrigation is the improved distribution of the fumigants in soil (Ajwa *et al.*, 2001).

5.3 Chemical Alternatives Adopted Commercially as Replacements to MB on a Large Scale

Since the 2002 MBTOC assessment report there have been some major advances in the commercial adoption of chemical alternatives to methyl bromide. Accumulated data clearly demonstrate the improved consistency of the alternative chemicals for control of target pests and improved crop yield (Porter *et al.*, 2006b). There are a few emerging chemical products under certain levels of development showing potential as replacements to MB, e.g. iodomethane (methyl iodide) is being trialled under permit in USA and Australia, and dimethyl disulfide (DMDS), sodium azide, propylene oxide show promise in combination with other chemical products. On the other hand, some initially promising chemicals included in the 2002 report have seen little further development, e.g. propargyl bromide and are no longer regarded as potential alternatives to MB. In the current situation, single chemical alternatives can be used for some specific pests. However, for pest complexes, combinations of chemicals and/or other pest control methods will usually be necessary, as discussed later in this chapter.

It should be noted that chemical fumigant alternatives in general, like MB, have issues related to their long-term suitability for use. In both the EC and US, MB and most other fumigants are involved in a rigorous review that could affect future regulations over their use. Present regulations on fumigants on area quotas, buffer zones and personal protective equipment are currently under review in USA and registrants are conducting research to reduce the impact of the regulations on use of all fumigants (Houtman 2000; Segawa, 2005). Moreover, in the EC, regulatory reviews and supermarket policies have placed doubts over the long-term future of several fumigant products and this is promoting the search for, and adoption of, more sustainable non fumigant strategies (refer EC Directive (91/414/CEE). Consideration of the long-term sustainability of treatments adopted as alternatives to MB is most important, and as a result non-fumigant alternatives are likely to become increasingly significant in future (in some regions).

Two groups of chemicals are providing alternatives to MB and either have the potential to achieve broad-spectrum control of pests, pathogens and weed seeds or propagative parts more targeted control of specific pathogens. The first group is the fumigants, which provide broad- spectrum control. Fumigants are volatile chemicals, which under typical field conditions exist as gases or as liquids that later convert into gases. For example, when the liquid formulation of metham sodium is applied to soil, it converts to gaseous methyl isothiocyanate (MITC) before further breakdown. Fumigant products are injected directly into the soil as liquids or gases (e.g. 1,3-D, MB and chloropicrin) or as a solid (e.g. dazomet). The second group is composed by non-fumigant chemicals, which kill target pests either by contact action (e.g. ethoprop) or systemic action (e.g. aldicarb, oxamyl, fenamiphos, fosthiazate and cadusafos).

Three major alternatives for preplant soil treatment - 1,3-D/Pic, chloropicrin and metham sodium - either alone or in combination with other alternatives are proving as effective as MB in many situations and continue to be widely adopted as key alternatives in many applications. Formulation changes and more adequate application methods have shown to improve the effectiveness of several alternatives (Pic EC, 1,3-D/Pic EC) and wider adoption has occurred where these are available. In many instances, this has involved a change in cropping practice, and a greater awareness of soil conditions, which improve the efficiency of alternatives. Modifications to application machinery have sometimes been necessary (TEAP, 2006a)

5.3.1 Combinations of chemical alternatives

Research has demonstrated that mixtures of fumigants or sequential applications of these chemicals integrated with or without other non chemical IPM techniques can provide pest control and yield increases which are equivalent to those obtained with MB (Gilreath and Santos 2004; Gilreath *et al.* 2005; De Cal *et al.* 2004; Elmore *et al.* 2003; Gullino *et al.* 2003; Kabir *et al.* 2005; Guo *et al.* 2005; Minuto *et al.* 2006; Porter *et al.* 2006; TEAP 2006a). A recent statistical analysis of more than 160 studies in strawberry fruit and tomato crops has shown that even across a wide variety of countries, climates, soil conditions and different pest pressures that there are still a number of chemical combinations that have been consistently proven to be as effective as MB and therefore should be considered for the remaining uses of MB (Porter *et al.*, 2006).

5.3.1.1 1,3-D/Pic

1,3-D/Pic is a key alternative to MB, which has been widely accepted commercially for the control soil nematodes and fungal diseases. A large number of studies and a recent review of over 160 trials undertaken internationally have shown that these formulations consistently gave yields equivalent to MB (Ajwa *et al.*, 2004; Ajwa *et al.*, 2003; Ajwa *et al.*, 2002; Peguero 2004; Porter *et al.*, 2006).

Formulations of 1,3-D mixed with chloropicrin (TC35 and TC17 which have approx 35% and 17% respectively) are now registered in many countries including Spain and other countries in Europe, the USA, Israel, Australia, Lebanon, Chile, Cuba, Morocco, Colombia, and Costa Rica (Dow AgroSciences 2001; Shanks *et al.*, 2004). Use of 1,3-D and chloropicrin has expanded rapidly for certain crops such as strawberry fruit, melons and ornamental crops, such as carnations. For example, by August 2004 a major MB fumigation company in Italy had converted about 2000 farms to 1,3-D/Pic (applied sequentially since the mixture is not yet registered) comprising 45% of the agricultural area where that company had previously applied MB in the past (Spotti 2004). By 2006, the majority of the industries in Australia and Spain had switched to these formulations as the key alternative to MB (López Aranda 2006; Porter 2006; Porter *et al.*, 2006a). Application costs are similar or less than those compared to MB. Small increases in crop yield may compensate for increases in pest control costs, particularly during the transition when farmers or applicators may need to learn new techniques.

In Japan, various mixtures containing chloropicrin and 1,3-D (40:52 and 35:60) are now registered. An improved application method utilizing this mixture has been reported to mitigate the odour problems associated with chloropicrin (Tateya 2002). 1,3-D/Pic with or without a follow-up treatment of metham sodium has proven effective for strawberries in several countries (Carrera *et al.*, 2004; De Cal *et al.*, 2004; Porter *et al.*, 2004a; Ajwa *et al.*, 2002; 2003; 2004). More examples of this combination are given below.

Limitation: Where registered, the TC-35 formulation is the main fumigant combination presently replacing MB. However, regulatory requirements limit the utility of this combination in some geographic regions. Present regulations on 1,3-D relating to regional quotas (e.g. township caps), buffer zones, restrictions in zones with Karst topography and personal protective equipment are regularly under review in USA and this has partly restricted its uptake as an alternative for MB in California and Florida, USA. Also, application to heavy soils in cold climates (<10°C), 1,3-D/Pic has shown phytotoxicity issues in strawberry runner crops (Mattner *et al.*, 2005).

5.3.1.2 MB/Pic

One key transitional strategy to reduce MB usage for the remaining uses in soils has been the adoption of MB: Pic formulations with lower concentrations of MB (e.g. MB: Pic 50:50 or less). Their use can be achieved with application machinery that allows co-injection of MB and chloropicrin or by using premixed formulations. These formulations have proven equally effective for controlling soilborne pathogens as formulations containing higher quantities of MB (e.g. 98:2, 67:33) particularly when used together with low permeability barrier films (Porter *et al.*, 1997; Melgarejo, 2004; López-Aranda *et al.*, 2004).

5.3.1.3 1,3-D and MITC

Combinations of 1, 3-D and MITC are used in Europe, Canada and other countries (Thomson, 1992). Combination of 1,3-D and metham (also known as metham sodium or methyl isothiocyanate) were shown to increase weed and pest control (Ajwa *et al.*, 2003; Csinos *et al.*, 2002; Jensen, 2001).. Ajwa *et al.*, (2005) have demonstrated that sequential application of metham sodium after reduced rates of 1,3-D/Pic EC or chloropicrin controlled soil pests and produced strawberry yields equivalent to standard MB/ Pic fumigation, without negative effects (Ajwa *et al.*, 2004 a, b).

1,3-D and metham sodium application have shown some limitations due to longer plant back periods, enhanced degradation in some sandy soils and compatibility issues with some fumigants. Repeated use of this combination over a number of seasons led to a reduced disinfestation effect (Zheng *et al.*, 2004; Guo *et al.*, 2005), however this problem can be avoided by sequential application methods (Zheng *et al.*, 2004). Additional research is desirable to increase the potential of these fumigant combinations.

5.3.1.4 MITC and PIC

The combination of chloropicrin and metham, applied sequentially, has gained new interest, particularly in regions where use of 1,3-D is limited by regulatory restrictions. Research has shown that sequential application of metham sodium after reduced rates of 1,3-D/Pic (InLine) or chloropicrin controlled soil pests in strawberry fruit and produced fruit yields equivalent to standard MB/Pic fumigation (Ajwa *et al.*, 2004). Demonstration trials confirmed earlier research that metham can be used to reduce application rates of InLine and pic without a loss in yield in strawberry fruit in California, USA, even though pathogen pressure was severe (Ajwa *et al.*, 2004). Further research on this option is presently in progress (Santos *et al.*, 2006)). True mixtures of these products are presently not available due to chemical incompatibility arising when combining them (Guo *et al.*, 2005). However, machinery has been developed which allows injection of metham sodium and chloropicrin independently without contact during application (Porter *et al.*, 2002) reducing any negative side effects (Guo *et al.*, 2005).

5.3.1.5 MITC, 1,3-D and Pic

Vorlex, containing a mixture of MITC, 1,3-D and chloropicrin, was registered in many countries and remains registered in at least 2 regions. It is highly effective against nematodes, fungi, weeds and soil insects (Thomson 1992). Vorlex is highly active even at low soil temperatures (4°C) but it can be phytotoxic and has long plant back periods (Porter *et al.*, 1999; 2002). The product was withdrawn from registration in the USA in 1992, but is still registered in Canada and recently has outperformed MB for control of pathogens in trials on strawberries in Australia (Mattner *et al.*, 2001). There has been renewed interest of this combination as an alternative to MB where it still has registration (e.g. Canada, Mexico).

Sequential applications of 1,3-D/Pic followed by metham achieved yields greater than MB in 8 studies on strawberry crops (Porter *et al.*, 2006b). This product provided enhanced weed control over the use of 1,3-D/Pic alone.

5.3.1.6 Formalin and metham sodium

A mixture of formalin and metham can extend the spectrum of pathogen control and can result in a synergistic effect particularly on fungal pathogens. The toxic effect of the mixture was seen at greater depths in soil compared with the application of each chemical alone. The formalin-MS mixture controlled *Fusarium oxysporum* f.sp. *radicis-lycopersici*, *Monosporoascus cannonballus*, and *Rhizoctonia solani*, pathogens often difficult to control by many chemical treatments. The synergistic effect was also evident when reduced dosages were applied (Di-Primo *et al.*, 2003; Gamliel *et al.*, 2005). The importance of Formalin-MS mixture is significant in soils where the phenomenon of accelerated degradation of MS occurs. For example, this combination resulted in effective control of Verticillium wilt and other diseases in soil where accelerated degradation and loss of activity of MS was observed (Di-Primo *et al.*, 2003; Gamliel *et al.*, 2005; Tricky-Dotan *et al.*, 2006). As Formalin and MS react strongly when they are mixed together (Zheng *et al.*, 2004) application of these two fumigants must be done from separated containers (Gamliel *et al.*, 2005).

5.3.1.7 Alternative fumigants combined with LPBF

Low permeability barrier films (LPBF) such as VIF (Virtually Impermeable Film) and semipermeable films, are being used in combination with alternative fumigants in several countries. LPBF improves the retention of fumigants in the soil, allowing reduced doses and/or improved efficacy. Reduced doses of 1,3-D/Pic under VIF controlled *Pratylenchus penetrans* and *Meloidogyne hapla* to a similar level as MB/Pic (López-Aranda *et al.*, 2004). US studies have shown that the application of fumigants under LPBF can enhance weed and pathogen control (Ajwa *et al.*, 2004; Gilreath *et al.*, 2005; Gilreath *et al.*, 2003; Hamill *et al.*, 2004; Noling and Gilreath, 2004; Fennimore *et al.*, 2004). LPBF increased the retention of 1,3-D/Pic and resulted in improved control of nutsedge (Gilreath *et al.*, 2004). Studies in strawberry fruit found that the use of LPBF with alternative fumigants (chloropicrin alone, and 1,3-D/Pic) increased the effectiveness of most treatments, with resulting yield increases, compared to the standard PE films used in California, USA (Ajwa *et al.*, 2004). Studies in strawberry fruit in Spain compared MB with 1,3-D/Pic/LPBF, Pic/LPBF and rotovated dazomet/LPBF and found similar control of nematodes and weeds, and similar yield (López-Aranda *et al.*, 2003).

US studies found that the use of LPBF with metham sodium improved its efficacy compared to traditional tarps (Martin, 2001). In China, LPBF with metham applied by drip irrigation was demonstrated to have comparable efficacy to MB (University of Torino, 2006). Researchers in Spain reported that DMDS under LPBF (400 kg ha^{-1}) performed much better than DMDS under LDPE (800 kg ha^{-1}) (López-Aranda *et al.*, 2003).
Combinations of 1,3-D with LPBF, and Pic with LPBF, have been adopted as MB alternatives in Italy, for example.

5.3.2 Single chemical formulations

5.3.2.1 Chloropicrin

Chloropicrin is a liquid fumigant (boiling point: 112°C), which is injected into soil under plastic. It is normally applied at rates of 15 - 25 g m^{-2} when applied alone or at lower rates of 10 – 15 g m^{-2} when used as a component of a mixture with MB. Chloropicrin is an excellent fungicide. It has some nematicidal activity (Gilreath *et al.,* 2004b), although it is not as effective as other existing materials, such as 1,3-dichloropropene (1,3-D). Where fungal plant pathogens are the primary problem it may be the only material needed (Gullino *et al.*, 2003). However, in many situations e.g. in Florida, USA and in Central and Southern Italy (Gullino *et al.*, 2003; Minuto *et al.*, 2006), the pest problems are more complex and chloropicrin is utilized as part of a mixture of pesticides. Chloropicrin is most often mixed with 1,3-D where it enhances herbicide efficacy for the control of nutsedge (Motis and Gilreath, 2002; Gilreath *et al.,* 2004a). It is now widely considered effective in areas where weed and nematode pressures are low. Chloropicrin by itself is as effective as MB for the control of fungal pathogens (Porter *et al.,* 1999) and for improved growth and yield responses (Gullino *et al.* 2002; 2003).

Formulation and application. New formulations of chloropicrin allow the use of different application methods that are more effective, less costly, and friendlier to the environment. Chloropicrin can be applied directly by injection or by drip application. Emulsifiable concentrate (EC) formulations are now considered to be potential replacements for MB in California, particularly where fungal pathogens are concerned (Ajwa *et al.,* 2003; Gullino *et al.,* 2002). Also, encapsulated formulations as chloropicrin capsules or chloropicrin tape in a water-soluble film are proving effective for control of a wide range of soil pests in China (Cao *et al.*, 2006) and Japan (Tateya 2002).

Limitations. Chloropicrin is a severe lachrymator and requires careful handling due to the stringent odour. Some countries e.g. France and Israel do not permit the use of chloropicrin by itself and regulations may prevent its use in certain areas. Plant back periods for chloropicrin and subsequent phytotoxicity have been shown to be of concern in some cold soil conditions (Porter *et al.,* 2006a). However, plant back periods for chloropicrin have been shown to be similar to MB under other conditions (Porter *et al.,* 2000; MBTOC, 2002). Research is still needed to determine effective and economical application rates in certain sectors and the long-term efficacy of chloropicrin when applied alone. Owing to the noxious nature of chloropicrin, extreme care must be taken to ensure proper sealing after application, as with MB application.

5.3.2.2 1,3-Dichloropropene

1,3-dichloropropene (1,3-D) is a liquid fumigant (boiling point: 104-112°C) that is highly effective for controlling nematodes. At rates of 35-50 g m^{-2} it also provides effective control of insects and suppresses some weeds and pathogenic fungi (Hafez and Sundararaj 2001, Martin 2003). 1,3-D is used as a fumigant nematicide in cropping systems where the important target pests are nematodes. Mixtures with chloropicrin are the main fumigant system presently adopted as alternatives for methyl bromide in most non-Article 5 countries and their use is expanding in Article 5 countries.

Formulations and application. Since 2001, Telone EC has been registered in some countries for use in drip application systems; this has enabled expanded use of this product, particularly in the USA where regulations favour use of this formulation. The spectrum of activity of the new emulsifiable concentrate (EC) formulations has been improved by combining it with other fumigants, although limitations arise in some cases, e.g. sequential application with metham sodium is more appropriate than mixing (Guo *et al.*, 2005; Zheng *et al.*, 2004).

Limitation: In some specific areas (Florida, USA and Prince Edward Island, Canada), 1,3-D is restricted because of possible seepage into groundwater. Another possible disadvantage of 1,3-D is that it has been shown in a few studies to be subject to accelerated degradation by soil micro organisms (Ou, 1998). MBTOC considers the impact of this on use of 1,3-D as an alternative to MB as quite small as few reports have been documented in the last decade (Leistra, 1972; Ou, 1998).

5.3.2.3 Metham Sodium

MITC-generating materials include metham sodium (metham sodium, Vapam) and metham ammonium and metham potassium (K-Pam), as well as dazomet (Basamid). These materials are limited in their applicability as stand alone fumigants as their efficacy can vary according to soil preparation and application methods as well as by location. In a recent study the generation and dissipation curve of MITC was found to vary in different soils thus affecting pest control and fruit yield (Triky-Dotan *et al.*, 2007).

Metham sodium - alone and/ or in combination with other alternatives (e.g. chloropicrin, 1,3/D) is proving as effective as MB and is being widely adopted as key alternatives in many preplant soil applications, for key sectors such as strawberries, tomatoes, peppers and other vegetables, ornamentals and cucurbits (TEAP, 2005 a, b; TEAP, 2006 a, b; Mann *et al.*, 2005; Trout and Damodaran, 2004; CDPR PUR data; Spotti, 2004; Carrera *et al.*, 2004; Porter, 2005).

Formulation and application. Metham is a liquid MITC generator. The placement of the MITC generating materials must be highly accurate in order to control specific target pests, as the movement of gas is limited in some soils and under some temperature regimes. Combinations with other fumigants can increase efficacy (Csinos *et al.*, 2002; Giannakou *et al.*, 2005; Porter *et al.*, 2006b). The high water-solubility of metham sodium makes it suitable for application to soil via injection or drip irrigation under plastic. Drip application has been successfully used for control of weeds, fungi and nematodes in many crops and regions including Morocco, Spain, Southern France, Israel, Italy and the USA (Besri 2002; Gullino *et al.* 2003; Ajwa *et al.*, 2003; Ou *et al.*, 2006). However, application through overhead sprinklers, although effective, has been prohibited or severely regulated in many countries. Application by rotating-spading fumigation equipment has been found to be more effective in general than shank injection because it provides a better distribution of MITC in the soil (Runia and Molendijk, 2006; Barel, 2004).

5.3.2.4 Dazomet

Dazomet is a granular MITC generator. It requires uniform distribution in soil by mechanical means and adequate soil moisture for good movement and efficacy. Under these conditions, studies have shown that rates of (35–50 g m^{-2}) can provide equivalent or better control than metham sodium (López-Aranda *et al.*, 2000). It has also been found to be efficacious in Israel and the USA, particularly for cut flowers (Reuven *et al.*, 2002; Reuven *et al.*, 2005; Elmore *et al.*, 2003; Gilreath *et al.*, 2005). Satisfactory control of weeds, nematodes, and fungi were obtained in Argentina, Australia, Europe, and Japan. As dazomet is a granular formulation it is easier to apply than most other fumigants including MB and therefore is a suitable replacement for use in small-scale applications where machinery is difficult to deploy.

Application. Although dazomet can be applied to soil by hand using appropriate protective clothing, specialist mechanical or manual applicators are available. Certain types of equipment provide a more uniform distribution of the product in the soil profile, increasing the overall efficacy and avoiding the occurrence of untreated pockets of soil. Dazomet has been very effectively applied on some food crops and non-food crops for over 30 years and many different types of application equipment have been developed.

Limitations. MITC generators can have long residue times in the soil and this has sometimes resulted in phytotoxicity and longer plant back periods than for MB for many crops (e.g. strawberries, tomatoes, melons, cut flowers) especially in cool conditions (Ajwa *et al.*, 2001a; Porter *et al.,* 2000). Biodegradation of compounds containing MITC after repeated applications to some specific sandy soil, predominantly sandy soils (Wharton *et al.,* 2001;2003; Di Primo *et al.,* 2003; Matthiessen and Wharton 2003) indicates that its desirable to avoid excessive application rates, rotate with other treatments, or add beneficial micro organisms such as *Trichoderma* following fumigation (as practiced in parts of Belgium, for example) (Barel, 2006 *pers. comm.*).

5.3.2.5 Formalin

A formulation of formaldehyde has been shown to provide effective broad-spectrum control of soilborne pathogens without the previously reported phytotoxicity (Kritzman *et al.* 1999). Since the last MBTOC report (2002), progress has been made toward developing formaldehyde as an alternative for MB (i.e. O'Neill *et al.,* 2005).

Formulation and application. The high water-solubility of formalin makes it suitable for application to soil via irrigation systems such as injection, or drip irrigation under plastic.

5.4 Emerging Chemical Alternatives with Significant Potential to Replace MB

Several new chemicals have been identified as potential MB replacements over the last 15 years e.g. methyl iodide, propargyl bromide, sodium azide, DMDS and cyanogens (also referred to as ethane dinitrile). However, although proving good control of many soilborne pathogens, the use of these as alternatives to MB is governed not only by their comparative efficacy, but also by their ease of application and particularly the registration process. Of those under development, methyl iodide has progressed further through the registration process as discussed below.

5.4.1 Methyl iodide

Methyl iodide, (MI) or iodomethane is a liquid pre-plant soil chemical with a boiling point of 42°C. This material was originally developed by researchers in California, USA where the bulk of initial testing was performed (Duniway *et al.,* 2002 a,b). It is an attractive replacement due to its soil mobility and broad-spectrum of activity. It is not associated with ozone depletion and rapidly breaks down when exposed to UV light. Since the 2002 report, numerous studies show that methyl iodide (iodomethane) provides similar efficacies to methyl bromide in trials (Ajwa *et al.*, 2003; Porter *et al.*, 2006b). A great deal of research has been conducted evaluating methyl iodide (MI) as a drop-in replacement for MB. Recent studies are focusing on lowering the dosage rate and validating performance when used in combination with chloropicrin (Browne *et al.*, 2003; Dickson *et al.*, 2003; Elmore *et al.*, 2003; Ren *et al.*, 2003; Schneider *et al.*, 2003).

Registration of a mixture of MI and chloropicrin is being sought by Arysta LifeScience, North America (San Francisco, CA) under the trade name of Midas®. It received experimental use permits for large scale trials in the US from October 2006 and Australia in 2007. It is also registered in Japan for non-food uses (post harvest timber insect pests). Registration of MI in Japan for monosporascus root rot and necrotic spot disease in melon and root knot nematode, bacterial wilt and Fusarium wilt in tomato is expected soon (pers. comm., Anonymous, Alternative Technology Development Programme Japan Fumigation Technology Association 2006). These registrations are particularly significant as methyl iodide is considered a one-to-one replacement to methyl bromide for most uses.

In California, USA, it has been tested in carrot, peach, cut flower, strawberry production systems, nurseries and vineyard replant (Schneider *et al.,* 2003; Schneider *et al.,* 2005; Ajwa *et al.,* 2005). In Florida, it has been tested alone and in combination with chloropicrin for control of *Phytophthora capsici*, root-knot nematode and yellow nutsedge. Disease control and yields of bell pepper were equivalent to MB when it was combined with chloropicrin (420 kg/ha and 84 kg/ha MI and pic) (McMillan *et al.,* 1997). Additional studies have been conducted to compare rates for nutsedge and nematode control (Dickson *et al.,* 2003; Gilreath and Santos, 2004). Gilreath and Santos (2004) found that the best control of nutsedge was achieved using 392 kg/ha of the 50/50 (MI:Pic) formulation. In studies conducted in Huelva, Spain, Florida, USA, and Australia shank applied MI:Pic produced marketable strawberry yields comparable with or better than MB:Pic (López-Aranda *et al.*, 2005; Mann *et al.*, 2005).

Current indications are that the cost of this product will be priced higher than MB for many crops, making its adoption more likely in higher-value crops.

5.4.2 Sodium azide

Sodium azide has been reported to control nematodes, fungi, and weeds in a variety of crops. Hard-to-kill weeds, such as nutsedges required high rates of sodium azide. Studies combining sodium azide with the herbicides, s-metholachlor and halosulfuron-methyl, demonstrated good weed control at the lower rates effective on nematodes and fungi (Rodriguez Kabana and Akridge 2003; Rodriguez Kabana *et al.,* 2003; Rodriguez Kabana *et al.,* 2005a; Rodriguez Kabana and Walker, 2006; Richards, 2006). The current formulation sodium azide is referred to as SEP-100™. Maximum use rate is 112 kg ai/ha. American Pacific Corporation is seeking US registration. According to USEPA officials, EPA has requested additional studies.

5.4.3 Dimethyl disulfide

Dimethyl disulfide (DMDS), currently under development by Cerexagri (ATOFINA Chemical) is considered to act as a nematicide, fungicide (Gamliel *et al.,* 2000), and herbicide (Church and Rosskopf, 2004). DMDS is a naturally volatile compound produced throughout the enzymatic degradation mediated by alliinase (Auger and Arnault, 2005). The enzymatic breakdown transforms the cysteine-based compounds in thiosulfate compounds. This also happens when soil is amended with cabbage and is then solarised (Gamliel and Stapleton, 1993; Auger and Charles, 2003; Gamliel *et al.,* 2000) and when fresh tissues of alliaceous and Brassicaceae plants are mechanically minced. DMDS has a complex mode of action that is through mitochondrial malfunction and inhibition of cytochrome oxidase (Auger and Arnault, 2005; Auger and Charles, 2003; Charles 2003).

Over the last 5 years, di-methyl disulphide has been developed and evaluated in France, Italy, Spain and USA as an alternative to MB for control of a number of soilborne fungi (*V. dahliae, S. sclerotiorum, R. solani, S. rolfsii* and *F. oxysporum lycopersici, F. oxysporum radicis lycopersici, F. oxysporum melonis*) and nematode species (*Meloidogyne incognita and javanica and Heterodera schachtii*) as a result of the application of DMDS through soil injection and drip application (Fritsch *et al.*, 2002; Charles, 2003; Church and Rosskopf, 2004; Minuto *et al.*, 2006). Results in combination with chloropicrin have been extremely promising (López-Aranda *et al.*, 2006) especially when used with LPBF as significant dosage reductions are possible (Robinson *et al.*, 2006).

5.4.4 Sulphuryl fluoride

Since the last report, research indicates that several new chemicals may have potential as MB alternatives for soil treatments. Sulphuryl fluoride (Cao *et al.*, 2002), carbonyl sulphide (Ren *et al.*, 2001), and cyanogen (Mattner *et al.*, 2006) have been trialled but there is little efficacy data and at this stage these chemicals need further development before being considered as alternatives for MB.

Laboratory and field tests in China showed that sulfuryl fluoride has high activity against root knot nematodes and mild activity to soil pathogens and to germinated weeds. Sulfuryl fluoride applied as a soil fumigant at the rate of 25g m^{-2} or 50g m^{-2} provided good control of nematodes. The vigour and yield of crops, such as cucumber and tomato, following soil treatment with sulfuryl fluoride was similar to that obtained with MB used at 50g m^{-2}. The application of sulfuryl fluoride is simple; it is distributed through a plastic strip with micro holes under plastic film sealed with water. Sulfuryl fluoride could be applied at low temperature and the plant back time is short. Sulfuryl fluoride cannot readily penetrate polyethylene film and therefore is safer than MB. Sulfuryl fluoride registered as a soil fumigant is under evaluation in China (Cao, 2004).

5.4.5 Cyanogen

Cyanogen, also referred to as ethane dinitrile, is showing promising results as an alternative fumigant to MB for soil disinfestation in trials in Australia and Spain in strawberry runners, strawberry fruit and carrots (Ren *et al.*, 2003; Mattner *et al.*, 2003; López-Aranda *et al.*, 2006). Preliminary results show efficacy against pathogens and weeds, but it has not been tested extensively against nematodes (Mattner *et al.*, 2003). Cyanogen has a high vapour pressure and does not persist long in soils. Newer application technologies need to be developed to increase its retention time in soils to provide adequate exposure times against some pests. Registration is proceeding through BOC Gases, Australia.

5.4.6 Other Possible Compounds

Studies are still continuing with several compounds, propylene oxide, furfural, fosthiazate, acrolein (2-propenal) and Dazitol (Slevin, 2003; Minnis *et al.*, 2004; Ginnakou, *et al.*, 2005; Gerik, 2005b; Rodríguez-Kábana and Simmons, 2005a; 2006; Buntting, 2006; Hensley and Myers, 2006; Simmons *et al.*, 2006; Leyes, 2006; Morris, 2006), however results indicate that they are not one- to- one replacements to MB but may still be used in combination with other products to achieve effective control.

5.5 Application Methods of Chemical Alternatives

A key to the success of identifying chemical alternatives to MB is to either develop new application methods or to modify existing methods, which take into account the characteristic properties of the chemicals being applied. In addition, soil fumigants should be applied to well-prepared soil, with appropriate moisture content. Most of the commercial fumigants, excluding MB and dazomet, are applied to soil in a liquid form to the desired depth with various equipment set-ups. The chemicals vaporize in the soil, or act through the liquid phase and diffuse in soil with the aim to reach all niches where pests exist.

5.5.1 Injection

Injection of fumigants, especially MB, with various chisel structures is common (Ogg, 1975). This type of application consists of "subsurface-spraying" of liquid formulation into the soil. The level of pest control depends on the distribution of the fumigant in the soil, the dosage rate, and the depth of injection. The depth of injection varies according to the target type and its location. For most crops the injection is usually confined to the upper 30 cm. In contrast, fumigation for orchard replanting usually involves deep shank application to a depth of 50-60 cm. The machinery for injection of many of the MB chemical alternatives is either similar or has been adapted from equipment used for broadcast application of MB.

This equipment often needs modifications to ensure alternatives are applied effectively. In Florida, a coulter plough application rig was developed to allow the use of 1,3-D/Pic formulations in sandy loam soils (Chellemi *et al.*, 2001; Gilreath *et al.*, 2004). This deep placement coulter system (Avenger, Yetter Manufacturing Co., Colchester, Illinois, USA) was modified to permit injection of 1,3-D or 1,3-D/Pic into undisturbed soil. The intact crust layer at the soil surface served as a barrier to slow fumigant emission from the soil. Sealing devices incorporated in the design further minimized movement of the fumigant up through airspace created by the coulter, thus enhancing the performance of the fumigant.

Eliminating the deep disking operation prior to fumigation reduced application costs, saved time, and expanded the application window.

A novel apparatus referred to as an 'under bed fumigator' was invented to inject fumigants into the soil for raised bed vegetable production in Florida (Chellemi and Mirusso, 2004). Fumigation under raised beds that were covered with VIF dramatically improved the retention of 1,3-D and chloropicrin in the soil. The under bed fumigation mitigates regulatory hurdles associated with worker exposure and the use of personal protective equipment by separating the fumigant application from land preparation activities. It also allows growers to make more efficient use of their production fields by creating opportunities to disinfest soil in fields that do not have access to fumigant injection through drip irrigation systems.

One of the main constraints of fumigant application to soil is the potential escape of the vapours to the air with a consequent lowering of the effective concentration of the fumigant. Using shank injection it is common for the fumigant to be lost through the channels created by the chisels. This phenomenon was especially evident with MB fumigation. In recent years a novel deep chisel, with 4-6 nozzles on each chisel, was shown to provide improved initial distribution of the chemical. In addition, the use of multi-nozzle chisels to inject MB minimizes the number of trenches created in the soil during injection, and thus reduces the channels available for gas escape (Gamliel *et al.*, 1997). The escape of vapours can be further reduced by covering them with an additional device on the injection equipment, such as power roller or shallow rotovator. Retention of fumigant gases in the soil is also improved by covering the soil with tarps or, to a lesser extent, by applying a water seal (Wang *et al.*, 2005, 2006; Rabasse, 2004).

New equipment used in the Carnarvon region of Australia applies metham at the same time as applying plastic mulch, with more effective results than traditional application methods. On the East coast of Australia some growers have modified injection rigs that are able to deliver metham more precisely with depth in soil (TEAP, 2005). Rotating-spading fumigation equipment developed in the Netherlands improves the mechanical distribution of metham in the soil profile, increasing efficacy (Barel, 2004; Runia and Molendijk, 2006). The equipment injects metham at 10-15 cm and immediately mixes it with soil at 25-30 cm depth by use of a rotating spader, disseminating metham more uniformly (Rabasse, 2004). This equipment meets the stringent water protection requirements in the Netherlands and has been adopted as a MB alternative in a number of countries such as France, South Africa, Chile and Uganda.

In Italy, the mixture of 1,3-D and Pic is not registered, however in recent years the largest company working in the field of soil fumigation developed a technique for applying both products sequentially. It uses a tractor with two tanks that inject both fumigants separately into the deep layers of the soil while simultaneously laying out sheets of VIF. The machine also seals the edges of the films together, thereby blocking the escape of gaseous emissions into the atmosphere (Spotti, 2004).

5.5.2 Drip irrigation

Application of soil fumigants through drip irrigation systems is receiving increasing attention as a method to improve the uniformity of fumigant application. This, however, requires a special emulsified formulation of the fumigant and appropriate irrigation system for effective delivery and uniform distribution. Accordingly appropriate emulsified formulations of 1,3-D, chloropicrin and 1,3-D/Pic have been developed in order to enable application through irrigation systems. The main advantage of applying fumigants via drip irrigation is the improved distribution of the fumigants in soil. Subsurface drip irrigation and plastic mulch are also used to improve distribution and minimize fumigant volatilisation (Ajwa *et al.*, 2002; 2003; Browne *et al.*, 2002; Papiernik *et al.*, 2004; Sullivan *et al.*, 2004).

The application of emulsified formulations of 1,3-D/Pic (InLine) through the drip irrigation system was shown to be effective and safe (Ajwa *et al.*, 2003; 2004). Similar results were obtained with metham sodium and formalin, (Gamliel *et al.*, 2005). Drip application of metham has been adopted on a commercial scale (Rabasse, 2004). Guidelines for the use of drip-applied metham sodium and metham potassium have been published in the USA and other countries (Ajwa *et al.*, 2001). Drip irrigation of 1,3-D/Pic EC has been adopted as a key alternative to MB for strawberry and vegetable production over the last five years (Ajwa *et al.*, 2003). This methodology has the potential to reduce offsite movement of fumigants and may also be more cost-effective than injected methods.

5.5.3 Emission control

Consideration of reductions in emissions of methyl bromide has enabled advances to be made in methods of sealing soils to improve the efficacy of MB and this has led to reductions in the dosage rates of MB being applied to control pathogens effectively. This has been important because it has allowed reductions in quantities of MB required under 'Critical Use' exemptions under the Protocol. Major advances since the 2002 report have been the development of semipermeable films, which offer an effective alternative to VIF films that have been mandated for use with MB in Europe under EC Directive. As with VIF films, the semipermeable films clearly allow for effective reductions of dose rates of fumigants applied. Updates on studies with emission controls can be found in Chapter 7 of this report and in past TEAP reports (TEAP, 2006 a, b).

5.5.3.1 *MB at reduced dosages*

Since 2002, lower MB dosages and less frequent fumigations have been a major factor enabling countries to satisfy the commitments for MB reductions under the Montreal Protocol (Miranda *et al.,* 2005; Hannah *et al.,* 2005; Gilreath *et al.*, 2005; 2006a). A key transitional strategy to reduce MB usage has been the adoption of MB: Pic formulations with lower concentrations of MB (e.g. MB: Pic 50:50 or less). Such formulations in combination with low permeability barrier films (LPBF, e.g. VIF or equivalent) allowed for increased retention of MB and extended the effective exposure periods for pests, thus controlling pathogens and weeds at reduced MB application rates compared to those used with conventional films (e.g. Gilreath *et al.*, 2003; Gilreath *et al.*, 2005a; Hamill *et al.* 2004; Minuto *et al.*, 2003; Reuven *et al.*, 2000; Santos *et. al*, 2005; Wang *et al.*, 1997).

5.5.3.2 *Use of barrier films*

Recent advancements in the cost and technical performance of barrier films have extended their suitability for use with MB and also some of the fumigant alternatives. The key advantage is that they allow for a substantial reduction in dosage rate and/or increased efficacy compared with conventional polyethylene films. Barrier films in combination with lower MB/Pic formulations (e.g. 50:50) are improving the efficacy of weed control, including nutsedge. Studies are also proving their use for effective dosage reduction of alternatives, such as 1,3-D (Gilreath *et al.*, 2004; 2005; Noling and Gilreath, 2004; Hamill *et al.,* 2004; Fennimore *et al.*, 2004). This is important because dosage reduction may increase areas available to be treated with specific fumigants that are limited by township caps and may lead to further reduction in MB use (Gilreath *et al.*, 2003; Fennimore *et al.*, 2004; Fennimore *et al.*, 2003). At present the state of California in the US prohibits the use of certain barrier films (VIF) with MB, but allows the use of LPBF with alternative fumigants.

5.5.3.3 *Application under plastic mulch*

One of the major changes in soil fumigation has been the adoption of plastic mulch in almost all soil fumigation. Plastic mulch has been adopted even for fumigants, which were traditionally applied without plastic, e.g. 1,3-D or dazomet. In Florida, USA, a novel apparatus referred to as an 'under bed fumigator' was invented to inject fumigants into the soil (Chellemi and Mirusso, 2004). Fumigation under raised beds that were covered with VIF dramatically improved the retention of 1,3-D and chloropicrin in the soil. The under bed fumigator further reduces possible fumigant emission, as the chemicals are injected under a mulched area.

Permeation of fumigants through a plastic tarp to the air occurs in the field after application and is a result of two thermodynamic and kinetic processes: solubility of the fumigant in the polymer and diffusion through it. The commonly used films for fumigation, made of low-density polyethylene (LDPE) or high-density polyethylene (HDPE), provide a poor barrier for all the commercial fumigants (Austerweil 2006; Gamliel *et al.,* 1998; Wang *et al.,* 1999). Permeability of LDPE or HDPE to fumigants increases exponentially with temperature and allows the escape of the gas after a short period. The effect of temperature on permeability of the film is very important, since fumigation is carried out in many cases on warm days when the temperature of the plastic can reach 50-60°C (Gamliel *et al.*, 1997). In contrast, films containing a layer of a barrier material such as polyamide (PA) or ethylene-vinyl alcohol (EVOH) are significantly less permeable (Gamliel *et al.*, 1998). Impermeable films together with improved application methods enable the use of reduced fumigant rates, achieve the desired level of pest control and minimize gas emission to the air. The use of LPBF such as VIF is now commercially accepted worldwide as a means to reduce emissions and dosage rates of MB and other fumigants (De Cal *et al.*, 2005; Gilreath *et al.*, 2003; 2004; 2005).

5.6 Environmental and Biological Issues of Fumigants

Consideration of environmental effects of MB and alternatives is an important factor affecting the long-term potential of fumigants. All products used for pest control are subject to review and soil fumigants are specifically targeted for review. Current reviews in the EC under Directive 91/414 and the US under the Cluster Analysis may have implications for the future use of MB and all other fumigants.

5.6.1 Fate of fumigants in the environment

Soil fumigation has recently been shown to increase emissions of nitrous oxide (N_2O) following application of fumigants, chloropicrin (CP) and MITC and is likely to occur for all fumigants, including MB. Results showed that N_2O production increased by 12.6 times following CP fumigation in a simulated system (Spokas *et al.*, 2003). This simulation effect was confirmed by a seven-fold increase in N_2O emission rates in field plots following CP fumigation (Spokas *et al.*, 2005; 2006). The mechanism of N_2O production appeared to be microbial related. Similar trends were also recorded for MITC. Both fumigants increased N_2O emissions rates significantly compared to non-fumigated controls, and the effects were still evident after 48 days. These findings are in contrast to fertilizer-induced N_2O emissions, which generally return to background within 2 weeks after application. MB is degraded in soil primarily by nitrifying bacteria and as a result is also likely to increase N_2O emission rates.

5.7 Registration Issues

Significant effort has been undertaken by many Parties to transfer, register and implement alternatives and to optimise their use. While an alternative may be technically appropriate as an MB replacement for a given situation, it may not be available in practice. Lack of registration may still be a constraint in some countries, affecting the availability of certain types of alternatives. In many countries, any product or sometimes even a process, which claims to kill pests, must be registered. Overall, the registration and approval process is often costly and protracted, with the outcome uncertain from the point of view of the potential registrants. In addition, the market size for a particular MB application may be too small to justify the commercial risk and investment involved.

Since the 2002 Assessment Report, registration of "new" fumigants has been primarily limited to new uses or mixtures of old chemicals such as 1,3-D and chloropicrin. Progress with adoption of chloropicrin was observed in Italy, where this chemical was registered and became available in 2002 (Triagriberia, 2002) and is now in use by growers of different crops. Whilst mixtures of chloropicrin with other chemicals such as 1,3-D are still not registered in Italy, sequential applications of these two fumigants are now possible and this widely increases the scope to control soilborne diseases and weeds.

Among alternatives currently under active development, but not yet registered are methyl iodide and to a lesser extent propargyl bromide; the former has received permits for large-scale trials in the US and Australia in 2007. However, MB and all chemical alternatives will be subject to continuing review and more thorough regulation. Furthermore, no one knows the actual prospects for registration of the new fumigants currently under development and there is a possibility that registered fumigants will not be available for large-scale use in soil indefinitely. Factors affecting acceptance of chemical alternatives include registration status, local availability, costs, new application technologies, labour requirements and efficacy against target pests.

5.8 Non-Chemical Alternatives Adopted Commercially as Replacements to MB on a Large Scale

5.8.1 Resistant cultivars

The use of plant cultivars, that are resistant to soilborne pathogens can offset the need for soil fumigation with methyl bromide. Multiple-disease-resistance to soilborne pathogens is becoming more common and has been possible because of disease resistance breeding that began about 70 years ago. Single, dominant, vertical genes that fit well with hybrid breeding programs that are common in today's world confer most of the resistant traits. Development of resistant plants has been most successful for soilborne fungal diseases affecting tomato such as Fusarium wilts (races 1, 2, and more recently 3), Verticillium wilt (race 1), Alternaria stem canker, *Phytophthora* spp., Fusarium crown rot, root-knot nematodes and some bacteria (Garibaldi and Gullino 1990; Fery and Dukes 1996; Besri 1997a,b; Cartia 1998; Browne *et al.*, 2001; Scott, 2005). It is important to note that development of resistant varieties, if genes are available, requires substantial research and development (Celada 1998; Tello 2002; Javier Sorribas *et al.*, 2005; Thies *et al.,* 2003) and may take 5 to 15 years depending on crop species and genetic resources. Nevertheless, seed companies have continued to develop and supply new resistant varieties, expanding the range available for vegetable crops in particular, e.g. tomato, peppers and cucurbits.

The major limitations to the use of resistant varieties are the appearance of new races, high population levels of pathogens, and environmental conditions, which may limit the level of resistance (Besri 1981; Besri *et al.,* 1984; Besri 1993; Cap *et al.,* 1993).

Since the 2002 Assessment Report was published some major advances have been made in finding resistance to pathogens that are major targets for MB. In tomatoes, the Mi-resistance gene can be an effective and economic alternative to MB in plastic-houses infested with root-knot nematodes (*Meloidogyne* spp), but should be used in an integrated management context to preserve its durability and prevent the selection of virulent populations due isolate variability and environmental conditions (Thies *et al.*, 2003). Resistance to root-knot nematodes can be broken at high temperatures (Schneider, pers. com, 2007).

Japanese growers use MB for control of *Pepper Mild Mottle Virus* (*Pmmov*) in pepper production. However, resistant genes are available to *Pmmov* and include: L^1, L^2, $L^3$and L^4. Japanese growers use pepper varieties like "Miogi" and "Kyosuzu" with L^3 resistant gene but now the *Pmmov* virus has mutated to produce a new strain ($P_{1,2,3}$ type), which overcomes the L^3 resistant gene. Thus MB fumigation is once again necessary. Research is being conducted in Japan to incorporate the L^4 gene with the aim of improving resistance to the *Ppmov* virus and new varieties such as "Pagu Ichigou" and "L4 Miogi" have been introduced. Already, however, a new strain of *PMMoV* strain has appeared which can overcome the L^4 gene (Sasaki *et al.,* 2006). No gene for resistance to this newly emerging *Pmmov* strain has as yet been identified.

Some strawberry cultivars developed in California, USA, exhibit promising levels of resistance to *Phytophthora* root and crown rots (Browne *et al.,* 2001; Duniway 2002). None of the current varieties, however, has sufficient tolerance to Verticillium wilt. Also, some Australian varieties have tolerance to black root rot caused by *Rhizoctonia fragariae* (Mattner *et al.*, 2006).

A race of *Verticillium dahliae*, virulent on cultivars with the Ve gene, designated race 2, was detected in 1975 and later reported in North and South America, Europe, Africa and Australia. Until recently the screenings of germplasm have not revealed a reliable source of resistance to race 2. Research to select resistant cultivars to V.dahliae race 2, are in progress (Stamova, 2005).

5.8.2 Grafting

Grafted plants combined with IPM or alternative fumigants have been adopted as MB alternatives in some regions, particularly for vegetable crops, e.g. tomatoes, eggplant, peppers and cucurbits. Although cost is usually still higher than that of non- grafted plants, the advantages provided by grafted plants means their use has become more widespread. The number of nurseries producing grafted plants has increased in many countries. Mechanical grafting techniques are now available and widely used (Oda, 1995).

Grafting offers the opportunity to achieve higher yields than non-grafted plants. This is possible because cultivars which are susceptible to a given pest or disease but otherwise have desirable traits from a commercial point of view can be grafted onto rootstocks which are resistant to those same pathogens. Grafting provides excellent protection against damage caused by soilborne pathogens of vegetables and fruit crops that are infested with l root-knot nematodes and fungal pathogens (e.g. *Fusarium* spp., *Verticillium dahliae* spp., *Phytophthora* spp) and is as effective as resistant cultivars (De Miguel, 1997; 2002; 1998; Nyczepir, 2000; Anonymous, 2001; Bello *et al.,* 2001; López *et al.,* 2002).

In addition to achieving control of soilborne pathogens, grafting offers a number of other benefits including growth promotion and yield increases when compared to non- grafted plants, low temperature tolerance, longer production periods and improved fruit quality (Besri, 2000). Also grafted plants are often more vigorous and fewer plants are required per hectare. In the case of tomato, grafted plants are planted at half the density (in plants per ha) used with non- grafted plants or 9,000 plants per ha instead of more than 18,000 plants per ha.

Grafting of annual crops is widely used in some non-Article 5 countries, e.g. Spain (Echevarria *et al.*, 2004; De Miguel *et al.*, 2004; López *et al.*, 2004) Italy, (Assenza *et al.*, 2004; Spotti, 2004), Greece (Athanasiadou, 2005) and other Mediterranean countries (De Miguel, 2004), Romania (Bogoescu *et al.*, 2004), and Japan (Nishi and Tayeta, 2006), as well as in Article 5 countries for example Morocco (Besri 2005) and Lebanon (Hafez *et al.*, 2003), Presently, 100% of the watermelon crop in Spain is raised from grafted plants, a practice that eliminated the use of MB on this crop (Tello 1998 a, b). The results, expressed as marketable yields, gall index or disease severity, are generally as fully comparable to those obtained with MB (Miguel, 2004 a, b; Koren, 2002; Besri, 2005; Hafez *et al.* 2003). Many rootstocks are commercially available, for example:

- For watermelon: Gourd (*Lagenaria siceraria)*, wax gourd (*Benincasa hispida*), pumpkin (*Cucurbita pepo*), squash (*Cucurbita moshata*, and *Sicyos angulatus*), *C. maxima* x *C. moshata, Citrullus lanatus, Lagenaria siceraria*
- For cucumber: *Cucumis sativus, C. ficifolia*, F1(*C. maxima* x *C. moshata*)
- For melon : *C. melo, C. maxima* x *C. moshata, Benincasa cerifera*
- For tomato: *Lycopersicon pimpinellifollium, L. hirsutum, L. esculentum, L. hirsutum x L. esculentum, Solanum torvum*.
- For eggplant: *Solanum integrifolium, S. torvum* (source of additional rootstocks: - De Miguel, 2004 a, b)

Rootstock resistance may break down under high pathogen population pressure, when new races of the pathogen evolve, and under some environmental conditions e.g. high temperature, salinity (Besri, 1981; 1993; Minuto *et al.*, 2005). Some minor pathogens can affect resistant rootstocks, particularly when soil fumigants are not used in combination with this technology. During 2003 *Colletotrichum coccodes* was observed on grafted tomatoes in Northern (Liguria, Piedmont), Central (Campania) and Southern Italy (Sicily). Standard tomato plants and also interspecific and intraspecific tomato rootstocks are susceptible to this pathogen. These observations show that in some particular conditions grafted tomatoes cannot be used as a single practice to control soilborne pathogens in soils infested by *C. coccodes* (Minuto *et al.*, 2005). In most cases grafted plants need to be combined with other relevant techniques to control the full range of target pest species. In some regions, applicability of grafted plants may be limited by availability of rootstocks tolerant to local pests and diseases. The use of grafted plants may not be as effective and economical for short growing cycles (Minuto *et al.*, 2005).

The use of rootstocks resistant to *Phytophthora capsici* and *Meloidogyne incognita* in soils treated with MB alternatives, has led to the selection of virulent populations of *M. incognita*, but not *P. capsici*. For this reason it is desirable to combine grafted plants with other relevant techniques, such as nematicides. In commercial greenhouses in the southeast of Spain, the use of resistant rootstocks in soils combined with 1,3-dichloropropene and chloropicrin at 25 g m^{-2} chloropicrin resulted in levels of pest control similar to methyl bromide (98:2) at 30 g m^{-2} .(Cebolla *et al.*, 2000) Grafted plants grown in soil treated with metham sodium at a dosage of 150 g m^{-2} was less effective than MB, however grafted plants grown in soil which had been subjected to biofumigation plus solarisation (fresh sheep manure plus chicken manure) were not affected either by *P. capsici* or by *M. incognita* and marketable yield was higher than that obtained with non-grafted plants (Ros *et al.*, 2005).

Eggplant cultivars grafted on rootstocks resistant to root-knot nematodes (*Meloidogyne* spp.) are increasingly grown in Italy to reduce nematode infection. A wilt disease in several greenhouses in Sicily (southern Italy) has been observed on the grafted plants recently and new more resistant rootstocks may be required (Garibaldi *et al.*, 2005) or alternatively the grafted plants may be combined with a suitable pesticide or fumigant for the control of wilt disease.

Grafting melons to control Sudden Wilt, caused by *Monosporascus cannonballus* significantly reduced wilt incidence by 84 to 87% when compared to untreated plots. Integrating grafting and a low dose of a fumigant may well improve the efficacy and reliability of this treatment (Edelstein *et al.*, 1999).

Grafting commercial Dutch type cucumber hybrids onto various resistant *Cucurbita* rootstocks is considered as an alternative to methyl bromide for root and stem rot caused by *Fusarium oxysporum* f. sp. *radicis-cucumerinumi* in Greece (Pavlou, 2002).
Over the last five years, projects funded by UNIDO were developed to gradually eliminate MB use in the cantaloupe melon crop in Guatemala (2002), Honduras (2002) and Mexico. By 2006, Honduras had planted nearly 200 ha with grafted melon plants and Guatemala 20 ha, but Mexico had not adopted this alternative. During the period grafting was widely adopted by Honduran watermelon growers and the area using this alternative reached nearly 800 ha (Marbán-Mendoza, *et al.*, 2006). Costa Rican growers have also found this alternative to be both technically and economically feasible for watermelons (Abarca, 2005, pers. comm). In Argentina, grafted tomatoes resistant to nematodes are being tested with promising results (Mitideri, 2005). These results have occurred in spite of grafting being difficult to suit the timing of the crop and representing high initial investment costs for specialised nursery production of plants. Further information on these efforts can be found in Chapter 7.

5.8.3 Systemic acquired resistance (SAR)

Systemic acquired resistance (SAR) is a natural plant defence mechanism in which plants activate their defences in response to a pathogen and pest attack. A plant expressing SAR can be protected against a wide range of pathogens for weeks to many months. There are some pathogens however, against which the mechanisms have little effect (Walters *et al.*, 2005). SAR can be activated in many ways but for wide scale agricultural use the most obvious is the use chemical inducers such as salicylic and jasmonic acid and their derivatives. Several companies now market products to induce SA, but few of these have been optimised to protect plants against soilborne plant pathogens. In the review by Walters *et al.* (2005) on maximizing the efficacy of elicitors that induce SAR virtually all treatments were for foliar diseases. The foliar application of plant activators is a promising control method for soilborne diseases and may provide an economically feasible alternative to soil fumigants such as MB. However, there is much to be learned as to how to utilize SAR inducing products. In studies by Kavroulakis (2005; 2006), elevated levels of proteins associated with enhanced resistance were observed in the root tissues of tomato plants grown on a compost derived from grape marc and extracted olive press cake and plant grown in such compost showed resistance to *Fusarium oxysporum* f.sp. *radicis lycopersici*.

In another study, application of Validamycin A or validoxylamine A, (antibiotics produced by *Streptomyces hygroscopicus* var. l*imoneus),* to foliage of tomato was shown to control tomato wilt caused by *Fusarium oxysporum* f. sp. *lycopersici* at > = 10 micro g ml^{-1}.

5.8.4 Transgenic Plants

In some situations, the conventional breeding methods used to control many diseases are inefficient, non-existent or too slow to be a practical solution. However, molecular genetics and plant transformation techniques can provide new tools to introduce foreign genes into plant tissues without compromising other economic characteristics of the cultivar.

Numerous laboratories throughout the world are cloning, mapping, and studying the genes of plant crops, pathogenic fungi, bacteria, viruses and nematodes. Once the genes have been identified and isolated, they are manipulated, modified, and transferred (Sasson, 2002). However, up till now, no transgenic resistant variety or root stock resistant to soilborne pathogens is available commercially (Sasson 2002; Madkour 2003).

In many countries, cultivated plants are infected with viruses some of them are soilborne pathogens (Tsuda *et al.*, 1998; Hamada *et al.* 2002; Krastanova *et al.* 1995; Lomonossof *et al.* 1995; Mauro *et al.* 1995). These viruses are causing reduction in yield and quality of the crop. An effective strategy to control plant virus infection could be based on developing transgenic resistant varieties incorporating virus derived transgenes e.g. coat protein.

An increase in food production may be achieved by protecting crops from losses due to pests, pathogens and weeds. Biotechnology-and especially genetic engineering-could offer great benefits to the environment by replacing chemicals with inherent engineered resistance to pests, and particularly to soilborne pathogens. Genetic engineering is highly suited to agriculture particularly in Article 5 regions (Bahieldin, 2002; Madkour, 2003), however their acceptance in some markets may be limited.

5.8.5 Substrates

Substrates are widely employed as plant growth media as means for bypassing soils and the pathogens they may contain. Most of the soilless culture occurs in covered or protected agriculture (Barry, 1998). Their use has replaced the use of MB by generally avoiding the need to sterilise. Substrates include artificial and natural materials such as rock wool, tuff, clay granules, solid foams (e.g. polyurethane), glass wool, peat, coconut plant materials, volcanic gravel (lapilli), pine bark, grape industry waste, and diverse other materials (Aquino 1997; Diaz *et al.* 1998; Kipp *et al.* 2000; Sawas and Passam 2002; Pizano 2006).

There are presently limited examples of use in open field operations, but novel technologies being developed should expand this application in open fields (Rumpel and Kanizcwski, 1998).

Adoption of crops grown in substrates continues to be a strong trend in protected, intensive agriculture (e.g. for cut flowers, nursery plants, vegetables) both in Article 5 and non-Article 5 countries. Soilless culture is used as a production method for crops such as tomatoes, peppers, strawberries, cut flowers, melons, cucurbits, nursery-grown vegetable transplants, strawberry plants and tobacco seedlings (De Hoog, 2001; Kipp *et al.*, 2000; Pizano, 2003; Savvas and Passman 2002; Pizano, 2004a, Leoni *et al.*, 2004). Although initial investment is generally high, increased productivity and yield due to higher planting densities and often better quality, pay off extra costs rapidly (Savas and Passam, 2002; Schnitzler and Gruda, 2002; Caballero and De Miguel 2002; KWIN 2003). An economic study that compared soil cultivation with various types of substrates systems in Greece concluded that substrates could substantially improve farmers' incomes (Grafiadellis *et al.*, 2000). Similar conclusions were reported in other countries (Engindeniz, 2004). When the Netherlands phased out MB in the early 1980s, many growers initially adopted cheaper substrate systems (e.g. bucket containers) which were relatively simple compared to the substrate systems currently used in the Netherlands (Barel, pers. comm.; Lieten, 2004). More recently, a number of countries have developed cheaper substrate systems based on local materials; these simple substrate systems have been adopted in vegetable production in Kenya, Hungary and New Zealand, and in strawberry production in parts of France, for example (Mutitu et al. 2006ab; Budai, 2002; Hunt 2000; Lieten, 2004).

Although the techniques are considered to have less potential to replace MB for large-scale open field operations because of limited availability of suitable local substrates, the growth of this technology has been tremendous in protected crops. In China for example, soilless culture increased from 1 ha in 1985 to 3150 ha in 2000 (Jiang *et al.*, 2000). In 1999, about $4 billion dollars worth of horticultural crops were produced globally with soilless culture (http://www.ars.usda.gov.is.np.mba/apr99/perlite.htm).

The floating tray method to produce tobacco seedlings is now used in many countries, such as Australia, Argentina, China, Brazil, Peru, Spain, and other European countries, USA, Zimbabwe and Kenya at both large and small production levels (Blanco, 1997; Thomas, 1999; Pearce, 2002; Pérez, 2002 a,b; PROZONO, 2003; Valeiro, 2005). This method has replaced a substantial proportion (about 70%) of the MB formerly used globally in tobacco seedling production and has potential to replace 100%. The float bed is a simple hydroponic system that was developed by the tobacco industry for transplant production. It involves germination of seed in substrates such as vermiculite or peat mix in polystyrene plug-trays floating on a shallow bed of nutrient solution. Modifications of this technique have been adapted for the production of various types of vegetable seedlings.

The incorporation of beneficial fungi such as *Trichoderma* and bacteria into the substrates has improved the use of soilless culture as an alternative to MB. Under appropriate conditions the soilless method offers a better cost-benefit ratio than treating with MB (Canovas-Martinez, 1997). Use of biocontrol agents and other IPM procedures are essential elements to keep pathogens out of the irrigation water and substrate media.

An economic analysis of growing cucumber plants in substrates in Turkey (Engindeniz, 2004) showed that soilless culture was an economically viable alternative to methyl bromide fumigation. Akkaya *et al.* (2004) found similar results for greenhouse vegetables (tomatoes and cucumbers) and cut flowers (carnations). For more in-depth economic analysis see Chapter 7.

Constraints on soilless culture may include lack of identification of suitable local substrates, potential ground water pollution from systems that do not recycle the nutrient solutions and the vulnerability of the system to pathogen attack. These constraints can normally be addressed by training and good management practices.

5.8.6 Steam

Steaming is the introduction of water vapour to kill soilborne pests with the latent heat released when steam condenses into water (Bungay, 1999). The normal recommended treatment is to maintain a temperature of 70°C for at least half an hour to control plant diseases and weeds (Runia, 2000), although some treatments may apply 60-80°C for about one hour. Soil temperature and treatment duration determine whether complete elimination (sterilization) or only partial removal of soil microflora (pasteurisation) occurs. When properly conducted, steaming is effective against all soilborne pests and a highly effective alternative to MB, having an equally wide spectrum of action, and not requiring a waiting period before replanting (Gullino, 2001; Miller, 2001; Pizano, 2001; Solís and Calderón, 2002; Triolo *et al.*, 2004).

Use of steam pasteurisation has continued to increase as an alternative to MB in intensive, protected, high-value cropping systems such as flowers and vegetables. This is largely due to new and more efficient equipment being available, such as negative pressure steaming, hood steaming (for seed beds) and improved, more flexible equipment for sheet steaming (Carrasco, 2003; Pacett, 2003; Runia, 2000; Barel, 2003a). Negative pressure steaming allows treatment at much deeper soil depths than sheet steaming, and uses almost half the fuel of sheet methods (Runia, 2000). Different fuel options for operating the boilers, for example gas in Argentina and Bolivia, and wood in Brazil, (UNIDO, 2005; Barel, 2005) are helping growers reduce costs, and making the treatment more useful as an alternative to MB.

Examples of soil steaming in commercial and routine use include: Australia (cut flowers), USA (cut flower production in California), South Africa (tomatoes, chrysanthemum cuttings), Kenya (chrysanthemum cuttings), Uganda (chrysanthemum cuttings), Tanzania (cut flowers and chrysanthemum cuttings), Colombia (cut flowers and cuttings), Brazil (flowers and cuttings), Italy (cut flowers, ornamentals and cuttings), Belgium (strawberry (protected), tomato, lettuce, leek and onion seedlings), the Netherlands (about 50% of cut flower production, including 900 hectares of chrysanthemum, cuttings and radish), UK (protected tomato and lettuce), Lebanon (strawberry), Guatemala (cut flowers), and in other crops and countries mentioned in MBTOC 2002 assessment Report (Shanks *et al.* 2004; VDPI 2005; Barel, 2004; Solís and Calderón, 2002; Haroutunian, 2003; Pizano, 2003, 2004a, b). Steam was used on about 2000 hectares in France in 2000 (Fritsch, 2002).

Steaming is also comparable to MB for sterilizing plug or seedling trays. This system is used in many countries, including the US, Netherlands, Belgium, Chile, South Africa, Argentina and Uganda (Pearce and Palmer, 2002; Melton and Broadwell, 2003; Rodríguez, 2006). Steam has replaced the use of MB for sterilization of substrates in a number of areas. Chile adopted steam as a MB alternative for substrates in the tree nursery sector, for example. Bolivia has recently adopted small steam boilers for sterilizing substrates (new and re-used) for seed potato, vegetables, and ornamentals, as part of a UNDP MB phase-out project (Barel, 2005).

As steaming is generally more expensive than treating with MB, it is normally used for high value crops. The treatment time is slower than MB fumigation, however the waiting period is negligible, providing a faster treatment overall than MB fumigation in smaller areas like greenhouses and tunnels. Traditional steaming methods require high amounts of water, power or fuels (Crump, 2001). However, improved steam application methods utilise less water and fuel (Runia, 2000; Barel, 2004). Water and fuel can also be reduced by using steam as a component of an IPM program (Pizano, 2001; Bennett *et al.*, 2005).

A self-propelled soil-steaming machine has been designed and tested for the release of steam after incorporation in the soil of substances such as potassium hydroxide (KOH) and calcium oxide (CaO) that result in an exothermic reaction (Triolo, *et al.*, 2004). Experiments were conducted from 1999 to 2003 in open field conditions (Pisa, Italy) for control of *Sclerotinia minor* on lettuce, *Rhizoctonia solani* on radish and *Fusarium oxysporum* f. sp. *basilici* on basil. The combination of steam and exothermic reaction chemicals reduced the incidence of lettuce drop by 92.4%, as well as *R. solani in* radish and *F. oxysporum* f. sp. *Basilici* in basil. The reduction in infection compared to the untreated control was 74.9% and 76.8%, respectively. Yields of lettuce in steamed + KOH plots compared to controls were 100-150% higher but were similar statistically to steam alone and steam + CaO. The results show the potential for this approach to control various soilborne pathogens and it may serve as an alternative to chemical soil disinfestation for high-value crops.

5.8.7 Hot water treatments

Recent progress of an old technology hot water percolation has been developed as a physical alternative to MB in plastic houses in Japan (Kuniyasu and Takeuchi, 1986). In this technology, field soil is slowly percolated with hot water at 70-95°C at a rate of 250 l/m2 through watering pipes or nozzles set on the soil surface. Recent trials have shown promising results on many soilborne pests (Eguchi *et al.*, 2002; Iwamoto *et al.*, 2000; Nishi, 2000; Nishi *et al.*, 2000; Nojima *et al.*, 2002; Sakai *et al.*, 1998). The technique controls *Monosporascus* root rot of melons, which is not controlled by soil solarisation (Eguchi *et al.*, 2002; Sakai *et al.*, 1998). When a field is treated, growth and yield is improved sometimes more than 30% due to the change of soil physical or chemical conditions such as desalinisation, nitrogen mineralisation due to decomposition of dead microbial organisms and high moisture content in the soil, etc. (Nishi, 2002; Hashimoto *et al.*, 2001). This treatment is becoming popular among farmers who do not wish to use pesticides (Kita, 2006; Odake and Wakaume, 2006).

5.8.8 Solarisation

Soil solarisation has replaced MB in certain regions with hot climates, long sunlight hours and high solar radiation values and it continues to be further adopted as an alternative to MB, particularly when used in combination with another technique as discussed below. Solarisation occurs when heat from solar radiation is trapped under clear plastic sheeting to elevate the temperature of moist soil to a level lethal to soilborne pests including pathogens, weeds, insects, and mites (Katan, 1993). Although it was first used in arid and semi-arid regions with intense sunshine and minimal rainfall, recent advances in technology have extended its use to other regions where it was once regarded as impractical (Horiuchi, 1991; Chellemi *et al.*, 1997a,b; Le Bihan *et al.*, 1997; Gullino and Minuto, 1997; Lamberti *et al.*, 2001; Besri 2002; Ozturk *et al.*, 2002). Soil solarisation has been studied in over 50 countries including Article 5 and non-Article 5 countries (Katan, 1991; 1993; Ghini, 1997; Tjamos, 1998; Ammati *et al.*, 2002 a,b; Besri, 2002; Chaverri and Gadea, 2002; Pérez *et al.*, 2002). Solarisation can achieve control of pathogens to levels approaching those obtained with MB (Yücel, 1995; Gamliel *et al.*, 2000; Minuto *et al.*, 2000; Di Vito *et al.*, 2000; Haidar *et al.*, 1999; Haidar and Siahmed, 2000).

Commercial adoption of solarisation continues to increase in countries where cropping and climate conditions make this technique an efficient alternative to MB (Roe *et al.*, 2004; Abdul-Baki *et al.*, 2004). In Costa Rica for example, an estimated 20% of the melon cropping area (about 2000 ha) is now using solarisation, which has proven particularly successful when combined with metham sodium (Chaverri, 2004). The same has been reported from China for the control of soilborne diseases affecting strawberry and tomato (Cao, 2006, pers. comm.). Research in Israel indicates that solarisation efficacy can be enhanced with special plastic covers, e.g. a double mulch of black polymer and anti-drip film for controlling sudden wilt of melons (Arbel *et al.*, 2003).

Results with solarisation are promising in many countries trying it for the first time (Katan, 1993; Ghini, 2006; Roe *et al.*, 2004; Ozores-Hampton *et al.*, 2004; 2005; Benlioglu, 2005; Stapleton *et al.*, 2005). Some important pests however, are not controlled in a consistent manner by solarisation alone e.g. root-knot nematodes (*Meloidogyne* spp.), nutsedge (*Cyperus* spp.), *Monosporascus* and *Macrophomina* spp., (Katan and DeVay, 1991; Gilreath *et al.,* 2001; López-Aranda *et al.,* 2002). Results of MLF demonstration projects carried out in Article 5 countries show that solarisation can be considered as an alternative to MB, if the environmental conditions, cropping systems, and target pests are favourable (MBTOC, 2002).

New technologies to improve the efficacy of solarisation and broaden its application are under development including sprayable mulches, double-layer plastic and virtually impermeable film (VIF). Painting the film with white latex paint after the solarisation period reduces the input costs (Tjamos and Niklis, 1990; Gamliel and Stapleton, 1993; Chellemi *et al.,* 1997 a,b; Gamliel *et al.,* 2001; Cebolla, 2002 a,b). New plastic formulations that increase soil temperature have extended the usefulness of solarisation to cool regions (Fritsch *et al.,* 2002; Stapleton, 2000; Tamietti and Valentino, 2000). Solarisation can also be used for disinfestation of containerised nursery soil (Stapleton and Ferguson, 1996; Stapleton *et al.,* 2001) and plant supports by storing these materials in empty plastic greenhouses during the off-season in hot climates (Besri, 1991).

Several studies have now examined the effects of long-term, large-scale use of soil solarisation and organic amendments on weed populations, nematodes, yields and soil fertility on peppers (*Capsicum annuum*) and cucumbers (*Cucumis sativus*) (Ozores-Hampton, *et al.,* 2004; 2005; Roe *et al.,* 2004). Experiments conducted in a commercial vegetable farm in Florida, USA consisted of: 3 years of soil solarisation and organic amendment; 2 years of soil solarisation and organic amendment; 2 years of soil solarisation and non-organic amendment; and MB as a control. At the end of the second crop, solarised treatments had higher % weed cover and were populated primarily by Bermuda grass (*Cynodon dactylon*) compared with the MB production system, which was dominated by redroot pigweed (*Amaranthus retroflexus*), an annual weed easier to control than the perennial Bermuda grass illustrating a weak point of a long-term solarisation system in this situation. Population levels of the root-knot nematode (*Meloidogyne incognita*) fluctuated throughout the experiment. Marketable yields of peppers appeared to be similar within the production systems for the 1998-99 seasons (Chellemi, 2001b) although it was evident that improvements were necessary to enhance the consistency of the treatment. Recent reports from the USA (Wang and McSorley, 2006; McSorley and Wang, 2006) indicate that solarisation combined with biocontrols and/ or cover crops can produce results that are comparable to those obtained with MB for the control of diseases, nematodes and weeds in flowers and peppers.

Benlioglu *et al.,* (2005) compared soil solarisation treatments with chemical treatments dazomet (1st and 2nd years), and metham and MB (2nd year) to determine efficacy for control of *Rhizoctonia* spp. and *P. cactorum*, *V. dahliae* in strawberry production in Turkey. Solarisation provided 163% higher yield than the control and +50% more than the high rate of dazomet.

5.9 Combination of Chemical and Non - Chemical Alternatives Available at Large Scale

The combination of chemical and non-chemical control methods has been recognized as an effective strategy to replace MB and to overcome problems due to the narrow spectrum of activity of single control methods. Soil solarisation and grafting vegetable crops onto resistant rootstocks for instance has proven to be a very valuable non- chemical alternative. Similarly the efficacy of grafted plants can be greatly enhanced by combining them with biofumigation, green manures, and chemicals such as MITC generators, 1,3-D or non-fumigant nematicides (De Miguel, 2004ab; Spotti, 2004; Besri, 2005). Even in hot climates, solarisation, for example, is more effective if combined with other methods (Lira-Saldivar *et al.*, 2003; 2004; Wang *et al.*, 2004; Montealegre *et al.*, 2005; Ghini, 2006).

5.9.1 Solarisation combined with organic amendments or biocontrol agents

Solarisation combined with organic amendments is a potential long-term alternative to consider instead of MB for warm climate locations, such as Florida in the USA (Ozores-Hampton *et al.*, 2004; 2005). Benglioglu *et al.*, (2005) compared the efficacy of solarisation with and without chicken manure to MB, and Metham for control of soilborne diseases and weeds of strawberry in the Western Anatolia region of Turkey. All treatments controlled four weed species but not horseweed. In year one total marketable yield from raised bed solarisation with or without chicken manure and 2 week solarisation + Metham gave equivalent yields to MB whereas only raised bed solarisation and chicken manure gave the same increase in the 2^{nd} year. These alternative treatments were considered to be economically cost effective. The effects of soil solarisation for 30 days and treatment with goat manure at 0, 20 and 40 t ha^{-1} were studied as to impacts on weed management and muskmelon melon yield (Lira Saldivar *et al.*, 2003; 2004). Solarisation reduced the emergence and growth of weeds. Goat manure also had an antagonist effect on weed density, but this effect was not clear on solarised plots. *Cyperus esculentus* was affected but not eliminated by solarisation. Higher melon yields were obtained in solarised treatments, compared to control plots (11.8 t ha^{-1} compared to almost 30 t h^{-1} of solarised treatments).

Yield was significantly increased by goat manure. Soil solarisation combined with organic matter could be a sustainable alternative to MB fumigation or to the use of herbicides for weed control and for increasing melon yield.

Recently, solarisation has been reported as a promising alternative for field-grown cut flowers in the USA (McSorley and Wang, 2006) when integrated with other measures such as biorational fungicides and biocontrol agents; for field grown strawberries in Spain when combined with *Trichoderma* (Porras *et al.*, 2007); and for peppers in the USA when combined with cover crops (Wang and McSorley, 2006). Biofumigation combined with solarisation was evaluated in tomato and cucumber in a greenhouse complex comprising 36 ha in Macedonia and the efficacy and yield were comparable to MB. As a result the researchers expect that this technique will be widely adopted as a MB alternative in this region (Popsimonova, 2002).

5.9.2 Solarisation combined with chemicals

Conventional soil solarisation requires a soil-mulching period of generally 4 to 6 weeks, depending on climate, and this sometimes leads to inconsistent results. A combination of soil solarisation with a reduced dosage of fumigants improves consistency and enables its use under a wider range of conditions, even shortening the mulching period necessary and improving control effectiveness (Frank *et al.*, 1988; Gamliel *et al.*, 1993; Katan, 1996; Chellemi *et al.*, 1994; Chellemi *et al.*, 1997; Cartia and Asero, 1994; Stevens *et al.*, 1996; Cartia, 1997; 2002; Cartia *et al.*, 1997; Lamberti, 2001; Llobell *et al.*, 2000; Ammati *et al.*, 2002 a,b; Cebolla 2002 a,b; López-Aranda *et al.*, 2002; Montealegre *et al.*, 2005).

Moreover, because the shift from MB fumigation to alternative strategies has increased the adoption of drip application methods (Ajwa *et al.*, 2002), the combined application of solarisation with drip irrigated fumigants now a possible replacement for MB when climate conditions are appropriate.

In particular, liquid formulations of MITC generators (metham sodium, metham potassium) and 1,3-D or 1,3-D/Pic are easy to deliver throughout drip irrigation and offer opportunities to enhance control of fungi, nematodes and weeds when combined with solarisation.

Formulations of 1,3-D and 1,3-D/Pic (i.e. Telone EC and InLine) are now registered in some countries as drip application formulations of Telone II and Telone C-35 respectively. Pic emulsifiable formulations, which may be combined with solarisation are also available. Such combinations generally shorten the solarisation period necessary for pathogen and pest control; improve control effectiveness; and allow for reduce usage of pesticides, which is beneficial to the environment. Several studies indicate that the combination of fumigants and solarisation improves the control levels of several disease agents, particularly fungi (Frank *et al.* 1988; Gamliel *et al.*, 1993; Katan, 1996; Chellemi *et al.*, 1994).

In field tests, metham sodium at reduced doses combined with short solarisation was more effective in controlling fungal pathogens than either treatment alone. Treatment sequence significantly affected pathogen control in the field, demonstrating a synergistic effect of the combined treatments, which allowed for reduced pesticide dosages (Eshel *et al.*, 2000).

Studies conducted in Turkey by Akkaya *et al.* (2004) further showed that solarisation alone or combined with alternative MB chemicals consistently produced profitable yields. Large- scale field experiments conducted with commercial growers showed that the severity of root galling induced by root knot nematodes was lower when soil solarisation was combined with 1,3-dichloropropene + chloropicrin (16.2 + 3.4 g/m^{-2}) and a gas-impermeable film (Chellemi *et al.*, 1997) than for solarisation alone.

Recently, combinations of soil fumigation with a mixture of 1,3-D/pic and soil solarisation for 7 days were evaluated under different plastic films and sequences of application for their effects on soilborne pests and marketable yield of fresh market tomato (*Lycopersicon esculentum*) and pepper (*Capsicum annuum)* (Chellemi and Mirusso, 2006). Shank injection of fumigants under a virtually impermeable film (VIF) using a novel application apparatus dramatically improved their retention in the soil (Chellemi and Mirusso, 2004). Survival of *Fusarium oxysporum* f. sp. *lycopersici* in soil declined significantly when fumigation or solarisation was combined with VIF compared with either soil disinfestation treatment applied under low-density polyethylene (Chellemi and Mirusso, 2006). When compared with an untreated control, significant reductions in yellow nutsedge (*Cyperus esculentus),* purple nutsedge (*C. rotundus*), and root-knot nematodes (*Meloidogyne* spp.) were achieved with a reduced dosage of fumigant when applications were made 7 days after planting beds were covered with VIF. A 7-day delay in fumigant application in beds covered by low-density polyethylene significantly increased marketable yield of pepper when compared with an untreated control (Chellemi and Mirusso, 2006).

The results demonstrate that chemical and non-chemical soil disinfestation methods can be combined with novel application technology and procedures to improve their spectrum of pest control and reduce fumigant application rates.

5.9.3 Grafted plants combined with chemical and non chemical methods

When combined with other treatments, grafted plants can avoid the need for MB fumigation (De Miguel, 2004b; Spotti, 2004). Grafted plants grown in solarised, biofumigated or chemically treated soils survive significantly better than ungrafted plants (Bello *et al.*, 2001).

As discussed earlier, grafting vegetable crops on resistant rootstocks is presently expanding, particularly in Mediterranean countries, Eastern Europe, the Far East and Central and South America; it is used to control pathogens such vascular wilts, basal and root rots and root-knot nematodes of various crops. Nevertheless in some particular climatic and operational circumstances, for example in areas where pest or disease pressure is severe or when suitable rootstocks are not available, grafting is unfeasible unless combined with chemicals. In Italy grafted plants are now widely used in a soil previously fumigated with alternative fumigants (e.g. 1,3-D or chloropicrin). The results, in terms of marketable yield, gall index or disease severity were equivalent to MB (Spotti, 2004).

The majority of the tomato hybrids used in the Mediterranean area are resistant to most of soil pathogens, except to *Verticillium dahliae* race 2, *Meloidogyne hapla* and several root and basal rot diseases. In addition, particular circumstances can break down the resistance to soilborne fungi and to root knot nematodes (e.g. the Mi gene is inactivated when the temperature is around or above 28-30°C, Besri 2005). In this latter case the combination of a pre-plant soil fumigant as 1,3-D is a feasible solution.

The wider spectrum of activity of MITC generators as compared to 1,3 D, can facilitate the use of grafting when nematodes are not a major pest. Applications of herbicides or fungicides may limit the negative impact of competitor weeds and minor pathogens such basal and root rot (*Rhizoctonia solani, Phytophthora* spp., *Colletrotricum coccodes*) (De Miguel, 2004; Minuto *et al.*, 2003; 2005).

Non- fumigant nematicides often offer an advantage over fumigants when used with grafted plants, since they can be applied before or during transplanting, or during the crop cycle when a pathogen is detected at damaging levels (Minuto *et al.*, 2003).

5.9.4 Steaming combined with biocontrol agents

Pasteurisation combined with *Coniothyrium minitans* considerably reduced sclerotia numbers of *Sclerotinia sclerotiorum* in the soil (Bennett *et al.*, 2005). Forest tree nurseries in Chile have adopted negative pressure steaming + *Trichoderma* to treat substrates used for container seedling or production; (Carrasco *et al.* 2003; Barel, 2003b). Steaming + biocontrols is also widely used in Cuba, for tobacco production (Pérez, 2002), and in Costa Rica and Colombia for cut-flower production (Abarca, 2005; Pizano, 2001; 2006).

5.10 Effective Technologies for Small Scale Farms

5.10.1 Biodisinfestation using crops that release volatile toxic gases (biofumigation)

The term biofumigation has been applied to the process where volatile toxic gases are released in the process of degradation of organic amendments, plant roots, and tissues and where such gases control diseases, nematodes, and weeds. Incorporation of residues of some Brassica or Composite species results in the release of a range of volatile compounds, particularly isothiocyanates, which have herbicidal, fungicidal, insecticidal, and/or nematicidal properties (Bello, 1998; Kirkegaard and Sarwar, 1998; Gamliel and Stapleton, 1993). In virtually all instances application of such amendments results in a huge increase in the overall soil microorganism populations, whereas populations of most plant pathogenic microorganisms, and likely some non-pathogenic ones, decrease substantially. This effect is very different from the effect seen with broad-spectrum fumigants such as MB, where populations of all microorganisms are severely depressed. The basis for this selective, or biodisinfestation effect, is not clearly understood but the term is much preferred over the concepts inferred by "biofumigation".

Since the last report (MBTOC, 2002), a large amount of research has been undertaken to improve to the efficacy of biodisinfestation and to develop a greater understanding of the action of the various by-products released from organic amendments (Bello *et al.,* 2002; García-Alvarez *et al.,* 2004). The effectiveness of biodisinfestation can be improved by applying plastic or other soil covers, which heat soils and trap the volatiles. Biodisinfestation combined with solarisation considerably shortens the time necessary to accomplish pest control through solarisation alone. The combination has been used successfully in the production of bananas, tomatoes, grapes, melons, peppers, and other vegetables (Bello, 1998; Sanz *et al.,* 1998).

Brassicas contain high levels of glucosinolates, which break down into biocidal compounds, mainly isothiocyanates and nitriles. Drying plants (*Rapistrum rugosum, Cleome hassleriana, Brassica juncea, Iberis amara* and *Lepidium sativum*) allowed for production of biocidal pellets, which can be used as organic treatments (Lazzeri *et al.,* 2003; 2004 a, b). Biocidal green manure treatments appear to have good potential, not only as an environmentally friendly alternative to MB in conventional agriculture, but also for organic agriculture.

Alternative management strategies to the use of preplant soil fumigation for the control of apple replant disease (ARD), including cover crops and strategies incorporating *Brassica napus* seed meal (rape seed meal [RSM]) amendment whilst not always achieving the growth and yields achieved by fumigation have provided growth responses and shown promise for future adoption in orchard situations (Mazzola and Mullinix, 2005).

5.10.2 Biodisinfestation using pest suppressive crops

Crop rotation and cover crops have long been used as an important non- chemical practice for soilborne pathogen management. A number of cover crops including castor bean (*Ricinus communis*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), crotalaria (*Crotalaria spectabilis*), sunn hemp (*C. juncea*), velvetbean (*Mucuna pruriens*), and various grasses, are known to be suppressive to root-knot nematodes. Although inferior to solarisation or soil fumigation, the performance of cover crops against nematodes may be improved by combining them with other methods, such as the use of nematode-resistant vegetable crops (McSorley, 1998; 2000; Elberson *et al.,* 1997; Subbarao, 2001; McSorley and Wang, 2006).

In Costa Rica, promising results have been obtained on demonstration plots using velvet bean (*Mucuna* spp.) as a cover crop in melon crops. These amendments suppressed the root knot nematode (*Meloidogyne* spp.) and nutsedge weed (*Cyperus* spp.), but this alternative was not suitable for continuous cropping systems, such as cut flowers (Chaverri and Gadea, 2001). Crop rotation and cover crops are more effective when considered in an IPM for the control of soilborne pests (Elberson *et al.,* 1997; McSorley, 2000; Abdul-Baki *et al.,* 2004) Abdul-Baki *et al.* (2004) found that alternating nematode resistant tomato cultivars carrying the Mi gene with legume cover crops that are non-hosts of the root knot nematode (*Meloidogyne* sp) could be used as a replacement for MB. The cover crops included velvetbean (*Mucuna prureens* var. Utilis), cowpea (*Vigna unguiculata* cv. Iron Clay) and sun hemp (*Crotalaria juncea* var. Tropic Sun) and were planted on raised beds in June, mowed in early August and left to regrow in the residue left on the surface. They were mowed again in October and then the entire residue was incorporated to the soil. Marketable yield of tomatoes grown after cowpea and velvet bean were comparable to MB but those obtained after growing sun hemp were lower. These treatments cost $1544 less per ha than MB and an additional $130 was saved nitrogen fertilizer. Many other long-term benefits were derived from this system.

5.10.3 Organic amendments, green manure and compost

Organic amendments such as composts, animal and green manures and by-products from agriculture, forest and food industries, have been used in many countries to manage certain soilborne pests (fungi, nematodes and *Orobanche*) in various crops (Bailey and Lazarovits, 2003; Millner *et al.,* 2004; Zinati, 2005; Zhou and Everts, 2004; López *et al.,* 2003; Ozores *et al.,* 2005; Haidar and Sidiahmed, 2006; Goud *et al.,* 2004; Mazzola and Mullinix, 2005). Organic amendments at this time cannot be considered as direct replacements for MB, but evidence continues to accumulate that alterations in the populations of soil microorganisms induced by the addition of organic amendments can lead to long term decline in soil pathogen populations or in the development of disease suppressive soils. Thus, this approach is a valid long-term approach for reducing the need to use soil pesticides. As the understanding of the mechanisms by which organic amendments control pathogen populations increases and the effect of soil factors that are involved become clearer, wider use of organic amendments is sure to develop (Tenuta and Lazarovits, 2002 a,b; Conn and Lazarovits, 2000; Ozores *et al.,* 2005).

The primary mechanisms by which organic amendments reduce pathogens are often chemical in nature (Lazarovits, 2004; Lazarovits *et al.,* 2005). High concentrations of volatile fatty acids (VFA) including formic, acetic, propionic acids, etc. were found to be present in many anaerobically stored organic materials such as liquid swine manure, fish emulsion and some young composts etc. (Conn *et al.,* 2005). When added to acid soil the VFA can be toxic to pathogens whereas many saprophytic organisms rapidly metabolise these materials. When VFA are added to soil with pH ranges above 7 they form salts and are not biologically active. Similarly, high nitrogen containing materials breakdown into ammonia in soils at pH ranges above 8.0 and into nitrous acids at pH ranges blow 5.5. Both compounds are very toxic to pathogens but nitrous acid is about 300 to 500 times more toxic than ammonia. The generation of these toxicants is greatly affected by soil pH, buffering capacity and organic matter content (Lazarovits, 2004; Lazarovits *et al.,* 2005). Since the pKa of the toxic materials is temperature sensitive processes such as solarisation would greatly enhance the quantity of active ingredients present in hot soils (Lazarovits *et al.,* 2005).

Incorporation of Hairy vetch (*Vicia villosa*) was tested as a soil amendment for the suppression of *Fusarium* wilt of watermelon caused by *Fusarium oxysporum f. sp. niveum* (Zhou and Everts, 2004). When mixed at 1 or 5% (wt/wt) in a loamy sand soil that was artificially or naturally infested with race 2 of *F. oxysporum* f. sp. *niveum*, pulverized dry hairy vetch, crab shell, and urea provided the best suppression (53 to 87% reduction) of

Fusarium wilt on watermelon seedlings of the material tested. Soil amended with hairy vetch at 0.25 or 0.5% (wt/wt) in micro plots resulted in 54 to 69% decreased wilt incidence and 100 to 220% increase of watermelon plant biomass. Hairy vetch winter cover crop incorporated into field plots under black plastic provided 42 to 48% reduction of wilt incidence, 64 to 100% increase of plant biomass, and a 34 to 68% increase in weight of fruit, comparable to improvements achieved by the soil fumigants MB or 1,3-DPic (C35). Soil amendment with hairy vetch also increased the sugar content of watermelon fruit 10 to 15%. Significant reductions in the populations of *F. oxysporum* f. sp. *niveum* were not observed in hairy vetch-amended soil in micro plots and field plots, but were observed in greenhouse pot soil amended with 5% (wt/wt) hairy vetch, which was attributed primarily to increased levels of fungicidal ammonia produced during decomposition. Incorporating hairy vetch into mulched soil can be an alternative or supplement to cultivar resistance and crop rotation for management of Fusarium wilt of watermelon.

The effects of different agronomic techniques on root-knot nematode (*M. incognita*) populations, in a cucumber-Swiss chard rotation were studied in Spanish greenhouses (López-Pérez *et al.,* 2003 a, b). Three treatments were established: a soil amendment of spent mushroom compost, metham sodium, and MB. The compost treatment showed effective control of plant parasitic nematodes, similar to the chemical metham-sodium alternatives but lower than MB. In a cucumber-Swiss chard rotation in greenhouses the compost treatment was effective against plant parasitic nematodes and provided a similar level of control to the chemicals metham and MB. The compost produced an increase in omnivorous and predator nematodes, which drastically decreased in the MB plots. Cucumber production was similar in both compost and MB treatments, with lower costs for the compost application.

Current limitations for the use of organic amendments include: lack of large scale manufacturers, inconsistency in product parameters due to lack of consistent quality standards, requirement for large amounts to be added to the soil, high transportation costs and regulatory constraints on use. Methods based on composting are by definition regionalized and efforts should be made to develop composts from inexpensive, locally available materials. This has occurred in some Article 5 countries (e.g. Chaverri and Gadea 2001; Rodriguez-Kabana and Martinez-Ochoa, 1995). The degree of efficacy of composts against soilborne pathogens will also vary regionally so that composts that control pathogens in one region may not do so in another region.

5.10.4 Pest suppressive crops: Tagetes spp

Tagetes spp (marigold) suppress populations of soil endopathogenic nematodes such as *Pratylenchus penetrans* and *Meloidogyne* species. Nematode suppression by marigolds is thought to be due to thiophenes, heterocyclic sulfur-containing molecules abundant in this plant. When activated, thiophenes produce oxygen radicals. Marigold roots release this biocidal agent and it is activated in soil, perturbing the microbial populations in the marigold rhizosphere (Topp *et al.,* 1998). However, *Tagetes* have no effect on fungal diseases and weeds, thus this is a selective disinfestation. The technique is used in many countries on specific crops, but because it is not a broad-spectrum option has not been considered as a direct alternative to MB (Bell *et al.,* 1998). When used as a rotation crop, *Tagetes* sp. is nevertheless useful for reducing MB used for controlling nematodes. Nematode populations have been shown to fall below economic thresholds for two following marigold planting and yields have also significantly increased (Reynolds *et al.* 2000)

In Morocco and other countries, crop rotation with marigolds (*Tagetes erecta. T. minuta* and *T. patula*) is widely used commercially to control *Meloidogyne* on tomato, cucurbits and other vegetable crops. Rotation of vegetables with *T. erecta* was found to effectively reduce nematode populations in Morocco (Siddiqui *et al.,* 1998; Lung 1997).

5.10.5 Reducing redox potential

A newly emerging technique that has shown promising results for reducing disease incidence and populations of soilborne plant pathogens is the use of organic amendments to create anaerobic and therefore, reducing conditions in soils (Blok *et al.,* 2000; Goud *et al.,* 2004; Shinmura, 2004; Takeuchi, 2004; Watanabe, 2006). Dutch researchers (Blok *et al.,* 2000; Goud *et al.,* 2004) have termed the process as biological soil disinfestation (BSD), but in Japan it is known as redox potential. The soil is amended with organic materials such as rice, wheat bran, sawdust, or grass, which are then mixed well into soil that has been thoroughly saturated with water. The surface is then covered by clear polyethylene sheeting for a solarisation treatment lasting thirty days. As the soil microorganism populations rise in response to the organic material, oxygen is quickly consumed and anaerobic, reducing conditions occur. Organic acids, such as VFA are formed and soilborne pathogens are killed. The long-term anaerobic status of the soil is also likely to be detrimental to the survival of the pathogen resting structures. In Japan, this treatment has shown to increase soil temperature to 30-40 °C; although this is lower than the temperatures achieved with solarisation, this option is effective in areas where solarisation does not work (Shinmura, 2004; Takeuchi, 2004; Watanabe, 2006).

Dutch researchers (Blok *et al.,* 2000; Goud *et al.,* 2004) compared the efficacy of BSD at two locations with a non-treated control, Italian ryegrass amendment alone, and plastic mulch alone. After the soil treatments, plots were cropped with *Acer platanoides* and *Catalpa bignonioides* and grown for 4 years. Relative to the control, soil inoculum levels of *Verticillium dahliae* were reduced by 85% after BSD and did not increase for 4 years. Populations of *Pratylenchus fallax*, known for their interaction with *V. dahliae*, in the soil and in roots were reduced by 95 to 99%. The incidence of infection by *V. dahliae* was reduced by 80 to 90%. Verticillium wilt severity was significantly reduced in *A. platanoides* in all 4 years at one location and in the first 2 years at the other location, and significantly fewer plants died at one location. Market value of the crop in BSD plots was up to € 140,000 ha-1 higher for *A. platanoides* and up to € 190,000 ha-1 higher for *C. bignonioides* than in the untreated control. BSD is an effective, economically profitable, and environmentally friendly control method for tree nurseries. The process is active against many soilborne plant pathogens.

5.10.6 Biocontrol agents

Biocontrol agents have been demonstrated to be effective for control of specific weeds, parasitic plants and soilborne pathogens (Montealegre *et al.,* 2005; Mennan *et al.,* 2006). Biological control of root pests uses non-pathogenic bacteria, fungi and other organisms that compete for space and nutrients or are antagonistic in some other manner toward pathogens in the rhizoplane, the rhizosphere or inside the root. In most cases they act as protectants against root infection.

Entomopathogenic nematodes have received considerable attention as control agent against insects (Castillo and Marbán-Mendoza, 1966) and nematodes (López-Robles *et al.,* 1997). The bacterium, *Pasteuria penetrans*, is effective for controlling root-knot nematodes

(*Meloidogyne* spp.) in cucumbers and other specific field situations (Stirling *et al.*, 1995; Tzortsakakis and Gowen, 1994; Rojas and Marbán-Mendoza, 1999). The nematophagous fungus *Pochonia chlamydosporia* infects and destroys the eggs of root knot nematodes. It is associated with the development of nematode-suppressive soils, and is being developed as a biological control agent (Kerry and Hidalgo-Díaz, 2006). Pathogen-antagonistic *Fusarium* spp. proved effective against *F. oxysporum* f. sp. *dianthi* and *F. oxysporum* f. sp. *gladioli* and have been exploited commercially as biocontrol agents (Gullino, 1995; Minuto *et al.*, 1995; Postma and Rattink, 1992). Compost enriched with beneficial organisms such as *Trichoderma* provides very good control to soil fungi such as *Phoma* and *Pythium* on cut flowers and bulbs produced in Article 5 countries (Pizano, 2004b). In Costa Rica, biocontrol agents are now considered as a promising complementary alternative to MB for melon and cut flowers (Abarca, 2006). *Muscodor albus* has received considerable attention for controlling soilborne fungi and may possibly be a successful alternative to MB when used together with other measures (Grimme *et al.*, 2007).

5.10.7 Suppressive soils

The term "disease suppressiveness" is commonly used to designate agricultural soils or substrates, where certain specific soilborne diseases are absent or occur only to a low degree, when the pathogen is present naturally or artificially introduced (Cook and Baker, 1983). Although the extent to which MB can be replaced by this mechanism is presently unknown, it is important to consider this concept as new knowledge is gained on this mechanism.

Two different broad types of disease suppressiveness are recognized: natural and induced. Natural suppressiveness is frequently associated with the physical properties of soils and is relatively independent of crop history. Induced suppressiveness is wholly dependent on agricultural practices. The isolation, identification, and culture of the antagonistic microorganism(s) responsible for suppressiveness in soils opens up the exciting possibility for controlling plant diseases by adding these antagonists to previously conducive soils or substrates. The inhospitality of these "suppressive" soils to some plant pathogens is such that either the pathogen cannot establish or they establish but fail to produce disease or they establish and cause disease at first but diminish with continued culture of the crop (Cook and Baker, 1983).

Suppressive soils to several soilborne pathogens (*Fusarium oxysporum, Rhizoctonia solani, Pythium ultimum, Phytophthora spp, Thielaviopsis basicola* etc.) have been reported in many agricultural regions of the world (Cook, 1983; Harisson *et al.*, 1999; Schneider, 1982). Soilborne diseases develop well in some soils (conducive soils) while in other soils (suppressive soils) they may not develop or exert much lower severity of infections. Wilt induced by *Fusarium* spp. in various crop such as vegetables, date palm etc. could be eliminated or managed in suppressive soils (Alabouvette, 2000).

In some suppressive soils, even if the inoculum is introduced, the disease is not expressed. It has been shown that fungistasis inactivates the inoculum. It has a biological origin, as disinfection suppresses it. This resistance may be successfully transmitted to conducive soils. According to some authors, soil resistance to vascular Fusarium wilts is due to Fusarium saprophytes and in particular to *F. solani* and *F. oxysporum*. These fungi, with a similar ecology, are responsible for the fungistasis as they inhibit the chlamydospores germination of the pathogenic forms. When introduced in a virgin soil, the saprophytic Fusaria reproduce the suppressive effect to a large extent. Thus resistance to *Fusarium* *oxysporum* has been successfully transmitted for carnation, melon, and tomato and cyclamen crops. The inclusion of 10 to 20% volume of resistant soil to a substrate gives a stable protection that is much higher as compared to chemical treatments, with a relative absence of specificity of the mixed soil. The transfer of resistant soils from one region (e.g. Chateaurenard in France) to another (e.g. Nice) and their use as a natural source of antagonists is successful for producing potted high yielding crops like carnation in the south of France (Alabouvette, 2000; Garibaldi, 1984; Weller, 2006).

The resistance of some soils to several other pathogens has also been reported. In the case of *Rhizoctonia solani, Sclerotium rolfsii and Sclerotinia sclerotiorum*, it is likely to be due to *Trichoderma harzianum*. In other cases, the resistance may be caused by bacteria or actinomycetes (Weller, 2006). A major challenge in research and farm advice on crop protection is to develop soil management and cropping systems, which improve the intrinsic resistance of soils.

Suppressive soils constitute good reservoirs of potential biocontrol agents, and several strains of fungal and bacterial antagonists have been isolated from them. However, to succeed with applications of biological agents it is necessary to know not only their modes of action but also the environmental conditions required for their establishment and the expression of their antagonistic activities. Lastly, according to European legislation, biological control agents have to be registered as chemical pesticides. Registration is based on efficacy and risk assessment in relation to toxicity for man, animal and the environment.

5.11 Crop Specific Strategies

Despite the diversity of soilborne pest problems worldwide only a subset of pests and diseases have traditionally been treated with MB. Historically, MB has been used because growers have resorted to narrow rotations to suit market windows and this has caused a build up of soilborne pathogens to levels that require thorough soil disinfestation such as that achieved with MB or its chemical alternatives. Owing to the cost of MB its use is restricted to certain high value crops. Table 4.1 summarises the major soilborne pathogens (nematodes, fungi, bacteria, insects and weeds) for which MB is used in one or more regions of the world. Several fungal pathogens, nematodes, and some weeds, particularly nutsedge (*Cyperus* spp) and broomrapes (*Orobanche* spp) are particularly problematic.

The sections below discuss the main crop specific strategies that have been identified as alternatives to MB (see also Tables 4.3, 4.4, 4.5) and also some barriers to the adoption of alternatives for crops and regions where MB is still used. Barriers to the adoption of MB alternatives can be classified as technical, regulatory, and economic and vary with different crop production systems.

Examples of alternatives to MB that have been implemented in non-Article 5 countries which have phased out MB before 1992 when controls were introduced under the Montreal Protocol are provided in Table 4.2. Table 4.3 gives examples of alternatives which have been adopted either partly or completely for crops in non-Article 5 countries. Table 4.4 details adoption of MB alternatives in California, USA, and Japan, major regions still using MB. Many Article 5 countries have successfully implemented a number of alternatives to MB for soil fumigation and examples are shown in Table 4.5.

Technical barriers include insufficient efficacy with the alternative management strategy, inconsistent performance of an alternative strategy, and, in cases such as perennial replant disease, inability to determine the specific problem in order to select an appropriate management strategy.

Regulatory barriers include the need for registration of new materials for what are often "minor" crops and the cost and length of time for a new chemical to complete a registration process. A commercial entity must be willing to commit the time and resources needed to complete the registration process. Additional regulatory barriers to adoption of alternatives include restrictions on the use of registered materials, such as large buffer zones, reduced rates, restricted application times, annual application limits per geographic area, and safety equipment requirements.

Economic barriers include the actual cost of using the alternative chemical or management practice, the cost of changing the production infrastructure, and the ability of large companies to absorb increased costs as compared to small producers who cannot absorb the increased costs and remain economically viable.

Cropping systems using preplant MB as part of their crop management strategies can be generally categorized into four production systems: annual fruit and vegetable crops (often grown with a plastic mulch), ornamental crops, certified propagative material, also known as "plants for planting", and perennial crops. Each of these production systems faces a range of challenging situations when switching to MB alternatives.

5.11.1 Annual Crops

Annual crops are often planted in the same ground, year after year, which can lead to an increase in pest and pathogen population levels. This can create situations where farmers become reliant on fumigation and it is harder to find suitable alternatives. In these cases, farmers may need to re-establish a more sustainable production strategy in order for alternatives to be successful. Use of wider crop rotations for instance can lower populations of pests and either avoid the need for fumigation or reduce dose rates required. In many cases where Critical Use Exemptions are being requested by non-Article 5 Parties, the basis for the request is that economic viability of these crops is often contingent on accessing key marketing windows to receive a higher price for their crop. Planting delays due to longer plant back times of some alternatives, may result in missed market windows. Annual crops are often double-cropped and the effect of MB fumigation applied to the first crop often carries over to the succeeding crop, which makes it necessary to evaluate for impact on both the first and second crops when considering alternative management strategies. As an option, industries may need to change crop rotation strategies to obtain adequate performance by the alternative. Additional challenges for annual crops include small terraced fields, sloping ground, and constraints related to fields located near residential areas.

5.11.1.1 Strawberry fruit

A significant proportion of strawberries are produced without methyl bromide in many regions of the world. The strawberry fruit production segment of the pre-plant soil use of MB has likely had more research resources devoted to it than most other crop sectors, and correspondingly has made more progress in transitioning to alternatives.

Chemical alternatives in strawberry fruit sector

The metaanalysis (Porter *et al.*, 2006b), identified that there were a number of alternatives, which produced equivalent efficacy as MB for strawberry fruit. The most effective chemical alternatives for strawberry fruit production include 1,3-D + chloropicrin and drip-applied formulations of either Pic alone or 1,3-D/Pic with or without a follow-up treatment of metham sodium (Carrera *et al.*, 2004; De Cal *et al.*, 2004; Porter *et al.*, 2004a; Ajwa *et al.*, 2002; 2003; 2004). They have been commercially adopted on a broad scale in those industries that have phased out use of MB, or adopted on a large proportion of the crop for those countries still applying for critical use. Substantial reduction or complete phase out of MB has occurred in non- Article 5 countries for strawberry fruit crops in Australia (Tostovrsnik *et al.*, 2005), Belgium, France, Greece, Japan, Portugal, Italy, Spain and the UK (TEAP 2006 a,b). For example, 1,3-D/Pic, whether injected or drip applied, has been consistently effective across major production regions in USA, Spain and Australia and has already been successfully adopted for a substantial proportion of strawberry fruit production in each country (Porter *et al.* 2004a).

1,3 –D/Pic is the dominant methyl bromide alternative being used commercially for strawberry fruit in Spain and Australia and Pic used alone to a lesser extent (López- Aranda *et al.*, 2006; Porter, 2006).

The combination of chloropicrin and metham, applied sequentially, has gained new interest, particularly in regions where use of 1,3-D is limited by regulatory restrictions. Previous research has shown that sequential application of metham sodium after reduced rates of 1,3-D/Pic (InLine) or chloropicrin controlled soil pests in strawberry fruit and produced fruit yields equivalent to standard MB/Pic fumigation (Ajwa *et al.*, 2004). Demonstration trials confirmed earlier research that metham can be used to reduce application rates of InLine and pic without a loss in yield in strawberry fruit in California, even though pathogen pressure was severe (Ajwa *et al.*, 2004).

Growers in China accept the good efficacy of chloropicrin for strawberry fruit production so that chloropicrin and dazomet are being extended as MB alternatives in this sector, so the consumption of chloropicrin is increasing gradually in strawberry in China (Cao, pers. comm. 2006).

Among the chemical products that are not registered, methyl iodide, cyanogen (ethane dinitrile, EDN), propylene oxide, cyanogen and sodium azide show promise (Mann, *et al*, 2005; Mattner *et al.*, 2003; Norton, 2003; Ren *et. al*, 2003; Rodríguez-Kábana, 2005). Israel has reduced use of methyl bromide for this crop by adoption of alternatives such as 1,3-D/Pic and soilless substrates and states that further transition is hampered by regulatory and economic barriers. New Zealand has adopted 1,3-D/Pic and chloropicrin alone as alternatives to MB, but faces challenges in years with high rainfall. In the U.S., California has reduced use of MB by 45% since 2005 is in spite of strawberry fruit acreage increasing by 34% since 2001. This has been achieved by using MB formulations with an increased percentage of chloropicrin and by adoption of drip-applied fumigants, such as 1,3-D/Pic and chloropicrin alone (Trout, pers. comm., 2006.). California faces regulatory challenges, particularly in the further adoption of 1,3-D and Pic.

Non-chemical alternatives in strawberry fruit sector

Substrate production of strawberries is practiced in cooler regions of the world, but has been considered uneconomic for warmer temperate zones. Strawberry production in substrates accounts for approximately 5% of world production, mainly in greenhouse production and cool climates with short cropping cycles, targeting early season markets or niche markets.

The Netherlands, Israel Japan, Italy, New Zealand, UK and China are some of the key producers using substrates for strawberry fruit production (Lieten, 2004; López-Medina, 2004; Nishi and Takeya, 2006). Whilst soilless systems are widely adopted in northern Europe and certain production regions in the US (North Carolina), their penetration into more temperate production systems has been more difficult. The performance of transplants after transplanting into soilless systems has produced variable yields. Also, efforts to reduce initial set up costs for substrate systems are expected to increase their adoption as a MB alternative worldwide for this crop.

5.11.1.2 Vegetable crops

The meta-analysis (Porter *et al.*, 2006b) has confirmed that a substantial number of alternatives presently used commercially proved to be as effective as MB for controlling soilborne pathogens attacking tomatoes and other vegetables. These are now adopted in many developed countries such as Belgium, Spain, Italy, Greece and France (Besri, 2004; Leoni *et al.*, 2004; Loumakis, 2004; Spotti, 2004; Tognoni *et al.*, 2004; Shanks *et al.*, 2004).

Effective alternatives include combinations of chemicals such as. 1,3-D, chloropicrin (Mann *et al.*, 2005), metham sodium and dazomet, and non-chemical methods (e.g. substrates, grafting, resistant varieties, biofumigation, solarisation, hot air) (Besri, 2004; Runia and Greenberger, 2005). In northern Europe the main alternative to MB in tomato production is to grow crops in soilless culture (often in association with other alternatives e.g. resistant cultivars and grafting), while in Southern Europe and the Mediterranean a much more diverse range of alternatives is used, selected according to their suitability to the cropping system and environmental conditions (Besri, 2004). In Japan, grafting with resistant stock and alternative chemicals (1,3-D, Pic, metham sodium and fosthiazate when nematodes are present) are used singly or in combination; MB use has been phased out of the tomato sector of that country: grafting is presently used in 60% of regular tomato production and 90% of cherry tomatoes in the Kumamoto region, where a large proportion of the country's production is concentrated (Nishi and Tateya, 2006a). Recent research is showing that grafting of eggplants can be efficiently achieved (Kah, 2005, Blestos, 2006) and may prove useful as a MB alternative.

Uptake of alternatives for vegetables has varied considerably depending on the crop and the region in the world where the crops are grown. Complete phase out of MB has been achieved in Spain and Australia, where vegetable crops used to be the major user of MB especially for tomatoes, peppers and eggplants (Bello, A, 2006; Shanks *et al.*, 2004; TEAP 2006 a,b). These countries use a range of IPM methods including wider rotations, resistant varieties and alternative chemical fumigants. Substantial reduction or complete phase out of MB has also occurred. For tomatoes: in Japan, New Zealand, Portugal and the UK. For peppers: in Greece, Israel, Malta, New Zealand and UK. For eggplant: in Belgium, Greece, Israel, Japan, New Zealand and UK (TEAP 2006 a,b).

Large-scale field validations were conducted in 2004 for fresh market tomato in Florida, USA, to compare the effect of a combined fumigation program (in-bed applied 1,3-D + Pic followed by napropamide + trifluralin and later injected with in-bed Pic) to MB, for controlling soilborne pests of tomato and with respect to growth and yield. Tomato yield and nutsedge (*Cyperus* spp.) control data demonstrated that the proposed alternative fumigation program is an effective replacement for MB + Pic (Gilreath *et al.*, 2006b). Similarly, large-scale trials conducted over three years also in Florida (Chellemi and Browne., 2006) have shown that Telone C-35 combined with fumigants or metham sodium and sealed with VIF as well as other alternative strategies are comparable to MB for the tomato industry. Further such trials are being expanded to other MB consuming sectors i.e. flowers and turf.

In Florida, growers are still using MB fumigation for peppers because of the severe pest pressure from root knot and sting nematodes and nutsedge. In previous reports it was reported that 1,3-D/PIC combined with the selective herbicide, pebulate, performed well in trials over several seasons for these pests, but this product is no longer registered. More recently, trials with other herbicides have shown control of nutsedge, nematodes and fungal pathogens similar to MB, however further trials are needed to prove consistency of these treatments for peppers and some double cropped systems (Gilreath *et al.*, 2004 a, b; 2005). Nutsedge continues to be a major target requiring more effective alternatives to MB.

5.11.1.3 Ornamental Crops

Floriculture is a complex industry in the worldwide context, with hundreds of flower types, production cycles and cropping systems involved. Most are grown annually, however some are grown as perennial crops over several seasons (e.g. roses and some carnation crops). Shifting to alternatives often requires growers to change production practices substantially and implement integrated pest management programs. This may include transition to soilless systems, at times with increased investment, but often with improved quality and yields (Savvas, 2003; Graffiadelis, 2000; Grillas *et al.*, 2001; Pizano 2004b; 2006). Some ornamental crops may have remnant bulbs, which may become weeds if they grow in another succeeding crop. This, together with the short cycle of some ornamentals, may influence the selection of pesticides that can be used in light of the following crop.

Other constraints to adoption of alternatives that apply to the cut flower sector are generally the same as those of other crops: regulatory issues (e.g. township caps in USA, products that are restricted for greenhouse use like chloropicrin), and registration (e.g. iodomethane; mixtures of fumigants). However, alternatives that do not need registration such as steam and substrates are used by many growers around the world particularly for flowers grown in protected environments.

Roses, carnations and gerberas are the flowers most commonly grown in substrates, but other flower types are also being produced with this cropping system (Nucifora, 2001; Gullino *et al.* 2003; Grillas *et al.* 2001; Pizano, 2004 a,b; 2006; Savvas, 2003). Substrates are used on about 600 ha (approx. 400 farms) for rose flower production in the Netherlands (De Hoog, 2001; Pizano, 2004a). Roses are presently entirely produced in soilless culture in Israel and this experience is leading the way for adoption of substrates on other crops such as gerbera, lily, anemone and carnation (Ausher, pers. comm. 2004). Although the initial set up cost of a soilless production system is comparatively expensive, growers are generally able to compensate the extra cost through significantly better yields and quality that result from higher planting density, optimum plant nutrition and better pest and disease control.

(Grafiadellis *et al.* 2000; Minuto *et al.*, 2005; Akkaya *et al.* 2004; Pizano, 2004b, 2005, 2006, Schnitzler and Grudda, 2002).

Steaming, although expensive, controls soil fungi at levels that are comparable to MB when properly applied (O'Neill *et al.* 2005; Reuven *et al.* 2005; Barel, 2003, Pizano, 2001; 2004b). Steam has been widely adopted in ornamental crops in the EC to offset the need for MB (Barel, 2004; LEI, 2004). It was found to work well when combined with formaldehyde in soils heavily infested with Fusarium and grown with column stock (O'Neill *et al.,* 2005). Steam is generally suited for protected flower production and for sterilizing re-utilised substrates. Costs associated with steaming may be reduced through implementation of IPM strategies and by considering different types of fuels, boiler types and steaming systems (Runia, 2000).

Solarisation, particularly when used in combination with other chemical and non-chemical alternatives is proving to be a promising alternative for field grown flowers (McSorley and Wang, 2006).

Chemical alternatives which are used increasingly in ornamental production include dazomet, metham sodium and 1,3 dichloropropene, the latter often combined with Pic. These have proven equally effective to MB for many kinds of flowers in Israel (Reuven *et al.* 2002; Reuven *et al.*, 2005), the USA (Schneider *et al.,* 2003; Gerik, 2005 a, b; Gerik and Green, 2004), Spain (Peguero, 2004), Australia (Mann *et al.*,2005; Tostovrsnik *et al.*, 2005) and other countries. Combined chemicals such as 1,3 D, Pic and metham sodium or dazomet have given good control of pests and diseases in field-grown cut flowers in the United States (Elmore *et al.,* 2003; Gilreath *et al.*, 2005)

Several Non-Article 5 parties previously requesting CUNs (e.g. Portugal, Greece, Belgium) have now phased out MB. The Australian outdoor flower industry for example, no longer uses MB and 1,3-D/Pic and metham sodium in combination with crop rotation is in widespread use. Several member states of the EC have adopted substrates, and different chemical alternatives.

5.11.1.4 Cucurbits

In Europe, grafted cucurbits are increasingly being used. When combined with other treatments, grafted plants can avoid the need for MB fumigation (De Miguel, 2004b). In Italy, for example, grafted plants are used with alternative fumigants (e.g. 1,3-D or Pic) as MB alternatives (Spotti, 2004). Applicability of grafted plants may be limited by availability of rootstocks tolerant to local pests and diseases.

In the Mediterranean region, grafting is one of the most commonly used MB alternatives in cucurbits (watermelon, melon and cucumber). Resistant rootstocks are available for pests and pathogens such as *Meloidogyne* sp. and *Fusarium oxysporum* in melon, watermelon and cucumber, *Monosporascus cannonballus* in melon, and *Phomopsis sclerotiodes* in cucumber (Blestos, 2005; De Miguel, 2004 a, b, c; López-Galarza, *et al.,* 2004). In Israel, grafting is also showing promising results, particularly when this system is carefully adapted to particular growing conditions of each region (Cohen *et al.*, 2005; Koren, 2002; Edelsietin *et al.,* 2004; Edelstein and Ben-Hur, 2006).

In the USA the main focus has been on alternative fumigants, combined with additional weed control when necessary, and grafted plants have not played a significant role as MB alternatives.

5.11.2 Propagative Material

The third type of production system is field-grown certified propagative material, or "plants for planting". These can be one or two year production cycles depending on the type of plant. Certified propagative material must be demonstrated to have roots that are free of economically important pests and pathogens and failure to achieve certification standards results in a crop that cannot be sold. In most situations these standards require high levels of pathogen control, equivalent to those achieved when using MB but do not necessarily prescribe use of MB. This same status of cleanliness may be possible with alternatives. Management strategies must be able to ensure the roots remain clean throughout the entire one or two year growing cycle. This is in stark contrast with other cropping systems where some level of infection by pests or pathogens can be acceptable, as long as the yield and quality of the crop is not compromised.

Critical Use Exemptions for propagative material nurseries, including strawberry runner production, were granted in 2006 to Australia, Canada, European Union, Israel, New Zealand, and the U.S. Recent advances in substrate systems and production of containerised plants has made possible extensive growing of disease-free nursery stock without need for MB disinfestation treatments. There are now well-established procedures for growing of tree seedlings and many other nursery plants previously grown with the aid of MB although some producers cite a loss of plant robustness when perennial crops are grown as containerised plants compared to plants produced in open field nursery production systems (Huecker 2007, pers. com.). However, other studies cite improved survival and growth of containerised trees compared to traditional bare root nursery plants. Initial capital cost is the primary economic barrier to transfer from open field growing systems to substrate and containerised systems for nursery crops.

5.11.2.1 Strawberry nurseries

Development of effective alternatives for production of strawberry nursery transplants in soil is limited by the high health requirement for strawberry runners and the need for excellent control of weeds, as is the case with all certified propagative material. In some situations the certification standards officially issued by Parties require the application of MB, however others do not mandate MB or specify a particular fumigant. Since a single strawberry runner grown in year one can expand to several million runners by year five, the adverse impacts of pests is of particular importance. This has limited the use of transitional strategies and the adoption of many alternatives as formulations of MB/Pic with low concentrations of MB are considered inadequate for weed control.

Presently, three potential alternatives have emerged for this use: The combination of 1,3-D + Pic, where allowed and registered appears to be the most viable alternative to MB at this time (De Cal, 2004; Kabir *et al.,* 2005; Porter *et al.* 2004b). Methyl iodide, which is not yet registered in any country, has provided comparable results to MB/Pic in the USA and Australia (Mann *et al.,* 2005). In Australia, cyanogen, which also is not yet registered, has provided encouraging results. In some countries large buffers restrict the use of 1,3-D + Pic (Kabir *et al.*, 2005). In some circumstances the inconsistent results using 1,3-D + Pic constrain its further adoption for runner production (De Cal *et al.*, 2005).

Production of strawberry plants in substrates as plug plants, however, offers a technique that produces high health nursery plants that avoid the need for MB fumigation. There has been a significant increase in interest and application of this technology to suit production of runners worldwide, although further studies are required to determine the effects on strawberry physiology and fruiting and cost effectiveness for all production regions (Durner *et al.*, 2002; Porter and Mattner, 2002). In Japan, a simple, economically feasible system using trays filled with substrate is proving particularly useful for the production of strawberry runners. Various materials are used as substrates (e.g. rock wool, peat moss, rice hulls, coconuts husk and bark) and can be reused after sterilising with solar heat treatment or hot water (Nishi and Tateya, 2006b)

5.11.2.2 Tobacco seedlings

The floating trays system (FTS) has replaced a very high proportion (about 70%) of the MB formerly used in tobacco seedling production worldwide and has potential for replacing 100% of the use. It is widely used at the commercial level in both Article 5 and non-Article 5 countries i.e. USA, Europe, Australia, Argentina, Brazil, Cuba, China, Macedonia, Croatia, Malawi, Lebanon and Turkey (Valeiro, 2005). A detailed description of this alternative can be found in Chapter 10.

Notwithstanding the remarkable adoption of FTS, chemical (metham sodium, dazomet) and non-chemical alternatives (steam, heat) are also used in many countries for tobacco ground seedbeds (Valeiro, 2005).

5.11.3 Perennial fruit and nut crops

The fourth type of crop production system is the perennial tree or vine system. Replanting of perennial crops, orchards and vineyards, creates challenges far different from those faced in annual cropping systems. When old orchards and vineyards are removed, many of the old roots remain in the soil, especially in the deeper soil layers. These roots can remain alive for several years and serve as a reservoir of pathogens and nematodes to attack the new trees and vines when they are planted. Methyl bromide is capable of killing those deep, old roots, as well as the pests and pathogens, thus eliminating the source for new infections. Additionally, perennial crops will remain in the ground for 10 to 100 years, so management strategies must be effective for the first several years of the young plant's growth, rather than just for a single growing cycle as is sufficient for annual fruits and vegetables and most ornamentals. A small failure of control, that might be acceptable in annual crops, will be compounded over each succeeding year in a perennial crop and can result in unproductive trees and vines.

Often, orchards planted without effective disinfestation are not characterized by all small or unproductive trees, but rather by non-uniform growth – some large trees, some moderate, and some small. Two Parties, the EC and the U.S., nominated Critical Use Exemptions in 2006 for perennial crop replant. In California, these cropping situations have been responsible for the largest decreases in use of methyl bromide since the baseline levels were imposed in 1995. The major chemical alternatives, 1,3-D and mixtures, have increased in usage as the cost of methyl bromide increased (Table 4.5).

A number of alternatives to MB are presently in use in many countries, particularly where specific pathogens are known to contribute to the problem and/or methods that are effective in removing or killing old roots exist. These include agronomic practices such as rotation where possible, resistant rootstocks, organic soil amendments, partially replacing old soil with fresh soil and others. The most appropriate chemical alternatives include 1,3-D used singly or with Pic, metham sodium and dazomet (Browne *et al.*, 2003; Tostovrsnik *et al.* 2005). Widespread commercial use of these mixtures occurred in Australia for example, before phase out of MB (Tostovrsnik *et al.* 2005; VDPI, 2004).

Constraints to adoption of alternatives exist and are mainly of regulatory nature. In California, USA for example, there is no effective chemical alternative for the killing of roots in heavy or fine textured soil with high moisture content. Although 1,3-D is effective in killing old roots and used in light sandy soils, the dosage needed for the heavy soils exceeds the maximum allowed under California regulations (Schneider *et al.,* 2005). *Metham* sodium and dazomet are inconsistent at the depths required although the development of improved application technologies and effective moisture control in the heavy soils is ongoing (Schneider 2002a, b). Schneider *et al.,* (2005) and Lampinen *et al.,*(2005) show that drip applications in heavy soils are less effective for nematode and pathogen control than shank applications of the same materials.

5.11.4 Other crops

In certain countries where the climate and cropping system allow, a significant proportion of MB use has been replaced for specific crop/pathogen complexes by an effective alternative (see Case Studies, Chapter 10 and Chapters 3 and 7.

Table 5.1 Major soilborne pathogens, nematodes, weeds and parasitic plants for which MB is used in one or more countries in various regions (one or more countries within the region) of the world from 2002 - 2006.

Target pests	North America	Central & South America	Northern Europe	Mediterranean Region	Sub-Saharan Africa	Asia	Australasia	Japan
Nematodes								
Meloidogyne spp.	+	+	+	+	+	+	+	-
Rotylenchulus spp.	+	+	-	-	-	+	-	-
Xiphinema spp.	+	+	-	-	-	-	-	-
Belonolaimus sp.	+	-	-	-	-	-	-	-
Fungi								
Armillaria spp/Rosellinia spp.	+	-	-	-	+	-	+	-
Fusarium spp.	+	+	+	+	+	+	+	-
Phytophthora spp.	+	+	+	+	+	+	+	-
Pythium spp.	+	+	+	+	+	+	+	+
Rhizoctonia spp.	+	+	+	+	+	+	+	-
Sclerotinia spp.	+	+	+	+	+	-	-	-
Sclerotium rolfsii	+	+	+	+	+	+	+	-
Verticillium spp.	+	+	+	+	+	+	+	-
Bacteria								
Agrobacterium tumefaciens	-	-	-	-	+	-	-	-
Clavibacter michiganensis	+	-	-	+	-	-	-	-
Pseudomonas spp.	-	+	-	-	-	-	-	-
Ralstonia solanacearum	-	+	-	-	-	+	-	-
Weeds and Parasitic Plants								
Orobanche spp.	-	+	+	+	+	-	+(QPS)	-
Cyperus spp.	+	+	-	+	+	-	+	-
Replant Problems (Perennial Crops)	+	+	+	-	+	-	+	-
Soil transmitted virus								+

- \+ Methyl bromide or alternative considered necessary for this pest; - Methyl bromide not considered necessary or pest not present (see notes on following page)
- Note 1: Those pests are listed that, if all other pests were excluded, would still be target pests for MB or alternatives
- Note 2: Pests affecting specific uses (e.g. crop specific certification) have not been considered in the table. In the United States a range of nematodes are controlled with MB to assist certification of nursery stock and turf.

- Note 3: This table does not imply that the pests currently targeted with MB cannot be controlled by other means.

- **Data Sources:**
  - Critical Use Applications for MB by Parties from 2003 – 2006; Survey data collected by MBTOC from Agricultural Ministries and Departments of Environment.
  - Californian Department of Pesticide Regulation.
  - Florida Agricultural Statistics Service (1995). Vegetable Chemical Use.
  - USDA (1994) Agricultural Chemical Usage. USDA National Agricultural Statistics Service, Economic Research Service, Washington DC.
  - Australian National Methyl Bromide Response Strategy (1998). Environment Australia.
  - MBTOC Assessment Reports (1998, 2002).
  - The Netherlands Policy Note, Lower House (1980)

Table 5.2. Some non-Article 5 countries that have phased out methyl bromide

Country	Crop	Proportion of Crop Treated with MB the Year before Phaseout	Quantity of MB Used (t) the Year before Phaseout [1]	Main MB Formulation Used prior to Restriction	Estimated Proportion of Alternative Cropping Practice Adopted to Replace MB Use since Phaseout
Holland [1]	Tomatoes	65%	1,200	MB (100) used in 1980	90% substrates 10% steam
	Cucurbits	30%	300	*Ditto*	90% substrates 10% steam
	Cut Flowers	25%	800	*Ditto*	60% substrates 30% steam 10% metham sodium with 1,3-D
	Flower bulbs (glasshouse)	90%	300	*Ditto*	70% metham sodium with 1,3-D 25% crop rotation and flooding 5% steam
	Strawberries	75%	200	*Ditto*	90% substrates 10% metham sodium
	Total all crops		**3,000**		
Denmark [2]	Tomatoes, lettuce, cut flowers	NA	26	MB/PIC 98:2	99% substrates 1% steam
	Total all crops		**26**		

[1] MB use shown for the year 1980 which represents levels in Holland before restrictions were imposed, total phaseout 1991.
[2] Total phaseout on 1 January 1998.

Table 5.3 . Examples of alternatives to soil fumigation with methyl bromide used in major crops in non-Article 5 countries

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/PIC Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2001	2006	2001	2006	2001	2006	Dec 2006
Australia (679 t MB baseline for soils)	Tomatoes (fresh) Pepper	35%	Nil	130	0	98:2	Not Used	10% 1,3-D/Pic 80% IPM (i.e. 50% use fresh land; 20% fumigate less often,10% nematicides)
	Flowers / Bulbs	15%	3%	65	29	98:2	50:50	70% MB/PIC 50:50 and 20% IPM 5% metham 5% dazomet 2% Telone C35
	Strawberry fruit	65%	Nil	55	Nil	50:50 or 70:30	Not Used	90% 1,3-D/Pic, 5% Pic, 5% metham
	Strawberry Nursery	98%	98%	28	37.5	70:30	50:50	Nil
	Protected crops (vegetables)	5%	5%	50	Nil	98:2 or 100%	98:2 or 100%	50% substrates
	Orchard replants	2%	2%	5	Nil	70:30	Nil	100% 1,3-D
	Turf	10%	10%	15	Nil	50:50	Not Used	100% dazomet
	Total all crops			**350**	**67**			

(Table 5.3 cont.)

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/Pic Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2001	2006	2001	2006	2001	2006	Dec 2006
Spain (4233t MB baseline for soils, 1992)	Pepper	8,6 %	1,1 %	591	50	98:2	67:33	92 % 1,3-D/ Pic 5 % Substrates 3 % Bio (BS) BS or 1,3-D / Pic + (1 %) Grafting Increased Pic formulations & dosage reduction MB 30 g /m² + VIF
	Cut-flowers	46 %	16 %	140	43	98:2	98:2; 67:33	65 % Change of crop 20 % 1,3-D/ Pic 5 % Dazomet 10 % Substrates Increased Pic formulations & dosage reduction MB 30 g /m² + VIF every 2 or 3 years, strip fumigation
	Strawberry fruit	74%	25%	650	168	50:50 67:33	50:50	90 % 1,3-D/Pic 5 % Pic, 5 % Others (Metham-Na, Substrates, etc) Increased Pic formulations & dosage reduction MB 10 g /m² in strip fumigation
	Strawberry runners	95 %	95 %	195	230	50:50	50:50	Dosage reduction MB < 15 g /m² + LBPF*
	Total all crops			**1,576**	**491**			

* LPBF - Low permeability barrier films adopted post 2001

(Table 5.3 cont)

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/PIC Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2003	2006	2001	2006	2001	2006	Dec 2006
Belgium 400t MB baseline for soils (1993)	Eggplant, Pepper, tomatoes	3%	-	12.64	Not licensed	98:2	Not used	60% grafted tomato plants (often + chemicals) 100% peppers on substrates 70% eggplant + pepper area on substrates Steam (protected) Grafting + chemicals also used for peppers, eggplants Pic, 1,3-D, Mna, Dazomet Resistant varieties (especially tomato, often + chemicals)
	Flowers, bulbs, ornamental plants	9%	-	8.2	Not licensed	98:2	Not used	50% steam 220 Ha of substrates 1,3-D, MNa Pic in open fields
	Strawberry fruit	1%	-	2.45	Not licensed	98:2	Not used	400 Ha substrates (protected) 1,3-D, Mna, Pic (open fields)
	Cucurbits (cucumber)	1.2%	-	3.1	Not licensed	98:2	Not used	60% substrates – 100% cucumbers
	Other vegetables, mainly lettuce	2.2%	-	31.8	Not licensed	98:2	Not used	50% substrates Mna, 1,3-D
	Orchard replant, tree nurseries	2%	-	1.84	Not licensed	98:2	Not used	1,3-D, Mna, Dazomet Grafted plants (often + chemicals) Steam (protected)
	Total all crops		-		-		-	

Sources of information: Maczey, N., Vos, J. and Ritchie, B. 2006. Pre-harvest study report to promote the phase-out of critical uses of MB in the European Community. Final report. CABI International, 104 pp
Critical Use Nominations 2003, 2004 – Belgium.
EC Management Strategy
EC Alternatives database
Belgium used about 300 tonnes MB in the past. The government of Belgium decided to phase-out CUEs for soil fumigation by 31 December 2005, and phased out postharvest CUEs by 31 December 2006. Proportions of alternatives are estimated.

(Table 5.3 cont)

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/PIC Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2002	2006	2002	2006	2001	2006	Dec 2006
Italy 7000t MB baseline for soils (1993)	Tomatoes	38%	13%	1,444	495	98:2	98:2	350 Ha Mna
	Eggplant	44%	6%	297	40	98:2	98:2	Grafting increasing rapidly Grafting + chemicals Resistant varieties + chemicals 1,3 – D, Mna, MK Steam Substrates.
	Flowers	18%	4.5%	302	74	98:2	98:2	MNa used for about 180 Ha Steam, substrates, for roses, carnations, gerberas 1,3-D Solarisation
	Strawberry fruit	28%	6.3%	600	135	98:2	98:2	Up to 500 Ha substrates 1,3-D, MNa, Pic Resistant varieties often + chemicals
	Strawberry runners	100%	40%	150	60	98:2	98:2	Pic, MNa, 1,3-D
	Melon	23%	3.5%	253	38	98:2	98:2	About 30 million melon and watermelon plants are grafted annually 1,3-D, Mna, Pic Solarisation + fumigants (i.e. MNa)
	Peppers	30%	8%	285	73	98:2	98:2	1,3-D, MNa Substrates Resistant varieties often + chemicals
	Total all crops			**3331**	**855**	98:2		

Sources of information:

Maczey, N., Vos, J. and Ritchie, B. 2006. Pre-harvest study report to promote the phase-out of critical uses of MB in the European Community. Final report. CABI International, 104 pp

Critical Use Nominations 2003, 2004 – Belgium.

EC Management Strategy and EC Alternatives database

(Table 5.3 cont.)

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/PIC Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2002	2005	2002	2005	2001	2005	Dec 2006
Japan 6,363 t MB baseline for soils in 1992	Melons	NA		741	175	MB/Xylene 99.5:0.5	MB/Xylene 99.5:0.5	
	Cucumber	NA		526	57	99:5.0.5	99.5:0	
	Watermelons	NA		963	32	99.5:0.5	99.5:0.5	
	Ginger	NA		557	142	99.5:0.5	99.5:0.5	
	Ornamentals	NA		225	-			
	Pepper	NA		273	129	99.5:0.5	99.5:0.5	
	Tomato	NA		323	-			
	Strawberry fruit	NA		326	-	99.5:0.5	99.5:0.5	
	Seedbeds	NA		359	-	99.5:0.5		
	Total all crops			**5,648**	**535**	**99.5:05**	**99.5:05**	

Source for Japan data: Ministry of Agriculture, Forestry and Fisheries
Quantities of MB used (t) of Japan respective crop for 2006 is for the ones of critical use exemption.

Country	Crop	Proportion of Crop Treated with MB		Quantity of MB Used (t)		Main MB or MB/PIC Formulation Used Prior to:		Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:
		2001	2005	2001	2005	2001	2005	Dec 2006
USA (22,716 t MB baseline for soils in 1992)	Almond	NA	NA	332	102	MB/PIC 98:2		
1.California	Almond	NA	NA	332	102	MB/PIC 98:2		
	Walnut	NA	NA	249	79	98:2		
	Grapes	NA	NA	956	446	98:2		
	Nurseries	NA	NA	1054	711	NA		
	Strawberry nurseries	100%	NA	174	1917	57:43 67:33		Nil
	Strawberry fruit	98%	NA	1,969		50:50 to 98:2		45% adoption of alternatives including 1,3-D/Pic, Pic alone
	Orchard (plum/peach)	NA	NA	287	135	98:2		
	Sweet potato	40%	NA	282	163	98:2		
	Tomatoes, Peppers (Fresh)	2%	NA	312	277	67:33 85:15		
	Total all crops			**>6742**	**3882**[1]			**For all crops, see Table 4.4**
USA **2. Florida** **2.Florida (cont.)**	Cucumber	100%	NA	113	NA	98:2	NA	<1%
	Eggplant	100%	NA	75	NA	98:2	NA	NA
	Melons	70%	NA	67	NA	98:2	NA	NA
	Peppers	100%	NA	1,569	NA	98:2 (80%) 67:33 (20%)	NA	5% adoption of 1,3 D/PIC combined with herbicides
	Tomatoes	100%	NA	3,732	NA	98:2 (60%) 67:33 (40%)	NA	5% adoption of 1,3 D/PIC combined with herbicides
	Strawberries	100%	NA	501	NA	98:2 (80%) 67:33 (20%)	NA	NA
	Total all crops			**Approx 6,000**				

1 Total of crops listed in table; actual use for all crops is greater. Usage numbers based on data from Cal. Dept. of Pesticide Regulation and T. Trout (pers comm.). Source for baseline data: MBTOC 1994 Assessment Report.

Table 5.4 Comparison of the changes in the quantity of chemical fumigant use in California and Japan, 1994 to 2001 and 2005

Country	Crop	Quantity of MB Used (t)			Quantity of 1,3-D Used (t)			Quantity of Chloropicrin Used (t)			Quantity of Metham Used (t)		
		1994	2001	2005	1994	2001	2005	1994	2001	2005	1994	2001	2005
USA California[3]	Almond	332	102	37	48	112	639	<1	3	3	0	4	0
	Walnut	249	79	111	7	28	129	Nil	11	4	2	1	0
	Grapes	956	446	73	24	289	638	4	5	9	19	25	31
	Nurseries	1054	711	394	4	70	129	109	177	121	50	95	146
	Strawberry nurseries	174	1917	205	NA	NA	0	NA	NA	122	NA	NA	31
	Strawberry fruit	1,969		1,443	0	6	727	864	1081	1561	18	30	138
	Orchard (plum/peach)	287	135	34	2	112	343	<1	6	10	1	3	0
	Sweet potato	282	163	<1	34	230	245	1	<1	110	85	46	<1
	Tomatoes, Peppers (fresh)	312	277	25	47	33	145	27	111	1103	296	252	74
	Total all crops	**>6742**	**3882**[1]	**2,716**[1]	**166**	**880**	**4,219**	**1005**	**1396**	**2,189**	**471**	**452**	**5,915**
Japan[2]	**Total all crops**	**7,782**	**3,016**	**547**	**13,205**	**8,633**	**11,838**	**7,433**	**8,013**	**9,006**	**1001**	**1,095**	**1,077**

1 Total of crops listed in table; actual use for all crops is greater. Use numbers based on data from Cal. Dept. of Pesticide Regulation
2 Source for data from Japan is the Ministry of Agriculture, Forestry and Fisheries, MAFF
3 Source of data for California: Trout, T. (2006). Fumigant use in California – Response to the phase-out. MBAO 2006.

Table 5.5. Some Article 5 countries which have implemented alternatives to MB for soil fumigation

Country	Crop examples*	Proportion of Crop Treated with MB			Quantity of MB Used (t)			Main MB or MB/PIC Formulation Used Prior to:			Estimated Proportion of Alternative Practice Adopted Commercially since 1994 to Replace MB Use as of:		
		1994	2001	2005	1994	2002	2005	1994	2001	2005	1994	2001	2005
Argentina	Tomato, pepper, eggplant (seedbeds, protected)	90%	33%	22%	7	296	174	98:2	98:2	98:2	20% substrates	NA	
	Tobacco (seedbeds)	90%	63%	27%	171	155	68	98:2	98:2	98:2	15% cultural, chemical	30% floating trays; MNa 20%; others	43% floating trays; 26% MNa; 4% other (i.e. steam, heat)
	Ornamentals	70 %	N/A	N/A	12	21	11	98:2			99% cultural / chemical		MNa, steam
	Strawberry (fruit + runners)	N/A	85%	85%	None		162	NA	98:2	70:30	100% MB/PIC 80:20 introduced		Steam
	Total reported consumption*all crops				**190292**	**631598**	**415475**	98:2	98:2		**348t 775t MB used in 1997**		
Brazil	Tobacco	100%	N/A	5 %	703	132	40*	98:2	98:2	98:2			Over 95% floating trays
	Flowers				21**	167	167	98:2	98:2	98:2	N/A	Use by sector was not characterised until 2003	15% Steam, solarisation + IPMSubstrates
	Strawberry					22	68	98:2	98:2	98:2	N/A	Use by sector was not characterised until 2003	10% Mna
	Total reported consumption*all crops				**724940**	**321429**	**275432**	98:2					

China	Strawberry				400	520	510	98:2	98:2	98:2			Chloropicrin and chloropicrin capsules have replaced 10% MB use in sector. About 20% solarisation
	Tomato					160	160		98:2	98:2			20% solarisation
	Cucurbits					40	40		98:2	98:2			
	Tobacco	N/A	100%		N/A	713	90		98:2	98:2			Over 90% floating trays
	Peppers, eggplants, flowers, tobacco, other					170	90		98:2	98:2			
	Total reported consumption*all crops					**1603**	**8901035**				MB increased very substantially 1997 - 2000		
Colombia	Banana	70%	0%	0%	45	Nil	0	98:2	Nil	None	93% dazomet + glyphosate with IPM	100% dazomet + glyphosate with IPM	100% dazomet + glyphosate with IPM
	*Total reported consumption*all crops*			0%	**72**	**10-0**	**0**			None			
Costa Rica	Melon	100 %	50%	30%	500	863	445	98:2	98:2	67:339 8:2	Sector increased MB use but trials with alternatives started (cover crops, solarisation, MS, 1,3-D, dazomet)	10% of melon area (500 ha) uses solarisation. Other alternatives like metham sodium, 1,3-D are implemented commercially	30% solarisation, 22% solarisation + chemicals,18% solarisation + biocontrols
	Flowers	10%	10%	5%	40	32		98:2	98:2	98:2	Sector started decreasing	10% Steam, 30% IPM + biocontrol 20% agents and other chemicals	10% steam, 40% IPM + biocontrols, 20% chemicals + IPM

	Total reported consumption*all crops				**546500**	**642680**	**456430**				**845 728 t MB used in 1997**	**780 t MB used in 2001**	**456 t MB used in 2005**
Lebanon	Strawberry (fruit + runners)			17%		81	17					Initial alternatives not economically feasible (steam), new alternatives selected	Crop rotation, MNa, 1,3-D/Pic with or without
	Flowers					27	5						1,3-D/Pic
	Tobacco						4						Floating trays
	Tomato, Cucurbits, peppers, eggplant, other					247	46						Solarisation, biofumigation, grafting, 1,3-D/Pic
	Total reported consumption*all crops				**476227**	**378365**	**7281**						
Morocco	Beans, pepper, bananas, ornamentals, lettuce, other vegetables		70%			162	96	98:2			Mna, MK , Pic, 1,3 D, 1, 3D /Pic, (Drip irrigation),Dazomet, VydateNemacur, MocapRugby	Alternatives for some crops e.g. banana are under development	Solarisation + 1,3D1,3-D/Pic. High adoption of alternatives in banana sector (46% reduction in usage)
	Tomato					710	650					Initial choice of alternatives not appropriate (steam), changes required	Solarisation + grafting, 1,3-D/Pic.
	Cucurbits						67					Grafting	Solarisation, grafting, Mna, 1,3/D
	Strawberry	N/A	80%	12%		259	62					MNa alone or with 1,3 D (Drip irrigation)	Large adoption of Mna.
	Total reported consumption*all crops	68%			**849884**	**25942701**	**875**						

Turkey	Tomato	N/A	80%	7%	175	254	16	98:2	98:2	98:2	MB consumption increased substantially in 1996 - 1998	Initial compliance with phase-out schedule was achieved through Mb dosage reduction + VIF	Solarisation + chemicals or biofumigation. Substrates. Grafting
	Flowers	N/A	80%	30%	130	50	27	98:2	98:2	98:2	MB consumption increased substantially in 1996 – 1998		Substrates, Mna, 1,3-D
	Peppers, eggplants, cucurbits	N/A	80%	10%	100	165	23	98:2	98:2	98:2	MB consumption increased substantially in 1996 – 1998	Initial compliance with phase-out schedule was achieved through Mb dosage reduction + VIF	Grafting (10% of watermelon area is grafted), solarisation, Mna, 1,3-D, dazomet
	Total reported consumption*all crops				**315702 (1995)**	**606571 (2000)**	**6648**						
Uganda	Flowers	Nil	85%	23%	**4**	**376**	**9.6**	Nil	98:2	98:2	Nil	MB consumption increased very significantly with development of floriculture from 1998 onwards	Steam, substrates
	Total reported consumption*all crops	N/A	**85%**	**23%**	**N/A2.5 (1995)**	**3637**	**9.6**						
Uruguay	Tomato, pepper	N/A	18%		10t inc. to 21t in 1997	35				98:2	98:2	MB consumption in the horticulture sector increased significantly in 1997	Biofumigation combined with Mna, solarisation, + IPM
	Flowers, forest tree nurseries, others	N/A	2%	Nil	N/A	4.5	nil			98:2	Nil		Steam + IPM
	Total reported consumption all crops	N/A	20%		**22**	**60**	**14**						

There may be more additional crops/ commodities etc that use MB in the country.

*Total reported use as appearing at the ODS Data Report Centre – Ozone Secretariat – UNEP (http://ozone.unep.org/Data_Access/).

Consumption = production + imports – exports. Figures may thus include MB stocked and not necessarily used for a given year.

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Chapter

6

Alternatives for Treatment of Durable Commodities, Structures and Artefacts

6.1 Introduction

This chapter covers alternatives to methyl bromide (MB) fumigation for durable commodities (foodstuffs), structures and museum components and historical or cultural artefacts. Treatment of wood and wooden materials is covered in Chapter 9. This chapter focuses on new problems and progress in alternatives since the 2002 MBTOC Assessment Report. To receive a more thorough understanding of pest control problems and treatments, the reader is directed to review MBTOC 2002, plus this chapter.

Durables are commodities with low moisture content that, in the absence of pest attack, can be safely stored for long periods. They include cocoa and coffee beans; cereal grains, such as wheat, rye, barley, rice, sorghum, maize; dried fish, dried meat and derived meals; dried fruit and nuts; grain products, such as flour, noodles, semolina and compounded dry animal feeds; herbs and spices; and pulses, such as peas, beans and lentils. Many alternatives in practice are measures designed to avoid methyl bromide use, and are not products that replace its use directly.

Most durable commodities currently treated with methyl bromide are foodstuffs that are stored post-harvest before being consumed, processed or traded between harvests. Many pests can survive and proliferate on durables in storage and infestations can spread further down the supply chain if left uncontrolled. Refer to Appendix Table 6.3 to review uses and target pests for structural and commodity fumigation.

A few commodities are held at intermediate moisture contents (water activities), but tend to be treated as durables, for example, fresh chestnuts and some fresh dates. These commodities may be subject to moulding and spoilage unless held under conditions included in this chapter. Perishable commodities are considered in the Chapter 9 on Quarantine and Pre-shipment (QPS), since their treatment with methyl bromide falls under the QPS exemption.

Structural pest control is aimed at preventing or controlling pests in either an entire structure or a portion of a structure. Many conditions and pests exist which require structural pest control; only some of these are treated by methyl bromide fumigation. There are two main applications: 1) control of direct structural damage by dry wood termites and wood-boring beetles found in domestic, commercial and historic buildings, 2) control of pests, for example moths, beetles, cockroaches, mites, nematodes and rodents, in storage, food processing and non-food facilities, and in transport vehicles. Refer to Appendix Table 6.2 to review the types of buildings and structures fumigated.

In this chapter, alternatives to MB treatments for commodities and structures are reviewed alphabetically. However, since the problems of pest control and conservation of museum components and historical artefacts are complex and unique, the alternatives for the uses of methyl bromide in this sector are covered separately at the end of this chapter.

There are a large number, and variety, of potential or existing alternatives to methyl bromide for disinfestation of durable commodities, structures and museum artefacts. The choice of an alternative is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of efficacy and the cost and the time available for treatment. Some alternatives (e.g. some fumigants, heat treatment) may be implemented as 'stand alone' treatments to replace methyl bromide in certain situations. Others may be used in combination to achieve an acceptable level of control.

6.2 Existing Uses of Methyl Bromide

Since the full phaseout of controlled uses of MB in non-Article 5 countries (except for QPS uses) fumigation use in these countries has been limited to those that have Critical Use Exemptions. Postharvest and structural uses for which CUEs were granted by the Parties for 2007 are given in Table 6.1.

Table 6.1. Post-Harvest and Structural Fumigation Critical Use Exemptions by Parties for 2007

Party	Structural Nominations	Commodity Nominations
Australia		Rice
Canada	Flour mills; pasta processing facilities	
France		Seeds for planting; fresh chestnuts
Greece	Flour mills	Dried fruit
Israel	Flour mills	
Italy	Museum components (including associated artefacts); mills and food processing facilities	
Japan		Fresh chestnuts
Netherlands		Strawberry runners (bare root)
Poland		Coffee beans; cocoa beans; medicinal herbs and dried mushrooms
United Kingdom	Aircraft; flour mills; rice mills; food processing facilities	Cheese in cheese storages
United States	Flour mills; rice mills; bakeries; food processing facilities; pet food establishments; herb and spice processors	Cocoa beans; walnuts; pistachios; dried fruit; dates; dry beans; dry cure pork in storages; cheese in storages

All these applications of methyl bromide are principally against common insect and mite pests. Remaining uses in Article 5 countries are also covered in Chapter 3 (MB Consumption chapter).

6.2.1 Types of fumigation enclosures

Structures form their own fumigation enclosure. In the case of structural fumigation, the gastightness varies from aircraft (often very gastight), to ship holds, modern food factories and mills (can be very gastight), to older buildings such as many flour mills (often not very gastight and in many cases, impossible to make more than partially gastight).

Fumigation facilities for commodities will vary from well-sealed, purpose-built fumigation chambers (portable and fixed) to poorly sealed bagged stacks. In between these extremes, are ships' holds (sometimes very well sealed, but not always); freight containers (often not very gastight); and well-sealed bagged stacks with laminated sheeting.

Preparation to allow a food processing structure to be fumigated is extensive and includes sealing windows, doors, personnel lifts, etc, and can include renovations such as filling sealing eves, replacing older (and less gastight) building elements to ensure improved gas tightness which decreases gas use and improves fumigation efficacy (which can decrease frequency of fumigation). In addition, methods to improve fumigation efficacy can include filling and providing a residual pest control treatment to wall voids, changing electrical conduit systems, making alterations to equipment to allow for thorough cleaning and numerous other changes.

Commercial systems are available from several countries that re-capture and sometimes reuse the methyl bromide from chamber fumigations that would otherwise be emitted to the atmosphere. For further information, refer to Chapter 4 on methyl bromide re-capture and recycling systems.

6.2.2 Uses for which MBTOC did not identify alternatives

Alternatives have been identified and are in commercial use for most durable and structural uses discussed in this chapter. MBTOC has not identified technically effective alternatives for only four uses: high moisture fresh dates; fresh market chestnuts, cheese in cheese storages with cheese present; and dry cured pork (ham) storages with the meat present. Global consumption of methyl bromide for these categories was <100 tonnes in 2005. Additionally, it is uncertain whether there are technically effective alternatives that are sufficiently protective of immovable historical objects and museum components when infested with fungi.

6.3 Alternatives for Durables and Structures

Some alternatives work as direct replacements for methyl bromide, while others may be used in combination to achieve the aims of a methyl bromide treatment. In the section below use of rational combinations of measures is discussed first, under 'integrated pest management (IPM)', followed by consideration of individual alternatives. Some individual alternatives are not fumigants; in this chapter they are grouped to include techniques that achieve the same pest control result as fumigation. Finally, the other fumigants that are alternatives to the use of methyl bromide are reviewed.

Postharvest and structural uses still needing alternatives to MB usually require fast treatment - typically less than 3 days, including airing.

The treatment of museums and museum artefacts has many unique aspects and considerations. Art and heritage conservators have developed numerous treatments that allow both the conservation of important cultural artefacts and buildings, while ensuring pest control. These are reported in journals and conferences targeted to this highly specialized audience, and detailed by individual components of historical or cultural artefacts. A short summary of the new techniques developed to replace MB is presented here, following the sections on fumigants.

6.3.1 Integrated Pest Management

6.3.1.1 Overall view

The concept of integrated pest management (IPM) as related to post-harvest commodities and food-processing facilities has received increased international attention since the Montreal Protocol phase-out of MB. Within the framework of an advanced sustainable food production system, IPM is the primary response for the agro-food industry facing consumer demands of high quality products while at the same time addressing environmental, safety and socio-economic issues.

IPM is a broad, rational, ecological approach to the solutions of pest problems by combining, either concurrently or sequentially, biological, physical and chemical tools to ensure pest control while ensuring protection of the environment, maintenance of profitability and fulfilment of consumer demand for decreased or no pesticide use. IPM targets the entire pest complex and related contaminants (fragments, remains and pesticide residues) of a food processing ecosystem, and generally tries to avoid or minimize the use of conventional neurotoxic pesticides by using non-chemical control methods and reduced-risk insecticides whenever possible. Although registered pesticides are safe when used as directed, one of the aims of IPM is to reduce exposure of pest management professionals, workers in food facilities, and consumers to pesticides and pesticide residues. Another objective of IPM is to improve pest control efficacy and also delay the development of insect resistance due to the repetitive use of single control measures. It is also an advantageous approach in the context of increasing restrictions for pesticide use and continuing reductions in the number of biologically active compounds registered as pesticides.

In the context of phasing out methyl bromide, IPM should be considered a required pre-requisite to the use of full site chemical treatments by methyl bromide and other fumigants. A correctly implemented IPM program can both improve sanitation (in keeping with HACCP processing), and reduce the frequency of fumigation. Some mills and food processing facilities have adopted IPM as a control strategy and are achieving control without methyl bromide. As examples, mills in Scandinavian countries, UK, Slovenia, Croatia and Australia have not used full site methyl bromide treatments for several years (Nielsen, 2000; Raynaud, 2002).

On the other hand, many mills in Canada, France, Israel, Italy, United Kingdom and United States all continue to declare (2005) a need for methyl bromide, although many of the mills have thorough IPM programs. Shilling (2006) surveying dry cure pork ('ham') establishments in Southern US, noted in a preliminary stage of their multi-year research program, that only very few establishments did not have mite infestation problems with their hams. At this initial stage the reasons for success in those few establishments seemed to be diligent IPM programs, and the production of hams that were not given the longest storage times. The curing times for Southern dry cure pork products vary and hams stored for less than 6 months were more often associated with lack of mite infestation.

There are numerous sources of information to assist the implementation of IPM in milling, food processing and food storage:

- A recent book edited by Heaps (2006) reviews the present status of IPM for mills and processing facilities. Previous reviews on the concept of IPM in stored products can be found in a number of sources (Subramanyam and Hagstrum 1996a, 2000, Hagstrum *et al.* 1999, Campbell and Arthur 2004).
- There is a working group on Integrated Protection of Stored Products of the IOBC (International Organization for Biological and Integrated Control of Noxious Animals and Plants, http://www.iobc-wprs.org/index.html). This group meets once every two years and the proceedings are published as the IOBC / wprs Bulletin.
- Every four years there is a meeting of the International Working Conference on Stored Product Protection (IWCSPP, 2006). Topics covered in this conference include biological, chemical and physical control of pests and diseases. The 8th conference was held in York, UK in July 2002 (Credland *et al.*, 2003) and the 9th conference in Campinhas, Brazil, in October 2006 (Lorini *et al.*, 2006).
- Also, there are a number of international (e.g. International Conference on Controlled Atmosphere and Fumigation in Stored Products, also known as CAF; the MBAO Conference on Alternatives to Methyl Bromide, www.mbao.org), national and regional meetings that bring together the scientific community, pest management professionals, food processors and policy-makers/regulators and provide an opportunity to update the knowledge on IPM.

6.3.1.2 Implementation of IPM Programs

Many local and national governments have promoted IPM through legislation and other means. In private industry, decisions and support from senior executives is almost mandatory for adoption of IPM through investment of resources, employee training and re-direction of resources. In many countries, there are consultants and pest control companies working to design, apply, and manage IPM programs including employee training. They have committed themselves to conduct pest control programs with minimal, and often, no pesticide usage, while monitoring the success of the whole pest management program. Using information from governments and pest control companies, millers and food processors can work towards adopting and adapting IPM for their facilities.

6.3.1.3 *Elements of IPM*

An IPM program has to provide effective pest prevention, based on an accurate pest monitoring system and provide training for industry staff on the tools employed for maintaining an acceptable level of control.

6.3.1.4 *Pest Prevention*

In developing an IPM plan, consideration may need to be given to building design improvements, the materials present, retrofitting of certain facilities and effects, and exclusion practices aimed at reducing or eliminating infestations in incoming food and ingredients (Imholte and Imholte-Tauscher 1999).

A major component of any IPM system for processing, storing, and marketing durable commodities is sanitation or 'hygiene', which generally involves elimination of harbourages for pests, cleaning and removal of food residues in which pests could multiply, and regular monitoring for the presence of pests (Mills and Pedersen, 1990). Good warehouse practices, including inspection of incoming goods and packages, stock rotation, and use of insect resistant packaging where practical, reduce the probability of infestation. Once packaged, food can be contaminated by insects penetrating the physical barrier provided by the package film. Several authors have reported on the ability of various insects to penetrate films of various type and thickness (Bowditch 1997, Highland 1991, Riudavets *et al.* 2007). Some species do not produce holes on packages materials but enter packages by existing openings. Some packaging systems deliberately poke holes in packages to allow air to escape and some packages are sewn closed instead of glue or heat-sealed.

6.3.1.5 *Monitoring*

Any integrated pest management (IPM) program begins with identification of existing and potential pests affecting the facility or commodity. Information on insect and mite pests and their identification can be found in various reference books (Gorham 1987, Meaney 1998, Rees and Ransi 2004). There are many on-line websites that provide educational materials and publications from research institutes, universities, and private industry that give detailed and specific information on insect species and their identification.

An important part of IPM use in facilities is to identify the infested area and the density, dispersion and changes in number of pests over time. This is essential to make pest management decisions, to know the effectiveness of a control measure and to avoid unnecessary or late control measures. Insect populations are typically spatially heterogeneous (clumped) in their distribution; this heterogeneity is often of considerable importance to the development of sampling procedures and of rational pest-management strategies.

Recent research also documents extensive insect infestations in and around storage facilities, which provide a constant source for population immigration, even after control measures have been introduced (Doud and Phillips 2000, Campbell and Mullen 2004, Campbell and Arbogast 2004). Spatial analysis is a branch of applied statistics that concentrates on estimating values of population levels over the entire facility, which are represented graphically by means of interpolated maps. In this process, a grid of traps is placed within the facility and is monitored. The trap catches are precisely plotted on a map over a set period of time. This allows the pest management professional to pin-point the infestation and target the treatment to the specified area in bulk grain, processing plants, warehouses, and retail stores and reduces the need for broad scale application of fumigants or other insecticides (e.g. Brenner *et al.*, 1998; Arbogast *et al.*, 2000). The contour maps generated are also useful in evaluating the effectiveness of control intervention and in providing documentation of pest problems and their mitigation. Spatial analysis techniques are helpful in improving IPM techniques for mills and storage facilities (Campbell *et al.*, 2002; Trematerra *et al.*, 2004).

Monitoring for insect infestation can be done either directly, by examining premises and products for insects, or indirectly by monitoring indicators of infestation that include monitoring temperature and carbon dioxide (Neethirajan, 2007). Direct methods include visual inspection, examining samples of a product, monitoring known problem areas and trapping with or without pheromones or food attractants. There has been much research on pheromone traps for monitoring stored-product insects, and detailed reviews can be found in Phillips (1997) and Cox (2004). Mating disruption through the use of mass trapping and releasing large quantities of sex attractants is another concept that is being refined through field experimentation (Ryne *et al.*, 2006). One obvious limitation of sex attractants is they only capture males, and it is therefore often difficult to relate trap catch to actual infestation levels (Campbell and Arthur, 2004). New generations of traps, which will count insects electronically as they are captured and GPS technology of data transfer and management are now commercialised for monitoring grain and structural infestations (Shuman *et al.*, 2003). The latest developments of these technologies have included: near infrared (NIR) analysis of grain (Throne *et al.*, 2003; Pérez-Mendoza *et al.*, 2005), rapid immunoassay methods based on polyclonal antibodies (Atui *et al.*, 2003; Schatzki *et al.*, 1993; Riudavets *et al.*, 2004), specific monoclonal antibodies (Dunn *et al.*, 2003), and molecular diagnostics tools with DNA markers based on the polymerase chain reaction (PCR) (Phillips and Zhao, 2003). These methods provide precise and consistent measurements of insect contamination, and can be used to assay a variety of foods products.

Although a variety of traps have been developed, research is still needed to relate numbers of insects captured to economic action thresholds. Action thresholds of pests should be determined for the situation, pest and commodity as reviewed by Subramanyam and Hagstrum (1996b). Mathematical modelling provides a unifying framework that ties effects of various environmental factors together and permits us to evaluate their relative importance in determining population behaviour (Throne, 1995). These models form the backbone of expert systems designed to assess risk and recommend control interventions (Flinn and Muir, 1995; Flinn *et al.*, 2003), and they can be applied to establishing economic thresholds.

6.3.1.6 Tools Used in IPM Programs

Heat treatments, controlled atmospheres (based on the use of gas mixtures with low oxygen contents and/or high carbon dioxide contents), and fumigation with phosphine and sulfuryl fluoride as discussed below, can be part of IPM programs; whereas IPM is a necessary part of their efficacy. Another category of control that is a valid component of IPM programs is targeted applications with either aerosols or surface treatments to replace whole-plant fumigations. Much of the available data on aerosols is either from laboratory studies or field data with older organophosphate compounds, not with the newer reduced-risk formulations and application systems that are currently on the market. Recent studies have shown that applications of contact insecticides can reduce insect populations in simulated and actual field sites (Toews *et al.*, 2005). Additional research is needed for these products to accurately assess their ability to control insect populations in large-scale milling and production facilities.

In implementing an IPM plan, a combination of biological, physical and chemical controls will most likely be required. Biological control with predators and pathogens (Schöller *et al.*, 2006; Navarro, 2004) remains an attractive option but the majority of biological control examples are from laboratory studies or from field studies on stored grains. Recent research by Grieshop *et al.* (2006) describes how biological controls can be effective in packaged food products, and additional field studies in milling and processing facilities would help establish the utility of biological control in those sites. Physical processes are responsible for a considerable amount of non-targeted pest control and also show promise for inclusion into IPM programs. For example in the case of rice, during the conventional polishing process high mortality is generated in the weevil population (>95%) (Lucas and Riudavets, 2000; Ducom-Gallerne and Vinghes, 2001).
Other mechanical control methods, including the simple turning of the grain or the "Entoleter" (centrifugation and mechanical shocks) killed a high percentage of insects including weevils inside cereal kernels (Vincent *et al.*, 2003). Creating temperature extremes provides effective control and heat treatment can be a technically feasible alternative for mills and food commodities (Dosland *et al.*, 2006).

New active compounds are sought among plant origin extracts with activity against insects and mites (Lee *et al.*, 2003; Tapondjou *et al.*, 2004; Saraç *et al.*, 2004). As with any pesticides, precautions need to be taken with these new compounds to avoid risks to humans, and registration of any new product is a requirement in most countries.

6.3.1.7 Constraints and future considerations

IPM requires a rational integration of processes and tools. Storage is understood as an artificial ecosystem, it being necessary to take into account biotic and abiotic components and operational practices such as cleaning (sanitation), inspection and sampling. IPM strategies require constant maintenance in order to succeed. Occasional full-site or curative treatments may be required to supplement IPM programs. These may involve fumigation or other processes. IPM is still relying on pesticides as a main tool in raw material and structural pest control. Therefore, resistance to insecticides has to be managed and taken into account in any pest management program. Many IPM strategies would benefit from targeted engineering research in order to be applied efficiently. New methods of application, increased energy efficiency, sealing methods and methods to allow gastightness to be determined for existing or new structures still need to be identified or implemented. Specific facilities and equipment may need to be designed or modified for use of multiple technologies particularly to allow the use of heat as a disinfestation treatment.

6.3.2 Treatments that are not fumigants

6.3.2.1 Cold

Cold treatments remain in widespread use for numerous commodities from grains to museum artefacts; however, there has been little new research in this field since 2002. Chapter 10 on case studies of commercial adoption of alternatives to MB includes one report of non-MB grain storage through the use of cold aeration and hermetic storage. Cold is used for storage of seeds, organic dried fruits, grains (primarily thorough aeration), and is extensively used for fibre containing museum artefacts (such as carpets) under very controlled conditions. Recently, Dupuis *et al*, (2006) examined the use of cold to kill all life stages of the bean weevil (*Acanthoscelides obtectus*) in beans immediately after harvest. The beans are used for both seeds and human food. They found that a temperature of -22°C has to be reached in the centre of the bean mass to ensure disinfestation. MBTOC's previous assessment report (2002) discusses the uses of cold as an alternative to MB more fully. Appendix Table 6.6 reviews the pest lethality of cold temperatures.

6.3.2.2 Contact insecticides, insect growth regulators and other residuals

Contact insecticides insect growth regulators and other residual treatments such as diatomaceous earth, unlike fumigants, may provide residual protection against stored product insects in bulk stored grain, wood and wood products, museum artefacts, and in storage buildings and transport vehicles. Contact insecticides are also heavily used, as surface, crack and crevice treatments to the floors and walls of grain storage bins, flour mills, food processing facilities, and food warehouses, and as space treatments to open areas inside storage sites. Where permitted, and where pest resistance is not a problem, they can provide a useful insect control method that avoids extensive infestations. Generally, fumigants such as methyl bromide have a somewhat different action on the insect pests and a different role in stored product protection compared to contact insecticides. Despite these differences, where permitted by market preference and regulatory authorities, both fumigants and contact insecticides can be used effectively to produce pest-free end products.

6.3.2.3 Effectiveness

Stored-product insects vary considerably in their susceptibility to insecticides. It is sometimes difficult to compare experimental results with the same insect species, because of differing methodologies and test conditions employed. However, there are some general trends that can be discussed regarding susceptibility of individual species. There is some evidence that *Tribolium* species are more difficult to kill with residual insecticides than most other stored-product beetles (Williams *et al.*, 1983; Subramanyam and Roesli, 2000). Individual life stages of insects may also respond differently to insecticides. Wandering phase-fifth instar Indian meal moth and almond moth, *Cadra cautella* (Walker), are much more tolerant than adult beetles to contact insecticides (Yue *et al.*, 2003; Arthur *et al.*, 1995). This variation in insecticide susceptibility between insect species, even closely related species, emphasizes the importance of accurate species identification, and selecting insecticides or treatment strategies based on the target pest species.

6.3.2.4 *Contact insecticides in stored grain and other commodities*

Organophosphorus compounds are still an important group of grain protectants and are used worldwide in many different countries. The stability of deposits on grain varies widely depending on the specific insecticide, ambient conditions, temperature, and grain moisture content (MC). In general, the rate of degradation increases with both temperature and MC, although toxicity usually increases with temperature (Arthur *et al.* 1996). Although the use of organophosphorus insecticides as grain protectants is widespread, registration issues could cause certain products to be withdrawn due to requirements of exporting countries. For example, dichlorvos is used in parts of Europe and elsewhere for direct application to stored grains; the European Community (EC) may adopt restrictions on the level of residues that that can be allowed on processed grains. This could eliminate the use of dichlorvos not only in countries comprising the EC, but also on countries that export grain to the EC.

The European review may also lead to the ban of pirimiphos methyl and malathion, two other common organophosphorus insecticides used on stored grains. Currently there are concerns regarding the development of resistance to organophosphates and the occurrence of residues on bulk grain itself and in finished products (Arthur 1996). Dalglish and Wallbank (2000) have indicated the continuing need for contact insecticides to meet the need for insect-free grain, to correct management practices and to prevent loss of products caused by insect resistance. Contact insecticides are mainly used to meet requirements of insect-free grain, but in particular, to control the lesser grain borer *Rhyzopertha dominica,* and weevils of the genus *Sitophilus.*

Pyrethroids are a group of synthetic insecticides with chemical constitution based on that of the active ingredients of natural pyrethrum. In contrast to organophosphates, residues from applications of synthetic pyrethroids are very stable on grain and in contrast to organophosphates, do not break down with increases in temperature and grain MC (Noble and Hamilton 1985, Nobel *et al.* 1982). Also, toxicity of pyrethroids may decrease with increases in temperature (Johnson 1990). Pyrethroids are generally very active against *R. dominica* at a much lower application rate that organophosphorus, but are comparatively less active against weevils (Arthur 1992). Pyrethroid insecticides used in different countries as grain protectants include resmethrin, bioresmethrin, deltamethrin, pifenthrine and cyfluthrin. In nut crops, Seigel (2006) investigated the use of methoxyfenozide plus permethrin. This has 3-4 weeks persistence to control navel orangeworm in pistachios and almonds. First determining ovipositioning timings for pistachio and almond crops, he saw 51 - 81% reduction at two farms, the lower effectiveness being with a higher starting population.

Kostyukovsky with co-workers in Kenya (2006a, 2006b) examined the use of phytochemicals as fumigants and repellents against stored product insects and rodents. They tested a wide range of essential oils (some proprietary compounds) extracted from plants in Israel and Kenya, testing for effectiveness against stored grain pests. They found that some essential oils have a species and life stage specific effectiveness. The most effective compound was Pulegone and it was active against all stored product insects. At 6microgram/litre concentration they had at best 65% effectiveness against larvae. But if they used 30 microgram per litre plus 15% CO_2, they had 83-100% effectiveness against all their pests (rice weevil, *R.dominica. O. surinamensis*, *C chinensis*). In Kenya they use wild basil leaves as grain protectant, and this team extracted the active ingredient and tested mortality. *T. castaneum* was the most resistant to this treatment. Wild basil leaves were very good at repelling adults (around 85% repellence). They took leaves and stems, dried them, ground to powder. At very high concentration they found high efficacy (about 80%).

Diatomaceous earth (DE) is a naturally occurring mineral compound from microscopic skeletal remains of unicellular plants called diatoms. Fossilized deposits are collected and processed for commercial use by drying, crushing, and milling to create a fine powder (Quarles and Winn 2006). Diatomaceous earth kills insects by adhering to and abrading the insect cuticle, thereby adsorbing lipids in the epicuticle and causing death due to water loss and desiccation (Quarles and Winn 1996, Korunic 1998, Subramanyam and Roesli 2000). The best results are obtained if grains are treated immediately after harvest at the moisture content of 12% w.b. or less, because higher moisture contents and equilibrium or relative humidity lead to loss of activity (Subramanyam and Roesli 2000). Even when used at label rates, physical properties of grain such as test weight and flow rate may be affected by the DE application (Korunic *et al.* 1996, 1998). In addition, the effectiveness of DE can vary depending on the source of the original deposits (Golob 1997, Korunic *et al.* 1996), the specific formulation and target insect species (Subramanyam and Roesli 2000), and grain commodity (Athanassiou *et al.* 2005ab).

Another class of grain protectants is the insect growth regulators (IGRs). The only IGR used extensively on stored grain is methoprene, which is effective against external feeders (Mian and Mulla 1982ab), and also *R. dominica* (Oberlander at al. 1997, Arthur 2004). However, it does not give good control of *Sitophilus* species (Samson *et al.* 1990). Methoprene has been used for a number of years in Australia, and in 2002 was re-labelled for stored grains in the United States. As with nearly all IGRs, methoprene does not kill adults.

Kostynkowsky (2006b) worked with novaluron a new insect growth regulator for control stored product insect pests on stored grain. This product belongs to the benzoylphenyl ureas group and is an active larvicide with broad-spectrum insecticidal activity, acting by inhibition of chitin synthesis. It is registered in Israel and US for field application but not as a grain protectant. During research trials it was spray-applied to ensure even distribution on grain. It is used as a preventive method against a wide range of common stored product and quarantine pests of grain to help avoid the need of fumigating the entire volume of grain later. It was 100% effective against *T. castaneum* and Indianmeal moth, but less effective against internal feeders. Its effectiveness continued for one year. With bags of 1 tonne treated at a dose of 2ppm, an 85 - 95% reduction of several stored product pests was achieved. It was concluded that novaluron showed high effectiveness against larvae, but was less effective against eggs (although internal feeders showed a decreased level of egg hatch).

6.3.2.5 Contact pesticides in structures

Contact insecticides can be applied in structures as general surface sprays, spot, or crack and crevice treatment. The insecticide label for a particular product will describe the application, so it is important to recognize the distinction between each of these applications. General surface sprays are applied to broad expanses of surfaces such as walls, floors, and ceilings or as an outside treatment. Spot treatment is application to limited areas on which insects are likely to occur. These areas may occur on floors, walls, and bases or undersides of equipment, and a spot will be defined as a given area, with restrictions on the total area of a facility that can be treated. Crack and crevice treatment is application of small amounts of insecticides into cracks and crevices in which insects hide or through which they may enter the building.

Because products labelled for use in structures will vary greatly among different countries, it may be more appropriate to emphasize the physical, biological, and environmental factors that can affect residual efficacy of contact insecticides, rather than to try and list all of the labelled products. One important component of integrated pest management (IPM) programs is sanitation, which is usually defined cleaning and eliminating trash material from storage facilities (Mullen and Pederson 2000). There are several recent tests with stored-product insect species, which show dramatic increases in survival when adult insects are given food material either during or after exposure to a contact insecticide or to inert dusts such as diatomaceous earth (Arthur 1998, 2000). The presence of food and trash material may provide nutrition which helps counter the effects of the insecticide, and may also provide a means for mechanical removal of insecticide particles. Extraneous material and concentrations of trash and food within a storage facility may also become refuge sites where insects can escape exposure to residual insecticides (Barson 1991, Cox and Parish 1991, Cox *et al.*1989, 1997) and also orient towards food patches (Stejskal 1995, Campbell and Hagstrum 2002).

The surface or substrate to which an insecticide is applied will often affect residual persistence and efficacy. There are many published references that cite reduced susceptibility of stored-product insects exposed on treated concrete compared to other surfaces (Collins *et al.* 2000). One factor that has been cited as contributing to this reduced efficacy is the high alkalinity of concrete, which leads to increased and rapid breakdown and hydrolysis of insecticides (White 1988). Concrete is perhaps the most common flooring surface in large storage facilities, but other surfaces may be found as well. Many older buildings have wood floors, and some tests have reported greater residual efficacy on wood compared to concrete (Samson and Hall 1989, Jain and Yadav 1989). Residual persistence on floor tile, a common surface in retail grocery facilities, is usually greater than on wood surfaces (Arthur 1997). A final surface that is often evaluated in comparison studies is non-porous galvanized metal. Although this is not a common flooring surface, storage containers and bins are often constructed with galvanized steel, and iron beams or bars may also be common. Residues of most insecticides are very persistent on galvanized metal, and residual efficacy is usually greater on metal than on either concrete or plywood (Willams *et al.* 1983, Jain and Yadav 1989, Samson and Hall 1989).

Temperature and relative humidity will also affect toxicity and activity of residual insecticides when insects are exposed on treated surfaces. The toxicity of organophosphates is usually positively correlated and pyrethroid toxicity is negatively correlated with temperature (Johnson 1990). However, other studies have shown either little or no effect of temperature on pyrethroid toxicity, or else no gradient-response to increasing temperatures (Arthur 1999). Heat treatments are receiving increased attention for disinfestation of flour mills, and elevated temperatures associated with these treatments may have a negative impact on residual persistence, but a positive impact on toxicity (Arthur and Dowdy 2003). Depending on the insect species, in some studies toxicity of the inert dust diatomaceous earth has increased with temperature, while other studies show negative effects (Korunic 1997, Fields and Korunic 2000, Arthur 2000). However, relative humidity seems to have a drastic effect on the response of stored-product insects to diatomaceous earth, and numerous studies have documented reduced efficacy with increases in either grain moisture content or relative humidity (Golob 1987, Korunic 1988, Subramanyam and Roesli 2000, Arthur 2000). Increases in temperature and relative humidity also seem to have a positive impact on toxicity of the IGR hydroprene (Arthur 2001).

Space sprays, which are variously described as aerosols, fogging, and ultra-low-volume (ULV) applications, are a part of many pest management programs in food production plants. Space sprays of contact insecticides usually involve dispersal of small particles below 50 microns in size dispersed in the air at a rate of 0.5 to 1.0 g m^{-3}. Particle size is a very important factor in achieving effective dispersion for space treatments. Equipment that delivers a median particle size in the range of 5 to 15 microns (Bennett *et al.* 1997) is considered ideal in food plant space treatments as it allows the particles to remain airborne for periods of 2 to 6 hours or longer, depending on the propellant used. This allows air currents to move the insecticide under and around easily accessible equipment. If particle sizes are too large, hang time is greatly reduced as the particles fall to the ground. Space sprays generally have limited residual properties, which affect their ability to kill the insects not directly contacted (e.g., insects hidden in walls, floor drains, and other protected areas such as production machinery from which insect infestations can spread).

Arthur (2006a), working in a highly infested food warehouse, installed a ULV system on a timer with particle size of 15 microns. The system used was pyrethrin and other insecticides, fogged from the ceiling. Red flour beetle was killed in 7 days, but Confused flour beetle was more resistant. Arthur concluded that aerosols were more effective against immature stages and that pest identification was needed first to ensure the ULV system will be effective. Aerosol applications have to be frequent and coupled with insect monitoring.

Worldwide there are a limited number of active ingredients are available for space treatments. The organophosphorus insecticide dichlorvos is labelled for the control of many stored-product insects that might be found infesting food manufacturing, processing and storage facilities. Though not a fumigant, the high vapour pressure of dichlorvos gives it strong fumigant characteristics such as the ability to move into cracks and crevices, under equipment and pallets, and very limited penetration of light product dustings. Much of the experimental research establishing the efficacy of dichlorvos was conducted in the 1960s and 1970s (Gillenwater *et al.* 1971; Cogburn and Simonaitis 1975). Natural pyrethrins synergised with piperonyl butoxide are also used, but they are fast acting with low residual activity. Pyrethroids are also used for as aerosol applications, but there are little published data regarding actual field efficacy or dispersal of these aerosols in large-scale commercial facilities. The IGRs hydroprene, methoprene and pyriproxyfen are also labelled in several countries as aerosol treatments, with a corresponding lack of field verification data for these insecticides as well. One study by Bell and Edwards (1999) documented reduced development of eggs of the red flour beetle, *Tribolium castaneum*, the confused flour beetle, *Tribolium confusum*, and the almond moth, *Cadra cautella*, exposed to a commercial hydroprene (Protrol®) fogged at 18 mg/m^2 (60 oz per 1,000 ft^2) per floor area. However, this was an unusual method of application, because most space sprays are calculated on a per volume basis, not an area basis.

6.3.3 Heat treatment

6.3.3.1 General overview

The replacement of methyl bromide (MB) in stored product protection has been difficult for disinfestation of flourmills and other food processing facilities. One option is the application of heat for insect control. Heat as a facility disinfestation treatment has a long, satisfactory commercial history and an extensive research history. (Appendix Table 6.7 review research in heat treatment for products and structures; Table 6.8 reviews insect response research; Table 6.9 reviews research studies by various subject aspects such as cost and method.) Those facilities relying on heat treatments made considerable investment and acknowledge a significant learning curve since techniques must be adapted for each facility. However, this requirement is similar to the work required for chemical fumigation.

Heat can be generated by a variety of sources, but usually electrical, steam or propane heaters are used in actual facility treatments. Electrical or steam heaters can be used inside the facility, while propane heaters are usually placed outside and the heat has to be introduced into the facility. Fields, (2004) described trials in mills using different heat equipment providing comparative results. Spot heat treatment in combination with IPM is described in a case study in Canadian mills and food processing in Chapter 10.

Dosland *et al*. (2006) discussed options for heat for pest control in milling and processing facilities in a useful review paper. As with other pest control treatments, heat treatments must be done properly to avoid sub-lethal doses and reduce the likelihood of insect resistance (Lakhotia *et al*., 2002). Although heat treatment kills insects by causing protein changes, resistance may not be a concern to the same extent as it is with chemical treatments, but behavioural resistance may be more of a concern with heat treatments.

Dean (1911) was one of the first researchers to investigate the effectiveness of heat in flourmills on a scientific basis, and to call attention to its practicality. The relative safety of heat treatments compared to fumigation was cited by Cotton (1963). This advantage of heat treatments continues to appeal to the milling industry. Unlike with a chemical fumigation, during a heat treatment, employees can work in other parts of the building (Hulasare, 2006). Additionally, workers can enter the heat treated parts of the building for process monitoring and control, to troubleshoot and check for equipment or structural problems, but while doing so, for safety, workers should be paired and given communication tools.

6.3.3.2 Pest Efficacy

Most stored-product insects are killed within hours after exposure to temperatures of 50°C or more (Fields, 1992), and, at lower temperatures, mortality can be related to the time that the insects are exposed (Mahroof *et al*., 2003b; Arthur 2006). Table 6.9 gives the temperature ranges that relate to insect survival. In addition, there have been a number of recent studies on stage-specific mortality of specific stored-product insects exposed to lethal temperatures (Wright *et al*., 2002; Beckett and Morton, 2003; Arthur, 2006), and also detailed modelling of the mortality of different species and life stages at a range of temperatures (Mahroof *et al*., 2003a, b; Boina and Subramanyam, 2004; Mahroof *et al*., 2005)

6.3.3.3 Notes on heat treatment methods

Improvements in heating and equipment technology have also simplified how treatments are accomplished because elaborate piping systems are not required and the heat can be evenly distributed in the space being treated. (Heaps and Black, 1994; Müller, 1999; Hofmeir, 2002). Several new companies are supplying heaters suitable for structural treatments, either through rental or sales arrangements.

Ensuring an even distribute of heat within a facility and attaining temperatures at floor level of about 50°C is critical for complete kill. It was stressed over 70 years ago by Pepper and Strand (1935) that by keeping the air in circulation it is possible to raise the floor surface temperatures high enough to kill all species of stored-product insects. One way to circulate heated air within the facility is to use fans or air movers that are strategically placed, based on recording temperatures in several locations. Recent field-scale research studies have shown how fans and other types of equipment can be used to help equalize temperatures throughout the facility that is being treated (Roesli *et al* 2003; Mahroof *et al*., 2003a. Areas within a facility that do not reach lethal temperatures may limit efficacy of the treatment (Adler and Rassmann, 2002).

6.3.3.4 Heat treatment preparation

Sanitation is also critical for success, and even small amounts of substrate or residues of food could slow the heating process and promote insect survival (Bell *et al*., 2004; Bartlett *et al*., 2005). A typical heat treatment of a processing facility consists of heating the building to a target temperature of 50-60°C and maintaining these high temperatures for 24-36 h (Mahroof *et al*., 2003ab; Roesli *et al*., 2003; Bartlett *et al*., 2005).

During facility heat treatments heating rates are generally around 2-5°C/h. However, in both cases the products or the facility subjected to high temperatures are allowed to cool down again back to ambient temperature, which may take several hours. It is important during heat treatments of products to ensure that the quality is not affected, while in the case of facility heat treatments, precautions must be taken to ensure that there is no damage to the equipment, uninfested materials stored within the facility, or the structure (after Dosland *et al*., 2006)

The effectiveness of a heat treatment depends on proper planning by a "heat treatment team", conducting a thorough sanitation of equipment and floors, removing heat sensitive products and materials that could act as heat insulators, determining the heat energy required for treating a portion or the entire facility, using air movers and fans for uniform distribution of hot air, and monitoring temperatures from as many locations as possible within the facility and taking corrective action to redistribute heat from hotter to cooler areas. Recently, researchers have been designing and testing models to understand, to be able to predict energy needs and to improve heat-treating efficacy. Subramanyam (2006), working in a pasta manufacturing facility, and Maier (2006) working in a large flour mill, provided intensively studied models that will assist the plant manager and heat treatment suppliers with needed assistance in planning structural heat treatments.

6.3.3.5 Evaluating heat treatment

Heat treatment effectiveness can be evaluated by monitoring insects several weeks before and after a treatment by using commercial food and pheromone traps and using life stages of insects in test cages (Dowdy and Fields, 2002; Roesli *et al*., 2003). In addition, the degree and duration of insect suppression obtained by heat treatments can be extended by using other recommended IPM tactics, such as crack/crevice treatments with residual sprays such as diatomaceous earth or liquid insecticides (Dowdy, 1999; Arthur and Dowdy, 2003), monitoring inbound and outbound products for insect infestation, regular sanitation and inspection within the facility, and use of plastic strips or air curtains near entrances to exclude pests. The effect of high temperatures on materials within food-processing facilities is poorly understood, but heat distribution can be modelled and the whole process warrants further scientific scrutiny, to realize effective and feasible heat treatments for pest control and to prevent the label of "not functioning" being put on this alternative method.

Presently, with advances in building and equipment designs, there is renewed interest in utilizing high temperatures for stored product insect management in food-processing facilities (Heaps, 1994; Mahroof *et al*., 2003a,b; Roesli *et al*., 2003; Bartlett *et al*., 2005). Heat treatment is becoming more widely used in flourmills, breakfast food and pet food processing plants in North America, Northern Europe, and Australia. However, the degree and duration of insect suppression obtained by heat treatments is influenced by various factors, including good exclusion and sanitation practices.

In addition, there has been a reluctance of the milling and processing industries to adopt heat treatments as a general replacement for methyl bromide. The reasons for this reluctance include but are not limited to the time required for complete penetration of heat throughout the facility, the perception that heat is not as effective as fumigation and more frequent applications are required, uncertainties relating to economic costs (or known higher costs), and the belief that heat treatments impose risk to the facility or equipment. In regions with cooler climates; older mills; or where roller mills are located in basements, Bartlett *et al* (2005) found that numerous cold sinks that would prevent insect death were found in some mill sections even when appropriate temperatures were achieved in other sections of the mill. The authors noted that use of diatomaceous earth and other residuals may be required on basement floors, windowsills and other cool areas to achieve full effectiveness. Additionally, where mills or food processing facilities include attached finished product warehouses, the application of heat treatment to the facility may be constrained because heat may damage packaging materials and some finished products (Bell *et al*., 2003).

One of the current limitations for using heat is a lack of detailed economic comparisons with chemical options, particularly aerosols and fumigants. There are some recent studies of heating equipment efficacy and economics notably Fields (2004) working in flour and cereal mills and Tilley *et al* (2007) in empty grain bins and Odeh *et al* (2004) analysing heat treatment technology effectiveness and costs in food processing facilities. These papers could be used as a guide to select appropriate equipment and understand comparative costs to more accurately analyse heat treatments for milling and processing facilities.

6.3.3.6 Heat treatment for commodities

Besides heat treatment of facilities, heat is also used to manage several other pests in dry, durable food products. High temperature treatments are used for disinfestations of dried fruits and nuts (Johnson *et al.*, 1992; Wang *et al.*, 2002a), and grains (Beckett *et al.*, 1998; Mourier and Poulsen, 2000; Beckett and Morton, 2003a). In heat treatments of bulk commodities like nuts, dried fruits, or grains, high temperatures of 60-85°C are used for short time periods (in minutes) in air flow systems. Typical heating rates during heat treatment of perishable commodities, nuts, dried fruits, and grains range from 1-15°C/min. (Hallman and Denlinger (1999) discuss heat-based methods including solarisation, electric heating, burning fossil fuels for heating, and steam heating that are being studied as replacements for methyl bromide fumigation.

Recently, heat treatment has been adapted to the treatment of dates in remote locations Israel by Navarro *et al* (2004). The treatment of 2 hours at 50°C resulted in 92% disinfestation of key pests; at 50 – 55°C, 100% mortality was observed. Navarro and co-workers noted that in their samples, the pests emigrated from the dates during the treatment, an important and necessary side effect.
Madhiyanon et al. (2006) modelled the heat transfer characteristics of a heat disinfestation system for rice, based on fluid bed technology. Some research has been conducted on heat transfer in cocoa, dried fruit (apricots), dried herbs, and walnuts (Bell and Conyers, 2002; Bell *et al.*, 2003). Effective modelling of the necessary heat transfer rates would provide guidance on the choice of heaters and air-flow systems that are best suited for controlling pests attacking food factories and stores. At present an abundance of mortality data available from laboratory studies, but detailed technical descriptions on how to treat infested commodities is lacking.

6.3.3.7 Summary information

Several tables are provided to summarize the research available on heat treatment of structures and commodities. Appendix Table 6.6 gives approximate temperature ranges for insect survival, Table 6.7 contains several references on the materials and products which have been described recently to be targets of heat application for pest control, Table 6.8 lists the organisms which have been mentioned in about the last five years in the context of heat control, and Table 6.9 gives information on economic issues and preservation of product quality. The quoted literature on the use of heat for pest control in stored product protection presents much useful information on the mortality data of the pest insects and modelling the uptake of heat to generalize and understand the prospects of heat for pest control.

6.3.4 Radio Frequency Treatment and Ionising Irradiation

Wang *et al* (2002b) and Mitchum (2006) developed thermal death kinetics of four insect pests of walnuts (codling moth, Indianmeal moth, navel orangeworm, red flour beetle) with large-scale industrial radio frequency treatments. At temps greater than 50°C, using 27.12 MHz, the most resistant species and life stage was 5th instar navel orangeworm. Mitchum suggested that radio frequency heating would be done just before washing and bleaching (bleaching is used for in-shell walnuts to lighten the shell), or after the static air-drying. Using it there could shorten the approx 4-hour static air-drying time since the treatment results in some drying through heat transfer. Radio frequency heating completely controlled navel orangeworm in in-shell walnuts with no significant effect on walnut quality. Radio frequency heating did not result in rancidity or change in walnut kernel colour beyond industry standards. A cost comparisons of methyl bromide versus radio frequency in this application found that MB price is $US9.70/kg in California in 2005. Electrical cost for RF was $US0.0024/kg in California. Costs do not include capital costs or changes in labour requirements for either treatment method. Wang *et al* (2006a) continued with considerations for commercial design of radio-frequency treatments for walnuts.

Research continues on irradiation pest efficacy and treatment methods suitable for non-quarantine treatment of durables, but commercial use in this sector is not known. Hallman (2000a) reviewed the use of irradiation for non-fruit fly pests, grouping his comments under processing parameters that affect irradiation outcome or to explain differences in the literature. Low oxygen conditions increased tolerance to radiation, while faster dose rates and increased oxygen increased mortality. Decreased temperature did not decrease mortality in one study on stored product pests and although counter-intuitive, diapausing insects were not more resistant to irradiation.

Irradiation methods that are effective and compatible with handling large grain volumes were developed by Cleghorn *et al.* (2002); they used a fluid bed system to irradiate grain while flowing past the energized electrons of an electron beam accelerator. Determining that there is a combination benefit of both dose and electron energy, Cleghorn noted that some of their methods resulted in sufficient kill of adults, while also noting that larvae internal to the grain would prove most challenging. They also tested dosimetry methods capable of measuring dose in fluid bed systems. However, fluid-bed processing for bulk grains, cereals and other similar products offer considerable practical improvements over other irradiation processing concepts for these commodities.

6.3.5 Vacuum systems and bio generated modified atmospheres

Since being reviewed in MBTOC 2002 Assessment report, vacuum systems and cocoons that create modified atmospheres (bio-generated) have increased in commercial use, and for on-farm applications. Navarro (2006) reviewed commercial uptake of aerobic metabolism in closed systems with infested products. This is the GrainPro® cocoon for hermetic storage. These cocoons and the related Volcani cube® are available in sized ranging from small on-farm sizes to bunker sizes. The systems are used for seed storage in China, Indonesia and Philippines. Navarro (2006) also used the GrainPro cocoon for hermetic storage of cocoa beans, nuts and tobacco where again, the commodity's respiration achieves the MA. Cocoons may also be used for semiperishables such as narcissus bulbs (see also case study on this subject in Chapter 10).

Bagci *et al.*, (2006) examined the effectiveness of vacuum against *O. surinamensis* (saw-toothed grain beetle), the significant pest of dried fruit in Turkey. At 48 mbar

(1% oxygen) complete mortality of adults was achieved within 5 hours, and larvae for 24 hours and pupae for 26 hours; eggs varied in tolerance becoming more tolerant as they are older, around 50 hours for three-day old eggs. At 96 mbar (2% oxygen), mortality took much longer (57 hours for mortality of adults and 52 hours for larvae and 54 hours for pupae).

Vacuum packaging is now used in Spain and other EU countries to ensure the pest free status of packaged rice. Oxygen absorbing sachets are also in use to help maintain hermetic seal of packages and a low oxygen environment that prevents pest development.

6.3.6 Fumigant Treatments

There are many compounds that have been considered as fumigants at one time or another. Many of these have potential to further replace methyl bromide. Phosphine has replaced many uses of methyl bromide where its slower action on pests can be managed successfully.

6.3.6.1 Carbonyl sulphide

Carbonyl sulphide is under development as a fast-acting fumigant and alternative to methyl bromide for grain and other durables. Registration is currently being sought in Australia. Successful commercial scale trials have been carried out on bulk grains and oilseeds (Ren *et al*. 2003). Carbonyl sulphide can be applied to grain directly as a liquid by direct injection into the bulk (Ren *et al*. in press).

6.3.6.2 Cyanogen

Cyanogen continues to show promise as a direct replacement for methyl bromide where a rapid kill of pests is required. Cyanogen is highly toxic to stored product pests both as a gas and applied in aqueous solution (Hooper *et al.* 2003), requiring a *ct*-product of only 19 g h m^{-3} against *T. castaneum* pupae at 30°C, with methyl bromide requiring about 100 g h m^{-3} against this tolerant pest and stage. Registration is currently being sought in Australia for use against stored product insects.

6.3.6.3 Ethyl formate

Ethyl formate in CO_2 (sold in Australia under the BOC Ltd trade name Vapormate) was recently registered in Australia for disinfestation of stored grains, oilseeds, grain storage premises and equipment and horticultural produce. Its action is as rapid as MB against adult pests (Damcevski and Annis 2000) and can disinfest bulk grain (Damcevski *et al*. 2004). It seems particularly suited, when used as part of an IPM program, to rapid disinfestation of regions in food premises (e.g. sampling chutes) that are difficult to access. Ethyl formate is being evaluated in France as a treatment for fresh chestnuts, with satisfactory initial results.

Ethyl formate can be synergised with either methyl isothiocyanate (MITC) or allyl isothiocyanate (Ren *et al*. 2006). In commercial trials, ethyl formate synergised with MITC, was effective in disinfesting stored wheat. Two 60 m^3 grain bins were treated with ethyl formate plus synergist (95:5 by weight) at 80 g m^{-3} under recirculation. After 5 days the ethyl formate free space concentration had fallen to below 100 ppm v/v, allowing out loading without airing. Complete kill of introduced bioassays of *T. castaneum* and *R.dominica* (all stages) was obtained with >99.4% mortality of *S. oryzae* (all stages).

6.3.6.4 Hydrogen cyanide

Hydrogen cyanide continues to be used for disinfestation of ships and aircraft in some countries, where its speed of action confers particular advantages over methyl bromide.

6.3.6.5 Propylene oxide

The use of propylene oxide (PPO) for stored nut products has significantly increased since Motor's previous Assessment Report. Although outbreaks of Salmonellosis from consumption of raw almonds drove the increased use, other nut commodities are using PPO and research is expanding on this versatile fumigant. Griffith (2006) noted that PPO can be used for pre-plant and post harvest uses including as an insecticide and to reduce microbial spoilage of commodities. Australia has a PPO residue limit of 50ppm. Japan a provisional MRL of 300 ppm for spices, cocoa, cocoa beans, nuts in shell and nutmeats. The US EPA has indicated it will reregister all existing uses for PPO and will eliminate the requirement for a 4 hour treatment time. The 4 hr treatment limit is effective for all uses except spices that need 10 hrs for treatment effect equivalent to ethylene oxide.

6.3.7 Phosphine and phosphine combination treatments

6.3.7.1 General overview

Phosphine continues to be the only fumigant other than methyl bromide that is registered worldwide for the disinfestation of durable commodities. Although used principally on cereals, legumes and dried fruit, it is also used to treat a variety of other commodities, and food processing facilities in some circumstances. Further more detailed properties of phosphine were reported in MBTOC 2002. (See Appendix Table 6.10 to determine phosphine treatment time in days for all life stages of stored product pests.)

6.3.7.2 Methods for generating phosphine

Solid formulations are the usual source of phosphine worldwide. These can be made of magnesium phosphide or aluminium phosphide in several presentations such as tablets, bags and pellets, which are widely available and have been in use for over 40 years in some countries. Cylinder-based formulations containing phosphine mixed with carbon dioxide or nitrogen have been developed in recent years and allow for more controlled release of phosphine. Because the fumigant from cylinder formulations is rapidly available (unlike solid-based formulations where slow release takes place), it has been possible to shorten the exposure time whilst still maintaining fully effective disinfestation. The availability and introduction of cylinder-based proprietary formulations is not yet widespread and manufacturers appear reluctant to make them available on a global scale due to high costs related to product registration and shipment. One recent solution to overcome the problem of shipping heavy metal cylinders containing a small quantity of phosphine (2%, balance CO_2) (the remaining volumeis CO_2), is to transport cylinders containing pure phosphine. The formulation in CO_2 is nonflammable at normal pressures, but pure phosphine is highly flammable and requires a special device to mix it in air to safe levels prior to injection into the fumigation enclosure.

Cylinderised gas and phosphine generating equipment in particular, are now used as a direct replacement for methyl bromide for several commodities. -These forms allow fumigation to be carried out a few hours faster, easier adjustment of concentration and fumigation at lower temperatures and/or humidity (but only because the evolution of phosphine from solid forms does not easily occur at low temperatures or low humidity.). Cylinderised or equipment generated phosphine has an advantage in that solid residues of phosphide are not left after the fumigation. Usually, regulatory officials require special measures for disposal of residues as toxic chemicals.

A new generator has been developed in Germany for the rapid release of phosphine gas from solid formulations (e.g. magnesium phosphide). The gas is pumped into the treated area from outside. This apparatus appears suitable for the treatment of bag stacks of cocoa and similar (Jakob and Schmidt, 2003). Furthermore, gas formulations of phosphine are now being used at major ports to disinfest incoming grains. Recently, in Japan phosphine gas generation acceleration apparatus, installed outside of grain elevators, was developed and registered for use for the control of non-quarantine pests in imported wheat. Currently, this technology is used in 22 Japanese ports (Tateya and Mizobuchi, 2005).

The use of phosphine supplied conveniently in cylinders or from generators has been responsible for a considerable reduction in use of MB for commodities.

6.3.7.3 Effectiveness

The toxic action of phosphine on insects is much slower than methyl bromide and in consequence, much longer exposure periods are required. In addition, phosphine is usually not recommended at temperatures below 10^0C, or even 15^0C in some countries Temperature dependence is not solely a formulation issue. Phosphine requires active oxygen metabolism to be toxic. Below 15 ^{0}C some insects become almost quiescent and so are able to survive very long exposures. Also, in conditions of very low relative humidity, solid chemical formulations generating phosphine may not be suitable because there may be insufficient moisture to enable release of the gas.

Depending upon the temperature and humidity, fumigations with phosphine require from five to fifteen days for full effectiveness, this is in contrast to the 24-hour period used for methyl bromide over a wide range of temperatures and humidity. The relatively long periods required for effective fumigation using phosphine make it unsuitable as a replacement for methyl bromide where short-period treatments are essential. Emekei (2002) working with figs at 15°C (seasonal fumigation temperature in Turkey) determined that 36 hours would be needed for effective phosphine fumigation.

Since MBTOC's last assessment report, phosphine, primarily in cylinderised gas forms, has largely replaced methyl bromide for tobacco warehouses and for dried fruit and nut storage in the US. These adoptions followed significant substitution of phosphine for methyl bromide which took place in the 1990s or earlier. Given the extent of adoption that has already taken place, there may be only limited scope for further substitution.

6.3.7.4 Insect resistance to phosphine

Resistance to phosphine was first detected more than 20 years ago and details of the problem associated with resistance can be found in earlier MBTOC Reports (1994, 1998, 2002). The appearance of resistance among insects was often linked with a history of repeated sub-lethal treatments under poor conditions of sealing. Considerable interest was shown in this topic during the 1980s and 1990s when many countries became involved in surveys of insect resistance. The problem continues to be under active surveillance. Resistance levels in many countries (e.g. China, India, Brazil and Australia) in some strains of common stored product beetle pests are high, sufficiently so to require increases in exposure period and sometimes dosage too in areas where resistance occurs to give full control.

There has, however, been research to evaluate the worldwide resistance status of the of the cigarette beetle, *L. serricorne*. In this research, conducted by the UK Central Science Laboratory, thirty one strains of the beetle were collected from tobacco in 25 countries and the insects tested for their susceptibility to phosphine. Of the 31 strains tested, 17 (55%), which originated from 12 countries and with two of unknown origin, were designated as resistant. In addition to evaluation of the resistance of tobacco beetles a more rapid knockdown resistance test was developed using adult insects and which would give results within a working day (Savvidou, *et al* 2003).

There has also been investigation of insects from Morocco, carried out in collaboration with the UK Central Science Laboratory, and in which resistance was detected in strains of *Sitophilus oryzae*, *Rhyzopertha dominica*, and *Tribolium castaneum* (Benhalima *et al*. 2004). Much of the investigation that has been undertaken recent years has been by Australian researchers leading projects not only in their own country, but also projects in Asia funded by the Australian government (ACIAR). Collins *et al.* (2003) have reported on monitoring programs for insect resistance over two decades in the cereal-growing regions of Australia, the purpose of projects being the management of problems arising from the development of insect resistance. Further research in Australia has included investigation of the genetics of resistance in *R. dominica* (Collins *et al*. 2002), and effects of time and concentration on the mortality of resistant *S. oryzae* (Daglish *et al l*. 2002). In Vietnam, strains of *R. dominica*, *S. oryzae*, *T. castaneum*, and in addition two psocid species, *Liposcelis entomophila* and *L. bostrochophila* were examined for resistance to phosphine. Strong resistance was detected in *R. dominica* and in some strains of both psocid species (Tu Duong Minh *et al*. 2003).

Studies in China have demonstrated the presence of resistance to phosphine in major stored grain pests (Yin *et al.*, 2004) and the psocid *Liposcelis decolor* (Bai *et al.*, 2005). In India, Rajendran and Gunasekaran (2002) examined the response of phosphine-resistant strains of *R. dominica* and *S. oryzae* in mixed-age cultures to varying phosphine concentrations. Resistant *R. dominica* required an exposure period of seven days with phosphine concentrations of more than 1g m^{-3} for control to be fully effective. Also in India, Rajendran and Muralidharan (2001) investigated the effectiveness of phosphine in seven-day exposures in sheeted stacks of paddy rice, both indoors and outdoors, at dosages of 2, 3 and 4 grams per tonne. Resistance was found in *R. dominica* in older stacks, where survival occurred at a *ct*- product of 210 g h m^{-3}. All other species including *T. castaneum, Cryptolestes* spp. and *Oryzaephilus surinamensis* were successfully controlled by *ct*- products of 70 g h m^{-3} and more in stacks of fresh paddy.

Although there appears to be less investigation into phosphine resistance on a worldwide scale currently than a decade ago, where investigations are taking place it is clear that resistance remains a matter for serious consideration in post-harvest pest management. Hosada (2006) noted that lesser grain borer is now showing resistance to phosphine in paddy rice in California. Now fumigation companies are only using sulfuryl fluoride if the pest is lesser grain borer (rice requiring fumigation has to be inspected ahead of time to identify pests present.) In order to ensure phosphine remains a useful alternative to methyl bromide, it is important to ensure proper fumigation techniques are used.

6.3.7.5 Phosphine use on grain in store and in transit

Phosphine continues to be used worldwide for fumigating bagged and bulk grain, grain products, cereals, oilseeds, legumes, cocoa, tobacco and dried fruit.

Combined treatments of heat, phosphine and carbon dioxide have been successfully adopted commercially in some milling and food processing structural uses (Mueller, 2003). Concern over the slow action of phosphine compared to MB has continued to limit its usefulness where rapid disinfestation is essential. Phosphine's corrosive effects on copper have largely precluded its use where electronic and electrical equipment is involved. Studies on phosphine's corrosive effects and suggestions for avoiding this problem were published by Brigham (1997, 1998, 1999) and Bond *et al.* (1984). New products used to generate phosphine gas may not only provide better control of gas release but could widen the scope for using phosphine in the future.

There is successful commercial experience with combination treatments of heat, phosphine and carbon dioxide for fumigation of mills and similar structures. Equipment that is sensitive to phosphine within the treatment enclosure is protected by being flushed continuously with CO_2. However, some millers have indicated concerns that insurance companies may object to such mitigation measures.

Phosphine is used to fumigate grain in-transit in suitable ships and details of the method are in the 2002 MBTOC Report. This technique may be transferable to replace methyl bromide treatment of other commodities, for example, cocoa beans where in-transit treatments with phosphine conducted at time of export from producing countries may be useful in reducing the need fumigation of incoming commodity (Watson *et al*, 2002).

6.3.7.6 Spot treatments

Spot fumigation of food processing equipment with phosphine is carried out principally to 'contain' a problem within a processing area. If the treatment is sufficient to kill all life stages, and if the targeted equipment is the only location of pests, spot treatment may be useful. But if the technique controls only larvae and adult insects as the eggs hatch, and if the process is carried out repeatedly in order just to keep controlling the mobile stages of insects, then this type of sub-lethal treatment seems likely to result in selection for resistant strains of insects. If eggs and pupae, the more tolerant life stages, are not killed then insect resistance may result. It is speculated that phosphine spot treatment of bulk grain, poorly conducted, has resulted in pest resistance. In the USA, two products are registered for the purpose: one is a Pre-Pac spot fumigant containing magnesium phosphide, the other a cylinderised mixture of phosphine and carbon dioxide (Sansone pers. com. 2006).

6.3.8 Sulphuryl fluoride

6.3.8.1 General overview

Sulfuryl fluoride (SO_2F_2) is a non-flammable, odourless and colourless gas (boiling point -55.2°C). Because of the low boiling point and high vapour pressure, SF readily vaporizes under normal fumigation conditions, thus allowing rapid dispersion during dosing. Sulfuryl fluoride is non-corrosive, an important characteristic for a fumigant, especially in settings where sensitive equipment and electronic devices are present. After successive fumigations at temperatures between 20 and 70^{o}C, computer equipment continued to operate normally after being fumigated 11 times with a combined dosage of over 40,000 g. h m^{-3} (Bell *et al.*, 2004). Polyethylene sheeting and gloss paint are effective barriers to SF (Bell, 2006) so that excellent gas containment should be achievable in painted brick-built chambers or in sheeted stacks of commodities. Sulfuryl fluoride has very low reactivity as a gas, an important factor for treatment of museum artefacts; however, it will react to form hydrogen fluoride at temperatures exceeding 400°C. This acid can etch metals, glass, or other surfaces near the heat source. Thus, prior to fumigation, all open flames and glowing heat filaments must be turned off or disconnected.

Sulfuryl fluoride was developed in the late 1950's in the USA as a structural fumigant, mainly for termite control. It has been marketed since 1961 under the trade name Vikane® for control of wood and structure pests and since 2003 under the trade name of Profume® for the control of food industry pests. The fumigant has also been manufactured and marketed in China by the Linhai Limin Chemicals Co. Ltd under the trade name "Xunmiejin®" since 1983. In China, SF is used mostly on museum artefacts, timber or wood products, and for treatment of export containers. Total yearly production is about 600 tonnes, with about 100 tonnes specifically used on ships for rat control. Projected production is expected to increase to 1,500 tonnes per year, and expansion of its use in food facilities and on food products is being actively pursued (Wangchang, 2004). Sulphuryl fluoride is now registered or licensed for use in Switzerland, Italy, the United Kingdom, the United States, Germany, Canada, France, Japan, Sweden, and the Caribbean, and other countries are expected to join the list in the next few years.

Sulfuryl fluoride, sold as Vikane, is registered for treatment of buildings, furnishings, construction materials, and transport vehicles to control a wide range of pests including dry wood termites, Formosan subterranean termites, longhorn beetles, powder post beetles, furniture and carpet beetles, clothes moths, cockroaches, and rodents. The type of registration, situations included and restrictions vary by country. In California, use of SF has replaced the use of MB as a fumigant against termites and other structural pests in domestic buildings. Registration of SF in the US is sufficient to allow nearly all mills and food processing facilities to begin or continue trial and adoption of this alternative. Registration of SF in Canada was achieved in mid-2006 for empty mills and food processing facilities. SF trials are being co-sponsored by the milling sector and government with science supervision from Agriculture and Agri-Food Canada.

Following the first registration of SF as Profume in Switzerland in June 2003 (Schreyer *et al.*, 2003), registration is still in progress with widespread approvals for use in flour mills and empty food processing facilities, and an increasing number of registrations for use on grain, beans, dried fruit and tree nuts. Registration for other commodities such as cocoa and legumes has been requested for several national authorities.

6.3.8.2 Effectiveness

Sulfuryl fluoride is highly toxic to post-embryonic stages of insects (Kenaga, 1957; Bond and Monro, 1961; Drinkall *et al.*, 1996; Bell, 2004, 2006), but the eggs of many moths and beetles are difficult to control, especially at lower temperatures (Williams and Sprenkel, 1990; Bell *et al.*, 1999), and most mite stages can survive *ct*-products higher than those recommended for control of insects (Bell *et al.*, 2004). Eggs of the Mediterranean flour moth *Ephestia kuehniella* at 25°C required a *ct*-product of about 1000 g h m^{-3} to prevent hatch and 800 g h m^{-3} to prevent emergence (Bell and Savvidou, 1999). Eggs of silvanid, anobiid and tenebrionid beetles may require up to double these doses for control in shorter exposures (Williams and Sprenkel, 1990, Bell *et al.*, 2004; Bell, 2006), while considerably lower dosages are adequate for control of bruchid, bostrichid, and nitidulid beetles. Early research indicated that the lower activity on eggs is primarily due to slow penetration through the chorion and eggshell (Outram, 1967). Effective dosages for all life stages can be obtained by varying concentration and exposure time, but in general higher temperatures (over 27°C) are needed to obtain satisfactory control at practical dosage levels. Lower dosages can be used at higher temperatures because of the insects' increased respiratory rate.

Efficacy research has been conducted both in the laboratory and in the field to define dosages and treatment practices to optimise the control of key post harvest insect pests, including their egg stages. A computer program, "Fumiguide™" (a proprietary product of Dow AgroSciences), has been produced that sets dosages for application under a range of conditions (Schneider *et al.*, 2003), based on this research. Dow AgroSciences has conducted laboratory efficacy studies in cooperation with the USDA-ARS in Fresno, California, and in Manhattan, KS; Central Science Laboratory in the UK; and Federal Biological Research Centre for Agriculture and Forestry in Germany, to define the dosages required to control all the life stages of target pests.

In the past few years, experimental and preliminary commercial fumigations have been undertaken to validate the activity of SF. An early trial in a semolina mill in Italy in July 2001 (Drinkall *et al.*, 2003) investigated the efficacy of SF against mixed cultures of *Sitophilus oryzae*, *Rhyzopertha dominica*, *Stegobium paniceum*, eggs and pupae of *Plodia interpunctella* and *Ephestia kuehniella*, and eggs and adults of *Tribolium confusum* and *T. castaneum*. No insect survival was recorded following 30 days of incubation, confirming previously determined efficacy findings from chamber fumigations of SF.

Additional trials were undertaken in association with the Federal Biological Research Centre for Agriculture and Forestry, Institute of Stored Product Protection, Berlin (Reichmuth *et al*., 2003). These were designed to validate that effective control of common flour mill pests, recorded in chamber fumigations, could be achieved under field conditions. In the three field trials the temperature was raised by the use of either coil in oil electric heaters placed in the mill or external oil burners creating hot air ducted into the structure. Following exposures that ranged from 30 to 48 hours, and aeration, the bioassays were removed and insect mortality determined. In all three trials a high level of control was achieved for all life stages of three stored product beetles and two stored product moths.

The laboratory findings continue to be validated by fumigations of wheat and rice mills within the United States and Europe. The initial field trials were designed to further refine fumigant dosages for precision fumigation practices, to enhance sealing techniques for gas confinement, to measure half loss time (HLT), and to standardise fumigant introduction, monitoring and aeration practices and better understand how to manage difficult problems such as high winds (Prabakaran and Mueller, 2006; Williams *et al*., 2001). Trials have continued in the US and in Europe in rice mills and flour mills (Williams *et al*., 2003; Bell *et al*., 2004) and have established that SF is a viable replacement of MB, though with a considerably increased treatment cost and with a narrower temperature range of operation for efficacy. For example, in cool temperate zones fumigators either need to supply supplementary heating or rely on the brief period of high summer temperatures. In the tropical zone or naturally hot countries, temperature may be sufficient, but the structures may require additional attention to proper sealing.

During the first applications of SF for in several countries, the results of treatments did not meet expectations. It was reported the there was resurgence of infestation that was sufficiently rapid to indicate significant survival of even susceptible developmental stages of pests. With experience and adjustments in the technique, this problem has now been much reduced. Recent studies show that extensive populations of stored-product insects are present in and around mills and processing facilities, which could lead to a potential population rebound even with successful fumigations with SF (Campbell and Arbogast, 2004).

Recently, fumigators and Dow AgroSciences in the US have begun commercial trials of ProFume on stored cocoa beans (Bookout and Milya, 2006). Following multi-rate and temperature assay fumigation studies and residue testing, they recommendation an application rate of 24 g m^{-3} for 24 h exposure, giving a *ct*-product of >750 g h m^{-3} at >4.4 ^{o}C. The fumigators indicated this was the same dosage and fumigation time as methyl bromide, with comparable costs. Similar equipment is needed, except that infrared monitors were used instead of indicator tubes for concentration measurement. From May to Oct 2006, just fewer than 250,000 bags of cocoa bean were fumigated with SF and chocolate manufactures have made no complaints about pests. Further cold weather trials are being conducted, together with an analysis of whether surviving eggs will be able to develop to larvae in the chocolate manufacturing facilities.

Klementz (2006) tested sulfuryl fluoride (referred to as sulfuryl difluoride in Germany) to control immature life stages of *Ephestia elutella* (warehouse moth) in *in vitro* tests. Results showed all larvae and pupae killed in 12 hr. More than 98% of all eggs were killed at 48 hour exposure. 24 h gave 75% kill of eggs with three-day eggs being most resistant. Klementz determined that dosage must be higher than 557g h m^{-3} (or their tested dosage at 48h). This test showed that eggs of this species have similar results to eggs of other stored product species

6.3.8.3 Food quality

Food quality studies have been conducted on a variety of dried fruits and tree nuts in cooperation with the California Dried Fruit and Tree Nut Association and other commodity groups. SF can offer a rapid treatment for walnuts under vacuum, as a direct replacement for methyl bromide (Zettler and Leesch, 2000). Similar studies on cereal grains, including examinations of bakeability, taste and other quality measures have been conducted in cooperation with leading research organizations. Protocols have been developed to meet the requirements of the food production industry in the United States and Europe. Food residue studies have been completed for cereal grains, dried fruit, and tree nuts and some food tolerances have been established. In March 2006, the Chocolate Manufacturers Association (a US trade association) said there were no serious sensory issues associated with the use of SF on cocoa beans.

6.4 Techniques to Control Pests and Maintain Conservation of Museum Components and Historical or Cultural Artefacts

Conservation of museum artefacts, items of historical, cultural or artistic importance and museum components is field where the need for pest control intersects with the need to preserve these items for the future. Many of the objects held in museums, libraries and similar repositories are subject to attack by rodent and insect pests and at high humidity by fungi. Infested materials include those made of wood, paper, leather, and skins, feathers wool and other natural fibres. Artefacts and similar objects made of organic materials are also objects of international trade and may carry pests of quarantine significance (Reichmuth 2002).

Many museums, libraries and similar repositories have installed a holding room that isolates artefacts newly introduced to museum premises but not yet on display in order to ensure that only insect-free artefacts enter the display location. This would also be a suitable QPS treatment when exporting or importing museum artefacts on loan for an exhibition. In museums, longer exposure periods for pest control are not a constraint (Reichmuth 2002).

There are numerous review articles available to conservators and to private owners of historical artefacts (Porck, 2000). Additionally many countries have government research institutes studying and providing information concerning conservation of items of national heritage. This section provides a short review of those techniques primarily developed in response to the need to find alternatives to methyl bromide. Pest control elements for conservation are similar in this field as in food processing, milling and commodities. An integrated pest management approach and program is the foundation for prevention, identification, monitoring and planning treatment approaches (National Park Service (undated); Jessup 1997).

6.4.1 Contact insecticides

Contact insecticides are used as part of pest management strategies in museums and repositories. A variety of specific insecticides are used, depending on national regulation/approval, but pyrethroids (e.g. permethrin, cypermethrin, deltamethrin, cyhalothrin) or organophosphates (e.g. dichlorvos, chlorpyrifos) seem to be the most common. In Japan, artefacts such as museum specimens, collections, library, antiques and art crafts are treated with the pyrethroids, cyphenothrin and phenothrin.

6.4.2 Heat treatment

Heat treatment through various application methods has been used by conservators and several methods have been developed. The heat treatment temperature and time required is similar to that discussed above for structures. Brokerhof (2002) reviewed heat treatment of artefacts and described a simple solar tent for treatment of objects.

Generally, a temperature of at least 50°C needs to be achieved and yet to ensure the item is not damaged the recommendation is to keep temperatures below 60°C (Strang, 1992).

Strang also has described a simple and inexpensive solarisation method to heat treat artefacts by wrapping them in black plastic and placing them outside in the sunshine, while carefully monitoring temperature to ensure the minimum temperature is reached and the maximum temperature is not exceeded. Smart (2002) described the use of Strang's method to disinfest large rugs, outside, under black plastic film in July in Newfoundland where temperature achieved 50°C in a half hour.

6.4.3 Fumigation treatments

In Japan, mixtures of MB + ethylene oxide have been utilized for fumigation to cultural properties since 2004. After the phase out of methyl bromide, conversion from this MB-containing mixture to alternatives has been completed. Four kinds of fumigant: ethylene oxide; propylene oxide; methyl iodide; and sulfuryl fluoride are used in cultural property fumigation. These alternative fumigants are usually used as a part of IPM program.

Propylene oxide (PPO) and methyl iodide are highly sorptive fumigants and sufficient time is required for degassing to ensure safety. Recapture and reuse systems for methyl iodide have been constructed by making use of its high sorptive characteristic to active carbon. An exclusive vaporizer is also required to use propylene oxide and methyl iodide.

Misumi (2006) confirmed that fumigation of museums and artefacts with PPO has been commercially practiced in Japan since 2000. In 2005, 56 museum collection rooms and 27 museum exhibition rooms were fumigated with PPO. The volume of fumigations: collection room - average 1,691m^3, max. 10,785m^3 and exhibition room - average 1,478m^3, max. 12,166m^3.

The prevention of explosion is most important risk to avoid when conducting PPO structural fumigations. It is perhaps for this reason that Yamamoto *et al* (1996), reported on the development of a new method to use propylene oxide at 2% diluted with argon as the explosion control agent in a new fumigant for the disinfestation of cultural properties. This new fumigant was tested on lacquer ware, silk, felt, paper, gold leaf, numerous metals and on 44 paintings. They declared the treatment safe for the disinfestation of cultural properties made from these materials.

Corrosion of silver-contained materials (such as photos) resulting from methyl iodide fumigation was reported because of inadequate methods used in first introductions. Propylene oxide is highly explosive; in order to prevent explosion, it is important to retain gas concentration below explosion limit at fumigation. Currently, the use of sulfuryl fluoride alone appears to be unpopular for cultural property fumigation due to the lack of efficacy against fungus.

To ensure safety in these specialized fumigations of cultural properties, the Japanese government conducts training programs for fumigators by authorities of independent administrative organization related to agency of cultural affaires, MEXT (Ministry of Education, Culture, Sports, Science and Technology).

Appendices

Table 6.2 Types of buildings and structures fumigated against wood pests

Structure fumigated	Associated pests
Dwellings including apartments, condominiums, trailer homes, historical buildings, commercial premises	Dry wood termites, furniture beetles, powder post beetles, long horned beetles
Museums	Wood boring beetles, dermestid beetles, clothes moths, cigarette beetles, drugstore beetles
Structural elements before building or in place, e.g., beams	Powder post beetles, long horned beetles
Antique vehicles	Powder post beetles

Table 6. 3 Uses and targets for structural fumigation to control urban and food pests

Description	Examples of Pests
Food Production and Storage Facilities	
Food processing plants Flour and feed mills Bulk commodity storage (e.g. silos) Warehouse Bakeries Ham smoke houses Cheese plants Refrigerated storage Restaurants	Stored product insects, rodents, cockroaches, psocids, mites, silverfish, beetles
Non-food Facilities	
Seed warehouses Museums Poultry houses Mushroom houses Condemned housing or public health compliance	Rodents, stored product insects Dermestid/anobiid beetles, clothes moths Lesser meal worm, mites, rodents Mushroom flies, mites Rodents, cockroaches, venomous spiders
Transport Vehicles	
Trucks, truck trailers, vans (empty) Ships, shipholds, gallery and quarters (empty) Railcars (freight or commodity) Buses Aircraft	Beetles and moths Insects and rodents Insects and rodents Insects Cockroaches, other insects, rodents, reptiles

Table 6.4 Estimates of the minimum *ct*-product (g h m^{-3}) of MB for a 99.9 % kill of various stages of a number of insect species at 10, 15, 25 and 30^{o}C and 70 % RH. (Heseltine and Thompson 1974)

Species	Stage	Temperature (^{o}C)			
		10	15	25	30
Callosobruchus chinensis	Pre-adult stages	175	85	40	-
Cryptolestes minutus	Cocoons	170	145	125	-
Ephestia cautella	Pupae	-	70	55	-
Ephestia elutella	Diapausing larvae	360	360	205	180
Ephestia kuehniella	Pupae	-	75	60	-
Lasioderma serricorne	Cocoons	-	180	100	-
Oryzaephilus surinamensis	Adults	85	85	50	40
Plodia interpunctella	Diapausing larvae	300	250	105	-
Ptinus tectus	Cocoons	170	155	100	-
Ptinus tectus	Adults	155	125	85	-
Rhyzopertha dominica	Early pre-adult stages	-	40	40	-
Rhyzopertha dominica	Later pre-adult stages	-	75	45	-
Rhyzopertha dominica	Adults	80	65	40	-
Sitophilus granarius	Early pre-adult stages	115	75	50	50
Sitophilus granarius	Later pre-adult stages	200	115	65	65
Sitophilus granarius	Adults	55	55	35	-
Sitophilus oryzae	Pre-adult stages	-	105	85	-
Sitophilus oryzae	Adults	50	30	30	15
Tribolium castaneum	Pupae	-	-	125	100
Tribolium castaneum	Adults	125	80	60	50
Tribolium confusum	Pupae	230	180	90	-
Tribolium confusum	Adults	115	85	60	45
Trogoderma granarium	Larvae	290	190	110	70

(A dash in the table indicates that no test was carried out).

Table 6.5 Methyl bromide dosage table. European Plant Protection Organization (1993a)

Group	Commodities	Dosage (g m^{-3})			Exposure period (h)
		<10^{o}C	10-20^{o}C	>20^{o}C	
1.	Rice, peas, beans, cocoa beans, dried vine fruits	25	15	10	24
2.	Wheat, barley, oats, maize, lentils	50	35	25	24
3.	Pollards, rice bran	70	45	30	48
4a	Sorghum, nuts, figs	75	50	35	24
4b	Groundnuts, oilseeds, dates, empty sacks	75	50	35	48
5.	Oilseed cakes and meals	120	85	60	48
6.	Fishmeal, dried blood etc.	140	100	65	48
7.	Flour	50	50	40	48

Notes:

1. These dosage rates apply to fumigations under gas-proof sheets and in freight containers which are usually fully loaded. If this method is to be used for mites, dosage rates should accordingly be doubled.
2. Penetration of methyl bromide into commodities in Groups 5 and 6 is poor and fumigation may be uneconomic using the recommended dosage rates. In such cases the use of phosphine should be considered and this is the preferred fumigant for Group 7 (flour).

To reduce the possibility of taint, the dose for flour should never exceed 50 g m^{-3}.

Diapausing larvae of *Trogoderma granarium* (khapra beetle) and *Ephestia elutella* (warehouse moth) are highly tolerant of methyl bromide. In this case, these dosages should be increased by one half and, where applicable, exposure periods increased to 48 h in order to achieve the requisite *ct*-products.

Table 6.6 Response of insects towards temperature

Zone	Temperature (°F)	Temperature (°C)	Insect response
Lethal	120 – 140	48.9 – 60.0	Death in minutes
Lethal	110 – 115	43.3 – 46.1	Death in hours
Suboptimum	95 – 100	35.0 – 37.8	Development stops
Optimum	75 – 90	23.9 – 32.2	Maximum development
Suboptimum	65 – 70	18.3 – 21.1	Development slows
Suboptimum	55 – 60	12.8 – 15.6	Development stops
Lethal	35 – 45	1.7 – 7.2	Death in weeks
Lethal	-5 – -10	-20.6 – -12.2	Death in days
Lethal	-20 – -10	-28.8 – -23.3	Death in minutes

Reference: Fields (1992), Dosland et al. (2006)

Table 6.7. Durable products and locations including empty structures which have been investigated for use of heat for pest control

Product/location	References
Artifacts	Pinninger and Child, 2003
Bambara groundnuts	Lale and Ajayi, 2000, 2001, 2003
Breweries	Hammond, 2003
Bromegrass	Opoku *et al.*, 2002
Cherries	Buransompob, *et al.*, 2003
Chestnut, chinese chestnut	Gao, 1999
Chestnut, horse chestnut	Orlinskii, 2002
Dates	Finkelmann *et al.*, 2006; Rafaeli *et al.*
Dried figs	Damarli *et al.*, 1998
Dried fruit	Johnson *et al.*, 2003

Flour mill	Adler and Rassmann, 2000; Mahroof *et al.*, 2003a; Roesli *et al.*, 2003
Green gram	Swaroop *et al.*, 2003
Hay	Opoku *et al.*, 2002; Sokhansanj *et al.*, 1989
Legume grain	Chauhan and Ghaffar, 2002; Ghaffar and Chauhan, 1999; Gungula *et al.*, 2001; Lale and Maina, 2002; Swaroop *et al.*, 2003
Maize	Mohammed-Dawd and Morallo-Rejesus. 2000
Medicago sativa, Lucerne	Opoku *et al.*, 2002
Nuts	Johnson *et al.*, 2003
Nuts, Walnuts	Buransompob *et al.*, 2003; Mitcham *et al.*, 2004; Wang *et al.*, 2002a, 2003a, 2006a, 2002b, 2002c
Oilseeds	Rajendran and Chaya Devi, 2004
Rice, husked	Nakakita *et al.*, 1989a
Wheat	Nakakita *et al.*, 1989a; Rashid *et al*,2003; Sutherland,1989
Wheat flour	Nakakita *et al.*,1989a

Table 6.8. Organisms –Mainly insects, mites and fungi which have been investigated for use of heat for pest control

Organism	References
Amyelois transitella	Johnson *et al.*, 2003; Wang *et al*,.2005a
Anaplophora glabripennis	Haack, 2003
Anastrepha ludens	Hallman *et al*.,2005
Anthrenus verbasci	Canovai *et al*,2001
Blatella germanica	Müller, 1999; Zeichner *et al*, 1998
Callosobruchus chinensis	Swaroop *et al*.,2003
Callosobruchus maculatus	Ghaffar and Chauhan, 1999; Gungula *et al*,2001; Lale and Ajayi, 2001; Lale and Vidal, 2000,2003
Callosobruchus spp.	Chauhan and Ghaffar, 2002
Callosobruchus subinnotatus	Lale and Vidal, 2000, 2003
Cameraria ohridella, leafminer	Orlinskii, 2002
Carpophilus hemipterus	Rafaeli *et al*,.2006
Carpophilus mutilatus	Rafaeli *et al.*,2006
Caryedon serratus	Lale and Maina, 2002
Ceratitis capitata	Hallman *et a*l.,2005
Cimex lectularius	Meek, 2003; Miller, 2002
Cryprolestes turcicus	Bell *et al*.2004
Cryptolestes ferrugineus	Rashid *et al*.,2003; Burks *et al*, 2000
Cryptolestes pusillus	Müller, 1999; Roesli *et al*, 2003
Cydia pomonella	Wang *et al*., 2004, 2002a, 2003, 2006b, 2002c; Yin *et al*, 2006
Ephestia cautella	Baysal *et al*.,1998; Damarli *et al*., 1998; Navarro *et al*., 2002; Roesli *et al*,2003
Ephestia elutella	Filipchuk, 2000
Ephestia kuehniella	Bell *et al*., 2004; Pradzynska, 2003
Gnatocerus cornutus	Bell *et al*., 2004

Lasioderma serricorne	Adler, 2003; Filipchuk, 2000; Navarro *et al,* 2002; Roesli *et al,* 2003
Legume grain	Chauhan and Ghaffar, 2002
Lepisma saccharina	Müller, 1999
Liposcelis bostrychophila	Rashid *et al.,*2003; Müller, 1999
Mayetiola destructor	Opoku *et al.,*2002
Mites	Bell *et al*.,2004; Mourier and Poulsen, 2000
Nemapogon granella	Müller, 1999
Niptus hololeucus	Müller, 1999
Oryzaephilus surinamensis	Burks *et al*.,2000; Müller, 1999; Nakakita *et al*., 1989[a]; Navarro *et al,* 2002
Periplanta orientalis	Müller, 1999
Plodia interpunctella	Johnson *et al.,*2003; Mitcham *et al*., 2004; Nakakita *et al*., 1989a; Roesli *et al.,*2003; Buransompob *et al,* 2003
Prostephanus truncatus	Mourier and Poulsen, 2000
Psocids	Beckett and Morton, 2003b; Bell *et al.,* 2004
Ptinus tectus	Bell *et al.,*2004
Rhyzopertha dominca	Sutherland, 1989; Adler, 2003; Beckett and Qaisrani, 2003; Nakakita *et al,*1989a; Rashid *et al.* 2003; Burks *et al,*2000
Saltatoria spp.	Müller, 1999
Sitodiplosis mosellana	Sokhansanj *et al*., 1989
Sitophilus granaries	Müller, 1999; Nakakita *et al,*1989a; Bell *et al*., 2004; Hofmeir, 2002; Mourier and Poulsen, 2000
Sitophilus oryzae	Burks *et al*., 2000; Kasevich and Beckett, 2005; Lim *et al.,* 1978; Nakakita *et al*., 1989a
Sitophilus zeamais	Mohammed-Dawd and Morallo-Rejesus, 2000; Nakakita *et al*., 1989a
Tenebrio molitor	Bell *et al.,*2004
Tenebroides mauritanicus	Müller, 1999
Termites	Lewis, 2003; Lind, 1997
Tribolium castaneum	Burks *et al*., 2000; Arthur and Dowdy, 2003; Beckett and Qaisrani, 2003; Bell *et al,*2004; Hofmeir, 2002; Lim *et al.,* 1978; Mahroof *et al.* 2003a, 2003b, 2005; Müller, 1999; Nakakita *et al.* 1989a; Roesli *et al,* 2003; Subramanyam *et al*., 2003[a], 2003b
Tribolium confusum	Bell *et al.,* 2004; Boina and Subramanyam, 2004; Dowdy and Fields, 2002; Heaps and Black, 1994; Müller, 1999
Trogoderma granarium	Müller, 1999; Navarro *et al*., 2002
Zophobas spp.	Müller, 1999

Table 6.9. Aspects related to heat control in stored product protection

Topic	Author (s)	Year
Cost	Beckett and Qaisrani, 2003; Burks *et al,* 2000; Rafaeli *et al*., 2006; Wang *et al*., 2006c	
Diapause	Wang *et al*., 2004	
Electrical heater	Heaps and Black, 1994	
Fundamentals	Dosland *et al*., 2006; Antic and Hill, 2003; Beckett, 2003; Caddick, 2004; Dosland, 1999; Burks *et al,*2000; Gooch, 2002; Hallman, 2000b; Hallman and Denlinger; 1998; Heaps, 1996; Longstaff, 1994; Nawrot, 2004; Olejarski, 2004; Rajendran and Devi, 2004; Vincent *et al.,*2003; Neeson and Banks, 2000 Orlinskii, 2002; Süss and Trematerra, 2003	
Germination	Swaroop *et al.*, 2003	
Heat and aclimation	Burks *et al.*, 2000	
Heat and Bacillus thuringiensis	Filipchuk, 2000	
Heat and CO_2	Damarli *et al*., 1998; Navarro *et al*., 2002	
Heat and contact cyfluthrin	Arthur and Dowdy, 2003	
Heat and container	Rafaeli *et al,* 2006	
Heat and conveyer	Sutherland, 1989	
Heat and damage	Heaps and Black, 1994; Pradzynska, 2003	
Heat and diatomaceous earth	Dowdy and Fields, 2002	
Heat and electrical heating	Zeichner *et al*., 1998	
Heat and energy consumption	Burks *et al.*, 2000	
Heat and gas	Filipchuk, 2000	
Heat and gas heater	Mahroff *et al*., 2003a; Roesli *et al,* 2003	
Heat and heat shock	Mourier and Poulsen, 2000	
Heat and history	Pepper and Strand, 1935; Dean, 1911	
Heat and IPM	Pinninger and Child, 2003; Süss and Trematerra, 2003; Zeichner *et al*., 1998	
Heat and microwave	Lewis, 2003; Lim *et al,* 1978; Lind, 1997; Wang *et al.,* 2005a; 2003b; Baysal *et al.*, 1998	
Heat and pyrethroid	Filipchuk, 2000	
Heat and radio frequency	Wang *et al*., 2005b, 2006, 2006 a, 2003b, 2006c, 2002a; Kasevich and Beckett, 2005; Mitcham *et al*., 2004; Nakakita *et al*., 1989a; Nelson, 1996	
Heat and solarization	Lale and Ajayi, 2001; Lale and Maina, 2002; Mohammed-Dawd and Morallo-Rejesus, 2000; Swaroop *et al*., 2003	
Heat and spouted bed	Rashid and Beckett, 2003	
Heat and steam	Mahroof *et al*., 2003a	
Heat and tunnel dryer	Sokhansanj *et al*., 1989	
Modelling	Akdoğan *et al*., 2005; Beckett, 2003; Burks *et al,* 2000; Mahroof *et al*., 2003b; Antic and Hill, 2003; Ikediala *et al*., 2000; Sokhansanj *et al*., 1989; Subramanyam *et al*., 2003; Wang *et al*., 2002a; 2003a, 2002b, 2003b, 2002c, 2006c; Yin *et al,* 2006;	
Organic fruits	Rafaeli *et al*., 2006	

Quality	Burks *et al,* 2000; Mitcham *et al.*,2004; Nakakita *et al.*, 1989a; Sutherland *et al,* 1989; Buransompob *et al.*, 2003; Wang *et al.*, 2002s, 2002b, 2003b, 2006b; 2002c
Quarantine	Opoku *et al.*, 2002; Orlinskii, 2002; Wang *et al.*, 2006b; Yin *et al,* 2006
ThermaPure method	Miller, 2002
Thermo Nox process	Hofmeir, 2002; Müller, 1999
Thermokill process	Hammond, 2002

Table 6.10. Minimum exposure periods (days) required for control of all stages of the stored product pests listed, based on a phosphine concentration of 1.0 g m^{-3}. This dosage is as recommended for good conditions and the dosage applied will usually need to be increased considerably in leaky situations (EPPO 1993b).

Species	**Common names**	**Temperature**	
		10 - 20°C	**20 - 30°C***
Oryzaephilus surinamensis	Saw-toothed grain beetle	3	3
Cryptolestes pusillus	Flat grain beetle	5	4
Oryzaephilus mercator	Merchant grain beetle		
Tribolium castaneum	Rust-red flour beetle		
Lasioderma serricorne	Cigarette beetle	5	5
Acanthoscelides obtectus	Dried bean beetle	8	5
Corcyra cephalonica	Rice moth		
Cryptolestes ferrugineus	Rust-red grain beetle		
Plodia interpunctella	Indianmeal moth		
Ptinus tectus	Australian spider beetle		
Rhyzopertha dominica	Lesser grain borer		
Sitotroga cerealella	Angoumois grain moth		
Tribolium confusum	Confused flour beetle		
Ephestia cautella	Tropical warehouse moth	10	5
Ephestia elutella	Warehouse moth		
Ephestia kuehniella	Mediterranean flour moth		
Caryedon serratus	Groundnut borer	10	8
Sitophilus granarius	Grain/granary weevil	16	8
Sitophilus oryzae	Rice weevil		
Sitophilus zeamais	Maize weevil		
Trogoderma granarium	Khapra beetle		

Notes:

* All species listed succumb to a 4-day exposure at this dosage level at 30°C or above. For certain commodities in long-term storage where it is necessary to control a mite infestation, two fumigations may be carried out separately by an interval dependent on

ambient temperature, allowing eggs surviving the first fumigation to hatch. This interval varies from 2 weeks at 20ºC to 6 weeks at 10ºC (Bowley and Bell 1981).

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Chapter

7

Factors that have Assisted with Methyl Bromide Phaseout

7.1. Introduction

This chapter discusses the Multilateral Fund projects carried out by Article 5 countries. It identifies the main types and objectives of MLF projects, and major technologies being implemented. It discusses lessons learned from projects and barriers to the adoption of alternatives. The chapter also outlines other factors that have contributed to MB phaseout, such as voluntary efforts of growers and others undertaken in both Article 5 and non-Article 5 regions.

7.2. MLF Projects in Article 5 Countries

Established under Article 10 of the Montreal Protocol, the Multilateral Fund (MLF) has provided financial assistance to Article 5 countries for phasing out MB. The MLF projects, together with the voluntary efforts of growers and users, have made a major contribution to the MB reductions described in Chapter 3. This section starts by describing the main types of MLF projects. It also gives an overview of the main alternatives that Article 5 countries have selected and adopted on a wide scale in phaseout projects. Technical descriptions and other background information about alternative technologies are not covered in this chapter but are provided in Chapters 5 (alternatives for soil treatments) and 6 (alternatives for commodity and structural treatments).

7.2.1. Types of MB users

MB users in Article 5 countries are diverse, ranging from small farmers (0.5 ha and less) to very large enterprises. There is also much variation with respect to the level of technical expertise, which is not necessarily correlated to the size of the operation, but possibly more to the destination of the crop - local market or export, the latter generally imposing stringent quality demands and in consequence being more technically demanding.

Consumption of MB is not restricted to technically advanced enterprises. Simple, low technology methods of MB fumigation using disposable MB canisters of about one pound are still available in many Article 5 countries. Disposable canisters have undoubtedly stimulated use of MB because they avoid the need for large and expensive injection rigs and professional applicators for soil treatments with MB. The transfer of disposable-canister technology to China, for example, in the mid-1990s (resulting from an Israel-Sino agreement) led to large increases in MB use in China at that time.

However, some Article 5 countries such as Chile, Kenya, Morocco and South Africa have banned the use of small canisters of MB; this is considered to be one of the key factors that helped Chile return to compliance with Montreal Protocol commitments regarding MB.

7.2.2. Overview of MLF projects

Many Article 5 countries are implementing MLF projects to reduce or totally phaseout MB, and these projects undoubtedly contributed significantly to the MB reductions achieved to date. By December 2006 the MLF had approved a total of 324 projects in more than 72 Article 5 countries, with an approved expenditure of approximately $103 million. This includes all types of MB-related activities: demonstration projects, technical assistance, training, project preparation, workshops, awareness raising and MB phaseout projects (which are also called investment projects, multi-year projects or national phaseout plans). The MLF projects can be classified into the following broad categories:

- 43 Demonstration projects, 1 of which was cancelled, giving a net total of 42. More information is given in section 6.1.4 below.
- 84 projects concerning information and awareness-raising activities such as workshops, technical assistance, information exchange on MB phaseout and alternatives, policy development and various other activities.
- 118 for the preparation of new projects, including collection of data on MB uses; and
- More than 46 MB phaseout projects, some of which include demonstration stages. More information is given in section 6.1.5 below.

In addition to the MLF work, a number of MB demonstration projects have been funded from other sources, by Article 5 countries themselves - for example China – or by the Global Environment Facility (GEF), or bilateral assistance for example from the governments of Australia, Germany (GTZ), Italy, Canada and Spain. In some countries farmers or exporters associations or private enterprises have also financed experiments to identify or adapt alternatives to MB; examples include those in Morocco, Egypt, Jordan, Lebanon and Kenya.
The MLF projects approved by December 2006 are scheduled to eliminate a total of 9105 tonnes of MB in Article 5 countries, with an additional 2,560 tonnes (estimated) scheduled for phaseout in later stages of projects that have been approved in principle (i.e. full approval is subject to countries achieving targets in currently-approved stages of projects). This makes a total of approximately11,665 tonnes approved for phaseout in principle. The total phaseout achieved by MLF projects by December 2006 was 5,245 tonnes (Table 7.1). Most Article 5 countries have achieved the MB reductions that were scheduled in MLF projects. In some cases there have been delays, in other cases projects achieved the MB reductions faster than scheduled.

Table 7.1: MLF MB Projects approved up to December 2006

Project type	No. projects or tranches[a]	MB phaseout planned in projects (tonnes)	Phaseout achieved by December 2006 (tonnes)
Preparation	118	-	-
Demonstration projects [a]	42	38	35
Phaseout projects (investment, multi-year and national plans)	>46 [c]	8,585	5,027
Training, technical assistance, workshops, others	84	482	183
Total approved	**290**	**9,105**	**5,245**
Further stages of phaseout projects, approved in principle [b]	-	2,560	-
TOTAL	-	**11,665**	**5,245**

Source: MLF Secretariat, December 2006

a. One cancelled demonstration project is not included in the table.

b. These are further stages of approved projects, which will be funded when countries meet the conditions laid down for first stages of the projects. Tonnage estimated from MLF projects

c. MLF Secretariat database indicates a total of 79 projects and sub-projects consisting of individual tranches, giving a total of 324 projects and sub-projects (tranches).

7.2.3. Demonstration Projects

In 1997, Decision IX/5 relating to conditions for control measures on MB in Article 5 parties stated, inter alia, that the MLF shall meet, on a grant basis, all agreed incremental costs of Article 5 Parties to enable their compliance with the control measures on methyl bromide. The MOP agreed that the Executive Committee of the MLF should develop and apply specific criteria for MB projects in order to decide which projects to fund first and to ensure that all Article 5 parties are able to meet their obligations regarding MB.

The Parties at that time agreed to give immediate priority to MLF activities for the purpose of identifying, evaluating, adapting and demonstrating alternatives. As a result the MLF approved a series of demonstration projects.

The demonstration projects aimed at transferring technologies to Article 5 regions from countries that already used alternatives, and established test plots on farms and research stations to evaluate and compare the efficacy (level of pest control), yields and practical viability of alternatives compared to MB. The intention was to test existing MB alternatives in the different climates and diverse agricultural practices and local conditions found in Article 5 countries. Table 7.2 provides a list of the countries and sectors for which Demonstration projects were approved.

Table 7.2. Demonstration projects of the MLF and other organisations

Region	Country	Target soil sectors	Target postharvest sectors
Latin America and Caribbean	Argentina	Tobacco, Protected vegetables, tomato, flowers, strawberry	Cotton and citrus
	Brazil	Tobacco	
	Chile	Tomato, pepper	Commodities
	Colombia	Banana	
	Costa Rica	Melon, cut flowers,	
	Dominican Republic	Tomato, melon, tobacco, flowers	
	Ecuador	Flowers	
	Guatemala	Broccoli, melon, tobacco, tomato, flowers	
	Jamaica		Tobacco
	Mexico	Tomato, strawberry, melon, flowers, tobacco	Structures
	Uruguay	Cucumber, pepper, tomato seedbeds, tobacco, nurseries	
Africa	Botswana	Tomatoes and cucurbits	
	Cameroon	Tobacco	
	Egypt	Strawberry, tomato, cucurbits	Stored grain
	Kenya	Flowers	Stored grain
	Morocco	Tomato, cucurbits, strawberry	
	Senegal		Peanut seed
	Tunisia		Dates
	Zimbabwe	Tobacco	Stored grain
Asia	China	Tobacco, tomatoes, cucumber, strawberries, ginseng	Stored grain
	Indonesia		Stored products: milled rice, wood products
	Jordan	Cucumber, tomato, other soil uses	
	Lebanon	Tomato, cucurbits, eggplant, strawberry	
	Malaysia		Stored timber
	Philippines	Banana, other soil uses	
	Sri Lanka	Tea plantations	
	Syria	Post-harvest and horticulture	
	Thailand	Stored grain: rice, maize, tapioca, feed grains, pulses	
	Vietnam	Stored grain, rice, silos, timber	
Europe	Croatia	Tobacco	
	Macedonia	Tobacco, horticultural seedlings, vegetables	
	CEIT region	Tomato, cabbage, pepper, celeriac, strawberry	
	Turkey	Tomato, cucumber, flowers	

Demonstration projects were carried out using a wide range of chemical and non-chemical alternatives, in diverse situations, climates, soil types and cropping systems, and for many different types of MB users, ranging from small producers with less than 0.5 ha, to medium and large producers, who produced under low, medium and higher levels of technical sophistication (which does not necessarily correlate with size of operation). MBTOC (2002) reviewed the technical results of demonstration projects and concluded that in general, one or more of the alternatives tested in each crop situation had proven comparable to MB in their technical effectiveness for the control of pests and diseases.

The projects showed that the tested alternatives could be introduced into an Article 5 country and adapted successfully within 2-3 years, in some cases even including registration of pesticide products. The types of alternatives tested in the demonstration projects and the results were described in MBTOC's 2002 Assessment Report (pages 219 -221).

A recent evaluation of the demonstration projects carried out by the Monitoring and Evaluation Unit, an independent unit attached to the MLF, concluded the following (MLF, 2004):

> *"...demonstration projects made a substantial contribution to the promotion of non-chemical, non-marketable MB alternatives. While private sector stands behind the chemical alternatives as well as behind marketable non-chemical alternatives such as biological control, grafting, steaming, soilless culture and resistant cultivars, demonstration projects tested not only those but addressed also practices such as crop rotation, sanitation, biofumigation and solarisation which could be supported only by public funding and involve public sector research and extension."*

The need for demonstration projects depended on the circumstances of each country and the kind of technologies tested. Tests in various locations were necessary. For example, the outcome of solarisation depends on a combination of various local factors (sunlight hours, temperature, duration of good conditions, soil type, pathogens populations, etc), which may be difficult to predict from a theoretical approach. On the other hand in the case of floating tray systems the local environment is less important, although it may become relevant in more extreme conditions, such as cold climates. Appropriate know-how is essential for achieving effective results for any alternative technology. It is therefore essential that local technical staff or grower-extensionists learn how to manage a new method before it can be transferred to other growers. Demonstration projects have assisted in this process. The regional and local specificity appears less pronounced for post harvest applications than for field crops.

An important and often under-reported aspect of demonstration projects was the participation of many local stakeholders in the planning and implementation of the various alternatives. In line with the guidelines for MB projects this laid the political and institutional groundwork for faster introduction of accepted alternatives during following investment projects, and for their sustainable use.

7.2.4. MB Phaseout Projects

MLF phaseout projects (also called investment projects, multi-year agreements, national phaseout plans or sector plans) are aimed at eliminating MB use by assisting the commercial adoption of alternatives that have been identified as technically and economically feasible for the particular country and crop situation, either as a result of demonstration projects carried out previously or from experience derived from similar regions and circumstances.

The projects normally provide assistance for growers and other MB users to adopt MB alternatives, by assisting with the procurement of alternative equipment and materials, and by training large numbers of MB users and extension staff on how to apply and adapt alternatives effectively. The projects also carry out other activities to overcome barriers or constraints to the widespread adoption of alternatives, including the development of policy measures.

The project guidelines of the Executive Committee of the MLF have described MB phaseout (investment) projects as follows:

> *"Projects whose primary objective is the reduction, and eventual elimination of methyl bromide consumption in sectors or for uses where there are clearly demonstrated efficacious alternative technologies. They should be accompanied by a package of policy measures that the country has committed to ensure that the use being phased out will not merely be replaced by an increase from other users shortly after the projects are completed (i.e. bans and import restrictions)..."* (Decision 32/80. UNEP/OzL.Pro/ExCom/32/44. MLF 2000).

The development of policy measures is emphasised in the Executive Committee's guidelines:

> *"It would also need to be demonstrated that the country concerned is committed to a package of policy measures directed to eliminating methyl bromide use (e.g., labelling of commodities produced without MB, taxes and levies on import of MB, mandatory registration by traders and farmers using MB, phase out schedule for MB) and to sustaining the alternative methodologies on a permanent basis or for as long as needed".* (MLF 2000).

The phaseout projects are typically executed by countries themselves with assistance from the implementing agencies UNDP, UNIDO and the World Bank, and several bilateral agencies (Germany/GTZ, Italy, Spain, Canada and France, for example).

Countries are only eligible for MB phaseout projects if they have ratified the Copenhagen Amendment of the Montreal Protocol, an amendment of 1992 which added MB to the list of controlled ozone-depleting substances (MLF, 2000).

The first MLF MB phaseout project was approved in 1998. By December 2002 the MLF had approved a total of 38 MB phaseout projects, which aimed to eliminate major uses of MB in 35 Article 5 countries. By December 2006 this figure had increased to more than 46 projects, and the funds approved amounted to $77 million. The phaseout projects have normally been accompanied by schedules or timetables for national MB reductions which are earlier than the Protocol schedules. Altogether, the MLF phaseout projects are aimed at phasing out 8,585 tonnes of MB; by December 2006 a reported 5,027 had been phased out by these projects (Table 7.3). Additional phaseout projects are being developed for some countries that still need assistance in phasing out MB in specific sectors which were not considered previously or which have encountered difficulties.

It has been observed that earlier MB phaseout than the Protocol schedule is beneficial to Article 5 countries due to the following reasons (Si-Ahmed, 2002):

a) Effective alternatives are available;
b) Article 5 countries want to catch up with non-Article 5 countries in terms of new technologies and
c) Article 5 countries want to ensure continuity of exports and market access to non-Article 5 countries that are placing restrictions on products grown using MB.

Table 7.3. MLF MB phaseout projects by region (at December 2006)

Region	Number of projects and tranches	MB initially scheduled to be phased out (tonnes)	MB phased out by Dec 2006 (tonnes)
Latin America	24	3,637	2,328
Asia	27	3,071	1,374
Africa	23	1,617	1,087
CEIT	5	260	238
TOTAL	**79**	**8,585**	**5,027**

Source: MLF data, December 2006

The phaseout projects address all the sectors where MB use is relevant in Article 5 regions: 8 are for strawberries, 13 for flowers, 15 for the tobacco sector, 7 for tomato, 7 for cucurbits, 3 for bananas, 2 for fruit tree production, 15 for unspecified horticulture and other vegetables and 12 for stored grain and dried vegetables (one project may address more than one sector, hence figures do not coincide with the total number of projects).

Table 7.4 below presents the phaseout projects approved up to December 2006, the implementing agencies undertaking them, the sectors addressed, and the current status of the project (whether finished or ongoing).

Table 7.4. MLF phaseout projects by country (at December 2006)

Country	MB to be phased out (tonnes)	MB phased out (tonnes) at Dec 2006	Imp. Agency	Sector	Project status
Argentina	552		UNIDO	Strawberry, protected vegetables, cucurbits, tomato, flowers	ONG
Argentina	298	538	UNDP	Tobacco, non-protected vegetables	ONG
Bolivia	3.3	3.3	UNDP	Strawberry, vegetable nurseries, potato seed, flowers	Finished
Bosnia and Herzegovina	20	10	UNIDO	Tobacco, flowers	Finished
Brazil	141	140	UNIDO	Tobacco	Finished
Brazil	364		UNIDO Spain	Flowers, ornamental plants, tobacco, strawberries	ONG
Chile	128	66.6	UNDP	Fruit tree production and replant	ONG
Chile			IBRD	Strawberries, tomatoes and other	Cancelled

China	1811	778	UNIDO Italy	Strawberry, cucumber, tomato, other vegetables, flowers, tobacco, commodities	ONG
Costa Rica	465	255	UNDP	Melons, cut flowers, bananas, tobacco, vegetable nurseries	ONG
Cote D'Ivoire	15	15	UNIDO	Commodities and storage	ONG
Croatia	26.6	26.6	UNIDO	Tobacco	Finished
Cuba	80	80	UNIDO	Tobacco	Finished
Cuba	40		UNIDO	Substrates, storage and structures	ONG
Dominican Republic	235	166.6	UNIDO	Melon, flowers, tobacco	ONG
Ecuador	61.6	61.6	IBRD	Rose propagation nurseries	Finished
Egypt	310	310	UNIDO	Strawberry, flowers, tomato, flowers, medicinal herbs, commodities	ONG
Georgia	21.0	10.0	UNIDO	Grain and storage facilities, soil fumigation	ONG
Guatemala	838.3	626.6	UNIDO	Melon, tomato, strawberry, flowers	ONG
Honduras	423.3	355	UNIDO	Melon, banana, tobacco	ONG
Honduras	207.54	-	UNIDO	Phase II – phaseout of remaining uses	ONG
Indonesia	63.3	8.3	UNIDO	Grain storage	ONG
Indonesia			UNIDO	Grain storage	ONG
Iran	45	45	UNIDO	Dried fruit and vegetables, grains	Finished
Iran	9.6		UNIDO	Olive seedlings, fruit tree nurseries	ONG
Jordan	300	168.3	Germany	Horticulture	ONG
Kenya	100		UNDP	Cut flowers	ONG
Kenya	61	81	Germany	Vegetables, fruit, nurseries, seedbeds, other horticulture	ONG
Lebanon	84		UNIDO	Strawberry	ONG
Lebanon	310	333.3	UNDP	Cut flowers, vegetables, tobacco	ONG
Libya	93.3	-	UNIDO	Tomatoes, peppers	ONG
Macedonia	45	45	UNIDO	Tobacco, horticulture	Finished
Malawi	185	185	UNDP	Tobacco	Finished
Morocco	101.6		France	Cut flowers and bananas	ONG
Morocco	1155	325.6	UNIDO	Strawberry, tomato	ONG
Peru	6.6	6.6	UNDP	Tobacco, horticulture	Finished
Romania	156.6	156.6	Italy	Horticulture	Finished
Senegal	1.6	1.6	UNIDO	Peanut seed	Finished
Syria	175	58.3	UNIDO	Grain storage	ONG
Thailand	98.3	-	IRBD	Grain storage	ONG
Turkey	50		IRBD	Grain storage, dried figs	Finished
Turkey	83	83		Strawberry, pepper, eggplant	Finished
Turkey	487	357	UNIDO	Tomato, cucumbers, carnations	ONG
Uganda	50	50	UNIDO	Cut flowers	Finished
Uruguay	40	25	UNIDO	Tomato, cut flowers	ONG
Vietnam	142	-	IBRD	Grain storage, soil fumigation	ONG
Zimbabwe	230	220	UNIDO	Cut flowers	Finished
Zimbabwe	300		UNIDO	Tobacco, grain	ONG

ONG = ongoing

7.2.5. Rates of MB reductions

The MB phaseout projects approved by 2003 required on average about 4.5 years per project for completion. The rate of scheduled reductions was more than 22% per year on average. This indicates that at that stage most of the approved projects were due to be completed in the period 2002 – 2007. The phaseout period depends mainly on the policies of national governments, the productive sectors involved and to a lesser extent on the quantity of MB and types of uses. The amount of MB scheduled to be eliminated per year varies greatly from project to project. Reductions of more than 100 tonnes per year were scheduled in some countries.

Analysis of actual MB reductions achieved by 2001/2 as a result of MLF projects and other activities in 47 individual Article 5 countries showed that very large reductions are feasible, especially in cases where governments and MB users make constructive efforts to transfer and adopt existing alternatives. The average MB reduction rate was 33% per year for countries that achieved reductions in 1998 to 2001/2[1]. This analysis included small, medium and large consuming countries, some of which were not yet implementing phaseout projects.

Article 5 countries in total achieved a substantial MB reduction of about 33% in the two year period between 2001 and 2003 (5,875 tonnes phased out). From 2003 to 2005 the reduction was 21% (2,535 tonnes phased out). The rate of reduction slowed down possibly because of the impact of CUEs on perceptions in Article 5 countries.

7.2.6. Alternatives chosen in phaseout projects

The fact that MB cannot generally be replaced by one in-kind alternative was highlighted in past MBTOC reports (1994, 1998, 2002) and has been confirmed in MLF projects. This often implies that growers and other stakeholders need to change their approach to production and may even have to make important changes in process management. Such changes mostly relate to the implementation of IPM practices but also time management as some alternatives require longer exposure times than MB. Reluctance to management change is often the major reason for resistance to adoption of alternatives, even above economic matters.

Projects in Article 5 countries have demonstrated that a similar range of alternatives to those in non-Article 5 countries can be successfully adopted. Differences in costs and resource availability can lead to a preference for different alternatives in Article 5 compared to non-Article 5s. Demonstration projects showed that it is feasible to introduce the tested alternatives into Article 5 countries and adapt them successfully within 2-3 years, in some cases even including registration of pesticide products. For a detailed description of alternatives please refer to Chapters 5 and 6 of this Assessment Report.

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[1] Analysis of 47 Article 5 countries that achieved MB reductions in the period 1998 to 2002 (or to 2001 in cases where data had not yet been reported for 2002).

Table 7.5. Technologies adopted in phaseout Projects, by region

Region	Country	Soil technologies selected	Postharvest technologies selected
Latin America and Caribbean	Argentina	Chemicals, steam, floating trays	
	Bolivia	Steam, substrates	
	Brazil	Floating trays, substrates, metham sodium, steam, solarisation	
	Chile	1,3-D/pic, steam, steam + Trichoderma, metham (rotary-spading injection)	
	Costa Rica	1,3-D/pic, metham, solarisation, biocontrols, steam	
	Cuba	Floating trays. Steam, grafting	Phosphine + CO_2 and heating , sulphuryl fluoride
	Dominican Rep.	Floating trays, solarisation+ metham sodium, steam, substrates	
	Ecuador	Substrates (rose mini-plants)	
	Guatemala	Chemicals, grafting, steam	
	Honduras	Chemicals, floating trays, grafting	
	Peru	Steam, floating trays, solarisation, biocontrols, biofumigation	
	Uruguay	Solarisation + chemicals, biofumigation, steam	
Africa	Congo	Metham, IPM	
	Egypt	Substrates, steam, biofumigation, grafting	Phosphine, sulfuryl fluoride
	Kenya	Metham (rotary-spading injection), substrates, steam, grafting, IPM	
	Malawi	Floating trays, chemicals (metham sodium, dazomet)	
	Morocco	1,3-D/pic, metham, grafting, solarisation + chemicals, steam	
	Senegal		Phosphine, (tablets of metallic phosphide) IPM,
	Sudan		Phosphine, IPM
	Uganda	Metham (rotary-spading injection), steam, substrates	
	Zimbabwe	Steam, IPM, others	
Asia	China	Metham sodium, grafting, chloropicrin, 1,3-D (not registered yet), limited biocontrol	Phosphine
	Indonesia		Phosphine, IPM
	Iran	Steam, solarisation, with IPM	Phosphine, IPM, Metallic phosphides
	Jordan	Solarisation, grafted plants, chemicals, biocontrols, others	
	Lebanon	1,3-D,, 1,3-D/ Pic, metham sodium, solarisation, solarisation + reduced doses of chemicals, grafting, crop rotation, biofumigation, floating trays	
	Libya	Solarisation + chemicals (low doses), substrates, grafting.	
	Syria		Phosphine + CO_2 IPM
	Turkey	Grafting, metham sodium, 1,3-D, 1,3-D/Pic, solarisation, substrates, grafting, resistant varieties, steam (limited)	CO_2 and magnesium phosphide
Europe	Bosnia & Herzegovina	Floating trays, solarisation, biofumigation	
	Bulgaria [a]	Metham (rotary-spading injection), dazomet	
	Croatia	Floating trays	
	Hungary	Metham (rotary-spading injection), dazomet	
	Macedonia	Floating trays, solarisation+biofumigation	
	Poland [a]	Metham (rotary-spading injection), dazomet, steam	
	Romania	Chemicals, grafting, solarisation + 1,3-D/ Pic, metham sodium	

Sources: UNIDO, UNDP, national experts and Desk Study on Methyl Bromide Projects, MLF, 2005c MLF. 2005 Evaluation of Methyl Bromide Phase-out projects. Sub-sector reports and country case studies.

[a] GEF regional project in CEIT countries

7.2.7. Crop specific technology choices

The main alternatives selected for the different sectors where MB is still being used are briefly described below. For a more detailed explanation of these alternatives please refer to Chapters 5 and 6.

7.2.7.1. Ornamental crops

Floriculture is a complex industry in the worldwide context, with hundreds of flower types, production cycles and cropping systems involved. Constraints to adoption of alternatives that apply to the cut flower sector are generally the same as those of other crops, for example regulatory issues, and registration. However, alternative fumigants have been registered in some countries, and alternatives that do not need registration such as steam and substrates are being implemented by many growers in Article 5 countries, particularly for flowers grown in protected environments. Roses, carnations and gerberas are the flowers most commonly grown in substrates in countries like Uganda, Kenya, Ecuador, Colombia and Brazil among others, but the system is increasingly expanding to other flower types. Although the initial set up cost of a soil-less production system is comparatively expensive, growers are generally able to compensate the extra cost through significantly better yields and quality that result from higher planting density, optimum plant nutrition and better pest and disease control. Finding cheap substrates which are often locally sourced, significantly contributes to the economic feasibility of substrate systems. The MLF evaluated the choice of alternatives made in projects and considered it was generally adequate in the floriculture projects evaluated (MLF, 2005c).

Steaming, although expensive, controls soil pathogens at levels that are comparable to MB when properly applied. Steam is generally suited for protected flower production and for sterilizing re-utilised substrates. Costs associated with steaming may be reduced through implementation of IPM strategies and by considering different types of fuels, boiler types and steaming systems. Steaming is used by flower growers in Brazil, Costa Rica, Uganda and Colombia and has been found to be particularly successful when combined with organic amendments such as compost and biocontrol agents such as *Trichoderma* spp.

Chemical alternatives which are used increasingly in ornamental production include dazomet, metham sodium and 1,3-dichloropropene, the latter often combined with chloropicrin (Pic).

7.2.7.2. Strawberry fruit

The most effective chemical alternatives for strawberry fruit production in MB projects include 1,3-D + Pic and drip-applied formulations of either Pic alone or 1,3-D/Pic with or without a follow-up treatment of metham sodium.

Chloropicrin alone has proven successful for example in China where its use has gained popularity since its registration as a soil fumigant in 2002. Results obtained are equivalent to those achieved with MB and at lower cost (Cao, 2006 and Case Study 9 in Chapter 10). It is expected that this alternative will have helped to phase out between 100 and 150 tonnes of MB in the Chinese strawberry sector by 2007.

Metham sodium and 1,3-D/Pic were implemented as alternatives in Lebanon to replace MB previously used by about 250 strawberry growers. In some cases, solarisation or crop rotation are combined with reduced doses of these chemicals with good results, particularly where infestation levels are low to moderate.

Treatments with metham or metham + VIF showed no significant difference from MB in yield, vigour and quality of strawberry in China (China-Italy Project, 2003).

Drip fumigation with metham sodium has increased sharply since 2002 in Morocco, from 6 ha in 2002 to 820 ha in 2006 whilst the MB fumigated area decreased from 1090 ha in 2003 to 140 ha for strawberry in 2006 (Chtaina, 2006 and Case Study 15 in Chapter 10). Yields and fruit quality obtained with metham sodium were equivalent to those achieved with MB. Adoption of other chemical alternatives is also taking place, like metham potassium, 1,3D/ Pic and metham sodium +1,3-D.

Steam and substrates have been adopted in specific circumstances where these alternatives are economically feasible, such as Argentina and China among others.

7.2.7.3 Strawberry nurseries sector

MB is used for the production of strawberry runners in some cases to meet the stringent certification standards for virtually pest-free strawberry runner stock, which is often grown in high altitudes under cold and wet conditions. Presently, the combination of 1,3-D + Pic, where allowed and registered appears to be the most viable alternative to MB at this time.

Simple, economically feasible substrate systems can prove particularly useful for the production of strawberry runners. Various materials are used as substrates (e.g. rock wool, peat moss, rice hulls, coconuts husk and bark) and can be reused after sterilising with steam, solarisation or hot water. Bunker steaming has been found to be a feasible alternative for example in Argentina. In Lebanon, soil solarisation combined with a crop rotation cycle of 3 years is used as an alternative to MB in strawberry nurseries.

7.2.7.4 Nurseries and propagation material for other crops

Propagation material of many types (bulbs, cuttings, seedlings, young plants and trees) is also subject to high health standards. Substrates, in trays or larger containers according to the plant type and size, are proving to be an excellent choice in many Article 5 countries, for example Costa Rica, Chile and Argentina.
In Chile the combination of steam + Trichoderma was successfully adopted as MB alternative for nursery trees grown in substrates. In some nurseries alternative fumigants have been adopted in MLF projects.

7.2.7.5. Tomato, pepper, eggplant and other vegetables

A substantial number of chemical and non-chemical alternatives which are used commercially have proven as effective as MB for controlling soilborne pathogens attacking tomatoes and other vegetables. Effective alternatives include combinations of chemicals such as 1,3-D, chloropicrin, metham sodium and dazomet and non-chemical methods such as substrates, grafting, resistant varieties, biofumigation, solarisation.

7.2.7.6. Tobacco seedbeds

The soilless float system is an effective MB alternative, applicable to most regions where tobacco is grown. Most Article 5 countries which have implemented MB phaseout projects in tobacco have primarily chosen to adopt float systems. Their use has become widespread in countries like Brazil, Cuba, Peru, Zimbabwe, Argentina, Macedonia and Croatia, and has shown very good potential in China. In some countries, effective results in tobacco seedbeds were also achieved with metham, steam, dazomet and dazomet + solarisation, e.g. Malawi, Macedonia and Argentina. For specific examples see Chapter 10 of this Assessment Report.

7.2.7.7. Cucurbits

When combined with other treatments, grafted plants can avoid the need for MB fumigation; this alternative has been proven in Mediterranean countries, Israel and other countries. Grafting is intensive in hand labour and requires appropriate training and investment, however its applicability is widespread due to the international availability of seeds of resistant rootstocks. This technique is being used successfully in some Central American countries like Guatemala and Costa Rica for watermelon crops, but its wide-scale adoption in the melon sector in these countries has proven more difficult.

Other alternatives selected for investment projects involving cucurbits include solarisation, which is presently used on several hundred hectares grown with melons in Costa Rica (Abarca, 2006) and chemical fumigants, mainly 1,3-D/Pic and metham sodium, combined with crop rotation and IPM practices.

7.2.7.8 Flour mills and food processing premises

The main alternatives to the disinfestation of flour mills and food processing premises include sulfuryl fluoride, heat and sanitation programmes that involve cleaning and pest monitoring (IPM). Phosphine, particularly in fast generating gas forms has also made good progress and become an important alternative in some applications, primarily commodities. There has been progress in the adoption of each of these alternatives. Sulfuryl fluoride, although still not registered in several Article 5 countries, has proven successful for example in Egypt.

Since 2002, considerable research and adoption of heat treatment in mills and other food processing has taken place mostly in non-Article 5 countries. Several manufacturers of heat treatment equipment have advanced with systems designed for flour mills and food processing facilities. Although heat treatments tend to be costly and time consuming, this appears as a significant alternative. Some food processing facilities have been able to achieve reliable pest control with heat treatments combined with IPM.

7.2.7.9. Stored grains, dried fruit and nuts

Phosphine has been the leading alternative implemented in projects dealing with stored grains, dried fruit and nuts. Newer, fast generating gas forms of this fumigant are proving particularly successful. Egypt, Iran, Indonesia and Senegal are examples of Article 5 countries where phosphine is being used as a replacement for MB. CO_2 and magnesium phosphide along with an integrated pest management programme has proven effective for the control of dried fig pests in Turkey (Meyvacõ *et al.*, 2003; Aksoy, 2006). MLF experts considered that for the post-harvest sub-sector the experiences from other countries and regions are easily transferable, as treatments relate to a limited number of commodities and structures with similar features everywhere. Thus, they considered there was no further need for demonstration projects but rather more intensive and thorough preparation of future investment projects in order to adjust them to local needs, management practices and constraints (MLF, 2005b, c).

7.2.8 Lessons learned from projects

A recent study on the results of MLF projects indicated that some lessons are apparent from all projects that have been completed to date (MLF, 2005 b, c):

- Technically effective alternatives to MB have been found for almost all pests and diseases. However, projects need to make more effort in documenting their economic viability and overall sustainability.
- The capability to adapt to site-specific conditions is essential to the success of any alternative.
- Successfully evaluated alternatives can be introduced to developing countries within periods of 2-3 years. In fact, activities related to demonstration projects have led larger or more technically prepared growers to adopt alternatives at their own initiative.
- Project implementation and follow-up is better when grower's associations, grower's cooperatives or large enterprises take part in them.

7.2.9. Cases of non-compliance

The number of countries in non-compliance with the freeze of 2002 or the 20% reduction of 2005 is small (5.5% failed to meet the 20% reduction step on time). A recent study conducted by the MLF (MLF, 2005a; 2006) found that common reasons to explain non-compliance exist among the countries involved such as

a) Political and economic transformation processes implying radical structural changes;
b) Late ratification of the Montreal Protocol (after 2000) and/or its Amendments;
c) Late preparation and implementation of country programme and/or phaseout projects;
d) Weaknesses of the National Ozone Unit (late start, delayed implementation, frequent staff changes; communication difficulties within the Environment Ministry and/or with other ministries)

e) Low baseline due to exceptional circumstances (war, economic recession, insufficient data collection);
f) Delayed approval and implementation of ODS-related legislation;
g) Reluctance of stakeholders to actively cooperate in the ODS phaseout process or lack of sufficient involvement of key sectors or stakeholders since the onset of the projects or other activities; and
h) Expansion of the main sector using ODS – particularly MB – after the baseline years.

Guatemala, for example, illustrates the situation of a country that expanded use of MB after the baseline years, and has experienced difficulties in achieving compliance with Protocol requirements on MB as well as CFCs. The problems cited by the Party included recent expansion of land for melon cultivation leading to greater use of MB and resistance to phaseout by MB users due to the approval of CUEs for the Party's primary export market (UNEP, 2006). The cost of grafting was also cited by growers as a barrier, however an independent evaluation reported that grafted seedlings with no addition of chemicals are competitive with the costs of chemical alternatives applied under plastic sheets (UNEP, 2006). There were also weaknesses identified in the NOU and reluctance by some of the stakeholders to cooperate in the ODS phaseout process. Guatemala's baseline is 667.8 tonnes, while consumption in 2001 increased to 1311 tonnes as the melon industry expanded. A MLF project was developed in 2002 for the gradual elimination of MB. Some progress was made and MB consumption was reduced to 807 tonnes in 2004, but increased again to 871 tonnes in 2005, and the implementing agency was obliged to halt the project because the project conditions of the MLF were not achieved. A MBTOC expert visited the producers in Guatemala in 2006 under the auspices of UNEP to help discuss the problems. The five large melon producers identified diverse reasons for not having complied with the MB reductions: they did not consider grafting (the main alternative promoted in this project) to be a good strategy for their production systems, they wanted more time to solve technical problems (better production patterns, improved methods of grafting, reduction of production costs, and others). They would like fumigants and other types of alternatives to be examined for the control of vine decline (probably caused by *Monosporascus cannonballus*) and root knot nematodes (*Meloidogyne* spp.). It is also apparent that the application methods currently being used for alternative fumigants in Guatemala are not sufficiently effective; improved methods need to be introduced (UNEP, 2006; University of Chapingo, 2006). A memorandum of agreement has been signed between the Government of Guatemala and the University of Chapingo-Mexico for technical assistance in validating a wider range of alternatives for growing melon without methyl bromide. UNIDO, Spain and UNEP will also provide support through MLF and bilateral projects (UNEP, 2006).

Honduras was also in non-compliance with Protocol requirements for several ODS. The melon sector had expanded its use of MB after the baseline years, as in Guatemala. Honduras submitted to the MOP a revised plan of action to ensure its prompt return to compliance with the Protocol's control measures (Decision XVII/34). The plan of action committed Honduras to reducing MB consumption from 568 tonnes in 2004 to 546 tonnes in 2005. Honduras achieved this by reducing consumption to 526 tonnes in 2005 (UNEP, 2006).

Another case of non-compliance occurred in Ecuador, where the flower sector is the main MB consumer. A MLF phaseout project assisted the main MB user (a rose propagator) to adopt alternatives, and completely and successfully replaced 60 tonnes of MB in his operation. MB is also used in summer flower production (protected and field). A demonstration project faced long delays because of difficulties in finding an appropriate counterpart agency, and was converted to a technical assistance project by 40th ExCom with the aim of phasing out 25 tonnes. Stakeholder participation and awareness-raising activities related to the demonstration project did not appear to be sufficient. There was a lack of clarity about the sectors actually using MB in the country at that time; the use of MB possibly increased recently in flower production (MLF, 2004b). Initial data reported from Ecuador showed zero consumption of MB for 2003 - 2005, however the data did not correspond to information obtained from the main importer in early 2006 during an evaluation visit from the MLF. MB is used in Ecuador as a soil fumigant particularly in summer flower production (protected and field). It was found that MB imports had been registered under a tariff position assigned to "other pesticides" by the Customs Authority and the Ministry of Agriculture of Ecuador, a position which is different to that used by the Central Bank of Ecuador, the official source of information. A detailed evaluation of all registered imports under the new tariff position was conducted by the NOU and a careful survey of MB users by the implementing agency in charge of MB projects (the World Bank) in order to determine correct imported amounts. Although imports for 2003 and 2004 were correct at zero as previously reported, in 2005, 255 tonnes were imported, which put Ecuador into non-compliance with the 20% reduction clause (UNEP, 2006). In spite of this situation, the above clarification helped Ecuador to better address the need for alternatives, design a plan for returning to compliance that is properly targeted to MB users, and undertake appropriate actions to help growers learn about effective alternatives and increase their adoption (MLF, 2006).

7.2.10. Revised phaseout schedules

Several countries have found it necessary to adopt a revised phase out schedule after subscribing multi-year agreements for an advanced elimination of MB. The main reason arose from scepticism towards alternatives on the part of growers, active campaigns in favour of MB and the CUEs granted to non-article 5 parties in similar sectors (cucurbits, strawberries, flowers). One such example is Argentina, which initially made strong progress in phasing our MB; at its 46th meeting the ExCom reported that Argentina had phased out 51 tonnes more than the amount committed in its MLF project agreement, i.e. MB reductions were achieved faster than the project schedule (Report of 46th ExCom meeting. UNEP/PzL.Pro/ExCom/46/47 page 34, paragraph 118). However, the project later encountered reticence from the strawberry sector and it was not possible to meet the original schedule.

Another case is Chile, which came into non-compliance with the MB freeze obligations of 2002. Through an Action Plan approved by the 16th Meeting of the Parties it returned to compliance, both with the freeze and the 20% reduction of 2005. Two investment projects were approved for the phaseout of MB in Chile: one executed by UNDP as implementing agency and aimed at phasing out 127 tonnes of MB in the replant and nursery sectors, which recently finished. And a second project, approved in April of 2005 with the aim of phasing out all remaining uses of MB with the World Bank as implementing agency. As a result of strong reticence towards the adoption of alternatives – mainly in strawberry fruit and runners - this project was cancelled at the request of the Government of Chile during the 48th Executive Committee. Chile remained nevertheless committed to reduce MB consumption to 283.3 tonnes in 2005, in line with the 20% reduction required and also to limit consumption to this level until 2015 using import restrictions and other policies as necessary.

Costa Rica also revised its schedule, which called for total phaseout by 2008. The country however revised consumption and import information in 2005/ 2006 and found that the initial breakdown for MB consumption and use was incorrect and consumption in the melon sector was higher than originally estimated (although total consumption figures were accurate). After lengthy negotiations with the stakeholders involved, a new phaseout schedule with 2010 as the final year was agreed during the 48th Executive Committee Meeting.

7.2.11. Constraints on adoption

One constraint noted with respect to more modern chemical alternatives in Article 5 countries is lack of registration (MLF 2005, bc). This relates mainly to 1,3-dichloropropene and its different formulations with chloropicrin for soil uses, and sulfuryl fluoride in the postharvest sector. However, in contrast to expectations, lack of registration has not turned out to be a substantial barrier to making progress in MB phaseout. Several Article 5 countries have now registered 1,3-D and chloropicrin formulations and sulfuryl fluoride, while others have been able to achieve substantial MB reductions using other types of alternatives that do not require registration. Many MLF projects have compiled information about the costs and economic feasibility of alternatives, however this has rarely been published beyond local level. The fact that substantial commercial adoption of alternatives has occurred in many Article 5 countries offers a good opportunity to document economic information in case studies.

Involvement of key stakeholders from the beginning of the projects is an accepted principle of MLF projects but was not always fully applied. Formal consultations and Government clearance are often not enough to clarify all reservations and obstacles. MLF reviews (MLF, 2005 b,c; 2006) note that growers having strong influence over the sector, or a progressive attitude towards implementing alternatives; trade associations; and institutions at the government level, e.g. extension services, research institutes and other stakeholders, need to be fully consulted about their preferences and constraints, and their views taken into account in an open exchange during project preparation and implementation. Steering committees were also found very useful in some cases, particularly when projects involve different sectors and regions within the same country, although committees can also cause long delays in project implementation.

Interdisciplinary technical teams consisting of research and extension personnel specialized in plant pathology, weed control, crop production and application of pesticides were successful in sharing an integrative field approach with horticulture growers in Turkey and Peru. In other cases, such as in the melon sector in Central America, producers are very reluctant to share their advanced information because of the intense competition and lack of government extension services (MLF, 2005c).

In accordance with the Executive Committee guidelines for the MB sector, phaseout projects and agreements normally include the development of policy measures (mainly import restrictions and bans) on the use of MB during and after completion of the phaseout. Article 4B of the Protocol also requires Parties to implement systems for licensing the export and import of MB. It is evident that a number of governments have put in place licensing systems dealing with MB imports, and some also control MB distribution and use. However, it appears at this time that political support through governmental regulations needs to be stronger in a number of countries, according to a MLF review (MLF, 2005 b,c; 2006). Several countries were not aware until recently that some of the MB imported into their country was re-exported, for example.

Since 2003/4 the unexpectedly large CUEs requested by some non-Article 5 countries have slowed the progress of projects in a number of Article 5 countries, because the CUEs reduced the confidence in alternatives and the feasibility of achieving MB reductions. This was illustrated by the reaction of growers in Guatemala, for example (UNEP 2006).

UNEP regional meetings have noted that MB consumption rates should be closely monitored within regions in order to prevent the growth of illegal commerce into countries that have already eliminated MB. The viability of promoting the prohibition of MB imports in non-consuming countries or agreeing on the implementation of accelerated phaseout schedules for low MB consumers surrounding former big MB users may create "buffer zones" that could help prevent illegal trade. An MLF evaluation (MLF, 2005b) recently recommended that UNEP CAP teams should explore the feasibility of regional agreements - for example between Central American countries, African countries or regions - in order to standardize regulations and to avoid or at least minimize illegal trade in MB. UNDP has recently suggested to UNEP CAP Africa that such a coordinated effort would be most beneficial to support the phaseout work underway in tobacco-producing countries in the sub-Saharan region.

7.2.12 Summary of progress achieved by Article 5 countries

As a result of the projects funded by MLF, GEF and bilaterals, as well as the efforts funded by MB users themselves, Article 5 countries have made significant progress in phasing out MB: (Further details are provided in chapter 3)

- The vast majority (92%) of 144 Article 5 parties achieved the freeze on national MB consumption in 2002. Only 11 parties did not achieve compliance with the freeze on the scheduled date.
- In 2005, 94% of Article 5 parties (136 out of 144) achieved the 20% reduction step by the required date; and many countries achieved the 20% reduction several years earlier than required by the Protocol. Only 8 Parties did not comply with the 20% reduction step in 2005. To achieve compliance, 4 of these Parties needed to phaseout 1 - 10 tonnes each; 1 Party needed to phaseout 45 tonnes; while 3 Parties

(Ecuador, Guatemala and Honduras) needed to phaseout 167, 337 and 180 tonnes respectively.

- 80% of Article 5 parties (113 of 144 parties) reduced their national MB consumption to less than 50% of national baseline in 2004.
  - 88% of Article 5 parties (127 parties) reported national MB consumption between 0 and 10 ODP-tonnes in 2005.
  - 67% of Article 5 parties (96 parties) reported zero MB consumption in 2005.
  - The 14 Article 5 parties that consumed most MB have phased out on average 34% of national baseline. These 14 countries eliminated a combined total of 11,373 tonnes MB (refer to section 3.6.6 for more information).

7.2.13 Sustainability of phaseout

An important goal of MLF projects is to achieve a sustainable phaseout that will be maintained after projects are completed (MLF, 2000). The ExCom guidelines therefore required countries that implemented projects to develop a "package of policy measures directed to eliminating MB use… and to sustaining the alternative methodologies on a permanent basis or for as long as needed." (MLF, 2000). Accordingly, the countries implementing MLF projects have normally carried out policy development work, as outlined in section 7.3.5. The technical suitability of alternatives is also a very important component of sustainability. A recent study conducted by the MLF found that technology choice has generally been found to be appropriate in the horticulture sector, based on the results of demonstration trials, following discussion with key stakeholders and information on commercial adoption taking place in the same country or in similar regions and sectors (MLF, 2005bc). However, there were several instances where advanced technologies were implemented or equipment delivered without a solid examination of their technical or economic sustainability. Examples of this are steam for open field strawberries and tomatoes, CO_2 and high pressure chambers for post-harvest treatments, and electronic meters that cannot be calibrated in the country. This may be partly following suggestions by bilateral and implementing agencies and/or its consultants, but may have also been at the request from NOUs, farmers or processing companies who wanted advanced technologies (MLF, 2005 bc). Some MLF projects also took steps to establish a self-sustaining infrastructure for alternative technologies by encouraging local companies to start importing or supplying alternative products, equipment and services (refer to section 7.3.4 for examples).

Strong emphasis on awareness raising activities, information transfer and training, not only within one country and sector but also with other projects, regions and sectors also appear most important in securing sustainable outcomes, according to a MLF report (MLF, 2005 b,c; 2006). Such horizontal experience-sharing has included technical seminars and regional meetings. MLF reports have also recommended that websites such as the one jointly developed by UNEP and UNIDO should be regularly up-dated, with bilateral and the other implementing agencies adding their experiences in the implementation of MB projects to this web site (MLF, 2005 bc).

7.3. Measures and Activities that have Assisted MB Phaseout

This section identifies the types of activities that have been carried out in MLF projects and other types of activities, which have contributed to the MB reductions identified in Chapter 3.

7.3.1. Research and trialling of alternatives

Article 5 demonstration projects funded by the MLF focussed on trialling and comparing the technical and economic aspects of several types of alternatives so that the most appropriate and cost-effective technology could be identified in each country that participated. A number of projects also adapted alternatives to better suit local conditions.
In addition, substantial research was carried out by individual companies for the development of new formulations and methods of delivery of existing products. Government research programmes, institutes and MB users have also conducted research aimed at adapting and combining alternatives to suit a wider range of situations. This work has been fundamental in contributing to the observed reductions in MB use.

7.3.2. Training and extension

The MLF projects carried out activities to build capacity within government bodies, agricultural institutions, growers associations, local companies and other stakeholders. Organised programmes of training and technology transfer were a major component of MLF projects, and as a result thousands of MB users were trained and assisted in setting up and using alternatives in the field.

In Argentina, for example, a project provided direct training to189 technicians and more than 9,000 growers, and technicians/extensionists provided technical assistance to 16,000 growers each year (refer to Case study 19, in Chapter 10 Argentina). In Brazil, trained technicians transferred alternative technologies and necessary know-how to 140,000 farmers by organising meetings, training videos and visiting farms (refer to Case study No. 20 Brazil, in Chapter 10). In industrialised countries, researchers, government extension personnel and growers associations were involved in transferring alternatives at farm level. Examples include Australia, Italy, Japan, Spain and USA (MBCG, 1998; Shanks *et al*., 2004; Gullino and Camponogara, 2002; Tateya, pers. comm.; Fernandez, 2002; Miranda *et al*., 2005; Noling and Gilreath, 2004). In Italy and Spain, for example, fumigation companies also played a significant role in providing extension services and technical assistance which enabled a number of growers to switch to alternatives (Spotti, 2004; Carrera *et al*., 2004). The Government of Spain, for example, has reported that technology transfer activities carried out by government researchers, fumigation companies and others led to a reduction of MB use from about 90% to less than 50% in one year in the strawberry fruit sector (Government of Spain, 2006)

7.3.3. Information and awareness raising

Information dissemination and awareness raising has been a significant component in many MLF demonstration and phaseout projects (MLF, 2005 bc). Examples of technical publications or extension materials resulting from projects include Cao *et al*. (2003), Haroutunian *et al*. (2001), Jiménez *et al*. (2003), Turšić (2001, 2003), Valeiro *et al*. (2001), Biaggi *et al*. (2003), Wontner Smith *et al*. (2001), Mills *et al*. (2003), UNEP (1999), and many others. Examples of general awareness publications include

González (1999), Pizano (2001), UNEP (1998a), UNDP and UNIDO (2005) and others. In non-Article 5 countries some awareness raising and technical materials for end-users were also produced. Researchers in Italy, for example, produced technical publications, leaflets and videos aiming to inform farmers, technicians, consumers and politicians, and as a result from 1999 the number of farmers who adopted alternatives increased in Italy (Gullino and Camponogara, 2002). The Canadian government produced a series of publications and case studies on MB alternatives (e.g. Environment Canada, 1995; Marcotte and Tibelius, 1998; MBIGWG, 1998; Lindberg, 2001). In Australia a national newsletter called *National Methyl Bromide Update* informed growers and others about results of trials and demonstrations, alternatives adopted in various sectors and news and updates about the Montreal Protocol. In the US, the USDA produced a newsletter called *Methyl Bromide Alternatives*, with the aim of providing information on research for MB alternatives from USDA, universities and industry. Numerous international conferences have also helped to inform researchers and MB users about developments in alternatives (e.g. MBAO, 1995-2006; Bello *et al.*, 1998; Müller, 1997; UNEP, 1992; 1998b: 2000; Batchelor and Bolivar, 2002; Batchelor and Alfaroba, 2004; and many others).

7.3.4. Infrastructure developments

A number of MLF projects encouraged local companies to start importing alternative products or equipment, in order to build up a self-sustaining infrastructure which supported the supply of alternatives within a country, again contributing to MB reductions. Jordan's MLF project, for example, encouraged local companies to form business arrangements with other companies in order to import alternative products such as fumigants (Hasse, 2001). Projects also encouraged local companies to start manufacturing necessary products and materials in order to avoid expensive imports and reduce the prices paid by growers. The Argentine project provided technical assistance so that local companies could manufacture agricultural inputs such as substrates, seeding machines and trays of the correct specification for use in float systems (refer to Case Study 2 Argentina). While in Jordan, for example, a local company was encouraged to start commercial production of grafted plants following the business success of grafted plant nurseries in Morocco (Hasse, 2001).

7.3.5. Regulatory frameworks and policies

As mentioned above, the Protocol requires parties to establish systems for licensing the exports and imports of MB (under Article 4B), and such systems enabled a number of countries to limit and reduce consumption of MB. ExCom guidelines required the countries that implemented phaseout projects to develop policy packages to support and sustain the MB reductions achieved in projects (MLF 2000). In most cases this work focussed on licensing and similar policy measures to control MB imports. In some cases governments also developed comprehensive national plans which assisted and coordinated the work, e.g. China and several CEIT countries (Slusarski, 2002). Hungary, for example, drew up a 5-year plan in 2000 and participated in a regional project (Slusarski, 2002; GEF, 2004):

- Surveys were carried out to identify MB uses, target pests, circumstances of users, and existing alternatives that were in used in commercial practice

- Identification of the main barriers to adoption of alternatives, and identification of means to overcome the barriers
- Demonstrations, extension and training programmes. These were carried out by major MB users (e.g. pepper and tomato producers) in Hungary as well as by regional GEF projects
- Awareness raising activities for MB users and the general public, including information materials, workshops and seminars
- Establishing a policy framework by preparing or modifying legislation on ODS and setting a phaseout schedule. Existing pesticide regulations were used to restrict MB uses to specific crops or uses (Slusarski, 2002; GEF, 2004).

7.3.6. Economic measures

The MLF played a significant role in overcoming the barriers to the capital or set-up cost of alternatives in Article 5 growers and users by providing financial assistance for the transfer and adoption of alternatives, as outlined under Article 10 of the Protocol and developed in ExCom guidelines (MLF, 2000). The MLF projects procured equipment and materials, covering the incremental (i.e. additional) costs of items that varied from seed trays for floating tray systems to equipment for applying alternative fumigants.

Other types of economic measures also played a role in MB reductions in some cases. Several countries introduced fees or levies on MB imports, which had the effect of raising MB prices and thus making alternatives more attractive for commercial use. In most cases the revenue was used for promoting alternatives. For example, from 1996 the Czech Republic's ozone protection legislation placed taxes on producers and importers of MB, and the revenue is used by a state Environmental Fund for ozone layer protection (Parliament of the Czech Republic, 1995). Similarly, regulations in Slovakia placed a fee on MB and other ODS imports; this fee increased the price of MB compared to alternatives, so encouraging users to shift away from MB (Slusarski, 2002). MB users in Australia decided in the 1990s to place a levy on MB imports and the funds were used for alternatives trials and information dissemination. From 1996 the Australian government charged import licence fees, and this also raised the price of MB compared to alternatives (MBTOC, 2002).

7.3.7. Industry certification programmes

Several industry certification programmes have had a significant impact on MB use in specific areas particularly in the cut flower and ornamentals export sectors in many countries. Growers who participate in certification programmes for flowers and ornamentals operated by MPS, EUREP-GAP, FLORVERDE and FLP certification programmes, for example, follow the relevant codes of practice and are not permitted to use MB if they wish to participate in the programme. The MPS programme is now implemented by more than 5,200 growers from more than 30 countries, such as Belgium, Canada, Colombia, Costa Rica, Ecuador, France, India, Israel, Kenya, Malaysia, Netherlands, South Africa, Spain, Tanzania, Uganda, UK, USA, Zambia and Zimbabwe (van't Hoff, 2004). The FLORVERDE programme was implemented by 80% of growers in Colombia and is starting to expand to other countries of Latin America (ASOCOLFLORES, 2007). The EUREP-GAP programme is implemented by the flower producers in many parts of the world who supply major supermarkets in

Europe; all flowers sold in these supermarkets are required to meet the EUREP codes which, *inter alia,* do not permit the use of MB (D'Hont, 2006; Moeller 2004). A similar code of production was developed in the vegetable production sector in Spain, where a certification programme called UNE 155001 was drawn up by growers and exporters associations with the AENOR Association of Normalisation and Certification. The crop production standard UNE 155001 did not permit use of MB for soil fumigation, and as a result MB was phased out in the major horticultural region of Almería in Spain, primarily for tomato, cucurbits and peppers before 2002 (Fernández, 2002).

7.3.8 Overview of activities

The European Community's *Management Strategy for the Phase-out of the Critical Uses of Methyl Bromide* (2006) provided an overview of the types of activities carried out by member countries of the EC to assist the adoption of alternatives. These activities are summarised in Table 7.6 below.

Table 7.6. Technology transfer activities and supporting activities in European Community Management Strategy (2006)

Technology transfer activities	Examples of supporting activities
Awareness-raising and improved knowledge-system of MB users and end-users	• Information transfer at the practical level, including tailor-made information about MB alternatives for end-users, relevant to specific pest species and local circumstances; • Information sheets, fact sheets, information websites, regular newsletters; • Role of fumigators in disseminating know-how to end-users; • Role for growers, pest control operators (PCOs), extension and research groups, supermarkets, companies that purchase farm products, consumers and credit suppliers; • Information exchange through workshops or conferences.
Training in the use of MB alternatives	• Practical, illustrated step-by-step training manuals; • Technical training in MB alternatives (particularly hands-on training) organised by PCOs, agricultural institutes, companies, growers associations, millers associations, governments, and others; • Demonstrations, field days, study visits, workshops.
Creation of conducive economic environment	• Taxes on MB imports, to promote alternatives; • Agricultural grants or bank loans to promote adoption of MB alternatives.
Restrictions on MB use	• Regulations limiting frequency of MB use; • De-registration of all uses of MB for which alternatives are available; • Measures to prevent illegal trade in MB.
Market signals	• Agricultural production standards and certification systems that do not permit use of MB, such as MPS, EUREP cut flower standards, and COEXPHAL growers association production standards; • Supermarket specifications that do not allow use of MB.

Source: EC, 2006.

7.4. References

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Chapter

8

Economic Issues Relating to Methyl Bromide Phase-Out

8.1 Introduction

A review of the existing literature on the economics of the impact of the methyl bromide phase-out shows that the existing peer-reviewed publications can be divided into three categories:

- Articles that report only the changed (increased) costs of using methyl bromide alternatives;
- Articles that use some form of partial budgeting technique to assess the impact of the use of methyl bromide alternatives on the revenues and costs of a particular application, i.e. on the net financial position of firms (mostly farmers in pre-harvest applications). In these cases the current use of methyl bromide (in terms of application methods and application rates, etc.) is used as the norm from which deviations are measured;
- Articles that report the impact of the use of methyl bromide alternatives on the sector (e.g. California strawberries, cut flowers in Spain) as a whole.

The review shows that much work needs to be done to increase understanding of the true impacts of the methyl bromide phase-out. The existing literature is narrow in the sense that more economic studies are needed in countries outside of the USA (especially in Article 5 countries) and on a wider range of methyl bromide uses.
The purpose of this Chapter is to provide *a* framework within which decisions on the economic feasibility of Critical Use Nominations *may* be made, and to survey the existing literature as a guide to what is known about the economic impact of the Methyl Bromide phase-out.

8.2 Formal Decisions to Guide MBTOC

MBTOC has been provided with several Montreal Protocol Decisions, requesting an assessment of the economic feasibility of Critical Use Nominations. The following appears in the Report of the first Extraordinary Meeting of the Parties:

> "Decision Ex.I/4. Conditions for granting and reporting critical-use exemptions for methyl bromide …

6. To request any Party submitting a critical-use nomination after 2004 to describe in its nomination the methodology used to determine economic feasibility in the event that economic feasibility is used as a criterion to justify the requirement for the critical use of methyl bromide, using as a guide the economic criteria contained in section 4 of annex I to the present report;

...

9. To request the Technology and Economic Assessment Panel:

a. To identify options which Parties may consider for preventing potential harmful trade of methyl bromide stocks to Article 5 Parties as consumption is reduced in non-Article 5 Parties and to publish its evaluation in 2005 to enable the Seventeenth Meeting of the Parties to decide if suitable mitigating steps are necessary;

b. To identify factors which Article 5 Parties may wish to take into account in evaluating whether they should either undertake new accelerated phase-out commitments through the Multilateral Fund for the Implementation of the Montreal Protocol or seek changes to already agreed accelerated phase-outs of methyl bromide under the Multilateral Fund;

c. To assess economic infeasibility, based on the methodology submitted by the nominating Party under paragraph 6 above, in making its recommendations on each critical-use nomination. The report by the Technology and Economic Assessment Panel should be made with a view to encouraging nominating Parties to adopt a common approach in assessing the economic feasibility of alternatives;

....

In Annex 1 of the same document, Section B on reporting requirements states the following:

"4. Economic feasibility

Where a nomination has been approved on the basis of the economic infeasibility of an alternative, the exemption holder should report any significant changes to the underlying economics. This could include any changes to:

(a) The purchase cost per kilogram of methyl bromide and of the alternative;
(b) Gross and net revenue with and without methyl bromide, and with the next best alternative;
(c) Percentage change in gross revenues if alternatives are used;
(d) Absolute losses per hectare/cubic meter if alternatives are used;
(e) Losses per kilogram of methyl bromide requested if alternatives are used;
(f) Losses as a percentage of net cash revenue if alternatives are used;
(g) Percentage change in profit margin if alternatives are used.

Notes: Where an exemption has been approved on the basis of the economic infeasibility of an alternative, the exemption holder must have clearly described the nature of the economic infeasibility in its original nomination.

The economics of methyl bromide and of alternatives can be subject to changes over time, and it is possible that those changes could have an impact on the exemption holder's claim that an alternative is not economically viable and on its continuing eligibility for an exemption.

Given that criteria for assessing the economic feasibility of alternatives have not yet been agreed by the Parties, at the current time the seven data points identified above represent the only guidance given. As criteria are developed and approved by the Parties for inclusion in the Technology and Economic Assessment Panel/MBTOC Handbook, the data to be provided in annual reporting would reflect those criteria and any accompanying new data requirements.

The following appears in Annex I of the Report of the 16th MOP:

"C. Further guidance on the criteria for the evaluation of nominations for critical uses of methyl bromide

1. On the availability of technically and economically feasible alternatives, and economic feasibility

...

19. To the factors already listed in annex I, part B, paragraph 4 of the report of the Extraordinary Meeting of the Parties, with regard to paragraphs 6 and 9 (c) of decision Ex.I/4, the following are added:

(a) The difference in purchasing costs between methyl bromide and the alternatives per treated areas, mass, or volume, and related costs such as new equipment, labour costs and losses resulting from closing the fumigated object for an extended period of time;

(b) Difference in yield per hectare, including its quality, and harvest time, between the alternative and methyl bromide;

(c) Percentage change in net revenue if alternatives are used.

20. In line with paragraph 4 above, in any case in which a Party makes a nomination which relies on the economic criteria of decision IX/6, MBTOC should, in its report, explicitly state the central basis for the Party's economic argument and explicitly explain how it addressed that factor, and, in cases in which MBTOC recommends a cut; MBTOC should also provide an explanation of its economic feasibility.

8.3 A Review of the Literature

The existing peer-reviewed literature on the economics of the methyl bromide phase-out is small, with approximately 25 publications appearing over the past decade. These follow on some peer-reviewed (US-based) publications from the early-1990s (e.g. Sharpe *et al*, 1993) and other articles such as Forsythe and Evangelou (1994); and Yarkin *et al* (1994a; 1994b).

The literature of the past decade can be divided into three groups, namely cost analyses, partial budgeting, and sector analyses.

8.3.1 Cost analysis

There are a number of studies that report the impact of the use of methyl bromide alternatives in terms of the impact on the cost structure of the firm, while in some cases this impact is extrapolated to the whole industry. Examples include the impact in postharvest applications of methyl bromide alternatives (Aegerter and Folwell 2000; Aegerter and Folwell 2001; Odeh *et al* 2004) and one example of a soils use (Sorribas *et al* 2002).

While these studies are useful in their own right, they do not contribute to an understanding of how to measure the economic (as opposed to the financial) impact of the methyl bromide phase-out, as is evident from the detailed description of the factors that have to be taken into account as set out in the Decisions contained in section 2 above.

8.3.2 Partial budgeting

Partial budgeting, as described below, is required to truly understand the impact of the costs changes of an alternative. A partial budget consists of a full financial analysis of an existing activity (in this case an activity using methyl bromide), and then a repetition of that financial analysis for the activity using an alternative to methyl bromide, where all costs and revenues that have changed as a result of the alternative are adapted. The profitability (some measure of total revenue minus total costs) of the two activities is then compared. The following outcomes are then considered:

Alternatives that result in negative net revenues are not financially feasible.

- In the unlikely event that the gross revenues are higher and costs are lower, the alternative is financially feasible. Economically rational methyl bromide users will voluntarily adopt alternatives that provide higher net revenues unless the alternative is unacceptably more risky, involves substantial capital investment, or confronts non-market forces that constrain adoption (such as lack of registration).
- In the unlikely event that changes in costs and revenues are absolutely equal, the alternative is financially feasible because of the environmental benefits accruing.
- When costs and revenues increase or decrease simultaneously, the result is ambiguous, and there is a need to define default values. These areas of ambiguity are identified in Table 8.1 below.

There have been at least ten publications over the last decade, which have used this approach to assess the impact of the methyl bromide phase-out. Six of these publications are based on research conducted in the USA (Byrd *et al*, 2006; Carpenter *et al*, 2000; Hueth *et al*, 1997; Nelson, 1996; Sydorovych *et al* 2004; Sydorovych *et al* 2006), and the rest in Europe (Akkaya *et al* 2004; Engindeniz 2004; Grafiadellis 2000; and Tullio *et al* 2006). Furthermore, the Global Horticultural Markets initiative at Michigan State University[2] has a program on the economics of methyl bromide alternatives, which aims to evaluate alternatives to methyl bromide in the production of herbaceous perennials and conifer seedlings, using partial budgeting techniques.

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[2] http://www.globalhort.msu.edu/

Table 8.1. Areas of ambiguity resulting from simultaneous increase or decrease of cost and revenue

	Alternative results in	
	Lower costs	Higher costs
Lower gross revenue	**Ambiguous.** **Alternative is financially feasible if costs decrease more than revenues (i.e. net revenue increases).** If revenues decrease more than costs, the alternative may or may not be financially feasible.	**Ambiguous.** The alternative may or may not be financially feasible depending on the extent of the loss in net revenue. In a practical sense the alternative may be financially feasible, e.g. where net revenue declines by a small amount, say $1.00 or 0.0001%. However, if net revenues decline by, say 99%, most would conclude that the alternative is not financially feasible.
Higher gross revenue	**Alternative is financially feasible**	**Ambiguous.** **Alternative is financially feasible if revenues increase more than costs.** If costs increase more than revenues, the alternative may or may not be financially feasible.

8.3.3 Sector-wide analyses

Partial budgeting is used to assess the economic (financial) impact of the methyl bromide phase-out at the level of the individual firm, although the results can be extrapolated to an entire industry in the event that the analysis is conducted for 'typical' firms in that industry. The problem, however, is that such analyses are based on the assumption that **an individual firm** cannot affect the market. In the case of most industries where methyl bromide is currently used this assumption probably holds; however, when extrapolating to the sector as a whole, this is in most cases not true. When a whole sector is affected, demand, supply and prices of the products and of the inputs to production change, affecting the eventual outcome in terms of impact on the individual firm. As a result, economists have devised a wide range of techniques to model the sector and economy-wide impacts of a change such as the methyl bromide phase-out. There have been few such studies published in the past decade, most of them addressing soils use in the USA, and most focusing on the California strawberry industry.

Carter *et al* (2005) point out that, while the benefits of the methyl bromide phase-out accrue globally, the costs are borne by producers using methyl bromide. However, these costs are not distributed equally amongst all users. High-cost producers and those with access to inferior substitutes will bear the cost disproportionately, as will producers who face competition from producers who are not subject to the phase-out (such as Mexican farmers, who can use methyl bromide until 1 January 2015). To measure this differential impact, they use different estimates of the price elasticity of demand for strawberries to assess the impact of the phase-out on different regions in California where strawberries are grown, and test the sensitivity of their results. These show that strawberry revenues will fall due to the elastic nature of demand, especially in the peak production period, and that regional differences in impact exist.

De Canio and Norman (2005) take a completely different approach in an article based on work that was originally done for the Agricultural Economics Task Force (AETF). This study focuses on the cost incurred by the MLF for the implementation of the Montreal protocol in methyl bromide phase out projects rather than the cost incurred by enterprises in eliminating MB. They argue that the environmental benefits of regulation (in this case the methyl bromide phase-out) must also be taken into account. This, they argue, can be accomplished by considering what non-Article 5 countries have paid to the Multilateral Fund, whose task it is to assist with phase-out projects in Article 5 countries which, they argue, reflects their "willingness to pay" to eliminate MB. By their estimate, this amounted to roughly $24 000 per ton of methyl bromide abated (or $24 per kg), i.e. if a firm (e.g. a strawberry farmer) could show that the use of an alternative would lead to a profit reduction of more than $24 per kg of methyl bromide used, that alternative was not economically feasible. The authors stress that a reduction in the use of an ozone depleting substance benefits the entire globe, regardless of where the reduction took place. However, their approach has been criticized on the grounds that projects have all been implemented in Article 5 countries where the costs of implementation are not the same as in non-Article 5 countries. The authors also recognize that the cost of the phase-out need not be borne only by the producers, as the state can implement programs (e.g. tax incentives, subsidies) that shift part of that cost on to society as a whole.

Deepak *et al* (1996) used a quadratic programming model to evaluate the economic impact of the methyl bromide phase-out on the US winter fresh vegetable market for tomatoes, green peppers, cucumbers, squash, eggplants, and watermelons. Their model accounts for "equilibrium prices and quantity consumed by month and crop in … New York, Chicago, Atlanta, Los Angeles … shipments by month and crop from … Florida, Mexico, Texas … to each market, and the acres planted to each cropping system in each supply region." Their results are based on increased production costs and reduced yields, hence a ban on methyl bromide has a severe negative impact on US producers and positive impact on Mexican producers, while consumers pay higher prices for fresh vegetables.

This study was repeated for a broader set of markets by Van Sickle *et al.,* (2000). They note that the results are critically dependent on the assumptions around the impacts of the methyl bromide phase-out on production costs and yields (showing that these classes of model are also dependent on typical farm budgets). They also note the important influence that a change in production practices (e.g. as a result of the methyl bromide phase-out) can have on producers' access to the market, i.e. on market windows. Deepak *et al* (1999) also model the impact of alternative policy instruments (i.e. as alternatives to a ban on methyl bromide) such as marketable quotas and a Pigovian tax, while the study of Spreen *et al* (1995) focuses on the impact of a ban on the state of Florida.

Ferguson and Lee (1997) take as their point of departure the observation that a ban on the use of a pesticide such as methyl bromide has predictable results: less efficient production and higher consumer prices, the latter providing a windfall gain to producers who a) did not use the banned product, and/or b) could find substitutes faster. Hence, they argue in favour of a phase-out as opposed to an outright ban, in order to provide all producers with the opportunity to adjust. The methyl bromide phase-out is used as an example of the benefits of the latter approach.

Goodhue *et al.*, 2005 discuss the pitfalls of a relatively simple budgeting procedures (e.g. what prices to use, what factors will affect prices temporally), then use detailed budgets from an experimental trial plot in the California strawberry industry as well as an assumption about the price elasticity of demand for strawberries to ascertain the industry-wide effects of the methyl bromide phase-out on producers and consumers, measuring the producer and consumer surplus respectively. Their analysis is based on an assumed yield loss of 10-15% for strawberries.

Ninghui (2003) has conducted one of the only analyses of this type outside of the USA: in this event, the market for vegetables, strawberries and ginseng in China. He developed a two-stage linear programming-type model that maximizes the production of each of the crops given the prices of methyl bromide and its substitutes as well as a budget constraint in the first stage. In the second stage total production is optimised, and the results tested under three scenarios that reflect different methyl bromide phase-out rates. He concludes that farmers get more profit by using MB than alternatives. Losses incurred by restricted use of MB increase yearly and are more significant in the 3rd scenario where MB use is reduced at a speed from high to low as opposed to scenario 2 (low to high speed) and scenario 1 (equal reduction).

Finally, Norman (2005) has provided probably the most satisfactory analysis of the impact of the methyl bromide phase-out to date – in this case again using the California strawberry industry to illustrate the argument. While there may be dissent about her results, the virtue of the article lies in the fact that she continues to ask the question behind every question. For example, other authors have noted the possibility that Mexican producers will benefit from the methyl bromide phase-in, largely because they can use it until 2015: Norman investigates the factors that will affect the supply and demand of Mexican strawberries on the US market.

Her main argument runs along the following lines:

- The US is a net exporter of fresh strawberries, with exports (mostly to Canada) at 10.5% of production and imports (mostly from Mexico) 6.3% of consumption; given that fresh berries are perishable, trade is only feasible within North America, and will take place only when prices in the export market are significantly higher. Norman's argument is, however, somewhat of an over simplification because the United States and Mexico export commercial quantities of fresh strawberries to the European Union. Further, the United States exports substantial quantities Japan and Taiwan and minor volumes to the Middle East. Thus, it would be feasible for Mexico to export to similar markets. Furthermore, while an increase in imports from Mexico can be expected, Mexican production capacity would have to grow at historically unprecedented rates if such imports were to have a material influence on the US market. The possibility of such investment is ameliorated by the fact that Mexico has to halt the use of methyl bromide in 2015, that new Mexican production will come from more marginal resources, and that the Mexican domestic market is growing rapidly.

- US demand for strawberries is increasing rapidly because of a) the price of strawberries relative to other fruit (which also means that if strawberry producers are adversely affected by the methyl bromide phase-out, they will switch to other strawberry substitutes that do not require methyl bromide), b) the longer availability of strawberries on the market, and mostly c) because of increasing per capita incomes in the US domestic market, i.e. the income elasticity of demand for strawberries is high;
- Even accepting that the reduction in net income to a 'typical' California strawberry farmer can be as high as the 20-57% as was put forward in the 2003 US Critical Use Nomination, Norman shows that the upward movement in the farmers' long-run cost curve has to be read in conjunction with the shift in demand for strawberries. In this regard, economic theory tells us how to estimate what share of the increase in costs is borne by producers, and what share by consumers, as long as the share of fumigation costs in production and the own-price elasticity of demand for strawberries are known. Hence, a more accurate estimate of the impact on farmers' net revenue is possible. Furthermore, as fumigation becomes more expensive, producers will substitute towards other, cheaper inputs. The extent to which substitutability is technically possible will determine the lower bound of the final share of the cost increase borne by producers.
- Finally, the impact on consumers depends on factors such as the spread of the burden of the increased costs over a large number of consumers; exactly when in the season Mexican imports are expected to be highest; the rate at which demand for strawberries is increasing; and the rate at which the cost of methyl bromide alternatives are becoming cheaper.

Norman comes to the basic conclusion that "actual net costs to growers will be much smaller than the simple increase in production costs cited in the US nomination for exemption."

8.4 Conclusion

This review has shown that much work needs to be done if we are to have a better understanding of the true impacts of the methyl bromide phase-out. While the literature that has been reviewed here provides a useful starting point to the types of analysis that is required, it is narrow in the sense that more work needs to be done on countries outside of the USA (especially in Article 5 countries) and on a wider range of methyl bromide uses.

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Chapter

9

Alternatives to Methyl Bromide for Quarantine and Pre-Shipment Applications

9.1 Introduction

MB is a controlled substance under the Montreal Protocol. Article 2H specifies the control measures on production and consumption of methyl bromide. Para. 6 of Article 2H specifically exempts application of these control measures to methyl bromide used for quarantine and pre-shipment (QPS). The Montreal Protocol provides no limitation to the production and consumption of methyl bromide for QPS purposes, although it is recognised as an ozone-depleting substance.

The Beijing Amendment to the Protocol included adding a requirement (Beijing Amendment, Art. 1, para. O) that "each Party shall provide to the Secretariat statistical data on the annual amount of the controlled substance listed in Annex E used for quarantine and pre-shipment applications", where Annex E lists MB as a controlled substance.

It was not stated why QPS MB was specifically exempted from control under Article 2H when this article was included in the Copenhagen Amendment to the Protocol. However, it has been speculated that, at that time, QPS use of methyl bromide was regarded as a highly important use of this ozone-depleting substance, and that technically and economically feasible alternatives for this category of use were considered not to be available. An exemption from phaseout provided a means of allowing the use to continue.

Quarantine pests, detected in a country or region previously free of them, can result in considerable cost caused by restriction of exports, eradication measures and implementation of disinfestation treatments, as well as causing extensive environmental and agriculture damage. In addition, environmental costs can also be high because of increased pesticide usage to control introduced pests or environmental degradation up to and including native species extinction caused by the direct effects of the exotic species.

This chapter first discusses the scope of the QPS exemption and the uses of methyl bromide that are considered to fall under it. It then discusses key technologies and alternatives, for the main QPS uses, and the limitations to their deployment and further development. The chapter provides an update to MBTOC's 2002 Assessment Report (MBTOC 2002). For additional information the reader is directed to the 2002 and previous Assessments (MBTOC 1995, 1998, 2002). Discussion of the quantities of methyl bromide used for QPS will be found in Chapter 3.

Several Decisions of the Parties (IX/28, XI/13, XVI/10) have related to obtaining information on the current uses of MB that are considered to fall under the QPS exemption. The Quarantine and Preshipment Task Force of TEAP have reported (TEAP 2005, 2006) on quantities of methyl bromide use for particular purposes by the Parties, and on some alternatives considered to be available for particular uses.

Decision XI/13(7) encourages "the use of methyl bromide recovery and recycling technology (where technically and economically feasible) to reduce emissions of methyl bromide, until alternatives to methyl bromide for quarantine and pre-shipment uses are available". Decision VII/5 urges Parties to adopt non-ozone-depleting technologies wherever possible and urges Parties to "minimize emissions and use of methyl bromide through containment and recovery and recycling methodologies to the extent possible". Description of available measures to restrict emissions from QPS treatments, including recovery and recycling technologies, will be found in Chapter 4.

In total, reported production of MB for QPS purposes (Ozone Secretariat data) has been approximately constant over the period 1999-2004 at around 10,500 metric tonnes annually but shows an increase of about 30% in 2005. The increase comes at a time when 'controlled' uses of methyl bromide are decreasing rapidly as a result of progress with phasing out of MB in both Article 5 and non-Article 5 countries. In 2006, the quantity of MB for QPS globally is likely to exceed either that used in total for Critical Uses in non-Article 5 countries or that remaining in use in Article 5 countries.

QPS treatments, including those using methyl bromide, come under a number of international and national agreements and regulations, including the International Plant Protection Convention (IPPC) and its regional bodies, as well as various national quarantine regulations. The reader may wish to consult, amongst others, the following websites as examples of international and national plant protection guidelines, regulations and treatments for perishable and durable commodities:

- International Plant Protection Convention (https://www.ippc.int/IPP/En/default.jsp)
- European and Mediterranean Plant Protection Organisation (http://www.eppo.org)
- The Ministry of Agriculture, Forestry and Fisheries of Japan (http://www.maff.go.jp/eindex.html)
- Canadian Food Inspection Agency (http://inspection.gc.ca)
- Australian Quarantine and Inspection Service (AQIS) (http://www.aqis.gov.au);
- United States Department of Agriculture (USDA) Animal and Plant Health and Inspection Service (APHIS) (http://www.aphis.usda.gov/plant_health/);
- North American Plant Protection Organisation (http://www.nappo.org)

Many countries have listings of allowed treatments for QPS for imports. Examples include the 'USDA-APHIS Treatment Manual', searched on line at: https://manuals.cphst.org/TIndex/index.cfm, the New Zealand listing of approved QPS treatments, at http://www.biosecurity.govt.nz/imports/plants/standards/152-02.pdf and the Australian listing at http://www.aqis.gov.au/icon32/asp/homecontent.asp .

The equivalent European document to the 'USDA-APHIS Treatment Manual' is contained within Directive 2000/29/EC and updates that contains the special requirements that must be implemented by all Member States to control pests and pathogens on plants, plant products and other objects that move into and within the Member States.

9.2 Definitions of Quarantine and Pre-shipment

The scope of the QPS exemption has been defined in decisions of the Protocol relating to the terms 'Quarantine' and 'Pre-shipment'.

The *Seventh Meeting of the Parties* decided in *Dec. VII/5* that:

> "(a) "Quarantine applications", with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:
>
> (i) Official control is that performed by, or authorized by, a national plant, animal or environmental protection or health authority;
>
> (ii) Quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled;
>
> (b) "Pre-shipment applications" are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or existing phytosanitary or sanitary requirements of the exporting country;
>
> (c) In applying these definitions, all countries are urged to refrain from use of methyl bromide and to use non-ozone-depleting technologies wherever possible. Where methyl bromide is used, Parties are urged to minimize emissions and use of methyl bromide through containment and recovery and recycling methodologies to the extent possible."

The *Eleventh Meeting of the Parties* decided in *Dec. XI/12* that "pre-shipment applications are those nonquarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country. Official requirements are those which are performed by, or authorized by, a national plant, animal, environmental, health or stored product authority."

In general, MB used in quarantine treatments targets quarantine pests, which are carefully defined by regulatory authorities. A quarantine treatment is officially authorised by the competent authority and not a commercial organization, and the time when the treatment can be carried out is undefined. In contrast, pre-shipment treatments are always carried out within 21 days of shipment; pre-shipment treatments may target or both non-quarantine and quarantine pests. Pre-shipment treatments must also be authorised by the relevant authority and not a commercial organisation.

The interpretation by individual Parties of the concepts of 'Quarantine' and 'Pre-shipment' to particular uses of MB results in some divergence of what constitutes a QPS use under the Montreal Protocol. TEAP (2002) provided some discussion of possible limits to the QPS exemption. Examples of treatments that TEAP felt fell within and outside the QPS definitions may be found in TEAP (1999), TEAP (2002) and MBTOC (2002).

9.3 Scope of Use of Methyl Bromide for QPS

Methyl bromide fumigations continue to be used on a diverse variety of goods in trade as a measure to prevent the spread of injurious pests and diseases. MB fumigation is one of many different measures that are applied to achieve this aim. It is the main quarantine fumigation treatment in use in terms of number of distinct specified treatments and by quantity of chemical consumed, and it is often the treatment quarantine officials resort to when presented with otherwise undescribed or uncertain situations. MB fumigation can also be used on modes of transport (e.g. ships, freight containers, aircraft, farm and military equipment) that may be contaminated with these pests or diseases of quarantine significance and potentially act as a vehicle for their spread. It can also be use as one measure for containment and eradication of such pests if they become established in a region. Many of these methyl bromide treatments fall under 'quarantine' measures under the definitions of the QPS exemption given above.

MB treatments falling under 'Preshipment' are typically official measures aimed at safeguarding the quality of goods in export trade that may otherwise be damaged by pests. It may also have an element of restricting the level of injurious pests entering or present in the receiving country.

MB has a long and successful history as a QPS fumigant and is generally regarded as a highly efficacious treatment. In many situations, it is the only treatment approved by national quarantine authorities. MB fumigation for pre-shipment may be selected when the commodity must be treated more rapidly than is possible with phosphine fumigation, or when alternative approved treatment facilities or equipment is not available at port of entry. Some importing countries have official regulations that specify the use only of methyl bromide for particular imports, origins and pests.

Most alternative treatments, currently approved, are approved on a pest and product specific basis, and following bilateral negotiations because their applicability to a pest and commodity are often quite limited. This process helps ensure safety against the incursion of harmful pests, but also often requires years to complete. Alternatives are also disadvantaged by their requirement of specialized equipment, and facilities not generally available at seaports and airports whereas, MB on the other hand needs no specialised requirement for equipment or facilities for fumigations conducted at ports. Alternatives find their greatest use for treatments performed in the exporting country on commodities that have enough volume to allow construction of specialized facilities to conduct the treatments, e.g. heat treatment of mangos. Most quarantine treatments, however, are performed at the port of entry of the importing country when inspection has discovered the presence or risk of a quarantine pest. In that case, product destruction (usually incineration) or re-export may be the only alternatives to MB available the plant health inspection official.

The Parties have been surveyed under Decisions XI/13(4) and XVI/10(4) to ascertain the purposes for which methyl bromide was used under the QPS exemption, and the quantities used for these purposes. Fig. 9.1. and Table 9.1 summarise the results of these surveys. The results are the most recent available on a global basis. They show a sample of categories of use and their annual quantities in the 2002 – 2004 period. The surveys covered about half the global reported consumption for QPS during the survey period. Independent evidence suggested the proportion of QPS fumigation on logs and wooden items may have been underrepresented (TEAP 2006a).

Fig. 9.1. Global QPS use by general category as found by survey (TEAP 2006a).

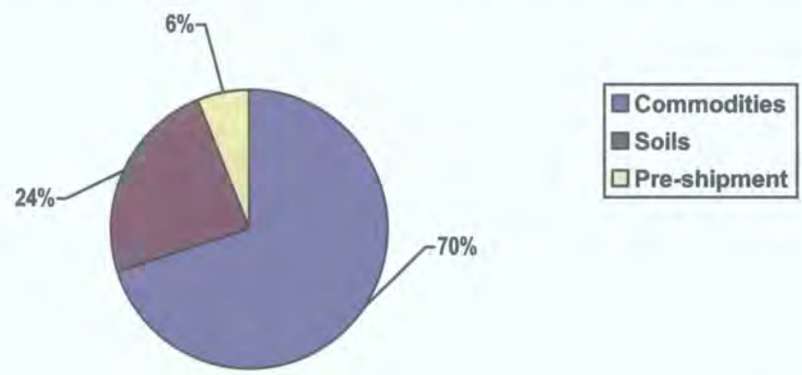

Table 9.1. Reported annual quantity of QPS methyl bromide by category of use.

QPS Use	Quantity (metric tonnes)	% of total
Soil (preplant)	1527	29
Grain and cereals for consumption	1262	24
Wood, including sawn timber	868	16
Fresh fruit and vegetables	722	14
Wooden packaging materials	335	6.4
Whole logs	209	4.0
Dried foodstuffs	160	3.0
Cotton and fibre	91	1.7
Equipment	36	0.68
Cut flowers and branches	32	0.61
Personal effects	19	0.37
Bulbs, corms, tubers and rhizomes	4	0.075
Nursery stock	4	0.072
Hay, straw, fodder	3	0.050
Seeds for planting	1	0.012
Total	5273	

Survey period – 2002-2004. Survey covered about 50% of total QPS consumption, with 32 Parties reporting details of their QPS uses.

Almost all QPS treatments are related to protection of plants and come within the scope of the IPPC. None of the Parties responding to the surveys reported QPS use for control of any organisms other than plant-related pests and diseases. MBTOC identified the following treatments as outside the IPPC scope: treatment of shipments of used car tyres against mosquitoes; treatment of personal effects against lice, bedbugs and cockroaches; fumigation of hides and skins; fumigation of beehives against insect and mite pests; fumigation of ships, aircraft and other transport against rodents and snakes. These non-IPPC uses of QPS methyl bromide are estimated by MBTOC to consume not more than 1% of the total 2005 QPS production of about 13,000 tonnes.

Most QPS uses, by volume and treated materials related to goods in trade, usually export trade across international boundaries. There was a small use (by volume) to meet internal quarantine restrictions. In the survey under Decision XVI/10(4), two Parties, USA and Chile, at that time, reported QPS use of methyl bromide on soils used, *in situ*, for growing of plants, specifically for production of certified, high health status propagation material. This use is distinguished from soil as a commodity, where soils may be moved from one area to another, or soil as a contaminant of goods in trade.

MB for QPS is typically used in the range 36 – 128 g m^{-3} with *ct*-products of 80-400 g h m^{-3} where insects, mites and vertebrate pests are targets of the treatment, but higher rates are required for control of nematodes, snails and fungi; and for devitalising seeds. Some treatments of the latter treatments may have dosages exceeding 5000 g h m^{-3}. For instance, timber, potentially infested by the oak wilt fungus (*Ceratocystis fagacearum*), is usually fumigated with MB as an approved quarantine treatment prior to export to Europe under gas-proof sheets or in chambers at the high rate of 240 g m^{-3} (Liese and Ruetze, 1985).

9.4 Alternatives to Methyl Bromide for QPS Treatments

This section describes approved alternatives for the 4 major categories of current QPS use for methyl bromide:

- Timber and wood packaging materials (quarantine)
- Export cereal grains (pre-shipment and quarantine)
- Perishables (fresh fruit and vegetables) (quarantine)
- Soils for production of certified propagation material (quarantine).

These categories cover 95% by quantity used for QPS in 2002-2004 as reported by Parties by survey (Table 9.2.). The remaining 5% is used for a diverse range of other QPS applications under 9 categories identified by Parties under Decisions XVI/10(4) and XI/13(4). The diverse small-volume uses are not covered in detail below, but several of those uses, and alternatives, were discussed in MBTOC (2002). Many of the alternatives that are feasible to the major categories of use will also be appropriate to particular small-volume uses.

In responses to surveys under Decisions XVI/10(4) and XI/13(4), some Parties responding identified areas of QPS use that had alternatives (see Table 9.2). These were not technically and economically feasible in all situations, but were available in at least some circumstances.

Table 9.2. Alternative QPS treatments identified by the Parties under

QPS category of use	Principal alternative identified
Timber and wood packaging materials	Heat treatment
Export cereal grains	Phosphine fumigation
Perishables	Systems approach
Soils for production of certified propagation material	Fumigation with 1,3-D/chloropicrin mixture

Decisions XVI/10(4) and XI/13(4), modified from TEAP (2006a).

On a global basis, there are technically effective and approved treatments available for more than half current QPS treatments by volume of methyl bromide consumed, but many individual QPS uses do not have proven, acceptable alternatives at this time. Frequently, actual application of technically effective and approved alternative treatments is constrained by local circumstances.

9.4.1. Requirements for alternatives to methyl bromide for QPS

Requirements for MB alternatives to methyl bromide for QPS are often compared against the properties of MB as a fumigant. These include such desirable features as:

- A long history of recognition as a suitable treatment by quarantine authorities;
- High levels of kill easily obtained;
- Similar toxicity to all developmental stages of pests including eggs;
- Capable of giving a rapid disinfestation treatment;
- Relatively non-corrosive and applied easily to shipping fumigation facilities, containers or to bagged, palletted or bulk commodities 'under sheets';
- Broad registration for use;
- Good ability to penetrate to the into the commodity where pests might be located; and
- In many cases, airs rapidly from the commodity after exposure.

Aside from its ozone-depleting properties, methyl bromide also has a number of undesirable features including:

- A high level of toxicity to humans;
- Odourless, making it difficult to detect;
- Adverse effects on some commodities, particularly phytotoxicity of plants and horticultural products, loss of viability of seeds, quality changes and taint;
- May be retained for long periods by some commodities, with slow gas release;
- Chemical residues retained in the product.

Some of these adverse effects are sufficiently severe to have driven for the last few decades a continuing search for alternatives for some treatment of commodities, independently of its ozone-depleting properties and in fact, long before these properties were known. For example, the vase life of some cut flower species is significantly reduced, with consequent economic loss, by methyl bromide treatments at a level required to kill some quarantine pests.

In some cases, the threat posed by quarantine pests to importing countries for some commodities is so severe, the importing country may require that a prescribed treatment be applied to the commodity in the exporting country as a condition of entry into the importing country. Such quarantine treatments are designed, tested and negotiated bilaterally on an individual product and treatment basis before approval of entry of the commodity in the importing country. The treatments must both kill pests and maintain product quality, both difficult hurdles. The pest-kill requirement hurdle is set particularly high; generally it must be demonstrated that the treatment kills over 99.9968% of the quarantine pests that might be present or that the risk from any survivors is acceptable. Constraints on development of alternatives to established QPS MB uses are further discussed in Section 9.5.

9.4.2. Alternatives for timber and wooden packaging materials.

Timber and wooden materials (e.g. sawn timber, wooden packaging materials, logs) are notorious for their ability to carry a variety of pests of quarantine significance. Some of these pests potentially attack forests and amenity trees, while others can attack timber in furniture, buildings and other structures. Targets of MB fumigation may be insects that infest green and dry wood (Table 9.3), nematodes (particularly pinewood nematode, *Bursaphelenchus xylophilus*) and some fungal pests of wood, notably oak wilt fungus (*Ceratocystis fagacearum*). Fumigations are often conducted to eliminate hitchhiker pests of quarantine significance, including pest insects and snails.

Table 9.3. Families of insects containing species of quarantine importance that are targets of methyl bromide fumigation. Modified from ISPM15 (IPPC 2006)

Pest family	Common name
Anobiidae	Furniture beetles
Bostrichidae	False powder-post beetles
Buprestidae	Jewel beetles
Cerambycidae	Longicorn beetles
Curculionidae	Weevils
Isoptera	Termites
Lyctidae	Powder-post beetles
Oedemeridae	False blister beetles
Scolytidae	Bark beetles
Siricidae	Wood wasps

Some wood inhabiting fungi that need to be controlled, usually for quarantine purposes, are: *Antroida carbonica, Ceratocystis fagacearum, Gloeophyllum sepiarium, Lentinus lepideus, Lenzites sepiaria, L. trabea, Postia placenta* and *Serpula lacrimans*.

9.4.2.1. Alternatives for wooden packaging materials

The ISPM15 'Guidelines for Regulating Wood Packaging Material in International Trade' (IPPC 2006) have been widely adopted globally. Timing of implementation has varied, but most major trading countries had in place a requirement for treatment of wooden packaging material to ISPM15 by the end of 2006. For implementation dates by country see AQIS (2007). Some countries have adopted this standard in place of their individual treatment specifications used previously, such as described in MBTOC (2002).

A revised methyl bromide dosage schedule was adopted for ISPM15 in 2006. Compared with the 2002 version, this did not change the initial methyl bromide concentrations needed, but raised both the exposure period and the retention of gas needed at the end of the fumigation, from 30% at 16 hours to 50% at 24 hours. While this retention is achievable with best practice, anecdotal evidence suggests that some fumigators are increasing the initial charge of methyl bromide to compensate for leakage in order to meet the final concentration requirement, thus avoiding the need to retreat or top up concentrations during the fumigation. Such practices were not required in 2005, prior to implementation of the revised schedule.

The only alternative to methyl bromide treatment accepted under ISPM15 at this time is heat treatment, including kiln drying. A temperature of at least 56°C, core temperature, must be maintained for at least 30 mins (IPPC 2006).

There is substantial use of the heat treatment specification in many countries to meet ISPM15 in place of methyl bromide fumigation, though methyl bromide treatment remains widely used, with a high total consumption of methyl bromide (see Section 3.7).

A variety of facilities are in use to achieve the specified heat dosage for ISPM15. They include timber kilns (many countries), hot water dipping (e.g. Bangladesh (Kabir, 2005)), modified freight containers or similar enclosures with either hot water heating (China) or electrical heating (Australia). CFIA (2007) describes procedures for measuring and achieving ISPM15 heat conditions with both green and dried wood.

Many fumigations with MB are currently conducted because of risk or presence of quarantine pests in timber or other packaging materials. The goods in the consignment may not be infestible or at risk of carrying quarantine or hitchhiker pests. Pallets made of uninfestible materials as an alternative to timber avoids the need for MB treatment. Pallets made of plastic or pressed wood composite (e.g. see http://www.presswood.org/) are available commercially, but not in widespread use in export trade. Their use is limited by price and availability, the need to return used pallets, and weight.

9.4.2.2. Alternatives for sawn timber and logs

Methyl bromide is most widely used fumigant for forest produce. It has limited penetration, particularly across the grain and into wet timber. Most arthropods associated with timber are quite susceptible to methyl bromide but much higher dosages are required to have mortality effect on fungi. Treatment specifications for logs and sawn timber have not been harmonised worldwide and schedules vary with country of import and target pest. Thus Korea may require 25 g m^{-3} for 24hrs at 12-15°C (Yu *et al.*, 1984), while Malaysia requires 128 g m^{-3} for a 24 hour exposure period at the higher temperature of 21°C.

Treatments of export sawn timber and logs may need to be rapid, such as at point of export or import, to avoid charges and congestion at ports associated with occupying restricted port area for the treatment. Where quarantine treatments can be applied outside port areas, such as prior to export or in-transit, slower systems can be used. Many pests of quarantine significance that attack green wood do not reinfest dry and debarked wood. Drying of sawn timber, such as by kiln drying, may provide appropriate protection in some circumstances without need for further treatment.

Specific approved QPS alternatives for logs and sawn timber are discussed below, followed by discussion of some processes under development. There is active research in progress to develop alternatives for logs and sawn timber.

9.4.2.3. Approved alternatives for logs and sawn timber - fumigants

Methyl iodide. Complete mortality of the pine wood nematode and the longhorn beetles, *Monochamus alternatus* and *Arhopalus rusticus,* were attained at 84 g m^{-3} at 10 °C, 60 g m^{-3} at 15 °C, 64 g m^{-3} at 20 °C, 48 g m^{-3} at 25 °C respectively using methyl iodide 50% and carbon dioxide 50% in commercial scale fumigation (Abe *et al.* 2005). This mixture is now registered in Japan for wood including wood packing treatment. However, Schmidt and Amburgey (1997) wrote that the limited amount of research that has been undertaken suggests it is no better than methyl bromide in controlling pathogens in wood and may in fact be inferior.

Methyl isothocyanate/ sulfuryl fluoride mixture. The mixed gas of MITC and Sulfuryl fluoride was registered in Japan for wood, including wood packing, infested with forest insect pests. It does have high sorption characteristics and a nasty odour. MITC used in mixture with CO_2 is effective against wood borers, bark beetles, and ambrosia beetles at 40-60 g m^{-3} for 24hrs at 15°C (Naito *et al.* 1999). It has been found to be particularly effective against pinewood nematode (Soma *et al.* 2001). In tarpaulin sheet fumigation of commercial scale, complete mortality of the pine wood nematode was attained at each of 27, 33, 42 g m^{-3} of MITC/SF at 10C, 27 g m^{-3} of MITC/SF at 15C and 15, 21 g m^{-3} of MITC/SF at 25C, respectively (Abe *et al.* 2005).

Phosphine. New Zealand has pioneered the use of phosphine for the in-transit fumigation of forest produce destined for China. It is now in routine use as a QPS measure replacing on-shore MB use. One of the major disadvantages of phosphine when compared to methyl bromide is the long exposure time (up to 10 days) required, but this is overcome by applying the phosphine in transit. Considerable efficacy data has been developed in support of this methyl bromide alternative (Frontline Biosecurity, 2003; Crop & Food, 2003; Hosking and Goss, 2005; Zhang, 2003; Zhang and van Epenhuijsen, 2005a).

The current dosage specification is for at least 200 ppm phosphine (v/v, 0.28 g m^{-3}) to be maintained for 10 days. Due to sorption of the gas by the logs (Zhang, 2004) top-up of phosphine is required 5 days into the voyage to prevent the concentration falling below 200ppm. In transit tests have shown an even gas distribution throughout the loaded ship holds. High concentrations of CO_2 also occur within the ship holds during the fumigation period that may assist action of the fumigant. The current dosage specification is based on Australian experience with stored grain pests (insects) and is likely to be significantly higher than required where no insect resistance is involved (Frontline Biosecurity, 2005).

Phosphine is typically produced in the reaction of aluminium or magnesium phosphide with water. There are some formulations of phosphine available in cylinders as technical grade, pure compressed gas or diluted with CO_2. The gas is highly toxic to insects (see section 6.3.7 in Chapter 6) and has remarkable penetration ability (Spiers, 2003). Because of the relationship between respiration and efficacy, the egg and pupal stages of insects are generally more tolerant than larval and adult stages. Phosphine is generally ineffective against fungi infesting timber (Zhang, pers. com.).

Phosphine has long been used for the treatment of grain insects but repeated treatment of grain silos and poorly conducted fumigations has led to high levels of phosphine resistance in stored grain pests in some countries (see Section 6.3.7.4 I Chapter 6). Such resistance is not an issue for one way commodities such as forest produce, so extrapolation of data on dosage requirements from grain insects may be misleading for forest produce.

The "Florani" experiment showed that phosphine could be successfully used as an in-transit fumigant for eliminating the pine wilt nematode from pine chips (Leesch *et al.*, 1989; Dwinell, 2001).

There is scope for application of directly generated phosphine to replace 24-hour methyl bromide QPS fumigations of stacks of sawn timber. Preliminary trials (Hosking, 2005) suggest it may be useful against hitchhiker and other pests on the surface of the timber. With generation of the gas from pellets, such as used for in-transit shiphold fumigations, maximum gas concentration is not reached for 1 or 2 days. Phosphine gas generators are now available that can deliver gas directly into containers or under sheets, with the added advantage that phosphine disperses much more rapidly throughout the treated material than MB.

Fumigation of logs using *phosphine* was effective in controlling bark beetles, wood-wasps, longhorn beetles and platypodids at a dosage of 1.2 g m^{-3} for 72h at 15 ºC or more. This schedule is registered only in the United States. The length of time required to complete treatments restricts its commercial acceptability. New developments include phosphine to treat bamboo in transit to avoid MB quarantine treatments in Japan (Reichmuth, 2002).

Sulfuryl fluoride. Several quarantine authorities (e.g. NZ-MAF, AQIS and USDA-APHIS) at one time accepted treatment of timber by sulfuryl fluoride at 64 g m^{-3} for 16 hours at 21°C for quarantine purposes as an alternative to methyl bromide against insect pests.

Sulfuryl fluoride is one of the most promising in-kind replacements for methyl bromide for logs and sawn timber, having similar properties and exposure requirements, with significantly better penetration of wood (Scheffrahn and Thomas, 1993).

Sulfuryl fluoride (SO_2F_2) has long been used for termite control in the USA where it is marketed under the trade name Vikane. The fumigant has been shown to be effective against adult bark and timber insects. However, its efficacy against eggs drops sharply below 21°C requiring increased application rates. It does not appear effective against the pinewood nematode (Soma *et al.*, 2001) either at 40 g m^{-3} for 24hrs or 20 g m^{-3} for 48hrs at 15°C. Its performance against the wide range of fungi of quarantine significance is unclear, though sulfuryl fluoride has successfully killed oak wilt fungus at rates similar to methyl bromide (Carpenter *et al.* 2000).

Recent research directly relevant to use of the fumigant for forest produce includes a trial by Chinese quarantine authorities comparing sulfuryl fluoride with methyl bromide for ship fumigation (Liangzhong *et al.* 2001). Zhang and van Epenhuijsen (2005b) evaluated the fumigant against *Arhopalus ferus* adults and eggs, *Hylastes ater* adults and larvae, and eight fungi associated with trees and timber in New Zealand. Adult insects and larvae were all killed at 15 °C at the lowest concentrations tested, 15 g m^{-3}. However, 60 g m^{-3} was required for 100% mortality of *Arhopalus* eggs although 15 g m^{-3} did achieve 98% mortality. Perhaps the most encouraging finding was that at 30 g m^{-3} all eight fungi failed to grow after re-isolation.

9.4.2.4. Approved alternatives for logs and sawn timber – other methods

Debarking. Bark removal has long been a key strategy in reducing contamination of logs and reducing the risk that logs and sawn timber carry insects and fungi of quarantine concern. While debarking removes surface contamination and also bark and cambium, areas particularly prone to pest attack, it does not affect insects and fungi already in the wood. Many countries require debarking of all imported logs. Because of the high cost, and the requirement by customers in major Asian markets that bark remain on logs, its application as a quarantine treatment is limited.

The presence of bark on wood is essential for egg laying with some insects, notably certain longhorn beetles and wood wasps. Bark removal can destroy the habitat where bark beetles breed and their larvae feed. Once removed the wood is unsuitable for bark beetle breeding. Debarking, together with conversion to sawn timber in country of origin, appears to have potential to reduce the need for MB where bark-borne pests are the object of the treatment, including quarantine treatments. Wood that is green or freshly cut is easier to debark than dry or seasoned wood.

Heat treatment. Heat treatment has been accepted as a quarantine treatment for logs and timber to be shipped to the USA and many other countries for many years (e.g. USDA 1996). The general specification has been to reach a core temperature of 71°C for 60 minutes. Kiln drying of timber to a moisture content of less than 20% using temperatures over 70°C is often a commercial requirement but also has long been accepted as a quarantine treatment by most importing countries.

Heat treatment of unprocessed logs is an approved risk mitigation measure for importation into the USA (Morrell 1995) but because of the energy required and the bulk of the commodity, it is rarely an economic alternative to fumigation. Steam heat is a more effective quarantine measure than dry heat (USDA 1994, Dwinell 2001).

Hot water and steam treatment has long been used for risk mitigation for hardwood veneer logs imported into New Zealand. Such logs are invariably attacked by pinhole borers (Scolytidae and Platypodidae before shipment. Moist heat treatment is an integral part of log conditioning prior to peeling but has the additional benefit of eliminating quarantine risk.

A considerable volume of literature addresses thermal mortality of insects and has been reviewed by Hosking (2002). Jamieson et al (2003) provides a good general summary of the literature on heat mortality of insects and fungi. A better summary of heat treatment applications for forestry produce is that of Dwinell (2001).

This literature suggests few if any insects and their close relatives can survive even short exposure (less than 24h) to temperatures above 50°C. Direct exposure trials of gypsy moth eggs (Hosking, 2001) found 100% mortality for the lowest temperature (55°C) and shortest exposure time (5minutes) tested. Fungi have been shown to be more variable in temperature mortality threshold and the required exposure time, some requiring exposures up to 6 hours at 57°C (Morrell 1995) while others are killed at 60°C for 10 minutes (Ridley and Crabtree, 2001). Heat treatment by steam has been shown to eradicate all tested fungi when 66°C is held at the centre of wood for 1.25 hour (Miric and Willeitner, 1990; Newbill and Morrell, 1991), but Dwinell (2002) reported that neither the APHIS-approved MB treatment for timber nor heat treatment up to 81°C killed all saprophytic fungal pathogens in imported hardwood pallets. Many fungal pathogens are also very tolerant of methyl bromide (e.g. Rhatigan *et al.*, 1998).

Irradiation. Gamma irradiation has been suggested as a treatment for wood and wood products (Reichmuth 2002). However, its practical application must overcome a number of hurdles, not the least being the construction of large irradiators to handle logs and bulk wood products. The technology is also limited by poor penetration into freshly cut logs. , (Note: degradation of fibre board and paper depends on the dose used – on the fibre board or paper, and depending on the dose. Who has done research first irradiating logs and then making fibre board or paper and seeing what the strength was? What is the dose approved for logs into Australia?, variation in effect on different insect groups, and very high dosages required to eliminate fungi (Morrell, 1995).

There is a paucity of information on the use of ionising irradiation for the control of pests associated logs and sawn wood (Dwinell, 2001c). Irradiation to eradicate the pine wood nematode (*Bursaphelenchus xylophilus*) in pine chips has been investigated. Pine wood nematode-infested wood chips were exposed (for periods from 1 h to 2 weeks) to gamma ray doses up to 12 kGy (the long exposure time resulting from the use of a small research irradiator). Lethal doses lay in the range above 6 to 9 kGy, which was considered too high to make irradiation an economically attractive means of decontaminating commercial wood chips. Forintek Canada Corp. researchers reported that a similar dosage of 7 kGy was required to kill pine wood nematodes in aqueous solution, which supports the contention that a higher dosage is necessary to eliminate the pine wood nematode in vivo than in vitro. Recent studies on irradiation effects on other nematodes confirmed the relative high dosages required to cause mortality (i.e. a dose of 7.5 kGy was required to kill all J2 larvae of *Meloidogyne javanica*). The use of irradiation for decontaminating logs and sawn timber in export trade does not appear to be economically feasible at this time, but be useful in managing pests on high-value forest products that cannot normally be heat-treated or fumigated.

Water soaking or immersion provides a process for control of pests on imported logs. Immersion of some logs destined for plywood manufacture is a useful process as it also improves the quality of the products. The storage of logs in water or under water spray has long been accepted as an effective treatment for terrestrial insects and fungi with salt water immersion for 30 days being an approved treatment for logs into Japan. The upper surface of the logs above the water level is sprayed with an insecticide mixture such as dichlorvos as part of the pest management strategy (Reichmuth, 2002).

The potential for use of water soaking for quarantine treatment of imported logs is limited by the large area of water required and the undesirable side effects of ponding large volumes of logs, making its application on a large scale unlikely.

9.4.2.5. Alternatives for logs and sawn timber –under research

Several measures are under research and development as a quarantine measure in some countries, but have already been approved in others. Where this is so, they are considered in the preceding section. Those discussed below are not yet approved at all.

Cyanogen. Cyanogen, sometimes referred to as ethanedinitrile, has been investigated as a replacement for methyl bromide. Registration is currently being sought. Ren *et al.* (2006) found direct exposure of Asian longhorned beetle larvae at 21 ^{o}C required a *ct*-product of 56.6 g h m^{-3} over 6 hours to give 99.5% mortality, equivalent to an exposure of unprotected larvae to 9.4 g m^{-3} over 6 hours. At a low temperature of 4.4 ^{o}C, an exposure to 94 g m^{-3} over 3 hours was required for 99.5% mortality. Trials reported by Dowsett *et al.* (2004) showed cyanogen to be more effective than methyl bromide on a *ct*-product basis against all life stages of two species of timber beetles and one species of termite. Full scale trials using cyanogen on stacks of sawn timber have been carried out in Malaysia under MLF-funded demonstration trials for methyl bromide alternatives (UNDP - MAL/99/G68/A/2G/99). Cyanogen penetrates wood quite rapidly both across and along the grain, in contrast to methyl bromide that travels along the grain but poorly across the grain (Ren *et al.* 1997). Unlike methyl bromide, it penetrates high moisture content timber well. It appears to have considerable potential as a methyl bromide alternative for logs and sawn timber (Wright *et al.*, 2002).

Microwave treatment. This is essentially a heat treatment using electromagnetic energy in the 10 – 30,000 MHz range. The relationship between field intensity, exposure time and mortality of individual insect species is not well understood, but has been shown to include considerable variability (e.g. Ria *et al.*1972).

Forest products pose special problems in the use of microwaves for disinfestation both in the wide variation in moisture content and the variety of target insects. However, recent research by Fleming *et al.* (2003) has shown microwave irradiation to be highly effective against Asian longhorned beetle in both green and dry wood packaging up to 100 x 100 x 100 mm. Microwave irradiation has also been shown to be effective against termites (Lewis, 1997). It seems unlikely however that microwave irradiation has application in the treatment of logs in the quantities exported, and even scaling up the technology to deal with quarantine risk wood packaging poses some serious challenges.

9.4.3. Alternatives for export cereal grain

Export cereal grains such as rice and wheat are prone to infestation by a number of cosmopolitan grain pests (see Chapter 6) that cause damage when in storage and are unacceptable to modern market standards. These pests are the target of the Pre-shipment treatments required either by official regulations of some exporting countries or by official requirements of importing countries. Export cereal grains from some locations may also be subject to Quarantine treatments against specific insect pests, notably khapra beetle (*Trogoderma granarium*) or contaminants such as specific snails (e.g.. *Cochlicella* spp.) or seed-borne diseases such as karnal bunt (*Tilletia indica*).

MB fumigation continues to be used for pre-shipment treatment of cereal grains where either logistical constraints or importing country specifications preclude the use of phosphine, the principal accepted fumigant alternative. Methyl bromide fumigation is often the treatment of choice or sole approved and available treatment for the situations where a quarantine treatment is required, though it is recognised that it may not be ideal for this purpose. In the older regulations that have resulted in the requirement to use MB for pre-shipment for grains, dosages required may be very high and exposures prolonged compared with typical fumigations of grain against common pests.

9.4.3.1. Alternatives for pre-shipment

Alternatives to MB for pre-shipment of cereal grains, including rice, vary with situation. In many export situations, a high throughput is required, as there is limited space at the port for treatments and demurrage costs on waiting vessels is high. Typical turnaround times for methyl bromide for a shipment can be 24-48 hours, a time that has to be accommodated in the organisation of the export consignment under pre-shipment treatment.

More rapid treatments would be welcomed in many export situations, as these would minimise delays handling the export consignment with associated costs and grain handling limitations. At this time there are no agreed and approved pre-shipment treatments that will meet the treatment speeds of large consignments that can be achieved with MB fumigation, though there are several in advanced stage of development and the regulatory approval process. The fumigants sulphuryl fluoride, cyanogen and carbonyl sulphide, and synergised ethyl formate all have potential to give similar treatment times and throughputs to methyl bromide. Details about the effectiveness of these fumigants are given in Chapter 6.

Alternatives to MB for pre-shipment treatment of grains and similar commodities are the same as described in Chapter 6 as alternatives to methyl bromide for stored grain protection and disinfestation. Their use may be restricted by economic and logistic issues, notably the need for rapid treatment of large volumes of product under conditions at ports where storage and handling capacities may be very limited. These include heat treatment and also dichlorvos treatment where regulations permit. Alternative fumigants are under development and registration, which may provide adequate speed of treatment.

Some importing countries may specify fumigation at point of export as a pre-shipment treatment, with indications as to what treatments are acceptable. Typically where methyl bromide is specified as one treatment, phosphine fumigation may be specified as an alternative. However, several countries specify use of methyl bromide as the only acceptable QPS treatment of imported grain from specified exporters, even though well-conducted phosphine fumigation may be expected to deliver the same technical outcome as methyl bromide treatment.

In-transit treatment of bulk or bagged grain in ships with phosphine may potentially replace some current pre-shipment uses of MB. It is already in use for some shipments. Typical examples where this might be used include shipments of rice and cassava chips. Phosphine treatments may be conducted at the dockside, in lighters or barges prior to loading a ship, or in the ship after loading and before sailing.

The International Maritime Organisation (IMO 1996) specifically recommends that cargoes should not be fumigated in ships with MB prior to sailing due to the risks resulting from the difficulty in ventilating the cargo effectively. Despite the recommendations of the IMO, the practice of MB fumigation in ships continues. As an alternative to MB and for safety and efficacy reasons, *in-transit treatment with phosphine* is restricted to specially-designed bulk carriers, tanker-type vessels and other ships where the holds are gastight or can be made so (Semple and Kirenga, 1997). In addition, equipment must be installed to circulate the phosphine through the cargo mass (Watson *et al.,* 1999). The circulation equipment ensures that the gas penetrates throughout the load and can be aired from the load prior to unloading. In-transit treatment of quarantine pests with phosphine requires treatment acceptance by regulatory authorities, in addition to requiring appropriate vessels and equipment (Watson *et al.*, 1999; IMO, 1996; Semple and Kirenga, 1997).

9.4.3.2. Alternatives for Quarantine treatments

Some winter wheat fields in Texas were infected with Karnal bunt disease, *Tilletia indica*, in 2001. When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. MB fumigation of emptied contaminated storage bins requires a high dosage (240 g m^{-3}) for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is an effective alternative to MB providing surface temperatures reach 77°C (Dowdy, 2002). Microwave technology has recently been reported as effective in controlling *Tilletia indica* teliospores (karnal bunt of wheat) in 10 seconds compared to 96 hours using MB (Ingemanson, 1997).

Many countries have strict quarantine regulations on grain and other durables originating from countries where khapra beetle occurs. Typically, methyl bromide treatment is specified against this notorious pest, using double normal dosages for stored product disinfestation often with extended exposure period. Cereal products from khapra beetle areas for import into Australia require 80g m^{-3} for 48 hours at 21°C with an end point concentration at 48 hours of 20g m^{-3}.

Despite its tolerance to quite high temperatures, around 41°C, it is quite susceptible to higher temperatures, more so than some common storage pests such as *Rhyzoperta dominica*. There is a surprising quantity of data available to substantiate this. Much of it is antique, but of good quality. For instance, Husain (1923) studied heat disinfestation of wheat from khapra larvae.

Pupae of *T. granarium* are the most heat tolerant stage, requiring 16 hours at 50°C or 2 hours at 55°C for '100%' kill, while other stages are eliminated in less than 2 hours (Mookherjee *et al*., 1968). *R. dominica* requires in excess of 24 hours for complete kill at 50°C, 5 hours at 51°C and 10 minutes at 55°C. Battu *et al*. (1975) found LT_{95} for diapausing and non-diapausing larvae to be 7.4 and 3.0 hours respectively at 50°C. Lindgren *et al* (1955) noted a slight dependence of time to complete kill an ambient relative humidity with treatment at high humidities taking slightly longer. At 55°, 75% r.h., 95% mortality was obtained after 8 and 15 minutes with 4^{th} instar larvae and pupae respectively.

Heat treatment appears to be a potential quarantine treatment against *T. granarium*.

Some cereal products imported into Australia may be treated with cold treatment. A core temperature of -18°C must be maintained over 7 consecutive days.

T. granarium is usually quite susceptible to phosphine (e.g. Hole *et al*. 1976), but no quarantine schedules using this gas were located. Resistance has developed to phosphine in the Indian subcontinent.

9.4.4. Alternatives for perishables

The principal perishable commodities that use MB as QPS treatments are apples and pears, berry fruit, citrus, cucurbits, cut flowers and ornamentals, grapes, root crops, stone fruit, subtropical and tropical fruit, and some vegetables. Treatments are against a wide variety of insect and mite pests of quarantine significance, varying according to origin and country of destination. In many cases, approved treatments are limited to a particular situation, i.e. a particular commodity with a particular pest from a particular country or region and a particular quarantine concern of the importing country. Often the commodity has only one pest of quarantine concern. Typical major pests include various species of fruit fly (Tephritidae), codling moth (*Cydia pomonella)*, mealy bugs (Pseudococcidae) and mites such as the Chilean grape berry mite (*Brevipalpus chilensis*).

Typical quarantine dosages of methyl bromide for perishables are about 48 g m^{-3} for 2-4 hours. At this level of exposure to methyl bromide, many perishables show significant loss of marketability and quality. There is continuing research to develop alternatives to replace methyl bromide treatment both for protection of the ozone layer and for improved quality retention and market access.

There are a wide variety of measures for perishables, applied individually or in combination, which can be used to achieve pest reduction to quarantine requirements. Individual treatments and practices are described below.

MBTOC (2002) recorded more than 300 alternative quarantine treatments for perishable commodities approved by a National Plant Protection Organisation. Tables 9.4 and 9.5 list examples of approved use of these alternatives for quarantine treatment of perishables. The list of approved alternatives was compiled mainly from the United States Department of Agriculture - Animal and Plant Health Inspection Service Treatment Manual. However, although this number is approved, actual use of these treatments is not well documented. Despite this number and range of quarantine treatments, only a small proportion of commodities in commercial trade are treated in the export country using these alternatives.

Discussion of alternatives by type of fruit or vegetable treated may be found in MBTOC (2002).

Table 9.4. Examples of approved quarantine treatments for perishables (fresh fruit and vegetables) where treatment of the commodity is mandatory to allow entry in the importing country.

Procedure or treatment	Examples of approved quarantine applications
Cold treatments	Many approved cases – see Table 9.5 for examples.
Heat treatments	Babaco for export to the USA from two areas of Chile (vapour heat) Bell pepper to the USA (vapour heat) Clementine from Mexico (vapour heat) Citrus from Mexico and Hawaii to the USA (high temp forced air) Egg plant to the USA (vapour heat) Grapefruit from Mexico (heated air) Litchi from Hawaii (vapour heat) Longan, litchi and mango from Hawaii (hot water immersion) Mango from Taiwan to USA (vapour heat) Mangoes from Australia, China, Hawaii, Philippines, Taiwan and Thailand to Japan Mango from Mexico, Central and South America and the Caribbean to the USA (heated air or vapour heat) Mango to the USA (hot water dip) Mountain papaya from Chile to USA (heated air) Mountain papaya to USA (vapour heat) Papaya from Hawaii, Philippines, Taiwan and Japan (vapour heat) Papaya from Fiji, Tonga, Cook Islands and New Caledonia to New Zealand, Rambutan from Hawaii (high temp forced air or vapour heat) Narcissus bulbs to Japan Orange, grapefruit and tangerine from Mexico to USA (vapour heat) Mango from Ecuador and Peru to NZ Papaya to USA (vapour heat) Papaya from Belize and Hawaii to USA (heated air)

	Papaya from Hawaii, Philippines and Okinawa Island to Japan Pineapple to USA, other than smooth cayenne (vapour heat) Squash to USA (vapour heat) Tomato to USA (vapour heat) Yellow Pitaya from Colombia to US (vapour heat) Zucchini to USA
Certified pest-free zones or pest-free periods	Cucurbits to USA Cucumbers from Australia to NZ Grapes, kiwifruit and other produce from southern Chile to Japan Immature banana to Japan Melons from a region of China to Japan Peach, nectarine from USA to Brazil, Ecuador, Colombia and New Zealand Squash, tomatoes, capsicum, eggplant from Tasmania (Australia) to Japan Strawberry, cucumber, bell pepper, tomato, eggplant, grapes, squash and melon from the Netherlands to Japan Ya pears from China to NZ
Systems Approach	Apples from USA to Brazil Apples from Australia and New Zealand to Taiwan Avocado from Mexico to 19 north eastern States in the USA Citrus from Florida to Japan Cherry from NZ to Japan
Pre-shipment inspection and certification	Apples from Chile and New Zealand to USA Certain cut flowers from Netherlands and Colombia to Japan Garlic from Italy and Spain to USA Green vegetables to many countries Nectarines and apricots from New Zealand to Australia
Inspection on arrival	Small batches of seeds for propagation to USA
Physical removal of pests	Hand removal of certain pests from cut flowers to USA Propagative plant materials (unable to tolerate MB fumigation) to USA Root crops are accepted by many countries if all soil removed
Controlled atmospheres	Apples from Canada to California, with cool storage
Pesticides, fumigants and aerosols, residual insecticides, residual insecticides	Asparagus and other vegetables to Japan infested with thrips and aphids (HCN) Bulbs to Japan Certain ornamental plants to USA Cut flowers from Hawaii and New Zealand to Japan Cut flowers from Hawaii to mainland USA Cut flowers from Thailand to Japan Propagative plant material to USA Tomatoes from Australia to NZ
Irradiation	USDA-APHIS regulations now allow use of irradiation for any imported fruit or vegetable against all class *Insecta* except pupae or adult Lepidoptera. Specific treatment levels are established for 11 fruit flies and one seed weevil, and a generic treatment level has been established for any fruit and vegetable commodity infested with or suspected to be infested with class Insecta (except as noted above). Plums from South Africa to France

Combination treatments	Hand removal + pesticide for certain ornamental plants, Christmas trees and propagative plant materials to USA Heat treatment + removal of pulp from seeds for propagation to USA Ornamentals from Hawaii to USA (hand removal + high pressure water + malathion / carbaryl dip if necessary) Soapy water and wax coating for cherimoya, limes and passion fruit from Chile to USA Vapour heat and cold treatment for litchi from China and Taiwan to Japan Warm soapy water + brushing for durian and other large fruit to USA Tomatoes from Australia to New Zealand Apricots based on pest free zone + cold storage for export to the USA from two areas of Chile

Source: Updated from MBTOC, 2002

Table 9.5. Examples of approved quarantine treatments for fresh fruit using cold conditions.

Perishable commodity	Examples of cold treatments approved for quarantine
Apple	• From Mexico, Chile, South Africa, Israel, Argentina, Brazil, Italy, France, Spain, Portugal, Jordan, Lebanon, Australia, Hungary, Uruguay, Ecuador, Guyana and Zimbabwe to USA
Apricot	• From Mexico, Israel, Morocco, Zimbabwe, Haiti and Argentina to USA
Avocado	• From Hawaii (cv Sharwill) to mainland USA • From Western Australia to eastern Australian states
Carambola	• From Hawaii, Belize and Taiwan to USA • From Florida to California
Cherry	• From Mexico, Chile and Argentina to USA
Citrus	• From Florida (USA), Australia, Israel, South Africa, Spain, Swaziland and Taiwan to Japan • From South Africa (Western Cape) to USA • Interstate USA
Clemantines	• From Israel, Spain, Morocco, Costa Rica, Colombia, Guatemala, Honduras, Ecuador, El Salvador, Nicaragua, Panama, Venezuela, Suriname, Trinidad and Tobago, Algeria, Tunisia, Greece, Cyprus and Italy to USA • Interstate USA
Durian	• To USA
Ethrog	• From Israel, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Morocco, Spain, Italy, France, Greece, Portugal, Tunisia, Syria, Turkey, Albania, Algeria, Belize, Bosnia and Herzegovina, Macedonia, Croatia, Libya, Corsica and Cyprus to USA
Grape	• From Taiwan and Chile to Japan • From South Africa, Brazil, Colombia, Dominican Republic, Ecuador, Peru, Uruguay, Venezuela and India to USA
Grapefruit	• From Israel, Mexico, Costa Rica, Guatemala, Honduras, El Salvador, Nicaragua, Panama, Colombia, Bolivia, Venezuela, Italy, Spain, Tunisia, Australia, Suriname, Trinidad and Tobago, Belize, Bermuda, Cyprus, Algeria and Morocco to USA • Interstate USA
Kiwifruit	• From Chile, Italy, France, Greece, Zimbabwe and Australia to USA
Litchi	• From China, Israel and Taiwan to USA
Loquat	• From Chile, Israel and Spain to USA
Nectarine	• From Israel, Argentina, Uruguay, Zimbabwe and South Africa to USA

Perishable commodity	Examples of cold treatments approved for quarantine
Orange	• From Israel, Mexico, Spain, Morocco, Costa Rica, Colombia, Bolivia, Honduras, El Salvador, Nicaragua, Panama, Guatemala, Venezuela, Guyana, Belize, Trinidad and Tobago, Suriname, Bermuda, Italy, Greece, Turkey, Egypt, Algeria, Tunisia and Australia to USA • Interstate USA
Papaya (mountain)	• From Chile to USA
Peach	• From Mexico, Israel, Morocco, South Africa, Tunisia, Zimbabwe, Uruguay and Argentina to USA
Pear	• From Israel, Chile, South Africa, Morocco, Italy, France, Spain, Portugal, Egypt, Tunisia, Algeria, Uruguay, Argentina, Zimbabwe and Australia to USA
Persimmon	• From Israel, Italy and Jordan to USA
Plum	• From Mexico, Israel, Morocco, Colombia, Argentina, Uruguay, Guatemala, Algeria, Tunisia, Zimbabwe and South Africa to USA
Plumcot	• From Chile to USA
Pomegranate	• From Israel, Colombia, Argentina, Haiti and Greece to USA
Pommelo	• From Israel to USA
Quince	• From Chile and Argentina to USA
Tangerine	• From Mexico, Australia and Belize to USA • Interstate USA
Ya pear	• From China to USA

Sources: updated from MBTOC (2002)

9.4.4.1. Cultural practices leading to pest reduction

The 'Systems Approach' as applied to perishable commodities is the implementation of multiple safeguard actions in the country of export that result in a commodity meeting the phytosanitary standards of the importing country (Shannon 1994). These actions have a scientifically derived basis and can be quantified at key points in the production-to-export system (hence the term 'Systems Approach'). The Systems Approach to achieving quarantine security is described in detail by Jang and Moffitt (1994).

The Systems Approach includes the following steps: (1) consistent and effective management for reducing pest populations in the field and monitoring this management; (2) prevention of contamination after harvest; (3) culling in the pack house; (4) inspection and certification of the critical parts of the system based on effective trace-back procedures; and (5) shipping using methods that prevent re-infestation. The Systems Approach is highly dependent on knowledge of the pest-host biology and phenology. Using pest risk analyses, the probability of accidentally exporting the pest is often shown to be minimal and in some cases exceeds the level of quarantine security achieved by fumigation alone (Moffitt, 1990). Provided there is no pest breeding in storage, the Systems Approach can achieve or exceed the level of quarantine security acceptable to an importing country and in some situations, without any further actions needed (Vail *et al.*, 1993). Whiting (1995) proposed integrating pre- and post-harvest pest control practices to reduce the incidence and viability of quarantine pests on export commodities. A recent example of 'systems' approach is described in Johnson and Hansen (2006).

Reduction in insect populations can be achieved by cultural practices such as: planting crops that are no longer the preferred host of the insect (host plant resistance); harvesting when the commodity is not susceptible to attack (e.g. papaya which is harvested immature and ripened later); harvesting when the pest is not active (e.g. when the pest is in diapause or over-wintering stage of the pest); improved harvesting practices that remove 'hitchhiker pests' in the field or orchard; the addition of biological agents such as parasitoids and predators; releasing sterile insects; using pheromones; using microbial agents as pest pathogens; or as practiced in some Asian countries by wrapping crops such as pears, apples and peaches on the tree with pesticide-impregnated paper. However, in some cases the presence of biological and microbial agents on the commodity after harvest may itself cause quarantine concern, which is a limitation on the widespread use of this form of pest control.

Commodity resistance to pest attack has allowed many commodities to enter trade without the need for a quarantine treatment. Sometimes this resistance is exhibited only at a particular physiological stage, such as maturity. On other occasions an apparent host may be found to be uninfestible by the particular pest. Drawing on mainly tropical commodities as examples, commodity resistance based on known susceptibility to pests, cultivar variability, stage of maturity and growing periods has been summarised by Armstrong (1994a). For example, Hennessey *et al.* (1992) found no Caribbean fruit fly (CFF) infestations in more than 100,000 Tahiti limes collected and examined from 184 groves in Florida over 60 harvest dates, effectively presenting a case for no disinfestation treatment required for this pest/commodity. Grapefruit also increase their oil content in the skin, which results in resistance to CFF attack. In Argentina it was found that methyl bromide fumigation of strawberries and tomatoes against fruit flies, *Anastrepha fraterculus* and *Ceratus capitata,* could be discontinued because they were not significant hosts (see Case Study 23 in Chapter 10).

9.4.4.2. Pest-free zones and periods

A pest-free zone or area is the establishment of a certified area where a regulated quarantine pest does not exist, even though it may be established in another area within the same country (Shannon 1994). ISPM 26 (IPPC 2006b) describes requirements for the establishment and maintenance of pest-free areas for tephritid fruit flies. Based on survey technology and data that confirm the area is free of the organism of concern, the exporting country establishes formal, specific regulatory measures to protect the area and an ongoing surveillance system that ensures early detection of any infestations in the area. These systems are dependent on scientific information, public awareness, judgements about organism's behaviour and survey technologies and methods.

Pest-free zones have been established by many countries and consist of geographic areas where commodities may be produced and exported without methyl bromide fumigation or other treatment because of the absence of pests of quarantine importance. MBTOC (2002) gave the following examples:

- melons from the Hsingchang Uighur Autonomous Region in China based on this area being a melon fly free zone (Anon 1988a);
- capsicum, egg plant and tomatoes produced in Tasmania (Australia) as free from Tobacco Blue Mold *Peronospora tabacina* (Anon 1996a), Mediterranean

fruit fly (Mediterranean fruit fly, *C. capitata*) and Queensland fruit fly (*Bactrocera tryoni*) (Anon, 1989a);
- strawberry, cucumber, pepper, tomato, egg plant, grapes, squash and melon from the Netherlands as free of Mediterranean fruit fly (Anon, 1993a); and
- grapes, kiwifruit and other produce from southern Chile as free from Mediterranean fruit fly (Anon, 1996b).

9.4.4.3. Inspection and certification

Some countries inspect a sample of the produce prior to export (termed 'pre-shipment inspection') and certify each consignment based on levels of acceptability for pests of quarantine importance. For example, Japanese quarantine officials inspect cut flowers in the Netherlands and Colombia. This reduces, but does not preclude the need for inspection and disinfestation with methyl bromide on arrival in Japan. Some commodities are accepted only after inspection of the packed commodity and endorsement of the procedures used by the importing country to kill any live pests (e.g. Japan, New Zealand) or that live pests are within permissible limits (e.g. New Zealand) (Baker *et al.*, 1990).

Post-entry inspection is typically used in USA to determine the need for treatment.

9.4.4.4. Non-chemical postharvest treatments

Non-chemical alternative treatments to MB can be environmentally sound and leave commodities free of chemical residues. However, compared with MB fumigation, they can require more technical expertise in their development, implementation and operation in order to kill pests without damaging the commodity. They may control a more limited range of pests than methyl bromide.

Heat and cold dominate those non-chemical alternatives commercialised to date and continuing and extensive research is needed in most cases to commercialise other non-chemical treatments.

9.4.4.5. Cold

Cold storage can be used as a quarantine treatment to ship perishable commodities to areas where the fruit would otherwise not be permitted. It is most useful as a treatment when it is used as part of the normal handling, distribution and marketing procedures.

Cold treatment is generally applied to fruit potentially infested with tropical pests, which have relatively little tolerance to cold conditions compared to temperate pests. The temperature range acceptable for the use of cold treatment is typically very narrow, with pest control parameters often being quite close to fruit damage parameters.

Normally, the use of cold treatment is limited to fruits that do not suffer from cold injury under the conditions required to eliminate the target quarantine pests. However, USDA APHIS allows the use of a quick freeze treatment, as an option to destruction, for fruit found to be infested upon inspection at their ports. The quick freeze method will not damage coconut or durian fruit, but other fruit can only be marketed for further processing (USDA APHIS Treatment Manual, 2007).

The duration and temperature of the treatment (typically -1°C to +2°C) depend on pest susceptibility and fruit tolerance to cold conditions. Cold treatments are quite slow. Duration of cold exposure against tephritid fruit flies must exceed 16-21 days at 1-2°C. Since pest mortality can vary with previous temperature exposure, fruit handling and environmental conditions from field to import inspection must be tightly controlled, and results of temperature change should be tested to determine if they disrupt efficacy.

As an example, Jang *et al* (2001) tested the effects of a transient (warming) temperature spike on efficacy of an APHIS approved quarantine cold treatment against Mediterranean fruit fly, (Ceratitis capitata), on Hawaii grown 'Sharwil' avocados. Heat shock treatment is advised to improve fruit quality, but in the development of the cold quarantine method, the potential for this heat shock to disrupt the efficacy was questioned. Results of this study indicated that a transient (warm) temperature spike of ca. 4.2°C of the type experienced during an in-transit cold treatment of Hawaii grown 'Sharwil' avocados will not compromise the efficacy of the treatment. Studies on the effects of prolonged (18-28 day) cold storage on fruit quality indicated that avocados can be stored at quarantine cold temperature (pulp, 1.1-2.2°C) for up to 24 days without significant loss of external and internal quality compared to fruit quality at 12-16 days storage.

Cuquerella *et al.* (2005), studied methods that would allow Spanish mandarine oranges to be shipped to the US under cold quarantine treatment while maintaining the good quality of the fruit. Appropriate degreening methods were suggested based on the fruit colour index, and other indicators such as total soluble solids. Additionally water waxing was necessary to reduce weight loss and physiological disorders.

Lanza *et a.l,* (2005) studied the effectiveness of cold treatment against Medfly (*Ceratitis capitata*) infestation in 'Tarocco' oranges (also referred to as blood oranges). In large scale disinfestations tests a static trial with simulation of transport was simultaneously carried out using a set of three different full equipped van containers with bottom air delivery system under a 14 day 1.5°C cold treatment schedule. Fruits were infested with the most tolerant Medfly stage (third instar). Experiments provided 100% larval mortality. Very low incidence of fruits with light chilling injury was found. Cold-treated 'Tarocco' oranges had good appearance, no substantial quality differences and did not exhibit excessive level of decay.

Lanza's work highlights an important need in the successful adoption of quarantine cold treatments: research conditions must be duplicated during commercial shipments. In 2005, cold treated clementine oranges from Spain, accepted into the US on the basis of their cold treatment, were found in the marketplace to be infested with Medfly. For a time the US closed trade in clementine oranges, with resulting heavy costs to Spanish industry and to the disappointment of US consumers. A review of the treatment parameters showed that while the treatment worked at lab scale, the practicalities of treatment in ship holds were very important, and in this case, ineffective.

9.4.4.6. Controlled atmospheres (CAs)

CA treatment is not known to be approved for quarantine use with perishables on its own (Anon 1998b), but can be used in combination with cold storage or heat to avoid need for fumigation. This approach is severely restricted by sensitivity of many fruit to these combinations at the levels used to effect control of quarantine insects.

Fruit shelf life can be extended by altering the normal atmosphere of 21% oxygen and 0.03% carbon dioxide to about 0.5 - 3% oxygen and 2 - 5% carbon dioxide and controlling it at these levels. Typically the treatments are carried out at optimum storage temperatures and times for the commodity, which may be too short for acceptance as a quarantine treatment. Although CAs have been widely used for at least 30 years for prolonging the storage life of apples and pears, there are few commercial uses of CA for disinfestation of fresh products because lengthy periods in standard CA cool storage are required to achieve high pest mortality which can result in an unacceptable reduction in commodity quality (Meheriuk and Gaunce, 1994). The use of CAs in the trade of perishable commodities has been summarised by Carpenter and Potter (1994).

CA is particularly suitable for controlling some pests on perishable products that store well such as apples (Batchelor *et al.* 1985, Whiting *et al.* 1991 for control of Lepidoptera under low and high temperature CA, Dickler 1975 for low temperature control of scale insects).

Commodities show great variability in their ability to tolerate CAs, which limits the development of a generalised CA treatment. Vegetables tolerate a minimum of 0.5% oxygen; some cultivars of apples and pears, broccoli, mushroom, garlic, onion 1%; most cultivars of apples and pears, kiwifruit, apricot, cherry, nectarine, peach, plum, strawberry, pineapple, olive, cantaloupe, sweet corn, green bean, celery, lettuce, cabbage, cauliflower and Brussels sprouts 2%; avocado, persimmons, tomato, pepper, cucumber, artichoke 4%; citrus, green peas, asparagus, potato 5% (Kader and Ke 1994). Carbon dioxide maximum tolerance shows similar variation by commodity from 2% to 15%. Most commodities exhibit low oxygen and/or high CO_2 injury and off-flavour development when exposed to insecticidal CA conditions outside of their tolerance range (Kader and Ke 1994) that limits the successful use of CA treatments for disinfestation to relatively few perishable commodities. In addition, insect pests can often survive low oxygen conditions for long periods, particularly at low temperatures.

More recently CAs have proven effective on a laboratory and semi commercial scale for quarantine control of some temperate and tropical pests (not tested inside the commodity) particularly when combined for short durations with temperatures above 30°C (Whiting *et al.*, 1991; Jessup, 1995; Neven, 2006). Unfortunately, in some cases the requirements for insect control damage the commodity (Smilanick and Fouse 1989).

Other factors limiting widespread adoption of this technology are inadequate data on the responses of pests and commodities to high-temperature CA, the difficulty of designing large high-temperature CA disinfestation facilities with adequate gas retention and regional variation in the cost of gases for CA (Whiting *et al.*, 1991; Benshoter, 1987). Carpenter *et al.* (1995ab) reported that the problems likely to be associated with the implementation of CA treatments at elevated temperatures (60% CO_2 + 40% N_2 at 35°C for 2, 4, or 8 hours) were variability in produce and pest responses and the limited ability to extrapolate laboratory data to commercial conditions for a variety of pests and produce.

9.4.4.7. Heat

Heat is particularly suitable for controlling pests found in or on most tropical and some subtropical commodities. The temperature, duration and application method must be sufficiently precise to kill pests and not reduce the marketability of the commodity. Heat is unsuitable for many highly perishable products such as asparagus, some stone fruit (cherries in particular) and leafy vegetables because their shelf-life and marketability is significantly reduced by the treatment. Currently heat treatment facilities capable of handling large volumes of commodities are limited in size and number. Numerous heat schedules have been published by USDA-APHIS attesting to its value as a disinfestation treatment for viruses, nematodes, insects, mites, fungi, bacteria and snails.

Heat-based treatments for disinfestation of perishable commodities have been reviewed (Anon, 1996c). Summaries describing the quarantine uses of heated water and air have been produced (Sharp, 1994 for hot water treatments, Hallman and Armstrong, 1994 for heated air treatments). A more specific review of potential controls for *Anastrepha* species of fruit flies describes a number of heat-based treatments as well as those using irradiation, refrigeration, modified atmospheres and combinations of these treatments (Wolfenbarger, 1995a).

Heat treatment facilities have been installed in commercial packing houses in many countries. For instance, on Hawaii, Kauai, Molokai and Oahu islands in Hawaii, USA (Lawrence, 2001) and in Australia, Fiji, Tonga, the Cook Islands and New Caledonia (Armstrong *et al.,* 1998; Waddell *et al.,* 1997ab).

Heat treatments for perishables include those using moist (>90% relative humidity (r.h.) also called 'vapour heat') or dry air (<90% r.h.) and immersion in hot water (Armstrong, 1994b; Paull and McDonald, 1994). In general, heat treatments are carried out for 10 minutes to eight hours (USDA, 2007) at temperatures that range from 40 - 50°C depending on the specific temperature and duration known to be lethal to the pest. For more heat-sensitive commodities, it may only be possible to control surface pests.

Commercial shipments of tropical fruit such as mango are immersed in warm water at 46.1°C and above for 65 - 90 minutes to kill pests, primarily fruit flies, that might be present (USDA, 2007). There may be a pre-treatment conditioning stage at an intermediate stage to minimise fruit damage. The water temperature and immersion period in this quarantine treatment are precisely maintained so that the pest tolerance to heat is exceeded without damaging the commodity. Papaya exposed to fruit centre temperatures of 47.2°C is commercially shipped from Hawaii to the mainland USA after 4 - 7 hours dry-heat (Armstrong *et al.,* 1989) or to Japan after the same exposure time to *vapour heat* (Anon, 1972). This treatment kills all stages of 3 species of fruit fly potentially infesting this commodity. Laboratory tests are being conducted to determine the potential of water dips and vapour heat treatments to kill temperate pests associated with apples, stone fruit, kiwifruit and citrus, and the effect of these treatments on their storage life.

Vapour heat is used commercially for control of oriental, melon, Queensland and Mediterranean fruit flies potentially infesting litchi, papaya and mango exports from Australia, China, Hawaii, Philippines, Taiwan and Thailand to Japan (Kawakami, 1996); as a quarantine treatment for oriental fruit fly potentially infesting papaya, mango and sweet pepper; for melon fly potentially infesting netted melon and bitter cucumber; and for sweet potato weevil, west Indian potato weevil and sweet potato vine borer potentially infesting Japanese sweet potatoes shipped to the mainland from the southern islands of Japan (Kawakami, 1996).

Pest control using heat generated from microwave technology is in the early stages of investigation. Microwave technologies and applications currently used by the military may eventually find use as quarantine treatments (Armstrong, 1994b). Microwaves may be useful to control pests that are in the seed of large fruits such as mango and avocado that are inaccessible to direct heating.

Sharp (1996) reported that increasing microwave power reduced the time to reach the target temperature but reduced the efficacy of the treatment in controlling Caribbean fruit fly larvae. Microwave technology may also allow on-site treatment of commodities, which could be advantageous for quarantine treatment of small shipments. Further research is required to determine the potential of microwaves to kill pests without reducing commodity quality.

Hallman and Mangan (1997) described a number of problems with quarantine treatment research based on temperature that should be considered by researchers. These problems were the methods and criteria used to assess pest mortality after treatment, potential differences in heat tolerance between laboratory and wild insects of the same species, temperature profiles achieved commercially compared to those tested, variability in the commodity that allows for survival of the pest and the ability of laboratory conditions to simulate those used commercially.

Certain cut flowers were more susceptible to heat injury during cool, rainy seasons (Hara, 1997). Conditioning flowers in hot air at 39 - 40°C for 2 - 4 h before hot water treatment eliminated seasonal phytotoxicity, but increased survival of mealybug cut flower pests. The increase in tolerance to heat by pests induced by a conditioning treatment needs to be carefully evaluated prior to commercialisation of the disinfestation treatment.

Houck and Jenner (1997) showed that, using a number of controlled-temperature glass houses, the pre-harvest environment affected the response of lemon fruit to cold, heat and fumigation treatments. Fruit preconditioned on the tree to cool temperatures were tolerant after harvest to cold treatment, but not heat, and the converse was true for lemons grown in a warm environment. Therefore the environment in which the fruit was grown is one of the factors that determines the type of disinfestation treatment that could be successfully applied.

In practice few heat treatment schedules have been approved for perishable commodities as approval depends on *in situ* pest/fruit trials, precisely controlled temperatures to avoid commodity damage, and compliance with regulatory treatment criteria and equipment certification. Development of these schedules is therefore largely empirical, costly and time-consuming resulting in the commercialisation of relatively few heat-based quarantine treatments.

9.4.4.8. Irradiation

Irradiation refers to the process of treating commodities with ionising energy and includes gamma rays, accelerated electrons and x-rays . Gamma and x-rays are efficient ionising energies for quarantine purposes as they easily penetrate the commodity, but electron beam can also be used under the right circumstances. A summary of irradiation is provided by Burditt (1994) and by the Institute of Food Science and Technology (Anon 1999).

Irradiation can control many pest species and has additional advantages of allowing the commodity to be treated in the final packaging with no appreciable increase in temperature. Extensive research on irradiation effects on tephritid fruit flies, the most important quarantine pests worldwide has formed the basis for acceptance of the treatment. Additionally, Hallman (2000) reviewed the potential of ionising radiation as a disinfestation treatment for insects other than tephritid fruits flies. Female insects, but not always mites, were reported to be sterilised with equal or lower doses than males. Low oxygen conditions often increase radiation tolerance. Insects in diapause were not more radiation-tolerant than non-diapausing ones. Some pests of several groups such as aphids, whiteflies, weevils, scarab beetles and fruit flies may be sterilised by exposure to less than 100 Gy while some lepidopterous pests and most mites required about 300 Gy. Stored product larvae required as much as 1 kGy to sterilise, and nematodes could need more than 4 kGy.

New regulations have driven the development of irradiation as a quarantine method.

Food Standards Australia New Zealand (FSANZ) has approved the use of irradiation as a quarantine measure for a range of tropical fruits (breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan) as a phytosanitary measure (Application A443). The aim is to have available an effective technique that will reduce or alleviate pest infestation in selected tropical fruits, to facilitate trade and market access within Australia and between Australia, New Zealand and other countries (Food Standards Australia New Zealand, 2003).

Several exporters are using an irradiation facility in Brisbane, owned by Steritech Pty, to irradiate mangos for shipment to New Zealand. The number of producers and exporters using irradiation for market access has expanded considerably and mangos are being irradiated at Steritech every day during the harvest season. Australia has sent ten shipments of mangoes (about 60 pallets) to New Zealand in 2004-2006 (Eustice, 2007).

In the US, a new generic approach to allowing irradiation as a quarantine method now gives one minimum treatment (400 Gy) for any fruit and vegetable infested with class *Insecta*, but not if infested with pupae or adults of *Lepidoptera* (Federal Register, 2006). Additionally, that generic dose is decreased if the fruit is infested with one or more of 11 fruit fly species or mango seed weevil. The new regulation moves the approval of irradiation for quarantine away from the laborious pest and host specific regulatory approach of other treatments Countries wishing to export irradiated fruits and vegetables to the US under this new regulation have to complete Framework Equivalency Agreements, inspection and other agreements with the US government. The US has signed Framework Equivalency Work Plans with India, Mexico and Thailand, facilitating the introduction of irradiated produce from those countries into the US.

A commercial x-ray facility owned by Hawaii Pride, opened in Hawaii, United States, in 2000, which allowed pre-shipment irradiation treatment of Hawaiian produce under USDA inspection. The approval and commercial adoption of irradiation as a quarantine treatment for the unique Hawaiian sweet potato, eliminated methyl bromide, increased shipments of sweet potato to the U.S. mainland, decreased grower costs, and improved product handling. In early July 2003, in the first week after publication of the interim rule that allowed irradiation treatment, growers irradiated 40,000 pounds of sweet potatoes. Growers have delivered from 40,000-50,000 pounds/week in the low season to 100,000-120,000 pounds/week in early August peak harvest. Hawaiian growers have doubled their acreage in planting and because the irradiation treatment also delivers sprout control, growers' unique seed is protected. Approximately 900 pounds of methyl bromide have been replaced each year since the new regulation allowed the use of irradiation as an alternative treatment (Marcotte, 2005)

Increased fruit consumption by Americans combined with migration of Asians and Latin Americans to the United States has created a growing demand for tropical fruit especially papayas and mangos, with resulting demand for quarantine treatment of those imported fruit. Papaya consumption in the US increased 16.1 percent between 1990 and 2000, followed closely by the consumption of mangoes at 14.2 percent.

Demand for imported fruit is driving the demand for irradiation in much of the world. A 2003 IAEA web publication listed food irradiation facilities in 34 countries, with 76 facilities where the type of food was specified and an additional 10 facilities where the food type was not specified. A 2005 report from the UN Food & Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) identified more than 20 new food irradiation facilities being planned, constructed or renovated in ten countries.

Of these new facilities, several are being built or have recently been built for quarantine disinfestation purposes:

- Brazil is the largest fruit producer in the world and is the third largest grower of vegetables. Brazil exported 115,000 tons of mangoes to foreign markets in 2005 alone and earned US$ 76 million from this activity. Brazil is currently the world's main papaya grower, responsible for 25% to 40% of the worldwide production. Brazil's mangos and papayas are traditionally treated for fruit flies with hot water dips. A Brazilian company, Securefoods, says the company will establish a network of irradiators in Brazil's northeast to treat mangos, papayas and other fruits for export to North America. Construction of the first

Securefoods irradiation unit in the state of Bahia is due to start in early 2007 with the first irradiated tropical fruit shipments to the US to begin in late 2007. As a result of expected increased shelf life, Securefoods plans to send fruit to the USA by ship instead of by air, which will result in a 50 percent savings in transportation costs.

- In Ghana, the West Africa Trade Hub of US AID funded a project to explore the scientific, legal, commercial and institutional merits of the commercial application of irradiation as a quarantine treatment to improve exports from Ghana, and other West African countries, to the US. As a result, the Ghanian food irradiation standard has been updated, an engineering feasibility study has been conducted and an investment group has been formed with plans of continuing the project to commercial reality (Marcotte, 2006).

- India is the world's largest producer of mangos, accounting for nearly half of all production, but it is only the world's third largest exporter. India moved to the top of the list of countries planning to use irradiation for market access when in 2006 it became one of first three countries to sign a Framework Equivalency Work Plan (FEWP) with the USDA. Under the agreement India will be allowed to ship mangos and other produce to the USA. Several commercial irradiation facilities are in operation and more are planned.

- In Mexico, Phytosan SA de C.V. is near completion of a facility in the State of San Luis Potosi built primarily for fruit disinfestation. Proximity to the USA and implementation of the North American Free Trade Agreement (NAFTA) provide Mexican produce growers and marketers with significant opportunities to expand sales to the US. Phytosan plans to add additional irradiation capacity in the state of Jalisco during 2008. A variety of irradiated produce, beginning with mangos, will eventually cross the US border at McAllen, Texas

- Pakistan's first irradiation plant, a joint venture of Pakistan Horticulture Development and Export Board and Pakistan Atomic Energy Commission (PAEC), will become operational in February 2007. Lack of proper post-harvest technology in Pakistan causes losses to fruit and vegetable production by 30-40 per cent. The new plant will provide commercial irradiation services to growers and processors for items such as rice, wheat, cereals, fruits, vegetables and processed food such as spices.

- South Africa has several food commercial irradiation facilities and has the capability of producing a large amount of irradiated fruit for export. South Africa can export irradiated lemons to the US and scientists are experimenting with citrus, apples and pears.

- Thailand became the first country to sign a Framework Equivalency Work Plan (FEWP) with the USDA on January 31, 2006. Under the agreement Thailand will be allowed to initially ship six irradiated fruits: mango, mangosteen, pineapple, rambutan, litchi and longan to the US. Dr. Manoon Aramrattana reports that irradiation facilities are being upgraded to be certified in compliance with the US requirements. Two facilities will be used initially, the government's own Thai Irradiation Centre (TIC) of the Thailand Institute of Nuclear Technology (TINT) (http://www.tint.or.th) Ministry of Science and Technology; and a private irradiation service provider in Thailand. It is expected that the first batch of irradiated Thai fruit will be exported by first quarter of 2007. Thai producers hope to send other pest-free fruits, such as coconuts, to the U.S. market.

9.4.4.9. Physical removal

Physical removal may be a sufficient measure with some fruit and vegetables to allow import from some regions without further quarantine measures, including MB fumigation.

Water under high pressure has been shown experimentally to remove large numbers of pests from the fruit surface (Honiball *et al.,* 1979 for scale insects, Yokoyama and Miller, 1988 for codling moth eggs). Air under positive or negative pressure has also been used experimentally to remove pests, but not in sufficient numbers to be acceptable as a disinfestation treatment. These treatments are only suitable for removing pests on the surface of fruit such as accidental contaminants ('hitch-hikers'), scale insects and mealybugs. The choice of air or water depends on the tolerance of the commodity to the treatment or convenience of use in the packing operation.

Physical removal may be a useful measure in combination with others to meet quarantine standards. For instance, use of a *high-pressure water* spray has been approved for *Succinea horticola* snails when followed by a dilute carbaryl insecticide dip, or hand-removal of the pests where practical followed by immersion in a malathion-carbaryl *dip* if necessary (USDA, 2007).

González (1997) reported that Chilean-grown cherimoya (*Annona cherimoya*) were damaged by MB fumigation. However, coating the fruit with wax killed *Brevipalpus chilensis* mites (probably by preventing respiration) to Probit-9 security level without fruit damage. The treatment has been approved by the USDA-APHIS.

Cherimoya (*Annona cherimoya*) can be treated with soapy water (20 seconds in one part soap to 3000 parts water) and wax (e.g. Johnsons Wax PrimaFresh® 31 Kosher fruit coating) to control the mite species *Brevipalpus chilensis* (USDA, 2007). Although the treatment was also effective on limes it was not effective on other citrus as the wax was unable to penetrate all regions of the fruit and stalk joints to suffocate mites in these areas (González, 1997).

9.4.5. Chemical postharvest treatments

Chemical treatments consist of using fumigants or immersing commodities in dilute insecticides ('chemical dips').

9.4.5.1. Chemical dips

Commodities can be dipped in a dilute pesticide solution after harvest to kill targeted pests that might be present in or on the commodity or plant. The dip must be able to reach pests often well hidden within the leaves and flower parts of plants but must not be phytotoxic.

Some countries discourage the use of chemical dips because of consumer concern for chemical residues, or because disposal of the pesticide solution after treatment is often environmentally unacceptable. For these reasons, a chemical dipping may be restricted to non-edible commodities such as ornamental plants, bulbs, nursery plants and cut flowers. Insecticidal dipping is one of the most common post-harvest treatments for cut flowers (Hara 1994). Fluvalinate, a synthetic pyrethroid, is registered for use on cut flowers in the USA and its use has been recommended as a dip for tropical foliage plants imported into the USA (Osborne 1986).

9.4.5.2. Alternate fumigants.

Fumigation treatments are usually carried out under very specific parameters to achieve complete pest mortality without damaging the commodity. For example, phosphine, sulphur dioxide and hydrogen cyanide require very low chemical concentrations, temperatures and exposure periods compared with MB to kill pests within the conditions known to be tolerated by the commodity.

Fumigants approved for treatment of particular perishables and combinations of exporting and receiving country include phosphine, sulphur dioxide, ethyl formate, and hydrogen cyanide.

Treatments with phosphine tend to be slower than with methyl bromide for quarantine effectiveness. This restricts its utility as a fumigant for perishables. Phosphine packaged in cylinders as a pure gas or mixed with CO_2 has recently become more available. These formulations do not contain ammonia, a material that was implicated in the phytotoxicity observes with phosphine generated from solid phosphide formulations. For instance, no injury was observed on Nijisseiki pears fumigated with phosphine at 1-3 g m^{-3} for 24 hours at 15°C (Soma *et al.*, 1997ab; 1999). These concentrations killed *Tetranychus urticae* but not the peach fruit moth (*Carposina niponensis*). In Japan, mites *T. urticae*, *T. kanzawai* and *Eotetranychus sexmaculatus* were controlled by 2 g m^{-3} phosphine at 15°C for 16-24h on Japanese apples and pears without damage to the fruit (Kawakami, 1999).

9.4.5.3. Combination treatments

Treatments may be combined to achieve required efficacy levels. The combination of two or more treatments, when the elements of each treatment are less 'harsh' than when used individually, often offers the advantage of controlling pests without damage to the commodity. As many single treatments cause damage, not unexpectedly, there is great interest in combination treatments – either carried out simultaneously, or one after the other. For example, MB fumigation combined with a short period of cold storage kills codling moth eggs on apples more effectively than either treatment alone (Waddell, 1993). The *combination treatment* of 18 days *cold* *treatment* at 0°C (± 0.5°C) followed by MB *fumigation* at a low rate of 12 g m^{-3} for 2 hours at 15°C for control of fifth instar diapause larvae of peach fruit moth potentially infesting apples for export to the USA was more effective than MB fumigation alone (Kawakami *et al*., 1994). A combination of *vapour heat* followed by *cold storage* is used to kill oriental fruit flies on litchi imported by Japan from Taiwan (Anon, 1980) and China (Anon, 1994a).

Inspection combined with a heat treatment is an accepted treatment for litchi exported from Hawaii to the mainland USA. Litchis must be thoroughly examined in the pack house and found free of *Cryptophlebia* spp. and other plant pests. Fruit must be submerged at least four inches below the surface of the water that must be kept at 45.5°C and above for 20 minutes (USDA, 2007). Hydro-cooling subsequently is recommended after treatment to avoid fruit damage.

The rarity of approved combination treatments compared with single treatment applications is probably due to extensive technical documentation required to demonstrate treatment efficacy for regulatory agencies.

9.4.6. Alternatives for soils for production of certified propagation material

Methyl bromide is used in several countries for some treatments of soil on which propagation material is grown. The treatments are for the production of certified high health stock, such as strawberry runners, tree seedlings and nursery material. In nearly all non-Article 5 countries in 2006 that applied for an exemption from phaseout for methyl bromide for this purpose, the consumption was permitted under a Critical Use Exemption, on the basis that there are currently no technically and economically feasible alternatives for the use, following Decision IX/6. These countries determined that it is appropriate to use the CUN process for methyl bromide to be used for production of strawberry runners and some other propagation stock. In one country, USA, a proportion of the methyl bromide used for production of propagation material is allocated to QPS use.

Target pests for this QPS use include a range of pest nematodes and pathogenic fungi. These pests and diseases, if allowed to remain unchecked, may have severe effects on the productivity and growth of the propagation material when it is grown out. Government and industry certification schemes for propagation material aim to reduce the level of pathogen or disease tolerance to a very low level (often < 1%). This has a major influence on reduction of disease when the propagation material is planted out in production fields. Plants show either no disease or very low levels of disease. Fruiting strawberry plants from runners from untreated soils typically produce 70% or less fruit compared with runners produced on land fumigated with methyl bromide.

Three key points to consider in these cases are:

1. Does MB reduce pathogen levels or eradicate pathogens (especially notifiable quarantine pests) to a reasonable depth in soil after treatment and does this prevent disease?
2. Can MB fumigation treatments 4 to 6 months before harvest of propagative material guarantee disease free status of plant material?

3. Can alternatives achieve a similar level of pathogen control or disease tolerance as MB treatments and thus replace the need for MB?

The limited data available (Horner, 1999, 2002; Horner *et al*., 2006; De Cal *et al*., 2004; Mann *et al*., 2005) indicates that methyl bromide fumigation of the soil cannot guarantee the soil is entirely free of pathogens, especially fungal pathogens. In addition, soil disinfestation with MB, whilst often being an effective tool for minimising disease levels on nursery stock, also does not guarantee a reduction in disease levels to zero, but only to a low and undefined level. For example, Horner (1999) showed that root material infested with *Phytophthora fragariae* could still survive MB:Pic/70:30 fumigation when placed at depths of 12 to 30cm in soil and that these infested roots could still cause both root and crown root symptoms. They also showed that alternative fumigants, e.g. chloropicrin or 1,3-D/Pic produced similar results to the MB/Pic treatments. De Cal *et al.* (2004) isolated *P. cactorum* (in up to 7% of plants), *Fusarium* (3%), *Pythium* (2.5%), *Verticillium* (0.2%) and *Colletotrichum* (0.2%) from strawberry runners produced in soils disinfested with methyl bromide. In this instance, the disease levels were higher than would normally be expected to meet certification standards for disease tolerance (usually <1% of plants affected).

Similarly, Mann *et al*. (2005) showed that hot-gas MB (100%, 60 g m^{-2}) did not eradicate consistently buried inoculum of *Fusarium oxysporum, Rhizoctonia solani, Rhizoctonia fragariae* or *Sclerotium rolfsii* placed at depths of 10, 20 and 40cm in a clay-loam soil, particularly at soil depths of 40 cm. Similarly, injected MB:Pic (30:70, 50 g m^{-2}) did not eradicate buried inoculum of *Phytophthora cactorum, F. oxysporum, R. solani, R. fragariae* or *S. rolfsii.* Survival was generally low, mostly at depths of 20 and 40 cm in soil and was higher when sample were taken further away from the injection point for methyl bromide.

In relation to Critical Use Nominations for propagation material, notably strawberry runners, TEAP (2004) noted that, in general, there was limited data provided on whether alternatives were able to produce adequately 'disease free' material, or whether appropriate levels of crop or commodity performance were achieved when compared to MB. Furthermore, there was a lack of detailed data on comparative disease tolerance levels and in field crop growth and performance for nursery stock treated with different alternatives and planted into subsequent cropping systems. Such data would provide a basis for selection of alternatives to methyl bromide for production of certified propagation stock in soil.

A statistical analysis of published studies (TEAP 2006b) demonstrated that alternatives to methyl bromide, notably 1,3-D/Pic, performed as well as methyl bromide/chloropicrin mixtures as judged by fruit yield in strawberries and tomatoes. This evidence suggests that some other soil treatments may perform as well as methyl bromide for control of pathogens and nematodes and may be suitable as alternatives for production propagative material of similar health status to that produced at present under schemes using methyl bromide.

9.5 Constraints to the Development and Adoption of Alternatives for QPS

Development of methyl bromide alternatives for QPS applications continues to be a difficult process exacerbated by the multitude of commodities being treated, the diverse situations where treatments are applied and a constantly changing trade and regulatory landscape. A variety of technologies are potentially suitable as replacements for some commodities and some circumstances. In many cases, uncertainty about phytotoxic effects and effectiveness against the target pests constrain use of alternatives. In other cases, the requirement to bilaterally negotiate quarantine agreements, and the complexity of trade impacts on importing countries, very considerably delays approvals of alternatives.

There will be considerable cost, effort and time required to gain the registrations and approvals that are required for many quarantine uses. At this time, it is not clear how or if this will happen. Though changing of quarantine regulations and bilateral quarantine agreements are the responsibility of governmental agencies, pesticide registrations are in the private sector. In the past, pesticide companies have been reluctant to invest money to register and market pesticides for small markets represented by many of these quarantine uses. Alternatives that do not require registration such as heat, cold and inert gases would be more easily adapted in cases where their use is appropriate to the commodity, situation and where they show sufficient efficacy. In addition, the type of broad generic quarantine approval for irradiation (i.e. not pest and host specific), as has recently been approved by the United States, shows potential for a much more efficient adoption of alternatives.

QPS uses are currently lumped together by the Parties. There may be an advantage to considering quarantine and preshipment issues separately. They differ markedly in their ability to adopt alternatives. The standard of efficacy for quarantine uses is extremely high because the consequences of exotic pests surviving treatments can be catastrophic to countries where the new pest becomes established. Preshipment uses on the other hand, are usually for cosmopolitan pests that are already found in the importing country. Treatments typically aim to reduce any level of infestation to that which will not be detected by inspection at point of entry to the importing country. Regulations requiring pre-shipment methyl bromide fumigation are often very old and may be unnecessary and outdated in the current circumstances. The efficacy standard for pre-shipment is not always as severe as in the case of quarantine; research requirements to establish efficacy can be less rigorous as well. It would appear that there are fewer obstacles to adopting alternatives for preshipment methyl bromide uses than for quarantine uses.

9.6 References

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Chapter

10

Case Studies on Commercial Adoption of Alternatives to MB

10.1. Introduction

This chapter contains a compilation of case histories prepared by MBTOC members or requested from national experts, extension specialists, researchers and others and reviewed by MBTOC. The case studies cover MB alternatives for production of the main crops where this fumigant is still used around the world (e.g. cucurbits, strawberries, tomatoes, ornamentals, tobacco, peppers, eggplants and others), and for postharvest uses. A short summary describing the alternative has been included at the beginning of each case study to facilitate consultation.

In past Assessments (1998 and 2002), case studies were focused on describing alternatives and methods that were already in use in some countries or sectors, sometimes by small groups of farmers or even individual companies. Large progress has been made in replacing MB use in non-Article 5 countries in view of the 2005 phaseout date.

Adoption of alternatives is equally considerable in Article 5 countries. The case studies included in the 2006 Assessment Report show progress made in the adoption of alternatives in large industries or sectors, even in entire countries or regions, in different situations and cropping systems. The case studies have been grouped by geographical region, to provide more ample coverage of global adoption of alternatives to MB.

Case studies are included in this Assessment Report to provide illustrations of alternatives that have been adopted in commercial practice, particularly adoption of alternatives that have lead to significant reductions in MB use in different crops and locations. MBTOC normally uses published and refereed documentation to substantiate information in its Reports, however Chapter 10 also uses information from 'grey' literature, industry sources or national experts because information about the adoption of alternatives in commercial practice is often not available in the academic or published literature.

Twenty-six case studies from about 20 countries in different regions are included in the Chapter as follows:

EUROPE

Preharvest (soils)

CS 1. Greece – Production of cut flowers in substrates
CS 2. Italy - Grafted plants + fumigant used in tomato, pepper and eggplant
CS 3. Spain - Phaseout of Methyl Bromide in pepper production
CS 4. Spain - Use of alternative fumigants in strawberry fruit production
CS 5. The Netherlands - Alternative practices in open field forest/tree nurseries, cut flowers and bulbs

Postharvest

CS 6. Germany - Heat + IPM in mills

NORTH AMERICA

Preharvest (soils)

CS 7. United States - Improved application equipment, alternative fumigants and herbicide combinations in tomato and pepper in Florida

Postharvest

CS 8. Canada - Sanitation, heat + IPM in mills and food processing plants

CS 9. United States - Sulfuryl Fluoride and other MB alternatives in Flour Mills and Food Processing Facilities

ASIA/ PACIFIC

Preharvest (soils)

CS 10. Australia - Phasing out MB from the strawberry industry
CS 11. China - Case study: Status of MB replacement with chloropicrin in Strawberry Fruit production
CS 12. Japan - Alternatives for controlling soil diseases and nematodes in tomatoes
CS 13. Lebanon - Phaseout of Methyl Bromide in the Vegetable, Cut Flower, Tobacco and Strawberry sectors
CS 14. Lebanon - Strawberry sector phaseout of Methyl Bromide for Soil
CS 15. Turkey - Phaseout of Methyl Bromide in Vegetable and Cut Flowers Production

Postharvest

CS 16. Cyprus - Alternatives to MB for grain storage and protection
CS 17. Israel – Bio generated atnospheres for disinfestation of narcissus bulbs as a quarantine treatment
CS 18. Israel - Thermal disinfestation of dates

LATIN AMERICA

Preharvest (soils)

CS 19. Argentina - Current status of MB phaseout in the tobacco sector
CS 20. Brazil -Use of the floating tray system as a methyl bromide replacement for the production of tobacco seedlings
CS 21. Colombia - Production of cut flowers without MB
CS 22. Costa Rica - The process for phasing out MB in melon and flower production

Postharvest

CS 23. Argentina – postharvest treatments for tomato and strawberry

AFRICA

Preharvest (soils)

CS 24. Morocco - Phase out of methyl bromide in the strawberry, banana and cut flower sectors

CS 25. Kenya - Use of MB alternatives systems in vegetable and flower sectors

CS 26. Malawi - Methyl Bromide phaseout in the tobacco sector

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10.2 Adoption of Alternatives to MB in Europe

European countries phased out 88% of their baseline MB consumption in 2005. MB consumption authorized for 2006 and 2007 in the form of Critical Use Exemptions is 8% and 3% of that baseline respectively. Growers around Europe have adopted a diversity of alternatives according to the specific circumstances of the crops.

10.2.1. Alternatives for preharvest (soils) uses

Case Study 1. Greece – Production of cut flowers in substrates

MB was used on about 40 ha cut flowers in Greece until 2002 – 100% of the Trizinia region where most flowers are produced. Substrates have been quickly and successfully adopted as an alternative to methyl bromide for the main flower types such as roses and gypsophylas and are proving efficient for other flower types as well as various kinds of vegetables.

Initial situation

In Greece, cut flowers such as roses and gypsophylas are generally produced throughout the year in greenhouses. Soils are typically sandy to loamy clay and the climate is sub-tropical Mediterranean, warm and dry. The temperature range inside the greenhouse during the cultivation period is 13 - 35°C. This range is maintained by heating (central heating system) during the winter and by spraying the greenhouse roof with calcium compounds for shading and by operating a fog system during the hot season (May-September).

The following key pests attack roses and gypsophylas in this region:

- Fungi: *Verticillium albo-atrum*, *Phytophthora*, *Fusarium* sp., *Sclerotinia sclerotiorum*, *Rhizoctonia* rot, *Pythium* root rot
- Bacteria: *Agrobacterium* sp. on roses
- Nematodes: *Xiphinema* sp., *Meloidogyne* spp. mainly on roses. The latter can be found in gypsophyla but are not a major threat.
- Weeds: Various species of Graminae (*Sorgum halepense*, *Cynodon dactylon*, *Echinochloa cruss-galli*), *Cyperus* sp., *Oxalis cernua*, etc. Weeds constitute a

serious problem in soil-grown gypsophila, which was controlled by disinfecting the soil using methyl bromide.

- Insects: *Agriotes* sp., *Agrotis* sp., *Gryllotalpa gryllotalpa*

MB was used on about 40 ha cut flowers in Greece until 2002 (Government of Greece, 2006). The area of cut flowers in Greece is about 200 ha.

Substrates have been used for 12-15 years in Greece and use is continuing to increase. Growers adopted substrates for three main reasons: to avoid nematodes and fungal diseases and to effectively control weeds; to increase the quality and the quantity of the products; and because in the case of rose cultivation, substrates enables use of rooted cuttings instead of grafted cuttings (Vos and Bridge, 2006).

Description of the alternatives implemented

Equipment and materials vary among growers. Some farms have a fully automated installation for fertigation and climate control, channels and tanks for recycling of the effluents, a sand filter for disinfection of the recycled drainage water (which is only effective against *Phytophthora* species providing a correct installation, Runia, 1996), substrate (coir), a reverse osmosis system, a fog system for the control of excessive temperature and a central heating system. Other farms have simpler systems. Substrate materials include coir, perlite, rockwool, pumice and others. Sometimes a combination of materials is used. Initially growers filled 10-litre pots with substrate, but in the last 2-3 years the tendency is to buy bags that are pre-filled with substrate. The typical number of days (on average) needed to prepare the greenhouse for planting is 5 to 8 days (Savvas 2005) according to the type of flower and the skill of the labourers.

Marketable yield - Typical marketable yield of roses when using soil was 100 flowers per m^2 per year, whereas the typical marketable yield using substrates is 130 flowers per m^2 per year (Savvas 2005). This is an increase of about 30%. Substrates provide a substantially earlier first rose harvest compared to soil (i.e. time from planting to the 1st harvest is shortened). When substrates are properly used the harvest starts nearly 15% earlier as compared to soil-grown rose crops (Savvas 2005). The typical marketable yield of gypsophila when using soil production was 22,000 bunches/ha per year, whereas the typical marketable yield using substrates is 30,000 bunches/ha per year (Savvas 2005); this is an increase of 35%. There is a significant improvement in the timing of harvest when using substrates compared to soil. When substrates are properly applied the growers gain 20% of the time taken for soil cultivation (Vos and Bridge, 2006; Savvas 2005)

Control of soilborne pests - Data on the level of control of soil borne pests when using substrates show complete elimination of the *Verticillium* and nematode problems in rose production, and complete control of weeds (Savvas 2005). In general, excess watering should be avoided and good IPM should be observed, scouting for diseases in particular so as to eliminate diseased plants as soon as they appear. Soilborne pests are controlled more successfully when the drain water is disinfected prior to recycling.

Costs and profitability - The initial set-up cost of the substrate system was 116,800 € per hectare in cases where a grower installs a closed-loop system for drainage solution recycling. Typical set-up costs for substrate-grown rose crops without drainage solution recycling amount to approximately 70,000 € per ha. In comparison, the set-up cost in soil grown rose crops is about 30,000 € per ha (Savvas 2005). The initial set-up cost for a gypsophyla substrate system is about 45,000 € per ha in Greece. This sum includes, a) the irrigation system, b) the levelling up of the greenhouse ground and the purchase of styrofoam plates, and c) the installation of an automated fertigation control. The set-up cost in soil-grown crops of gypsophila amounts to nearly 10,000-11,000 €/ha (Savvas 2005). Water disinfestation by methods different to slow sand filtration e.g. UV-radiation which is very commonly applied and effective against fungi and nematodes (Runia, 1995) are more expensive.

The typical gross revenue from a rose crop grown in soil in this region amounts to 140,000 – 160,000 € per ha per year; the cultivation on substrates increased the gross revenue to 180,000 – 200,000 € per ha per year (Savvas 2005; Vos and Bridge, 2006).

Table 10.1. Comparison of cost of MB and substrate system for roses**

Input	**MB/soil system** €/ Ha	**Substrate system** €/ Ha
Drip irrigation system	10,200 €	21,600 €
Levelling and configuration of the ground to facilitate drainage run-off and disposal	0 €	3,800 €
Cultivation & preparation of the soil	4,700 €	0 €
Channels	0 €	18,000 €
Fumigant (MB)	9,800 €	0 €
Pesticides	18,700 €	14,200 €
Plastic sheets for covering up the ground	3,600 €	4.300 €
Substrates	0 €	17,800 €
Advice from experts	0 €	1,000 €
Fertilizers	15,500 €	18,700 €
Labour	64,000 €	52,500 €
Installation for automated fertigation control (including stock solution tanks and pumps)	2,000 €	12,600 €
Sand filter	0 €	9,700 €
Reverse osmosis system (installation, 4.2 m^3/h)	0 €	30,000 €
Reverse osmosis system (operation costs/ yr*	0 €	1000 €
Total in 1st year (set up and running costs)	**128,500 €**	**204,200 €**
Total in 2nd year (running costs)	98,200 €	87,400 €
Total in 3rd year (running costs)	98,200 €	87,400 €
Average of the initial 3 years	108,300 €	126,333 €
Average in 4th year	98,200 €	87,400 €
Average in 5th year	98,200 €	87,400 €
Average in 6th year	98,200 €	87,400 €
Average of the initial 6 years	**103,250 €**	**106,867 €**

Source: Savvas, 2005; Vos and Bridge, 2006

* The operation cost of reverse osmosis per m^3 water is 0.2 €.

** The table is based on the assumption that the rose plants will be maintained in production for 6 years (common practice in the region is 5-6 years).

Average gross revenue for gypsophila grown on substrates in this region is approximately 120,000 -130,000 € per hectare. The corresponding value for crops grown in soil is approximately 90,000 - 100,000 € per hectare (Savvas, 2005)

Table 10.2. Comparing the cost of MB and substrate system for gypsophila

Input	MB/soil system €/ Ha	Substrate system €/ Ha
Drip irrigation system	8,850 €	17,600 €
Soil cultivation	3,650 €	0 €
Styrofoam plates - Levelling and configuration of the ground to facilitate drainage run-off and disposal	0 €	15,000 €
Fumigant (MB)	7,100 €	0 €
Pesticides	12,500 €	8,500 €
Plastic sheets for covering up the ground	3,400 €	4,600 €
Substrates	0 €	11,500 €
Advice from experts	0 €	1,000 €
Fertilizers	11,400 €	17,000 €
Labour	34,500 €	26,300 €
Installation for automated fertigation control	1,800 €	12,000 €
Total in 1st year (set up and running costs)	83,200 €	113,500 €
Total in 2nd year (running costs)	72,550 €	51,800 €
Total in 3rd year (running costs)	72,550 €	67,900 €
Average in 1st 3 years	**76,100 €**	**77,733 €**
Total in 4th year (running costs)	72,550 €	51,800 €
Total in 5th year (running costs)	72,550 €	67,900 €
Total in 6th year (running costs)	72,550 €	51,800 €
Average of 6 years	**74,325 €**	**67,450 €**

Source, Savvas, 2005; Vos and Bridge, 2006

*Assuming that the substrate is reused in the second year but is replaced by new substrate in the 3rd year

Lessons learned

The main problems encountered when changing from soil to substrates was that growing in substrates is more sensitive to errors made by the grower. Some growers overcame these problems by purchasing an automated installation for fertigation control from a supplier who also provided an advisory service for nutrient solution recipes and nutrition management. After a while these growers gained sufficient experience, and became capable of successfully tackling various routine problems. Overall, growers in Greece report that it was not difficult to implement this alternative (Savvas, 2005) and reported the following advantages: substrates enable a more efficient management of soilborne pests, diseases, and weeds, provided that proper sanitary measures are taken during cropping. Moreover, the cultivation of roses and gypsophylas in substrates provides better quality and higher yields. Successful growers are very satisfied with the crop yields and crop quality when using substrates (Vos and Bridge, 2006).

Substrates are suitable for vegetables and various types of cut flower production in Greece and other countries (Savvas, 2005; Savvas and Passam, 2002). The system is particularly suited for cases where high pest pressure prevails. Experts believe that substrate systems can be used in almost any climate, but some modifications taking into account the local climate conditions may be needed in some cases (e.g. in summer, it is necessary to deal with excessive air temperature which may result in excessive root temperatures since the substrate is above the ground and the volume of substrate per plant is much lower than the volume of soil per plant).

Substrate systems that require a high initial set-up cost are not suitable for very small units and very simple greenhouse constructions because the investment is usually too high and in this case the advantages of this method cannot be completely utilized because other factors restrict the performance of the crop (Vos and Bridge, 2006).

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Case Study 2. Italy - Grafted plants + fumigant used in tomato, pepper and eggplant

In 1995 about 2882 tonnes MB were used for tomato in Italy, which went down to about 1,195 tonnes in 2001. By 2005 MB use had been reduced to 615 tonnes, less than the quantity of MB that the tomato sector was allowed for CUEs in 2005. In 1the same year more than 780 and 580 tonnes MB were used for pepper and eggplant respectively; in 2003, MB use was reduced to 290 and 300 tonnes; by 2005 these quantities had been further reduced to 100 and 88 tonnes, less than the tonnage allowed by the EC for that year.

Initial situation

Approximately 7,860 ha of greenhouse tomato are grown in Italy. The estimated value of the sector was €383.8 million in 2004 (Russo *et al*., 2005), which makes Italy the 4th largest producer of tomatoes in the world. MB was used on up to 7,600 ha tomato in the past or the vast majority of the protected tomato crop in Italy (Gasparrini, 2003). Most of it was used in Sicily and other parts of southern and central Italy. In 1995 about 2,882 tonnes MB were used for tomato (Russo *et al*., 2005), which went down to about 1,195 tonnes in 2001. By 2005 MB use had been reduced to 615 tonnes, less than the quantity of MB that the tomato sector was allowed for CUEs in 2005. Based on the above data the recent annual rate of MB reductions was 290 tonnes per year from 2003 to 2005 (Vos and bridge, 2006).

The area of protected sweet pepper and eggplant is about 2,835 ha (value €97.3 million) and 1,991 ha (value €56.8 million) respectively (Russo *et al*., 2005). Italy is the 6th largest eggplant grower in the world, producing approx. 373,635 tonnes in

2005 (FAO, 2006). MB was used on more than 1,560 ha pepper and more than 1,160 ha eggplant in 1995. The main regions using MB for eggplant were southern and central Italy, and for pepper Sicily and other southern regions, central and northern Italy. In 1995 more than 780 and 580 tonnes MB were used for pepper and eggplant respectively; in 2003, MB use was reduced to 290 and 300 tonnes, respectively; in 2005 these quantities were further reduced to 100 and 88 tonnes respectively, which was less than the tonnage authorised by the EC: The eggplant sector, for example was permitted to use 96 tonnes but used only 88 tonnes (EC 2006a). The recent annual rate of MB reduction was 125 tonnes per year from 2003 to 2005 for pepper and eggplant combined (Vos and bridge, 2006).

The main soilborne pest species targeted are nematodes e.g. *Meloidogyne* spp., soilborne fungi e.g. *Phytophthora* spp., *Fusarium oxysporum* f.sp. *lycopersici, Verticillium dahliae, Pyrenochaeta lycopersici, Sclerotinia sclerotiorum, Sclerotium rolfsii* and weeds e.g. *Cyperus* spp. (nutsedge), and others.

Protected production in tunnels or greenhouses is characterized by small-sized, highly specialized, and intensive cultivation systems with high plant densities and repeated plantings of the same crop (Gullino *et al*., 2003). Growers typically grow crop sequences of either tomato only, or tomato – pepper, or tomato - lettuce – tomato. Pepper producers normally grow pepper-tomato or pepper-pepper.

The climate of Southern Italy, where most of the production (and previous MB usage) takes place is Mediterranean (temperate-arid) with primarily sandy to sandy loam soils. The average minimum temperature is 10 – 12 °C in January to average maximum 28 – 30 °C in July.

Actions for replacing MB

The production of grafted tomato in Italy increased from about 2-3 million to 12.4 million plants by 2005. The rate of adoption was at least 8-10 million grafted tomato plants over several years in Italy (Morra and Bilotto, 2005; De Miguel 2004b; EC 2006). From 2002, SIS, a major Italian fumigation company that had used MB for 35 years, promoted the use of grafted plants combined with fumigants 1,3-D and pic. By mid-2004 about 2,000 growers were involved, and 4,000 applications of alternative fumigants had been carried out (Spotti 2003, 2004; Spotti and Piardi, 2003).

Formulations of 1,3-D and pic suitable for greenhouse use (applied via drip irrigation) were registered in Italy in November 2001 and July 2002 respectively. Metham potassium was registered in June 2002. Metham sodium was already registered and available at an earlier stage (Minuto *et al*. 2003a; Russo *et al*., 2005).

Growers in Sardinia were assisted in the adoption of grafted tomato plants and new agronomic techniques by cooperatives, nurseries and agricultural researchers in the region (Leoni *et al*. 2004). University researchers were also involved in extension activities (Minuto *et al*. 1998; Gullino *et al*. 2002, 2003). Growers received technical assistance and alternative fumigants from a major fumigation company which had a network of agronomists and large-scale extension programme involving 50 technical staff, 38 teams and 4 logistics centres in the north, centre and south of Italy. They assisted growers to adapt existing irrigation systems so that alternative fumigants could be used. Fumigations were carried out by trained, specialised operators. The company also produced grafted plants, supplying them to growers with a fumigation service using 1,3-D or pic, as appropriate (Spotti 2003, 2004).

Description of the alternatives implemented

One of the alternatives to MB which has been widely and successfully adopted for tomatoes and eggplant and to a lesser extent pepper in Italy is the use of grafted plants combined with a fumigant such as 1,3-D, Pic or metham sodium. In particular for tomato and eggplant, grafting has greatly expanded for various reasons: reducing infection by soil borne pathogens (i.e. *Fusarium oxysporum* f.sp. *lycopersici, Verticillium dahliae, Pyrenochaeta lycopersici, Meloidogyne* spp.), growth promotion, yield increase, low temperature tolerance, growth period extension, and improvement of fruit quality (Besri, 2005; Spotti, 2004).

Grafted plants are generally produced by specialised nurseries. High-quality scions are grafted onto selected rootstock that are resistant to several common target pest species such as *Pyrenochaeta lycopersici, Fusarium oxysporum* f.sp. *lycopersici, Verticillium dahliae, Meloidogyne* spp. (Cartia, 2002; De Miguel, 2004b). The resistances of Beaufort rootstock, for example, are V, F1, F2, N, Fr, K, Tm (Ganz *et al*. 2005). Grafted plants with two stems are often used, because the strong rootstock is able to supply nutrients to support more than one stem, substantially increasing crop yield per m^2 (Vos and Bridge, 2006).

Soil is prepared by deep ploughing or rotary hoeing, and brought to suitable moisture level. An alternative fumigant (1,3-D, pic or Metham) is applied to the soil via an adapted drip irrigation system. Some fumigators cover the soil with VIF during fumigation.

When nematodes are the primary problem, 1,3-D or a nematicide is used. When fungal pathogens are the primary problem, pic or fungicides are used. When both nematodes and fungal pathogens are present, Metham or a sequential application of 1,3-D and Pic may be used.

Efficacy / control of soilborne pests

The combination of grafted plants with alternative fumigants has been found to be as effective as MB in Italian conditions (Spotti 2003, 2004). The following soilborne pests can be managed by use of grafted tomato plants (De Miguel 2004b; Spotti 2004; Besri, 2005):

- Fungal pathogens: *Fusarium oxysporum* f. sp. *lycopersici* (FOL), *Fusarium oxysporum* f. sp. *radicis-lycopersici* (FORL), *Verticillium dahliae, Pyrenochaeta lycopersici,* 'corky root'
- Nematodes: *Meloidogyne incognita, M. javanica, M. arenaria* (Table 3.3)
- "Collapse" probably due to Pep MV + *Olpidium*. True resistance to 'collapse' has not been reported, but tolerance in grafted plants is probably due to greater sap flow rate than normal plants under stress conditions (Escudero *et al*., 2003)

Resistance to gall nematodes (*Meloidogyne* spp.) provides effective protection as long as the soil temperature does not exceed about 27°C or 32°C in some varieties (Table 10.3 below; Messiaen, 1995; De Miguel 2004b). When the temperature is higher, resistance is inefficient so it is necessary to use an additional treatment such as 1,3-D or a traditional nematicide. Resistance to FOL and *V. dahliae* is extremely stable (Tello 2002; De Miguel 2004b), nevertheless it is advisable to practice rotation with cultivars that are not sensitive to Verticillium or to disinfect the soil from time to time.

In cold greenhouses where 'corky root' is a serious problem grafting on hybrid rootstocks (*L. esculentum* x *L. hirsutum*) is as effective as MB. Vigorous rootstocks of this type (combined with sanitation to avoid mechanical transmission of disease) is also an effective solution for "collapse" in tomato (De Miguel 2004b).

Effective control of a wider range of fungal pathogens and nematodes is achieved by combining grafted plants with an appropriate fumigant such as 1,3-D, pic or metham. The efficacy of this combination has been confirmed for tomato and other vegetable crops in a number of regions (Besri 2000, 2003, 2005; Ganz *et al.*, 2005; De Miguel, 2004ab; Bogoescu *et al.*, 2004), indicating that this alternative is effective under diverse agronomic conditions (Vos and Bridge, 2006). If necessary, weed control may be supplemented by mechanical weeding, hand weeding or herbicides, or by the use of VIF during fumigation.

Table 10.3. Gall index in tomato: comparison of MB fumigation, grafted plants + alternative fumigant, grafted plants and non-grafted plants

MB + non-grafted plants	Grafted plants + alt. fumigant	Grafted plants	Non-grafted plants, control	Source
1.4	0.3 (a)		4.9 (b)	(1)
		1.2	4.7 (c)	(2)
	0.4 a (e)	1.2 a	3.9 b (d)	(3)
		0.5	2.7	(4)

Source: Vos and Bridge, 2006

(a) 1,3-D, pic; (b) gall index: 0 (no galls) to 5 (high); (c) gall index: 1 (1-2 galls) to 5 (>100 galls); (d) index 0 (zero) to 5 (100%); (e) metham sodium

Data sources: (1) Ganz *et al.*, 2005; (2) Besri, 2003; (3) Bogoescu *et al.*, 2004; (4) Miguel, 2002

Crop yields – The yield of some types of grafted tomato plants was found to be 2 or 2.4 times greater than the yield of conventional non-grafted plants in Italy (Spotti 2004). A number of studies and field experience have confirmed that appropriately selected grafted plants + alternative fumigant (or in some cases grafted plants alone) often provide greater yields than MB fumigation, in tomato, pepper and eggplant, as illustrated in Tables 10.4 and 10.5 (Ganz *et al.*, 2005; Budai, 2002; Bletsos *et al.*, 2002; De Miguel, 2002, 2004b; Besri, 2000, 2003). In the case of tomato, the yield of grafting + alternative fumigant is about 6% to 23% higher than MB fumigation (Table 10.4)

Table 10.4. Tomato: comparison of crop yield using MB fumigation, grafted plants + alternative fumigant, grafted plants alone and non-grafted plants

MB + non-grafted plants	Grafted plants + alt. fumigant (a)	Grafted plants	Non-grafted plants, control	Source
24.8 t/1000m^2	30.0 t/1000m^2	25.5 t/1000m^2	14.6 t/1000m^2	(1)
24.8 t/1000m^2 (b)	26.5 – 30.5 t/1000m^2	22.0 – 29.0 t/1000m^2	13.0 t/1000m^2	(1)
112 b t/ha	138 a t/ha	129 a t/ha		(2)
	133 a t/ha	122 ab t/ha	97 c t/ha	(2)
		134 a t/ha	121 a t/ha	(3)
		174 b t/ha	151 a t/h	(3)
	122 a t/ha		97 b t/ha	(4)
		200 – 240 yield index (c)	100 yield index	(5)

Source: Vos and Bridge, 2006
Numbers in the same row followed by the same letter are not significantly different (in most cases P=0.05)
(a) 1,3-D pic or metham; (b) estimated; (c) Various grafted rootstock in Italy: Bridgeor, Heman, Nun.9712, BX1677647

Data sources: (1) Ganz *et al.*, 2005; (2) Bogoescu *et al.*, 2004; (3) Besri, 2003; (4) Minuto *et al.*, 2003b; (5) Spotti, 2004;

Table 10.5. Eggplant and pepper: comparison of crop yield using MB fumigation, grafted plants and non-grafted plants

Crop	MB + non-grafted plants	Grafted plants	Non-grafted plants, control	Source
Eggplant	3125 a g	3322 a g	1472 b g	(1)
Eggplant		20.5 b kg/plant	13.1 a kg/plant	(2)
Eggplant		45.5 b t/ha	27.5 c t/ha	(3)
Sweet pepper	12-13 kg/m^2	16.5 kg/m^2		(4)
Sweet pepper		12.2 kg/m2	6.5 kg/m2	(5)

Source: Vos and Bridge, 2006
Numbers in the same row followed by the same letter are not significantly different

(1) Bletsos *et al.*, 2002; (2) Khah, 2005; (3) Rashid *et al.*, 2004; (4) Budai, 2002; (5) Clerc and Lanave, (undated)

Costs and profitability - The cost of grafted plants + 1,3-D or pic in Italy generally competes favourably with the cost of MB fumigation (Spotti, 2004). Table 10.6 provides an example of the costs in Ragusa, Sicily, where the production cost of MB fumigation is similar to the cost of grafted plants + alternative fumigant: about 46,250 and 45,906 €/ha, respectively. The net revenue from grafting + fumigant is higher than from MB fumigation: 28,600 €/ha compared to 24,700 €/ha.

Table 10. 6. Comparison of tomato production cost using MB fumigation and grafting in Ragusa, Sicily

Item	MB fumigation (€/ha)	Grafted plant + alternative fumigant (€/ha)
Mechanical operations for soil preparation	2,000	2,000
Chemical fumigation	5,400	2,200 (a)
Other materials for preparation	3,900	3,900
Purchase of transplants	5,250 (b)	7,950 (c)
Transplanting	500	500
Cultural operations, covers, pesticides	18,700	18,700
Fertigation, irrigation	7,500	7,500
Harvesting	3,000	3,180
Production costs	**46,250**	**45,930**
Gross income (marketable yield x price)	70,950	75,207 (d)
Gross net revenue	**24,700**	**28,600**

Source: Vos and Bridge, 2006

(a) metham or 1,3-D; (b) Planting density of non-grafted plants estimated 2.5 plants/m2; (c) Planting density grafted plants estimated 1.5 plants/m2 (De Miguel, 2004b) @ average 0.53 €/plant in south Italy (Morra and Bilotto, 2005); based on 6% increase in yield but in some cases the yield is significantly greater

Data sources: Russo *et al*., 2005; De Miguel, 2004b; Morra and Bilotto, 2005; Ministry of the Environment and Territory, 2005

Current situation

By 2004 alternative fumigants, in some cases combined with grafted plants, had been adopted on large areas of production that previously used MB in Italy:
Protected tomato: the use of alternative fumigants increased to 53% (2,753 ha) of the total fumigated area (5,241 ha), overtaking the use of MB for the first time in this crop
Protected pepper: the use of alternative fumigants reached 80% (2,051 ha) of the total fumigated area in this crop (2,551 ha)
Protected eggplant: the use of alternative fumigants reached 78% (1392 ha) of total fumigated area in this crop (1,792 ha) in 2004 (Vos and Bridge 2006).

The reduction of MB use has continued since 2004 and further growers have adopted alternatives. The CUEs authorised by the EC and Member States in 2007 were 80 tonnes MB for tomato, 50 tonnes for pepper and 0 tonnes for eggplant.

Lessons learned

The use of grafted plants was initially impractical for growers, but became feasible when nurseries started producing and selling grafted plants. Considerable problems surfaced initially among growers who were rather fixed in their habits with regard to the use of MB. The use of grafted plants required better farming skills than in the past. The work carried out by agronomists and specialised licensed fumigators in Italy was therefore crucial in informing farmers about soil preparation and other factors, and in checking the suitability and safety of irrigation systems when applying fumigants (Spotti, 2004). Growers found that the waiting period was longer in regions where fumigations are carried out in cool seasons; however most growers addressed this issue by carrying out fumigations earlier or at a different time of year (Vos and Bridge, 2006) .

Growers found that grafting provided good performance in terms of conformity in size and resistance to cold in winter (Spotti, 2004). In Sardinia it was noted that the further uptake of grafted plants by growers will depend strongly on future consumer preferences for tomato varieties. If consumers increasingly favour traditional, specialised varieties, the use of grafted plants will certainly expand. But if consumers favour large-production hybrids, growers are likely to favour resistant hybrids more than grafting (Leoni *et al.* 2004).

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Case Study 3. Spain - Phaseout of Methyl Bromide in pepper production

Non-chemical alternatives to MB for soil disinfection in pepper crops have been evaluated and are being increasingly adopted in Spain. They show that integrating practices like biofumigation with fresh pepper crop residues, chicken manure and sheep manure, biosolarisation, and grafting on resistant rootstocks, can be as effective as MB for controlling plant parasitic nematodes and fungi. MB consumption in Spain has been reduced by 96% since 1997.

Initial situation

About one million tonnes of pepper are produced each year in Spain, accounting for 7.6% of the total volume and 13.5% of the value of vegetables produced in the country. Pepper is grown mainly in Andalusia (64.8% of total production), Murcia (15.0%) and Castilla-La Mancha (5.9%). The total area grown with peppers is 22,388 ha. 98.4% of this area is irrigated; 55.2% is under glasshouse (mainly Murcia and Andalusia) and 44.8% in open fields (MAPA, 2003). In Southern Spain, where most of pepper is grown, the crop season extends from January (transplant) to July (last harvest) and farmers usually grow peppers continuously, without crop rotation.

As a result of the intensive cultivation system and lack of crop rotation, sanitary problems and "soil exhaustion" have become a problem in pepper fields, and causing dramatic losses unless precautions are taken. The main pathogens are root knot nematodes (*Meloidogyne incognita*) and fungi, particularly *Phytophthora capsici*. These two key pests required fumigation with MB until recently; in fact, Spain requested CUN's for pepper crops in recent years.

Actions for replacing MB

Since 1997, several projects coordinated by the Spanish Ministry of Environment with participation of the Ministries of Education and Science and of Agriculture, have been undertaken with the aim of evaluating chemical and non-chemical alternatives to MB. Additionally, ministerial laws have been issued to reduce the dosage and concentration of MB, and awareness-raising activities such as seminars, conferences and workshops on the subject have taken place (Bello *et al.*, 1998; Lacasa *et al.*, 2004).

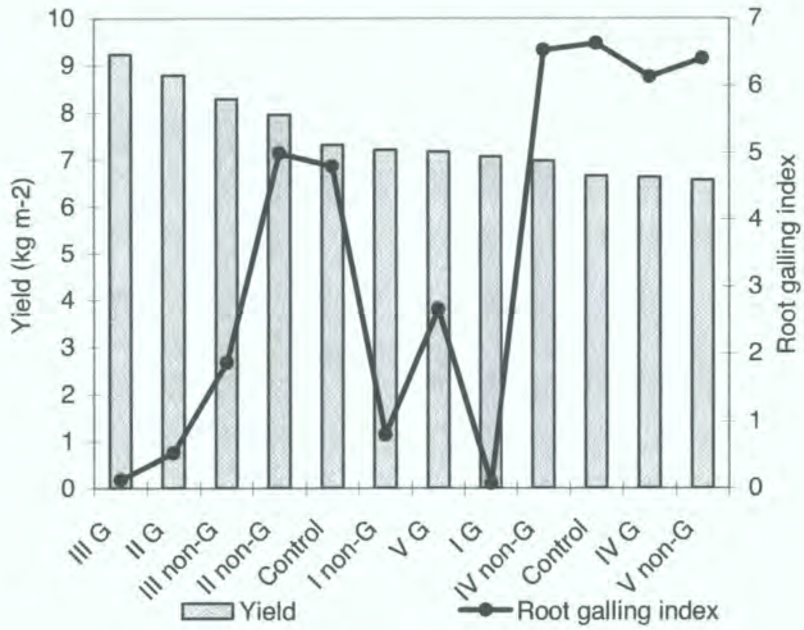
Description of the alternatives implemented

The following non-chemical alternatives were evaluated: biofumigation with fresh pepper crop residues, chicken manure and sheep manure; biosolarisation; and grafting onto resistant pepper rootstocks (Lacasa *et al.*, 2004; Piedra Buena *et al.*, 2006). These treatments were compared with MB and an untreated control. Each treatment consisted of three replicate plots measuring 3 x 18 m each (54 m^2) and each replicate had two rows: one with susceptible peppers grafted on rootstocks resistant to *M. incognita*, and the other with non-grafted susceptible peppers. The control treatment consisted of non-grafted plants only. Biofumigation was carried out for 12 weeks, from mid-August to the beginning of November, at which time MB was applied. Pepper plants were transplanted two months later. At the end of the cultivation period (August) root galling indices and commercial yields were evaluated.

Results are presented in Figure 10.7. Biofumigation alone (without plastic cover) was not as effective as biosolarisation in reducing root-galling indices. On the other hand, grafting susceptible pepper plants on resistant pepper rootstocks significantly reduced root galling indices, indicating that grafting is a good alternative for nematode control. However, it was also observed that the repeated use of grafted plants in the same field eventually leads to a loss of effectiveness, possibly due to the selection of virulent populations of *M. incognita*. Incorporation of pepper crop residues along with fresh sheep or chicken manures together with solarisation enhanced the biofumigation effect, with satisfactory results as measured through root galling indexes.

Highest commercial yields were obtained from grafted plants grown in soil treated with biosolarisation plus pepper residues, fresh chicken and sheep manure applied for three consecutive years. These yields were not statistically different from non-grafted plants grown with the same treatment or grafted plants in similar circumstances but where treatment had been applied for two consecutive years only. Most of the other treatments produced intermediate yields, statistically different from the highest but similar to the two following treatments. Lowest yields were obtained with the control and with non- grafted plants in soil treated with biofumigation plus fresh pepper residues, fresh chicken and sheep manure applied for two and three years.

Figure 10.1. Commercial yields (kg m^{-2}) of pepper plants at the end of the cultivation period.



Control: no disinfected soil, without grafting and without plastic cover; treatment I: MB 98:2 (30 g m^{-2}) + pepper crop residues, with plastic cover; treatment II: biosolarisation with fresh sheep manure (4 kg m^{-2}) and fresh chicken manure (1.5 kg m^{-2}), for 3 consecutive years; treatment III: biosolarisation with pepper crop residues, fresh sheep manure (4 kg m^{-2}) and fresh chicken manure (1.5 kg m^{-2}), for 3 consecutive years; treatment IV: biofumigation with pepper crop residues, fresh sheep manure (4 kg m^{-2}) and fresh chicken manure (1.5 kg m^{-2}), for 3 consecutive years; treatment V: biofumigation with pepper crop residues, fresh sheep manure (4 kg m^{-2}) and fresh chicken manure (1.5 kg m^{-2}) for 2 consecutive years; G: grafted; non-G: non-grafted.

Commercial yields agree with root galling indexes observed in pepper plants at the end of the crop season. This was particularly true for the three higher and four lower yields, while the intermediate values showed a least consistent relationship with root galling indices.

Results obtained under laboratory and greenhouse conditions show that a system using pepper crop residues (PCR) for biofumigation, combined with nitrogen-rich organic matter such as fresh sheep manure and fresh chicken manure and covered with plastic for solarisation, is an efficient alternative to MB. This is particularly true when the pepper crop is grafted onto rootstocks that are resistant to *M. incognita*. However, it should be noted that repeated use of resistant cultivars could lead to the selection of virulence in *Meloidogyne* populations (Robertson *et al.*, 2006). When necessary, additional control methods for nematodes are used in combination with grafted plants.

Current situation

In 1995, MB consumption in Spain for pepper production totalled 1,176 tonnes in the Alicante, Almeria and Murcia provinces (Bello *et al.*, 1998). In 2007, MB consumption was reduced to about 50 tonnes of MB as a CUE for Murcia and

Alicante. Historical consumption is illustrated in Table 10.7.

Table 10.7. Historical consumption of MB in peppers in Spain

Total MB consumed * (metric tonnes)					Total CUN MB nominated (metric tonnes)			
1997	**1998**	**1999**	**2000**	**2001**	**2005**	**2006**	**2007**	**2008**
1,150	574	581	572	591	150	50	0.07 for research	0.07 for research nominated

* As reported by the Party.

The first strong decline in consumption occurred in 1997 and was due to the compulsory use of VIF, which reduced average dosages from 60 g/m^2 in 1997 to 30 g/m^2 (MB:chloropicrin 98:2 and VIF plastic), and to 40 g/m^2 (MB:chloropicrin 67:33 and VIF plastic) in 1998 and subsequent years. After that, the expanded adoption of biofumigation, biosolarisation, soilless culture, alternative chemicals and other techniques (Lacasa *et al.*, 2004) led to an average replacement rate of 91 tonnes per year.

Provided by Antonio Bello, MBTOC member, A. Piedra Buena Díaz and M. A. Díez-Rojo, Dpto. Agroecología (CCMA-CSIC) c/Serrano 115 dpdo 28006 Madrid-SPAIN

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Case study 4. Spain - Use of alternative fumigants in strawberry fruit production

Spain is the second largest producer of strawberries in the world, producing approximately 308,000 tonnes in 2005, and exporting about 226,820 tonnes. The MB-fumigated area reached a peak of 5,981 ha in 2004, the year before the scheduled phaseout date, when about 90% of the crop used MB. However MB use was reduced to about 45% of the crop area (approx. 3,200 ha) in 2005, and to 30% of the crop area (1,800 ha) in 2006. In 2007, only a small amount of MB entirely destined for research purposes was requested to the Parties of the Montreal Protocol.

Initial situation

Spain is the second largest producer of strawberries in the world, producing approximately 308,000 tonnes in 2005, and exporting about 226,820 tonnes (FAO, 2006). Strawberry production is concentrated mainly in the southern Huelva region where 85-90% of strawberry production occurs in about 7000 ha in 2005. The sector comprises more than 2000 farms of 0.5 to 10 ha in size and employs 60,000 people either directly or in related sectors (Moral, 2005).

The continuous production of strawberry fruit, year after year, promotes 'soil fatigue' and many soilborne pests such as nematodes, e.g. *Meloidogyne* spp., *Pratylenchus penetrans,* fungi, e.g. *Phytophthora cactorum, Verticillium dahliae, Rhizoctonia* spp., *Fusarium* spp., *Phytium* spp. and weeds, e.g. *Cyperus rotundus*
In 1994 MB was used on about 3,500 ha of strawberries in Spain, including 64% of the Huelva production area (Bonté, 1995). This area increased during the second half of the 1990s, until in 1999 about 97% of strawberry growers in Huelva used MB; heavy reliance on this fumigant continued until recently (Calatrava, 2002; Moral, 2006). The MB-fumigated area reached a peak of 5,981 ha in 2004, the year before the scheduled phaseout date, when about 90% of the crop used MB. However MB use was reduced to about 45% of the crop area (approx. 3,200 ha) in 2005, and to 30% of the crop area (1,800 ha) in 2006.

Use of MB was reduced by about 2,571 - 2,784 ha/year in 2004-5 (Table 10.8). In 2007, only a small amount of MB entirely destined for research purposes was requested to the Parties of the Montreal Protocol.

Table 10.8. Historical trends in use of MB in strawberry fruit in Spain

Year	MB use (tones)	MB-fumigated area (ha)
1994	1,106	3,500
1995	964 or 1,225	3,045
1996	1,225	3,052
2000	800	n.d.
2002	556	5,560
2004	598	5,981
2005	319 or 341	3,197 or 3,410
2006	180	1,800

Sources: Bonté, 1995; Bello *et al.*, 2001; Varés, 1998; Moral, 2006; EC 2006a; Maczey *et al.*, 2006; López-Aranda *et al.* 2006b

Actions for replacing MB

Growers in this case study include large, medium and small farms, and even family run operations; they carry out intensive strawberry fruit production on raised beds covered with plastic mulch in plastic tunnels and greenhouses. The sector is highly specialised and produces only strawberry fruit; there is little or no crop rotation. The climate is Mediterranean moderated by influence of the Atlantic sea. Rainfall is about 516 mm, with temperatures of 19–32°C in summer and 7–17°C in winter; soil types comprise sandy soil (about 60%) and loam to clay-loam soil (about 40%). Varieties are primarily short-day varieties, mainly Camarosa, some Ventana and Spanish varieties; plants are planted in October, with the harvest generally starting in January and continuing until June (Vos and Bridge, 2006).

Fumigation is typically carried out in August to September when the temperature is about 25-30°C. Several alternatives are available for strawberry fruit production in Spain (EC 2005; 2006b): Pic, 1,3-D, metham sodium, metham potassium, dazomet; nematicides e.g. enzone, fungicides, herbicides; short solarisation + fumigant; resistant varieties + fumigant or other treatment; substrates (used on 60 ha in 2004, about 130 ha in 2005, and 160 ha in 2006).

Few farms used alternatives in 2004, however in 2005 51% of the strawberry crop in Huelva used alternatives, and this increased to 70% in 2006 (López-Aranda *et al.*, 2006b). A mixed formulation of 1,3-D+pic was first registered provisionally in Spain for strawberry in 2000. Subsequently both drip-applied and shank-injected formulations were registered with varying proportions of pic for fungicidal properties and 1,3-D for nematicidal properties (Carrera *et al.*, 2004). 1,3-D+pic was used on approx. 2,400 ha in 2006 (Maczey *et al.*, 2006; López-Aranda *et al.*, 2006b). Pic was registered recently and used on about 160 ha strawberry in Huelva in 2005, rising to approx. 600 ha in 2006 (Maczey *et al.*, 2006; López-Aranda *et al.*, 2006b). 1,3-D+dazomet was estimated to be used on about 140 ha strawberry in Huelva in 2006 (López-Aranda *et al.*, 2006b). Metham has been registered for a number of years and was used on about 1,500 ha strawberry fruit in Spain, including approx. 900 ha in Huelva, in 2006 (EC 2006b; López-Aranda *et al.*, 2006b; Vos and Bridge, 2006)

Description of the alternatives implemented

The farms that adopted alternatives early did so mainly because of increases in the price of MB, and to ensure the continuity of production in the face of MB phaseout. Applying alternative fumigants was not difficult for farmers because fumigation companies did a large proportion of the work. The most important problem was the farmers' lack of knowledge about alternatives and reliance on MB for many years. Problems were overcome by conducting trials and demonstrations that compared alternatives with MB, and fumigation companies provided technical support to growers (Carrera, 2004). They found it useful that alternative fumigants can be applied either by mechanical injection or via the irrigation system, providing more flexibility (Vos and bridge, 2006).

The fumigants degrade quickly in the soil and leave no residues in plants or fruit. Initially there were concerns expressed about potential water pollution from 1,3-D, however a large study took 5,000 water samples in localities that use a lot of 1,3-D in Spain and three other European countries; they found residues in only 2 of 5,000 water samples. Fumigators found that alternative fumigants are safer to handle than

MB because they are liquids rather than pressurised gas, decreasing the risks to operators (Peguero, 2004). Some farmers have now used alternative fumigants every year for more than 5 years for strawberry production in Huelva without a reduction in crop yields.

Efficacy - control of soilborne pests - Pic has been shown to be very effective against major soilborne fungi affecting strawberries e.g. *Verticillium dahliae, Phytophthora fragariae* (MBTOC, 2002). It is a weak nematicide and can kill some germinated weed seeds (MBTOC, 2002; Porter *et al.*, 2002). There is now wide acceptance that when nematode pressures are low, pic alone is as effective as MB for control of fungal pathogens and for improved growth and yield responses (MBTOC, 2002).

1,3-D is highly effective against nematodes; at suitable rates it also provides effective control of insects and suppresses some weeds and pathogenic fungi (MBTOC 2002). Metham is effective for controlling a wide range of arthropods, soilborne fungi, nematodes and weeds when applied using appropriate methods (MBTOC, 2002; Rabasse, 2002; Haglund, 1999; McKenry, 2001).

Combinations of Pic, 1,3-D or metham (with VIF when appropriate) can be as effective as MB in strawberry fruit, depending on the application methods (López-Aranda *et al.* 2004c; Miranda *et al.* 2005; Ajwa *et al.*, 2003; 2004; Nelson *et al.* 2002; TEAP, 2006). Additional weed control practices may be used when necessary. Good soil preparation and application methods that distribute fumigants uniformly in the soil make an important contribution to efficacy and the consistency of results. Combining alternative fumigants with VIF generally enhances performance and pathogen control in strawberry (López-Aranda *et al.*, 2004b, 2004c; Ajwa *et al.*, 2004; Fennimore *et al.*, 2004; Duniway *et al.*, 2003; Martin, 2001). VIF also improves control of weeds, including difficult-to-control weeds such as yellow nutsedge (Fennimore *et al.*, 2003; Ajwa *et al.*, 2004).

Crop yield - Fumigators found by 2004 that 1,3-D+pic generally provided yields comparable with MB fumigation (Carrera, 2004). Researchers who carried out eight years of trials and commercial validation work in Huelva (1998-2005) concluded that the average yield and fruit weight obtained with 1,3-D+pic or pic alone (normally with VIF) are similar to those obtained with MB (López-Aranda *et al.*, 2004ab, 2004c; Miranda *et al.*, 2005). There is no loss in fruit quality, nor in the timing of harvest. Similar yields from MB and alternative fumigants have been found in other regions of Spain that produce strawberry fruit (Cebolla *et al.*, 2002). Average yields obtained from Pic+VIF are also similar to the standard MB treatment in Huelva (López-Aranda *et al.*, 2004a, 2006b). Pic has also provided yields comparable with MB in other countries (Porter *et al.* 2004; TEAP, 2006). Pic+MS also provides strawberry fruit yields that are comparable with MB (Ajwa *et al.*, 2003; 2004; Porter *et al.*, 2004; Gilreath *et al.*, 2003; TEAP 2006).
Table 10.9 presents marketable yield obtained with MB and alternative fumigants.

Table 10.9. Marketable yield, MB and alternatives in strawberry fruit, Spain

Marketable yield					units	Source
MB/pic	1,3-D+pic (d)	Pic (d)	pic + metham (d)	untreated control		
499 ab	540 a	511 a		304 d	g/plant (a)	(1)
619 abcd	674 ab	683 a		510 fg	g/plant (a)	(1)
1022 ab	1081 a	1008 ab		791 d	g/plant (b)	(2)
1064 ab	1019 ab	1091 a	973 ab	704 c	g/plant (b)	(2)
1256 a	1226 a	1295 a	1229 a	897 b	g/plant (b)	(2)
1175	1175			640	g/plant	(3)
66.5 a	70.2 a	68.8 a		46.6 c	t/ha (c)	(4)
37	38			(e)	t/ha	(5)
1103	1067			(e)	g/plant	(6)
1336	1411			(e)	g/plant	(6)
1292	1330			(e)	g/plant	(6)
964	962			(e)	g/plant	(6)
971	952			(e)	g/plant	(7)
1055	1112			(e)	g/plant	(7)

Source: Vos and Bridge, 2006

Data sources: (1) López-Aranda *et al.* 2004a; (2) López-Aranda *et al.* 2004c; (3) Peguero, 2004; (4) López-Aranda *et al.*, 2006b; (5) Moral, 2005; (6) Miranda *et al.*, 2005; (7) Miranda *et al.*, 2003. Treatments in a row followed by the same letter do not differ significantly; (a) Average yield of 4 years (1997-2001); (b) $P \leq 0.01$; (c) 5% significance level, based on Fisher's protected LSD test; (d) In some cases VIF was also applied; (e) Commercial demonstrations therefore no untreated control

Costs and profitability

The cost of 1,3-D+pic was about 17% less than MB for strawberry fruit in Huelva in 2004: MB fumigation was about 1,583 €/ha, while the cost of 1,3-D+pic (injected) was about 1,303 €/ha (Carrera *et al.*, 2004). In 2006 the costs and net revenue in Huelva were reported as follows (Moral, 2006):

- MB: 858 €/ha cost; 4371 €/ha net revenue
- Pic+1,3-D: 817 €/ha cost; 4691 €/ha net revenue

The cost of the alternative fumigants is typically lower than MB in Europe and the Mediterranean. Since the yield and quality of fruit is the same, fumigant alternatives generally provide greater net revenue for growers, as illustrated in Table 10.10.

Table 10.10. Cost comparison of MB and 1,3-D+pic in strawberry fruit production in Spain

Cost items	MB fumigation €/ha	1,3-D+pic fumigation (injected) €/ha
Fumigant (applied at 200 kg/ha)	920 (4.60 Euro/kg)	640 (3.20 Euro/kg)
Plastic sheet (415 kg/ha)	519	519
Fumigation fee (labour)	144	144
Total	**1583**	**1303**

Source: Carrera *et al.*, 2004; Peguero, 2004; Vos and Bridge, 2006.

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Case Study 5. The Netherlands - Alternative practices in open field forest- tree nurseries, cut flowers and bulbs

In the past, The Netherlands was one of Europe's largest consumers of MB for soil fumigation, using about 3,000 tonnes in the late 1970s, which then rose to about 5,000 tonnes around 1981. During the late 1970s the Dutch Government set up *several inter-Ministerial working groups to conduct research on the long-term acceptability of MB. The phaseout was implemented almost immediately, and was achieved between 1981 and 1991.*

Initial situation

The Netherlands is an important supplier of horticultural crops to Europe, producing large volumes of nursery plants, bulbs, cut flowers, strawberries, tomatoes and others. Tree nurseries and bulbs for example, are produced on tens of thousands of hectares and exported to many countries in the region. Growers range from highly capitalized to those with very few resources.

In the past, the Netherlands was one of Europe's largest consumers of MB for soil fumigation, using about 3,000 tonnes in the late 1970s, which then rose to an estimated 5,000 tonnes around 1981. It was widely used for both open field and protected crops.

Soilborne pests and diseases controlled with MB in tree nurseries, cut flowers and bulbs included nematodes, e.g.. *Meloidogyne* spp., *Rotylenchus robustus* and *Pratylenchus penetrans;* fungal pathogens, e.g. *Phytophthora* spp., *Verticillium* spp. *Fusarium* spp., *Pythium* spp., *Rhizoctonia* spp., *Sclerotinia* spp.; and weeds of many kinds including *Cyperus* sp. (yellow nutsedge)

Actions for replacing MB

During the late 1970s the Dutch Government set up several inter-Ministerial working groups to conduct research on the long-term acceptability of MB. One working group examined the effectiveness, practicality and financial aspects of alternatives. Other working groups examined MB's toxicity; its pollution potential in water, food and air; and safety risks to workers and communities. In 1981 the Dutch government decided to phaseout most uses of MB as a soil fumigant due to the occurrence of serious worker accidents, water contamination, food residues, toxicity concerns, risks from stored MB cylinders, and air pollution in regions where fumigations were carried out (Parliamentary Session, 1981). The phaseout was implemented almost immediately, and was aimed at ceasing most soil uses by September 1983. Use of MB was prohibited in situations where soil could be steamed. They aimed to phaseout MB for tree nurseries, gladioli and bulbs by June 1982, and to reduce MB use in other flower crops and greenhouse vegetables as much as possible (Parliamentary Session, 1981). As a result, 80 – 90% phaseout occurred in one year.

The MB reduction and phaseout measures adopted in the Netherlands included: lowering doses by using less permeable plastic film; issuing permits for each MB fumigation case by case; prohibiting MB use where alternatives were available; and for an initial period, providing grants to assist growers to invest in steam equipment (Prospect, 1997). Phaseout was assisted by innovative fumigators and companies who developed improved application methods for steam and metham; researchers, agricultural advisers, and industry-government cooperation (UNEP, 1992; Prospect, 1997). As a result, the majority of MB uses were prohibited and ceased approximately within a year. Small uses continued in the soil sector until 1991. All remaining MB soil fumigation was banned by 1992.

During and following MB phaseout the techniques for steaming, substrates and application equipment for alternative fumigants (e.g. metham sodium and dazomet) were improved and made more effective through work undertaken by fumigators, growers and research institutes.

Description of alternatives implemented

The main alternatives adopted in the open field nursery sector were metham sodium and containerised plants. Metham sodium is the main soil fumigant used in the Netherlands, although dazomet is also used to a lesser extent. In open field flowers and bulbs, metham was adopted. In chrysanthemums steam is the main alternative because this method controls certain pest species that MB was unable to control. In protected nursery production, the main alternatives adopted were steaming, substrates and container plants.

The case of the Boomkwekerij Dries Luijten B.V. forest tree nursery provides an example of nursery production methods (open field and protected cultivation) that do not require MB. 10 ha in this farm are dedicated to producing young conifer plants in plastic tunnels, shade houses and open fields. The nursery comprises 7,000 m² of greenhouse structures for rooting; 5,000 m² of plastic tunnels for the post-rooting stage; 2,000 m² for mother plants production, and another 7.5 ha for growing plants the first year. The nursery is located in Noord-Brabant region; it has predominantly light sandy soils typical of the region, and a temperate Northern European climate. The main alternative used in the greenhouse nursery production is a peat substrate sterilised by steaming. For open field nursery crops it is metham-sodium injected with rotating-spading equipment. This chemical is applied using rotating spading injection fumigation equipment that has been specially designed to provide a more uniform distribution in the soil, at depths up to 40-50 cm if necessary.

In the Netherlands soil fumigants are permitted to be used only once in 5 years, so this treatment is complemented by a crop rotation to control pests: year 1 fumigation followed by conifer nursery crop - year 2 sugar beet - year 3 maize corn - year 4 conifer crop without fumigation - year 5 sugar beet - year 6 maize - year 7 fumigation and conifer crop. However, this crop rotation is not essential; it would be equally effective to use metham fumigation each year instead of crop rotation (Vos and Bridge, 2006).

The metham fumigation is carried out in the fields in the fall (Oct- Nov), sometimes very late in the year when the soil temperature is as low as 6-8 °C. The soil is sealed with a roller and left over winter. In the end of March (spring) the soil is opened with a ripper and the nursery plants are planted out in the beginning of April.

The crop quality is very high, making it easy for these plants to be marketed in a country where there is over-production of nursery plants. The yield and crop quality is better than when MB was used, and better quality than in nurseries in Belgium where MB continued to be used until very recently.

Current situation

Because soil fumigation with MB was a common and important practice in 1980, its removal acted as a catalyst for the development and widespread adoption of new and modified technologies (MINVROM, 1997). As a result, during the phaseout period between 1981 and 1991, Dutch growers maintained, and actually increased, production in crops that at one time depended heavily on MB fumigation (MINVROM, 1997). The alternatives adopted in the Netherlands continued to be improved in the years during and following phaseout, providing a high level of productivity (Prospect, 1997).

The work that was done to achieve this, and the alternatives developed, provided an example of how MB can be phased out in sectors that have depended heavily on this fumigant. It also led to the development and improvement of a number of effective, viable alternatives for open fields and protected cropping (Vos and Bridge, 2006; MINVROM, 1997).

Provided by Marten Barel, Consultant, The Netherlands, MBTOC member

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10.2.2. Alternatives for postharvest uses

Case Study 6. Germany - Sanitation + IPM in mills

Germany used more than 80 tonnes of Methyl Bromide per year in the past, primarily for structures and postharvest uses. Germany was granted a CUE for flour mills in 2005, but the exemption was not used because national authorities did not allow mills to use MB if they could use alternatives. At this time, alternatives used for flour mills and other structures in Germany include sulfuryl fluoride, heat, IPM, and phosphine in some circumstances. A combination of heat + IPM (sanitation), which has proven particularly successful is described.

Initial situation

Germany used more than 80 tonnes MB a year in the past, primarily for structures and postharvest uses. For over four decades, the majority of flourmills in Germany were fumigated with MB during the spring, when outside temperatures were favourable. In some cases, when heavy infestations were present, a second fumigation was required in autumn (Böye and Gürtler, 2005).

The main post-harvest pest species present in flourmills include the red flour beetle (*Tribolium castaneum)* the confused flour beetle (*T. confusum)*, the granary beetle (*Sitophilus granarius)* and the Mediterranean flour moth (*Ephestia kuehniella)* (MBTOC, 2002; Böye. and Gürtler, 2005). Fumigations became necessary especially when pest insects occurred in the sifters. Mill managers stated that often only a few weeks after fumigation with MB, living beetles were found again. One possibility is that not all eggs and pupae of pests had been killed during MB fumigation because pests were observed within one generation of the pest species (Böye. and Gürtler, 2005). Or pests may have re-entered the mill with new shipments of grain, or from populations living in the exterior environment.

Actions for replacing MB

The 2005 deadline for phasing-out MB in non-Article 5 countries led to many efforts to develop alternatives by fumigation companies and milling companies. A number of mills examined heat and IPM practices (particularly sanitation), phosphine, and more recently, sulfuryl fluoride. Although Germany was given a CUE for flour mill treatment in 2005 the exemption was not used because national authorities considered that alternatives were available.

Description of alternatives implemented

Presently, alternatives used for mills and other structures in Germany include sulfuryl fluoride, heat and IPM. Phosphine may be useful in some circumstances. It has been stated that heat treatment alone is too complicated and works only in smaller facilities. However, mills in Germany have reported that heat can be effective even for large mills, when special circumstances are considered, and that cost of heat treatments can be lower than MB fumigation (Böye. and Gürtler, 2005). This case study describes adoption of heat plus IPM in German flourmills.

Sanitation + Heat - In general terms, the heat treatment consists in maintaining the temperature of 50°C or slightly above for 48 hours. The preferred time frame is from Friday afternoon to Sunday afternoon or evening, since this is the best time to undertake the treatment, with minimal impact on production. The temperature is monitored to ensure it does not exceed 56°C, because the technical staff prefer a moderate temperature for 48 hours rather than a higher temperature for a shorter time. Various heat treatment procedures have been tested in Germany in the past, mostly in smaller mill facilities. The best known method in Germany is the ThermoNox procedure with small heating units that are placed inside the buildings.

Heat treatments are performed when insect infestation levels require them. Improved sealing and IPM practices help reduce pest entrance and dissemination, which enhances the efficiency of heat. In particular, it is important to learn to identify pests and set up a system to allow for evaluating pest population density (i.e. insect traps). Thorough sanitation and regular cleaning are extremely important. After the treatment the mill is free of insects for 2 to 3 months, sometimes even longer. In a normal year, one main treatment takes place in April/May and if necessary, a second treatment is performed in September/October.

This alternative is used in a large flourmill, for example, which mills wheat and rye, with a capacity volume of about 40,000 m^3, and a flour silo of 60,000 m^3, producing about 1300 tonnes flour per 24-hour day. Both structures – 100,000 m^3in total - used MB once or twice a year until the 1990's. The mill was about 70-80 years old, and the flour silo and ancillary buildings are about 25 years old. The construction is brick and concrete with some sections in wood and steel. The mill used between 1.2 to 2.5 tonnes of MB per year, and some years up to 5 tonnes. The last MB fumigation took place in 1994/95. It was impossible to work with small heating units as described above, so the mill management decided to use large size external heaters. First trials started in 1995, so the system has now been in place for over 10 years. A comparison of the system with previous MB treatment appears in Table 10.11.

Table 10. 11. Comparison of general features of MB vs. heat + IPM for treatment of flour mills in Germany.

	Methyl Bromide	**Heat + IPM (sanitation)**
Frequency of treatment	Once or twice a year	Once or twice a year
Dosage	Initially with 17 – 25 g m-3 or higher if gastitghtness not sufficient. Later 12 g m-3 by German regulation.	50° C
Exposure time	24 to 48 hrs	24 – 36 hrs
Equipment/ application requirements	Applied by licensed fumigating companies only	10 large external heaters, vacuum machines, temperature metres, ventilators. Can be applied by mill staff as needed
Pest efficacy	Reinfestation often detected 2 – 4 weeks after treatment	Reinfestation 3 months after treatment
Cost		Reported to be at least 30% less than MB in the long term
Other comments		Consumer satisfaction high due to non-toxic nature of treatment. Reduced complaints. No registration needed.

Source: Böye. and Gürtler, 2005

Results

MB was found to be a successful alternative in these mills and related structures. The heat treatment + sanitation (through IPM) provided better pest control levels than MB both in the small and the large mill, provided the method was correctly carried out. Further, the treatment was cheaper than MB.

After 10 years in use, there has been no indication of any heat-related damage and both mills and customers were very satisfied with the treatment.
In the long term, this alternative has been found to offer better technical and cost efficiency than MB. Pest mortality is often 100% and re-infestation only occurs after 3 months or more (re-infestations after 2-4 weeks were reported with MB in the past) (Böye. and Gürtler, 2005).

Overall, this mill is very similar to other large mills in the country that continued to use MB for insect disinfestation until the end of 2004. There are no major differences in terms of construction, products, hiding places for insects etc. The same alternative system has been trialled in smaller mills with equally good results (Böye and Gürtler, 2005).

Lessons learned

In implementing this strategy, it is most important that the entire staff working at the mill supports the program and is involved in the cleaning and heating process. Training and attitude change thus become essential components to ensure success of this alternative system (Böye. and Gürtler, 2005; Böye. and Mück, 2004; MBTOC, 2002).

Adequate cleaning of all machines and the building itself is an essential prerequisite for the heating process. All residues (remnants of flour, dust and dirt) need to be taken out and destroyed. Favourable weather conditions are preferable during the period of heating up the facility avoiding stormy and rainy conditions. Outside temperatures of more than 20°C are favourable. Good sealing improves efficiency of the method; sealed doors and windows are very important to keep insects out during the production process and to hold the temperature in the building during the heat treatment (Böye. and Gürtler, 2005).

Mills that carry out heat treatment themselves have the advantage of being independent of service companies. Whereas normally with MB it is necessary to contract the services of a licensed fumigator, with heat treatment the management can decide whenever they want to start a treatment without relying on third parties, giving more flexibility. It also enables the management to directly supervise procedures such as insect control and cost control. Heat treatment can also be undertaken as spot treatments when localised problem areas are identified through pest monitoring.

Compiled from published literature as cited.

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10.3. Adoption of MB Alternatives in North America

The North American region (comprising the United States and Canada) reduced their MB consumption by 72% in 2005 with respect to the baseline for that region. Although a number of Critical Uses still remain, examples of MB reductions and adoption of alternatives are available.

10.3.1. Alternatives for preharvest uses (soils)

Case study 7. United States - Improved application equipment, alternative fumigants and herbicide combinations in tomato and pepper in Florida

New application equipment and improved application methods were developed for combinations of alternative fumigants (1,3-D, pic, metham) and herbicides in tomato and pepper production in Florida.

<u>Initial situation</u>

Tomato and pepper account for 7% and 3% of Florida's total agricultural receipts. In 2003/4 tomato was produced on 17,159 ha with a value of $500 million, while pepper was produced on 7,487 ha with a value of approximately $218 million (Rosskopf *et al.*, 2005). Soil fumigation with MB has been an important component of the Florida production system since the early 1970s. In 1997 Florida fresh market tomato and pepper production accounted for 24% of the MB consumed in the US for soil fumigation (EPA, 1997), while all crops in Florida used about 38% of the MB used in the US (Chellemi and Browne, 2006). Florida tomato crops used about 3500 tonnes MB in 1994, falling to an estimated 2207 tonnes in 2002. Historically MB was used on all the commercial acreage of pepper in Florida (Mossler *et al.*, 2006). Pepper production used more than 1500 tonnes MB in 1994, falling to about 1000 tonnes in 2002 (Rosskopf, *et al.*, 2005).

The main target pests in tomato are nutsedge (*Cyperus* spp.), *Meloidogyne* spp., *Phytophthora* spp., *Fusarium oxysporum*. The main target pests in pepper are nutsedge (*Cyperus rotundus* and *C. esculentus*), other weeds (*Solanum* spp., *Trifolium repens, Ambrosia artemisifolia*), *Phytophthora* spp., *Rhizoctonia solani*, *Pythium* spp., *Sclerotinia sclerotiorum* and *Meloidogyne* spp. (USG, 2007).

Growers use raised bed plastic mulch systems. Commercial vegetable production takes place throughout Florida in climates ranging from humid sub-tropical to tropical, and soils are sandy with minimal organic matter (Rosskopf *et al.*, 2005).

<u>Actions for replacing MB</u>

Since the mid-1990s the USDA-ARS provided funding to conduct small-plot research and field-scale demonstration/validation studies at multiple sites in the major crops that use MB. Significant funding was also provided by universities, companies, and commodity groups such as the Florida Tomato Committee, Florida Fruit and Vegetable Association and Florida Strawberry Growers Association (Noling and Gilreath, 2002). During the past 10 years this extensive research effort identified potential technically feasible MB alternatives for some crops (Chellemi and Browne, 2006). However, widespread industry adoption of these alternatives did not occur for several reasons such as: variability in the effectiveness of the alternatives coupled with incomplete knowledge regarding the sources of variation and the means to manage it; the need to combine many of the alternatives with supplementary herbicides or other inputs; failure to demonstrate the benefits from integrating the MB alternatives into a more comprehensive pest management approach; inadequate regionally coordinated efforts to transfer the alternative technologies expeditiously; and regulatory restrictions that limited uses of specific alternatives (Chellemi and Browne, 2006).

In the 1990s initial trials with alternative fumigants using traditional application methods such as parachisels or swept back shanks did not provide satisfactory results (MBTOC, 2002). Various edaphic, environmental, biological, and cultural factors are known to influence gas phase movement and thus fumigant treatment performance and consistency (Noling, 2006). Research was carried out to identify application methods that provided a more uniform distribution of fumigants in the soil profile. Soil moisture was identified as another key variable responsible for inconsistency seen in some alternative treatments, and as a result optimum soil moisture levels were identified for several alternative treatments. Uniform incorporation of herbicides was also found to be essential to avoid early season phytotoxicity and so ensure adequate yields (MBTOC, 2002). By 2004 more than 21 large-scale demonstration/validation trials were carried out using improved equipment and application methods for 1,3-D/pic + herbicides in Florida, suitable for areas not subject to karst restrictions. Information about these alternatives was made available to growers in various regions through demonstration trials, extension talks and popular press articles in the last three years (MBTOC, 2002).

The Montreal Protocol controls and increased MB prices led to reduced use of MB (Noling and Gilreath 2002). Recent further increases in MB prices and the potential diminishing supply of MB are also anticipated to influence growers' decisions (Noling *et al.*, 2006).

In 2006 the USDA-ARS established an Area-Wide Pest Management programme on alternatives to MB. The work focuses on pre-plant MB alternatives for soil fumigation in South Atlantic and Pacific regions (i.e. South-Eastern states and California), for the production of food crops, ornamentals and plants for planting (Chellemi and Browne, 2006). The Area-Wide Pest Management project supports: the establishment and completion of field trials with MB alternatives; collection and analysis of data from trials; research to facilitate transition to MB alternatives; and educational outreach designed to demonstrate and transfer the technology and pest management concepts to affected industries and institutions. In cooperation with growers and institutions representing the affected industries, scientists and educators will test and optimise MB alternatives in commercial-scale field trials and transfer resulting concepts, assessments, and technology needed for adoption of MB alternatives. A key goal of the project is to sustain the economic competitiveness of the affected industries while facilitating their transition to MB alternatives (Chellemi and Browne, 2006).

Description of alternatives implemented

One of the methods comprises deep placement coulter equipment for the injection of 1,3-D and pic and appropriate methods for the incorporation of herbicides (e.g. napropamide, trifluralin or others). Twenty-one large scale demonstration/validation trials were conducted on 12 tomato and pepper farms in Florida from 2000-2004, summarised in Table 10.12. The soilborne diseases studied were Fusarium wilt and crown rot in tomato and Phytophthora blight in pepper. Disease control was equivalent (within 5% of adjacent MB fumigated areas) in 19 trials, inferior in one and superior in one, as indicated in Table 10.12 (Rosskopf *et al.*, 2005). Nematode control was equivalent in all trials. Weed control was initially inferior in 2000, but following improvements it was equivalent in all cases but one after 2000 (Table 10.12). Repeated applications in the same field over several years did not lead to an increase in soilborne pests (Rosskopf *et al.*, 2005).

Table 10.12. Results of commercial field demonstration/validation trials for broadcast chemical alternatives.

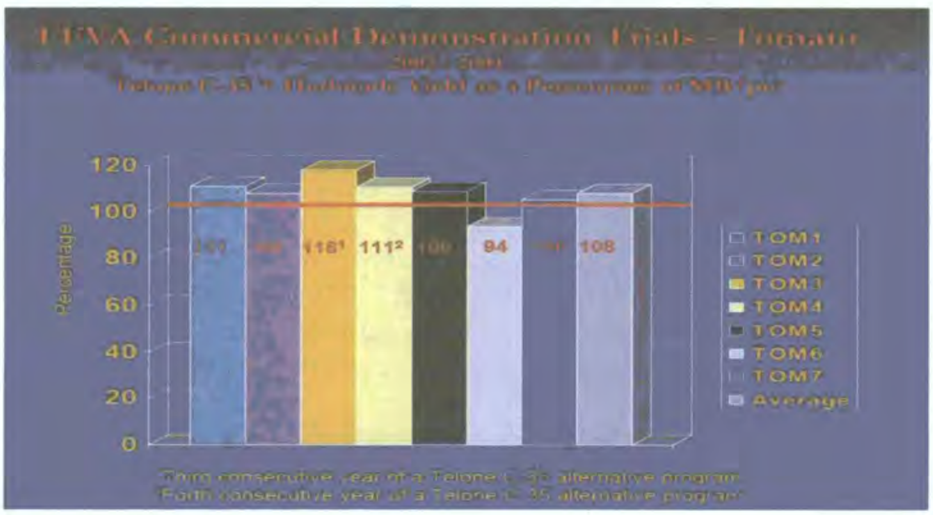
Site	Year	Crop	Comparison relative to adjacent methyl bromide fumigated areas				
			Size (ha)	Disease	Weeds	Nematodes	Yield
1	2000	tomato	4.1	equivalent[v]	inferior[w]	equivalent	ND[x]
2	2000	tomato	5.4	equivalent	Inferior	equivalent	ND
3	2000	tomato	3.2	equivalent	Equivalent	equivalent	ND
4	2000	pepper	4.7	equivalent	Equivalent	equivalent	ND
5	2000	pepper	4.8	equivalent	Equivalent	equivalent	ND
6	2000	pepper	1.6	equivalent	Equivalent	equivalent	ND
7	2000	pepper	0.9	equivalent	Equivalent	equivalent	ND
8	2000	tomato	0.8	equivalent	Equivalent	equivalent	ND
9	2000	tomato	4.0	equivalent	Equivalent	equivalent	ND
1	2001	tomato	46.0	equivalent	Equivalent	equivalent	ND
4	2001	pepper	20.0	equivalent	Equivalent	equivalent	ND
5	2001	pepper	32.0	equivalent	Equivalent	equivalent	ND
7	2001	pepper	0.9	equivalent	Equivalent	equivalent	ND
1	2002	tomato	20.0	equivalent	Equivalent	equivalent	+17%
7	2002	pepper	0.9	equivalent	Inferior	equivalent	+15%
10	2002	tomato	1.2	equivalent	Equivalent	equivalent	-7.5%
1	2003	tomato	10.1	equivalent	Equivalent	equivalent	+18%
11	2003	pepper	10.0	equivalent	Equivalent	equivalent	-11.5%
12	2003	pepper	3.6	superior[y]	Equivalent	equivalent	+14%
11	2004	pepper	13.5	Inferior	Equivalent	equivalent	-7%
1	2004	tomato[z]	10.1	equivalent	Equivalent	equivalent	-15%

Total area treated 197.8 hectares
Total area treated 494.5 acres
[v]Levels within 5% of adjacent methyl bromide: chloropicrin fumigated area.
[w]Levels 5% or more above adjacent methyl bromide fumigated area.
[x]Not determined.
[y]Levels 5% or more below adjacent methyl bromide fumigated area
[z]Fields were prepared for planting (disked and plastic mulched beds) 4-6 days after broadcast application was made.
Source: Rosskopf *et al.* 2005

The Florida Fruit and Vegetable Association initiated seven commercial demonstration trials in tomato in 2002-2004. In 6 of the 7 commercial trials 1,3-D/pic + herbicides provided higher yields than the MB standard, and in one commercial trial the yield was lower (Figure 10.2).

Figure 10.2. FFVA commercial demonstration trials – tomato, 2002-2004

Yield of Telone C-35 + herbicide as percentage of yield of MB/pic



Source: Chellemi and Browne, 2006

To permit the fumigation of existing mulched beds without drip irrigation systems, 'Under Bed Fumigator' equipment was invented to inject fumigants into the soil (Chellemi and Mirusso, 2004). The application of 1,3-D/pic under VIF dramatically improved the retention of fumigants in soil (Rosskopf *et al.*, 2005). This soil disinfestation program was validated in six large-scale trials conducted on commercial tomato and pepper farms, providing 3-8% higher yield than adjacent MB fumigated areas in the 4 trials where yields were reported, as shown in Table 10.13 (Rosskopf *et al.*, 2005). In other studies, 1,3-D/pic + herbicides (e.g. napropamide) was found to provide tomato yield comparable with MB (Gilreath and Santos, 2004). Studies on the long-term effect of fumigants and herbicides in bell pepper also identified several combinations that provided yields comparable with MB (Gilreath *et al.*, 2003). Some of the above application methods enable the fumigant to be applied by a single operator in a fully enclosed cab equipped with an organic filter, thus removing the need for personal protective equipment for field workers (MBTOC, 2002).

Table 10.13. Commercial field demonstration/validation trials applying 1,3-D/pic into established plastic-mulched beds using 'Under Bed Fumigator' and VIF.

Site	Year	Crop	Size (ha)	Comparison relative to adjacent methyl bromide fumigated areas			
				Disease	Weeds	Nematodes	Yield
12	2003	pepper	0.4	superior[w]	inferior[x]	equivalent[y]	+3%
13	2003	tomato	1.0	Superior	equivalent	equivalent	+8%
13	2004	tomato	2.0	Not determined due to damage from 2 hurricanes			
14	2004	tomato	2.9	Not determined due to damage from 2 hurricanes			
15	2004	tomato	0.2	Equivalent	equivalent	equivalent	+7.5%
16	2005	tomato	2.5	Equivalent	equivalent	equivalent	+3.3%

Total area treated 9.0 hectares
[w]Levels 5% or more below adjacent methyl bromide fumigated area
[x]Levels 5% or more above adjacent methyl bromide fumigated area.
[y]Levels within 5% of adjacent methyl bromide:chloropicrin fumigated area
[z]Not determined
Source: Rosskopf *et al.*, 2005

Areas without karst topographical features and having low nutsedge pressure can successfully employ a fumigation system relying on 1,3-D and pic in Florida (USG, 2007). Recommendations for the application of several MB alternative systems were developed for 1,3-D/pic + herbicides; 1,3-D/pic + VIF; 1,3-D/pic + metham; and methyl iodide/pic (Chellemi and Browne, 2006; Rosskopf *et al.*, 2005). Methyl iodide/pic received an experimental use permit for commercial use on 405 ha in south eastern states from October 2006.

In 2004 the alternative fumigant systems cost more than the standard MB treatment, as indicated in Table 10.35 (Rosskopf *et al.*, 2005). However, the price of MB increased from $1350/ha in 2004 to about $3000/ha in 2006 (Mossler *et al.*, 2006).

As a result several alternative systems now have a lower price per hectare than MB (Table 10.14).

Table 10.14. Estimated prices for alternative soil disinfestation programs in Florida fresh market tomato and pepper production.

November 2004 price estimates, with updated MB price in 2006

Methyl bromide standard (67:33), in 2004 and 2006					
Chemical	Price per unit	Application rate per acre: broadcast	Application rate per acre: bed application*	Price per acre	Price per ha
MB:Pic in 2004	$2.70/ lbs	400.00	200.00	$540.00	$1,350.00 in 2004
MB:Pic in 2006	n.d.			$1200.00	$3,000.00 in 2006
Broadcast-based fumigant alternative					
Chemical	Price per unit	Application rate per acre: broadcast	Application rate per acre: bed application*	Price per acre	Price per ha
Devrinol	$10.60/lbs	2 lbs	--	$21.20	$53.00
Treflan	$28/gal	1 pt	--	$3.50	$8.75
Chloropicrin	$2.25/lbs	140.00	70.00	$157.50	$393.75
Telone C-35	$17.50	22.00	--	$385.00	$962.50
			TOTAL	$567.20	$1,418.00
Broadcast-based with Goal applied to bed surface					
Chemical	Price per unit	Application rate per acre: broadcast	Application rate per acre: bed application*	Price per acre	Price per ha
Devrinol	$10.60/lbs	2 lbs	--	$21.20	$53.00
Treflan	$28/gal	1 pt	--	$3.50	$8.75
Goal	$90/gal	2 pt	1 pt	$11.25	$28.13
Chloropicrin	$2.25/lbs	140.00	70.00	$157.50	$393.75
Telone C-35	$17.50/gal	22.00	--	$385.00	$962.50
			TOTAL	$578.45	$1,446.13
Under Bed Fumigation					
Product	Price per unit	Application rate per acre: broadcast	Application rate per acre: bed application*	Price per acre	Price per ha
VIF** (white/black)	$211 per 2400 ft	---	---	$766.00	$1,915.00
Telone C-35	$17.50/gal	30 GAL	15 GAL	$262.00	$655.00
HDPE (.75 mil)	$190 per 6000 ft			-$275.00	
			TOTAL	$753.00	$1,882.50

* bed application = 50% of area treated. 5ft row centres

** Note - VIF plastic is replacing HDPE as the plastic mulch

Source: Rosskopf *et al.*, 2005. MB prices in 2006 from Mossler *et al.*, 2006.

Current situation

In the 2001/2 growing season about 1,298 ha of commercial production fields were treated with 1,3-D/pic + herbicides in Florida (MBTOC, 2002). This alternative system is also used by commercial producers of fresh market tomato, pepper, strawberry, watermelon, cantaloupe and cucumber in Georgia and South Carolina (Mirusso 2002 cited in MBTOC 2002). Historically MB was used on all commercial acreage of pepper in Florida, however nematicides such as oxamyl, 1,3-D and metham are now being used in approximately thirty percent of operations for nematode control (Mossler *et al.*, 2006).

Herbicides (e.g. napropamide, sethoxydim, trifluralin and others) are applied to 26% of Florida's pepper acreage. Analysis of the trends in authorised tonnage of MB in Florida indicated that the adoption of chemical and non-chemical alternatives would be anticipated to be about 40% of the acreage by the end of 2006 (Noling *et al.*, 2006).

The current situation was recently summarised as follows: Local competitive pressures have led Florida growers to be reluctant to transition to new integrated pest management strategies which include co-application of different fumigants and herbicides, and adoption of other alternative cultural practices to achieve pest control efficacy and crop yield response similar to that of MB (Noling *et al.*, 2006). Transition to the alternatives also suggests that growers will have to implement other significant changes to current practices, including integration of new fumigant distribution and soil injection technologies, and new tillage and irrigation practices to enhance the performance of alternatives. Transition implies an incremental change from a 40 year old system of being totally reliant on MB to a new multitactic pest control and crop production system. The transition will require a different outlook on the entire production system. The transition is not likely to be as easy or seamless. However if the transition plans are well designed and implemented effectively, problems are likely to be few (Noling *et al.*, 2006).

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10.3.2. Alternatives for postharvest uses

Case Study 8. Canada - Sanitation, heat + IPM in mills and food processing plants

In the past, approximately 100% of flour mills and 40% of food processing facilities were fumigated with MB in Canada. In view of the 2005 deadline for phaseout, Canada started conducting active research on alternatives and although still applying for CUEs for treatment of mills and pasta manufacturing facilities, has shown a *steady decline in the amounts requested over the past three years. This case study describes an alternative system providing control levels that are fully comparable to MB.*

Initial situation

In the past, approximately 100% of flour mills and 40% of food processing facilities were fumigated with MB in Canada. Typical MB dosage was 1.8-2.3 kg (4-5 lb) per 1000 m^3 (Stanbridge, 2005).

The main pest species prevalent in the region are stored product insects such as red and confused flour beetle (*Tribolium castaneum, T. confusum)*, saw-toothed grain beetle (*Oryzaephilus surinamensis)*, Indian meal moth (*Plodia interpunctella)*, Mediterranean flour moth (*Ephestia kuehniella)* and rusty grain beetle (*Cryptolestes ferrugineus)*.

Description of alternatives implemented

Heat has been used for more than 80 years in Canada, but heating techniques have been greatly improved, and augmented by IPM. A robust, thorough IPM program is key to the success of this alternative system (MB Industry Working Group, 1998; Nielsen, 2000; Pierce, 2000; Raynaud, 2002; Stanbridge, 2002).

Since stored product pests have a relatively predictable biology, including life cycle and habits, it is possible to implement consistent control strategies. The first step is to correctly identify the pest species that exist within the facility and conduct a population density assessment (e.g. with the use of pheromone monitoring devices).

Monitoring insect activity and quantifying insect levels or populations in critical zones is used to determine cleaning frequency and to improve cleaning procedures. Monitoring pest populations contributes to a careful review of cleaning procedures to ensure they address the insect critical areas, for example by reaching areas that are difficult to clean, and improving cleaning methods for equipment that is difficult to clean and may otherwise allow insects to reproduce without detection. Once these critical zones are established, it is important to determine what effect the cleaning procedures have on insect levels. Practitioners aim to correlate the frequency of treatment with the data collected on insect activity.

Information collected from traps, cleaning records and general monitoring assists in evaluating whether the strategies implemented are working well in each area. In areas where improvements to cleaning are not sufficient, it may be necessary to make changes to the design of the equipment or the structure (Raynaud, 2002; Stanbridge, 2004). Where these are not practical or are cost prohibitive, a heat treatment is performed directly to the critical zone and possibly to the immediate adjacent zones. Experience in the last decade has shown that it is seldom that an entire facility requires a heat treatment. Renting heat equipment rather than purchasing it is therefore an option that can help reduce costs in some cases.

The aim of this spot heat method is to treat only portions of the facility, when necessary. Preparation for heat treatment is less difficult than for fumigation because the structure does not need to be gas tight. Although it is preferred to arrange heat treatments during warm periods, there are numerous examples of facilities being treated when outside temperatures are below –10 °C (Stanbridge, 2005).

The alternative system described above was compared in three facilities in 2005 as summarised in Table 10.15 below (Stanbridge, 2005). These facilities were similar to other structures still using MB in Canada and selling their products in the same markets:

Table 10.15. Characteristics of Canadian food processing plants using heat + IPM technology as an alternative to MB in 2005

Type of facility	Capacity	Production volume and workload	Type of structure and age	MB used in the past	Length of time using alternative
Cookie processing plant	300,000 ft^2	13,500,000 kg/ yr 24 hr/ 7 day production	From 20 to 80 yrs old, wooden structure with wooden support members and tongue and groove ceilings; and also new steel structure	Yes 1 fumigation per year	14 years
Bakery mix plant	80,000 ft^2	38,500,000 kg/ yr 24/5/7 production	From 10 to 50 years. Concrete structure (old) and steel (new)	Yes, 1 fumigation per year	6 years
Bakery mix plant	150,000 ft^2	40,000,000 kg per year 24/5 production	15 years old, concrete and steel	Yes, 1 fumigation per year	34 months

Source: Stanbridge, 2005

Current situation

The level of pest control from IPM + heat is comparable to that achieved by MB fumigation, and heat treatment time was approximately the same as MB (Fields, 2004; Stanbridge, 2005). Some advantages of heat over MB are that portions of the facility can continue to operate while a heat treatment is taking place, whereas the entire facility was shut down during MB fumigation. Compared to the period when MB was used, the facilities now carry out more pest monitoring, more intensive cleaning, and better inspection of all in-coming products. Facilities that implemented this alternative reported that customer complaints and product risk have decreased overall (Stanbridge, 2005).

The alternative proved to be cost-effective because the IPM allowed for conducting spot heat treatments to be conducted in most cases, so the facilities needed to purchase or rent less heating equipment. There were no regulatory barriers to be overcome because the alternative did not need to be registered or approved by regulatory authorities. Facilities were very satisfied with this alternative and continued to use it (Stanbridge, 2005). Since 2005, more companies have adopted this system.

Lessons learned

The heat treatment is easy to implement, but requires relevant know-how. The IPM programs are more complex and time consuming at least during the initial 6 – 12 months. Training of all personnel is required and some adaptation or change is necessary (Fields, 2004; Stanbridge, 2004). IPM requires a commitment starting from the top management downwards. Staff should be specifically assigned to supervising IPM programs and ensuring that appropriate scouting and information gathering takes place. A major issue is training staff to think "micro" when cleaning, because cleaning often needs to be very detailed. Further, cleaning should be intensively targeted towards critical areas as this will reduce labour costs. If proper IPM is not implemented larger areas will usually need to be heat- treated or heat treatments will need to be performed more frequently (Stanbridge, 2004; 2005; Nielsen, 2000; Pierce, 2000).

Use of heat plus intensive modern IPM as an alternative to MB in mills and food processing facilities is very feasible. These methods are used in other countries worldwide, in food processing, milling and pharmaceutical sectors.

Finally, consumers are increasingly concerned about the use of pesticides in food processing and storage and registration pressures for chemical alternatives are high. This is driving companies into reducing reliance on pesticides and looking for alternative measures. Heat and IPM options are well accepted by the public and do not require registration. For this reason they are being increasingly adopted in the mill and food processing sector (Stanbridge, 2004; Raynaud, 2002).

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Case Study 9. United States - Sulfuryl Fluoride and other MB alternatives in Flour Mills and Food Processing Facilities

Alternatives adopted in mills and food processing facilities in the United States include sulfuryl fluoride, heat, IPM, phosphine, and phosphine + $C0_2$ + heat.

Initial situation

The milling and food processing industries have a very high economic value. More than 175 million pounds of flour, for example, are produced daily in the US. The 46 member companies of the North American Millers Association produce 95% of American wheat, oat and rye flour at mills in 150 cities. Milling capacity is greater than actual production needs, and competition in the sector is fierce (Marcotte 2004).

Food processing facilities are frequently warm and sometimes moist, providing good conditions for insects and other pests to multiply. Incoming raw ingredients and many different suppliers can deliver pests to the facilities or warehouses. MB has often been used for pest control because it is able to penetrate into difficult-to-reach parts of equipment and crevices in the fabric of buildings. MB has been used in the milling and food processing industry to disinfest structures and reduce the impact of these pest insects. Historically most of the 220 flour mills and hundreds of food processing plants in the US used MB, traditionally carrying out MB fumigations from one to four times per year (Mueller, 2004a).

The common target pests in mills are *Tribolium confusium, Tribolium castanium, Plodia interpunctaella, Lasioderma serricorne, Trogoderma variabile and Musca domestica.*

Actions for replacing MB

Substantial research and development was carried out by food companies and mills, fumigation companies, pest control companies, pesticide companies, researchers in universities, USDA institutes, IPM specialists, and others. The USDA also funded work in this sector. Citations of studies on existing and potential treatments in structures, and summaries of the main results of this R&D effort, can be found in the previous MBTOC reports.

Description of alternatives implemented

Several alternative strategies have been implemented by a number of mills and food processing facilities. Modern IPM methods are used in place of some MB fumigations in companies such as Nestlé Purina, FritoLay, Kellogg, KanKan and pharmaceutical companies, snack food plants and pet food plants (Mueller, 2003; Corrigan, 2002, MBTOC 2002). The IPM systems include alterations that exclude pests and remove pest harbourages in and around buildings, comprehensive cleaning programmes, pest monitoring, careful selection of suppliers, and closer monitoring of pest levels in in-coming products, accompanied by 'quarantining' and fumigation with phosphine or other treatments if pests are detected in incoming goods. Improved grain fumigations reduce the need for structural fumigations later in the supply chain (Mueller 2004a).

Several North American food companies, such as Nabisco, Con Agra, General Mills, Nestlé Purina, Lauhoff (now Bunge) and Seimer Milling have also used heat treatments to eliminate insects in some facilities (Heaps, 1998; Mueller, 2003; MBTOC 2002). As a result of such IPM programmes, many facilities have not used MB for a decade (Mueller 2003; MBTOC, 2002).

Cylinderised phosphine has been used in grain fumigations for 20 years and in structures for ten years (Mueller, 2004a). Cylinderised phosphine + $C0_2$ + heat treatments were tested and found to be effective in circumstances where sensitive metal components could be removed or sealed and shielded from exposure. More than 70 applications of phosphine + $C0_2$ + heat were performed by August 2004 in North America and Europe, replacing more than 100 tonnes of MB in flour mill and food processing structures (Mueller, 2004a).

Sulfuryl fluoride (SF) was registered in January 2004 for use in flour mills and in 2005 for use in food processing plants in the United States. Following federal registration in the US, more than 200 SF fumigations of structures have been performed; additionally, 160 SF fumigations have been performed in other countries. SF is sufficiently registered in the US to allow virtually all mills and food processing facilities to consider adoption as an alternative to methyl bromide (MBTOC, 2006). SF offers the closest prospect for a like-for-like replacement of MB in the post-harvest sector for many uses, although there are some significant differences. It offers a viable method for whole site disinfestation, an area of MB use that has been difficult to replace (Bell, 2004; Small, 2007).

Data are available on the effects of SF in over 50 species of insects infesting food or timber products, with particular emphasis on pests of flour mills (Bell, 2004). Insect eggs are less susceptible to SF than to MB (EPA, 1996; Bell 2004), and higher doses are required to kill eggs, although this increases the cost. However, the efficacy of treatment of eggs was significantly enhanced by increasing the temperature from 25 to 30°C, and complete control of eggs of most species was obtained by a concentration time product of 1000 g h m^{-3} at 25°C and about 700-800 g h m^{-3} at 30°C (Bell *et al.*, 2004). The manufacturer's Fumiguide computer programme permits users to choose the target pest life stages, indicating the relevant dose required. In some situations, particularly larger mills with complex design and/or mills in cooler climates, a combination process with heat has been used. In this method, pest kill efficacy has been high and fumigant costs have been minimized (MBTOC, 2006; Reichmuth *et al.*, 2003). In many cases, initial efficacy problems have been resolved through additional experience, such as improved sealing of structures. This alternative requires careful adaptation on an individual mill basis by knowledgeable and experienced fumigators (Mueller, 2006c). Training provided by Dow AgroSciences LLP on suitable use of the fumigant, combined with fumigators' knowledge of heat methods and individual mill situations has resulted in more reliable treatments (MBTOC, 2006).

Many experimental and commercial-scale fumigations were performed on SF to gather data and to obtain practical field experience to provide technical and economic information for registration in 2004. More recently, a comparative study of commercial MB and SF fumigations was made by scientists at Purdue University involving commercial fumigators and four flour-mills in the Midwestern USA (Indiana and Michigan). Facilities varied in size (6 to 10 floors) and age (10 to >120 years) (Tsai *et al.*, 2006). The following pest efficacy was reported in bioassays (Tables 10.16 and 10.17):

- 100% of Red flour beetle larvae and adults were killed after the SF and MB fumigations, except in one sample location in a MB fumigation;
- Very low survival of pupae populations;
- Egg mortality in both SF and MB was about 90% on average; greater variation was observed in the MB fumigations (Table 10.17).

The comparison of mortality of these two target pests of the milling and food processing industry in four flour mills of various sizes, age, and conditions showed that MB and SF achieved similar mortality on the eggs, larvae, pupae, and adults. No surviving eggs reached reproductive adulthood after fumigation with either SF or MB (Tsai *et al.*, 2006).

Table 10.16. Mortality (%) of Plodia interpunctella (Indianmeal moth, IMM) in flour mills fumigated with MB and SF.

Facility	Eggs	Larvae	Pupae	Adults
SF 1	100	100	100	100
SF 2	100	100	100	100
SF 3	90.65	100	100	100
SF 4	98.89	100	100	100
SF 5	87.21	100	100	100
MB 1	88.67	100	100	100
MB 2	100	100	100	100
MB 3	98.67	100	100	100

Source: Tsai *et al.*, 2006

Table 10.17. Mortality (%) of *Tribolium castaneum* (Red flour beetles, RFB) in flour mills fumigated with MB and SF.

Facility	Eggs	Larvae	Pupae	Adults
SF 1	100	100	100	100
SF 2	99.33	100	100	100
SF 3	89.47	100	100	100
SF 4	98.61	100	100	100
SF 5	86.46	100	100	100
MB 1	70.58	100	100	100
MB 2	100	100	100	100
MB 3	97.62	100	100	100

Source: Tsai *et al*., 2006

Larger food facilities and mills often operate 7 days a week and 24 hours per day. As a result the shutdown time is an expensive component of any fumigation or treatment. In the US it costs about US$60,000/day to shut down a flour mill, and many times over $1,000,000 /day to shutdown a food processing plant. SF fumigation, or the use of phosphine + heat + carbon dioxide, can result in shutdown periods that are shorter or equal to that of MB (Mueller 2004a).

Current situation:

Since registration in 2004, more than 193 commercial SF fumigations have been conducted in the USA, involving 282 individual structures at 103 locations in 20 states, with the following breakdown in 2004-2006:

- 2004: 43 commercial fumigations at 23 locations
- 2005: 65 commercial fumigations at 43 locations
- 2006: 85 commercial fumigations at 64 locations

112 of these commercial fumigations were carried out in wheat mills, rice mills, food processing plants and related warehouses. The remaining fumigations were carried out in commodity bins, silos, chambers and stacks. 35 of 103 locations (34%) have chosen to carry out SF treatments on subsequent occasions, with up to six SF treatments carried out in some locations by the end of 2006, indicating a high degree of customer satisfaction.

A major US fumigation company reported that they have not used MB on structures in the two years since 31 December 2004, and that the switch to SF from MB caused great changes in their business practices (Mueller 2006a, pers.comm.). The company announced their phaseout of MB to customers in 2004, and unexpectedly experienced an increase in business. Most customers agreed to the replacement of MB and embraced the use of SF or other alternatives in the past two years. More than 150 tonnes of MB has been replaced with SF in the United States by this mid-sized fumigation company, and the results of the fumigations have shown equal results with SF compared to MB. Additional tonnes of MB were eliminated by the use of other alternatives such as heat, IPM, phosphine and phosphine + CO_2 + heat.

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10.4. Alternatives to MB Adopted in Asia/ Pacific

MB consumption fell in the Asia/ Pacific region from a peak of 5,025 tonnes in 2000 to about 1,780 tonnes in 2005, which represents a reduction of 65%. Although some consumption remains, substantial reduction is now reported in both Article 5 and non-Article 5 countries in this region. Large reductions in CUNs requested by non-Article 5 parties have also taken place.

10.4.1. Alternatives for preharvest uses (soils)

Case Study 10. Australia - Phase-out of MB in the strawberry fruit industry

Since 1994, the Australian strawberry fruit industry has been proactive in replacing MB use for soil disinfestation with several alternatives. This resulted in complete phase out of 90 ODP tonnes by 2006. A key to the industry's success was a coordinated national research and extension program that involved all stakeholders. More than 50 research and commercial trials supported by field days and other extension activities built the confidence of growers in the alternatives, and a sense of collaboration and trust between researchers, fumigators and industry. These partnerships and relationships were equally as important as individual trials in allowing growers the assurance to successfully adopt alternatives. A large proportion, over 70%, adopted alternatives before 2005. In 2005, the industry was granted a critical use exemption for a small proportion of the industry to assist the final scale-up of key alternatives, predominantly 1,3-D/Pic and chloropicrin applied alone. Following two subsequent growing seasons for the total industry without MB and over 5 seasons with alternative use by some growers, the industry has reported no significant yield loss and adapted to the new disinfestation treatments..

Initial situation

The Australian strawberry fruit industry is worth $200 million to the Australian economy. The industry is important nationally, producing 26,000 tonnes of fruit annually. The majority (90%) is destined for local markets and 10% is exported, mostly to Asia. The industry comprises over 1000 growers producing on 1200 ha of land. Fifty million plants are grown throughout Australia, with northern regions producing short-season crops under sub-tropical conditions and southern regions producing long-season crops under temperate conditions. Most strawberry production occurs in clay or clay-loam textured soils, although pockets of production occur in sandy-loam textured soils in the west.

In 1995, most of the industry (87%) relied on soil disinfestation with MB to control key pathogens (*Phytophthora* spp., *Rhizoctonia* spp., *Verticillium dahliae*, and

Fusarium spp.), weeds (including *Cyperus rotundus*) and other pests (e.g. plant parasitic nematodes); and to increase yields (by about 35%). Without a suitable replacement for MB, the industry was expected to lose about $70 million annually, and this severely threatened its ongoing viability. In 1995, the temperate industry used formulations of MB/Pic 70:30 and the sub-tropical industry used 98:2 both injected into planting beds. During the period 1995 to 2005, before totally switching to alternatives a large proportion of the industry transitioned to MB/Pic 50:50 or MB/Pic 30:70 in order to reduce MB dose rates and need for MB.

Actions for replacing MB: Significant steps in the phase out of MB in the Australian strawberry industry included:

(1) First National Workshop on Alternatives to MB
In 1994, a national workshop was organised to ensure a national coordinated response by Australian horticultural industries to phase-out MB. This workshop provided a forum where those affected by the phase-out could strategically plan how to effectively replace MB for soil disinfestation.

(2) MB Consultative Group
As a result of the first national workshop, a national consultative committee was formed in 1995 to inform MB users of all policy and technical issues in relation to MB phaseout and to represent growers on the issue. The Consultative Group was comprised of representatives from all stakeholders affected by the phaseout, including horticultural industries, MB importers, MB contractors, researchers and policy makers.

(3) National MB Response Strategy
In 1995 the MB Consultative Group produced a National MB Response Strategy involving consultation with government, chemical companies and producer representatives, to address the possible MB reductions to facilitate easy transition to alternatives and assist Australia meet its obligations to the Montreal Protocol. The strategy also prioritised research and communication activities and set adoption targets for individual industries.

(4) MB Levy
In order to fund research and communication activities, the MB importers agreed to establish a Aus $0. 20/kg levy on all MB imports into Australia. This levy was subsequently raised to Aus $0. 40/kg in 1997 and was matched 1:1 by the Federal Government.

(5) National Research Program
Over a period of 10 years, Australian researchers worked on the development, registration and/or evaluation of over 40 different fumigant and non-fumigant alternatives to MB. More than 50 trials were conducted in the strawberry fruit industry Australia-wide, across diverse soil types and climatic conditions. Trials included commercial evaluations on farm, and provided growers with a scientific basis for the move to alternatives.

(6) National Communication Program

An extension program was conducted in conjunction with the research program, and ensured rapid dissemination of research outcomes to industry. The program worked in close collaboration with regional authorities, fumigation contractors, researchers and grower associations. Information was extended using a range of tools, including: road-shows, a biennial 'National MB Update' newsletter, best-practice booklets on MB alternatives, an Internet site, conferences and workshops, farm-walks, and a CD-Rom. One of the most useful tools proved to be the establishment of on-farm trials, which provided growers with first-hand experience in the use of the alternatives prior to phase-out.

Another important issue which assisted uptake of alternatives included the strawberry industry's open mindedness about alternatives and their proactive support for research. Further assistance was provided by the fumigant contractors rapid acceptance that although more difficult to use, yields with alternatives were similar to MB, and that a commercial advantage could be achieved by actively marketing alternatives and assisting growers with application of alternatives (e.g. 1,3-D/Pic).

Description of alternatives implemented

The adoption of MB alternatives in the strawberry industry followed an exponential pattern during the last 10 years (Figure 10.3). In 2005, the industry applied for a critical use exemption for one year to allow the scale-up trialling of newly registered alternatives such as 1,3-D/Pic. On Jan 1 2006 the industry ceased using MB, and the proportion of alternatives adopted is reported to be 70% use of 1,3-D/Pic (Telone C35), 15% chloropicrin, 10% methyl isothiocyanate generators (mostly metham sodium), and 5% non-fumigant methods (e.g. hydroponics), and IPM.

All of the alternatives adopted by industry have different physical properties to MB, and this meant that growers needed to understand the environmental conditions under which they were efficacious. For example, growers needed to allow longer plant-back periods for the alternatives compared with MB. However, when applied under optimal environmental conditions, the alternatives have all delivered similar or better fruit yields to MB (Table 10.18).

Current situation

Growers easily transitioned to the alternatives because most could be applied through the same injection equipment (with slight modifications) as MB. Initially, there were isolated incidences of crop phytotoxicity to residues of 1,3-D/Pic due to unusually cold weather conditions, followed by periods of high rainfall, and inadequate plant-back periods. However, growers now have a greater understanding of the environmental conditions under which the alternatives are most effective. There have also been marginal increases in weeds in some areas, but growers are managing these issues with herbicides, cultivation or hand labour. In most instances, yields have been maintained with the alternatives. Growers are awaiting the registration of new products, such as methyl iodide and cyanogen that have shorter plant-back periods than the other alternatives. Significant numbers of growers have been using the alternatives for 4 years in the same soils, and treatments do not appear to be losing effectiveness. No evidence of enhanced biodegradation or pathogen build-up has occurred over time.

Figure 10.3. Response of Australian strawberry fruit growers to the question ' Have you trialled methyl bromide alternatives on your farm?' The response reflects the adoption patterns of alternatives by the industry over time.

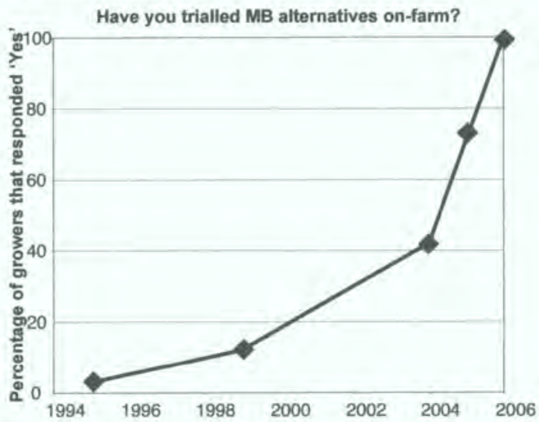

Table 10.18. Comparative performance of chemical alternatives relative to MB for yields of strawberry fruit in replicated field trials in Victoria, Australia.

Treatment	MB/Pic	No Fum.	TC35	Pic	MS	MI/Pic	MS &Pic	Daz
No of studies	11	11	5	3	3	5	3	2
Relative yield	100	76	118	101	92	108	101	101

MB/Pic = methyl bromide/chloropicrin (50:50); No fum = Non fumigated control; TC35 = 1,3-dichlorpropene/chloropicrin (65:35) ; Pic = chloropicrin; MS = metham sodium; MI/Pic = methyl iodide/chloropicrin (30:70); MS & Pic = metham sodium and chloropicrin; Daz = dazomet. Application rates are equivalent to 500 kg/ha

Provided by Ian Porter, MBTOC co-chair and Scott Mattner, Department of Primary Industries, Australia

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Case Study 11. China - Status of MB replacement with chloropicrin in strawberry fruit production

Fumigation with chloropicrin has expanded rapidly since the registration of this chemical in China in 2002. Growers find this alternative simple to implement, with results comparable to those obtained with MB, and general costs lower than those of MB.

Initial Situation

Strawberry growing in Mancheng, Hebei Province has a history of more than 50 years; presently, this is one of the three biggest strawberry production regions in China. As in other parts of the country, farmers in Mancheng have access to very limited land area for cropping. The average area for one family (three persons) is 3 Chinese *mu* (0.2 hectare). Typically, a family will grow 2 Chinese *mu* with wheat/corn and one *mu* with strawberry. Total income derived from two *mu* of wheat and corn is about USD$ 200 per year, while one *mu* of strawberry and tomato yields about USD $1,500. In consequence, strawberry production has become the most important source of income for many farmers in Mancheng, where about 5,000 ha are cultivated per year. Mancheng County is located on the eastern lowlands of Taihang Mountain, about 150 km from Beijing, the capital of China, and Tianjin, a municipality directly under the Central Government. The total area is 718 square kilometres and 33,000 ha of land are devoted to agriculture. Population is 424,000. The climate is continental with an average annual precipitation of 596.8 mm, 62% of which occurs in July and August. Soils are of the silt loam kind.

Two types of strawberry cultivation systems prevail in Mancheng: greenhouse and open field. Greenhouse sizes range from 330m^2 to 400m^2. Soilborne diseases have become a big problem due to continuous cropping. Because of the long period of time needed for rotation and limitations on land available for cropping, crop rotation is quite difficult.
In recent years, farmers have started intercropping tomato between the strawberry rows in order to use greenhouse space more efficiently and increase their income as follows:

Strawberry: Distance between rows - 75 cm (wide rows) and 25 cm (narrow rows). Planting density 133,000-200,000 plants/ha.

Tomato: Distance between rows - 75 cm. Planting density 45,000 plants/ha.

Strawberries are watered by flooding with underground irrigation immediately after transplanting, at a rate of about 750 t/ha. Transplanting takes place on open fields during the summer (35°C) when evaporation is high, which makes it necessary to water plants every 3-5 days. Top fertilizer is applied at a rate of 675 kg ha^{-1} and the soil is covered with mulch. In late October when the temperature drops to about 5°C, the rows are covered with plastic tunnels. No irrigation is supplied during the winter months. The temperature in the tunnel is kept at 10-15°C and humidity at about 70%.

Major soilborne problems arise due to combined infection by *Fusarium, Verticillium, Phytophthora* and *Rhizoctonia*. Average yields generally reach 60-70% of the standard but it is possible to loss the crop completely. Root knot nematodes have not been reported locally.

MB use: along with economic development during the past decade, protected cultivation and intensive cropping have grown rapidly in China. Protected strawberry culture is presently an important source of income for the Mancheng area. At the same time however, soilborne diseases and pests have become increasingly severe and large quantities of MB have been used for soil fumigation since 1995. Presently Mancheng is the largest MB consuming region in China, with reported usage between 400 and 500 tonnes per year.

For initial disinfestation, farmers use 22 canisters (681 g/can) of MB (37.5 g/m^2) for a 400 m^2 greenhouse. Thereafter the rate is increased by 2 canisters per year reaching 28 cans (47.7 g/m^2) per greenhouse. Growers first sterilise half the greenhouse and then the other half using the same sheet of plastic.

Actions for replacing MB

In order to phase out MB, The Ministry of Agriculture of China initiated an investment project in 2005, implemented by UNIDO and funded by the MLF. Its aim is to screen and demonstrate alternatives to MB. Among these alternatives, chloropicrin has popularity in Mancheng and manufacturers of this product have increased their extension network. Chloropicrin was registered in China in 2002.

Description of alternative implemented

Before applying chloropicrin, the soil should be rototilled and crop residues removed. Plough depth should be at least 20 cm and the soil should be kept at moist, just like when using MB. Three application techniques for chloropicrin are used in Mancheng: injection by hand, injection by small tractor, and capsule application under plastic film.

After removing the film, the soil is left unattended for 4 to 6 days after which residual gas is checked by smelling. If the smell of residual gas is still present, farmers will plough the land with shovels or rolling cultivation equipment. Farmers proceed to seeding or planting when the smell has disappeared. According to farmers using this alternative, vigour and yields obtained with chloropicrin are similar to those achieved with MB. Production costs are lower than for MB as shown in Table 10.19 below:

Table 10.19. Cost comparison for treating strawberries with chloropicrin and MB in Mancheng, China

	Inputs	Quantity (kg/ha)	Price (USD$/kg)	Cost (USD$/ha)
MB fumigation	MB	400 kg	3.48	1392
	Plastic film	500 kg	1.65	825
	Labour	15 day	3.8	57
	Total			**2,273**
Chloropicrin hand injection	CP	450 kg	2.15	967.5
	Plastic film	500 kg	1.65	825
	Labour	30 day	3.8	114
	Total			**1,906.5**
Chloropicrin machine injection	CP	450 kg	2.15	967.5
	Plastic film	500 kg	1.65	825
	Machine	3 day	10	30
	Labour	3 day	3.8	11.4
	Total			**1,833.9**
Chloropicrin capsule Broadacre	CP	450 kg	3.8	1,710
	Plastic film	500 kg	1.65	825
	Labour	30 day	3.8	114
	Total			**2,649**
Chloropicrin capsule bed treatment	CP	300 kg	3.8	1140
	Plastic film	500 kg	1.65	825
	Labour	30 day	3.8	114
	Total			**2,079**

Current situation

Chloropicrin use has been extended quickly; in 2006 this chemical replaced 40 tonnes of MB (10% of initial consumption) and replacement of an additional 100 to 150 tonnes is expected for 2007. Chloropicrin is generally cheaper than MB (except for capsule broadacre treatment), application is simpler (no bamboo arcs are needed) and can be applied with old plastic film, which reduces costs even further.

As stated before, yields obtained with chloropicrin are similar to those achieved with MB. These benefits help farmers accept the technologies quickly, however chloropicrin is a strong eye irritant and has a strong unpleasant smell, which can be barriers to its adoption. The capsule formulation seems to offer a good solution to these constraints.

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Case Study 12. Japan - Alternatives for controlling soil diseases and nematodes in tomatoes

MB is no longer used for tomatoes in Japan. Tomato growers have adopted grafting, chemical alternatives, resistant v varieties and hot water treatments to avoid damage caused by soilborne fungi and nematodes.

Initial situation

Japanese agriculture comprises numerous small-scale farmers producing crops in fields that have passed from generation to generation within the same families. The number of farming families in the country was estimated at 3,120,215 in 2000 (Statistical Information of Agriculture and Forestry of Japan). In 2005, 13,000 ha grown with tomatoes were reported in Japan.

Tomato production depends on an intensive, labour-consuming production system in which yield losses frequently result as a consequence of successive cropping. Soilborne diseases are the major cause of yield reduction and were traditionally controlled with MB and chloropicrin; recently however, biological and physical controls such as microbial antagonists, resistant varieties and heat sterilization have been successfully adopted.

Actions for replacing MB

The Ministry of Agriculture, Forestry and Fisheries (MAFF) established a "Panel for Promoting MB Reduction" in February 2000. This panel has been promoting the adoption of alternative technologies since its creation. MAFF also informs farmers on ways to reduce use and emission of MB and promotes alternative techniques through local governments. The core of the national project is full phaseout of methyl bromide and eradication of virus diseases.

MAFF has evaluated the feasibility of alternative chemicals, their formulations and application methods; of hot water and steam, and solar treatment; of reducing the redox potential of the soil with bran applications; and of combining these methods with emission control techniques.

Description of alternatives implemented

Complete replacement of MB has been achieved in tomatoes with chemical alternatives, resistant varieties, hot water treatment and grafting. These alternatives are used independently or in different combinations.

The major soilborne diseases attacking tomatoes are bacterial wilt (*Ralstonia solanacearum*), Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici)*, crown and root rot (*Fusarium oxysporum* f. sp. *radicis-lycopersici*) and corky root (*Pyrenochaeta lycopersici).* The major nematode problem is root- knot (*Meloidogyne* sp). Alternative chemicals and grafting are used either independently or in combination for controlling bacterial wilt and root knot nematodes. Corky root and Fusarium crown and root rot have been successfully controlled with chemicals.

Grafting is widely used for tomato production in Japan: Presently 60% of growers of regular tomatoes and 90% of growers of miniature- sized tomatoes in Kumamoto, one of the major production regions in Japan, use this technique. In 1997 when a new strain of *F. o.* f.sp. *lycopersici* race 3 broke out, the disease was controlled by grafting onto the resistant rootstock known as "Protect 3". Several rootstocks showing resistance to diseases and nematodes are available (Table 10.20).

Table 10.20. Resistant rootstocks (diseases and nematodes) suitable for grafting tomatoes in Japan

Rootstock	Breeder	Variety resistance degree for each disease and nematode							
		B	C	J3	V	F1	F2	F3	N
Ganbarune 3	Aisan shubyou	□	□	□	□	□	□		□
Ganbarune 11	Aisan shubyou	□	□	□	□	□	□		□
Spike	Aisan shubyou	○	□	□	□	□	□		□
Brock	Sakata shubyou	○	○	□	□	□	□	□	□
Voranch	Takii shubyou	□	○	□	□	□	□		□
Protect 3	Takii shubyou	○		□	□	□	□	□	□
Tie up	Musashi breeding	□		□	□	□	□		□
Couple T	Musashi breeding	□		□	□	□	□		□
Couple O	Musashi breeding	□		□	□	□	□		□
Duet O	Musashi breeding	□		□	□	□	□		□
White base	PSP	□	○	□	□	□	□	□	□

□Resistant, ○Slightly resistant,

B: Bacterial wilt, C: Corky root, J3: Fusarium crown and root rot, V: Verticillium wilt, F1: Fusarium wilt caused by *F.oxysporum* f. sp. *lycopersici race* 1, F2: Fusarium wilt caused by *F.oxysporum* f. sp. *lycopersici* race 2, F3: Fusarium wilt caused by *F. oxysporum* f. sp. *lycopersici* race 3, N: Root knot nematode

Resistant varieties and grafting are made more effective by combining with chemicals, for example chloropicrin or metham sodium. If nematodes are a problem 1,3- D or fosthiazate are most commonly used. Recently, heat treatments have become popular because Japanese consumers prefer products grown with as few pesticides as possible. Hot water and reduction of the soil redox potential are becoming the preferred non-chemical treatments. Hot water treatments show efficient and consistent control of a broad spectrum of soil pathogens and weeds, particularly in protected crops. Efficacy of this alternative is enhanced by good soil preparation including good drainage and a levelled surface. The soil redox potential reduction treatment is mostly used during the hot season (early summer to early fall). Its control efficacy is considered better than that of solarisation, particularly for corky root and *Fusarium*. Although there is wide experience with solarisation, results can be inconsistent.

Current situation

Tomato is one of the most important vegetables grown throughout the year in Japan. The sector was once a large MB user, but has completely phased out the use of this fumigant. In fact, national MB use has been strongly reduced from 6,106 metric tonnes in 1991 to 525 metric tones in 2005.

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Case Study 13. Lebanon - Phaseout of Methyl Bromide in the Vegetable, Cut Flower, Tobacco and Strawberry sectors

Lebanon uses MB for soil fumigation only. Through demonstration and later investment projects implemented by UNIDO and UNDP, over 90% of the baseline MB consumption has now been eliminated through adoption of different alternatives.

Initial situation

The MB consumption baseline for Lebanon is 394 ODS tonnes. This quantity is exclusively used for soil fumigation in the production of vegetables, cut flowers, tobacco seedlings and strawberries, all of which are grown in greenhouses or small plastic tunnels. A survey carried out by the Methyl Bromide Alternatives Project in 2001 revealed that 5,618 farmers were potential users of MB in 33,781 greenhouses and 17,023 small tunnels, on a total area of 2,043 ha. The major target pests are nematodes, fungi such as *Fusarium* and *Verticillium*, and weed seeds.

Actions for replacing MB

Following the successful completion of a demonstration project (1999-2001), two investment projects were initiated in 2002 with the aim of achieving complete phase out of MB in Lebanon by the end 2006. Funded by MLF, these projects were launched by the Ministry of Environment of Lebanon with UNDP (vegetables, cut flowers and tobacco sectors – 310 tonnes) and UNIDO (strawberry sector – 84 tonnes) as implementing agencies.

Selection of the most appropriate alternatives for each case was made according to the major soilborne diseases prevailing in each site and based on the following criteria: technical efficiency; economic feasibility; and environment friendliness and public health safety.

A variety of targeted information tools, including technical manuals and a booklet on the methyl bromide issue and potential viable alternatives, were prepared and disseminated to farmers and extension staff in each region through agricultural extension channels. The project also developed policy instruments, market measures and a national plan for phasing out MB in the sectors involved. Special care was taken to involve all relevant stakeholders, including farmers, policy makers, government staff, private agricultural companies and others.

Simultaneously, the first nematode analysis laboratory was established by the UNDP-Methyl Bromide Alternatives Project at the premises of the LARI, and put in the service of all Lebanese farmers.

Description of alternatives implemented

Alternatives proposed and applied by the Lebanese MB projects were both chemical and non-chemical. Non-chemical alternatives included solarisation, bio-fumigation (with the use of oil-radish), and grafting (vegetables sector), floating trays (tobacco sector), crop rotation and steaming (strawberry sector). Chemical alternatives were 1,3-D (vegetables), metham sodium and 1,3-D / Pic (strawberry and cut flowers).

Results obtained with most alternatives were effectively comparable to MB, in some cases even better than targeted (a minimum of 85% efficiency relative to MB was sought) in terms of production and yield (Table 10.21).

Some relevant results of alternatives

Positive results and the relatively lower cost of most alternatives encouraged Lebanese farmers to adopt the alternatives proposed. In many cases, farmers voluntarily phased out additional quantities of methyl bromide than required by the project.

Table 10.21. Comparative efficiency of alternatives and MB (where MB is 100%)

Alternative	Crop	Site	% of production as compared to MB
Basamid (Dazomet)	Strawberries	Shweifat	85
Condor (1,3-D alone)	Cucumbers	Jbeil	93
Rugby (Cadusafos)	Cucumbers	Kherbet Anafar	95
Solarisation	Tomatoes	Jbeil	113
Solarisation + 1,3-Dichloropropene	Tomatoes	Aakbiyye	115

Table 10.22 below summarises costs for alternatives adopted in Lebanon. Fumigation with MB costs around 650 US$/1,000 m^2.

Table 10. 22. Application costs for MB and alternatives

ALTERNATIVE	TOTAL COST USD $/1,000 m^2
Soil Solarisation	130
Bio-Fumigation (with PE cover)	145
Grafting (tomato plants)	315
1,3-Dichloropropene	340
1,3-Dichloropropene + Chloropicrin	500
Methyl bromide	650

Current situation:

Since the investment project started in early 2002,

- 796.3 ha have switched from MB to alternatives in 3,216 production sites;
- 9,321 farmers have received training on proper and safe application of alternatives;
- Activities of both projects have reached more than 150 villages and towns in Lebanon;
- 330 tonnes of MB have been phased out by the two projects and all deadlines have been met.

There is a remnant of about 52 tonnes, the phaseout of which was delayed due to political turmoil in Lebanon. Complete phase out is expected to be achieved by end 2007.

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Case Study 14. Lebanon - Strawberry Sector phaseout of Methyl Bromide

Although the initial alternative proposed for this sector (steaming) turned out to be economically unfeasible, other alternatives, both chemical and non-chemical or a combination of both have been successfully adopted and MB has almost been phased-out from the Lebanese strawberry sector.

Initial situation

The methyl bromide phaseout project for the strawberry sector in Lebanon follows the ratification of the Montreal Protocol by the Government of Lebanon. The project, funded by the MLF, is executed by the Ministry of Environment (MoE) and implemented by UNIDO. The project started in 2002 and is due to finish by 2007. Its goal is to phase out about 80 tonnes of MB used by the strawberry sector according to the following schedule:

Table 10.23. MB phase out schedule for the strawberry sector of Lebanon

Year	Tonnes to be phased out
December 2002	9.6
December 2003	16.2
December 2004	22.7
December 2005	17.8
December 2006	14.4
All Years	80.64

Initially, steam sterilization used within an IPM approach was the main alternative proposed, however this choice had to be revised later as described below. The project covers all strawberry farms in Lebanon, which together comprise about 200 ha in production and include coastal areas (mainly at the south of Beirut and in Akkar in the North), the northern Bekaa valley and a few villages of Mount Lebanon located at an altitude of 1,500m. The total number of strawberry farmers is estimated to around 250. The project operates simultaneously and in collaboration with another MB project for vegetables, cut flowers and tobacco implemented by UNDP (see Case Study 13 in this same section).

Actions for replacing MB

The project management implemented a MB phase out program in the different strawberry producing regions in Lebanon. A training and awareness-raising plan has been applied at different levels: trainers, farmers and representatives from related ministries. Training comprised various areas ranging from MB alternatives and their correct implementation, to IPM, identification of pests and diseases and cultural practices.

The project management has further collaborated with the Ozone Office and the Department of Legal Affairs of the Ministry of Environment with the preparation of a draft decree that would limit MB imports in accordance with the phase out actions taken through the projects. The draft decree will be enacted by the Council of Ministers in the near future.

Description of the alternatives implemented

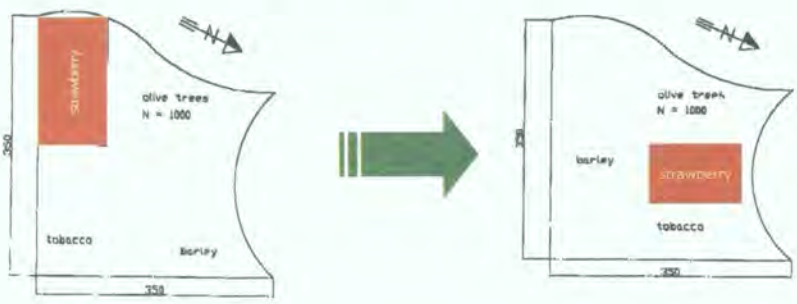
In Lebanon, fungi are the main pathogens attacking strawberry, particularly *Rhizoctonia spp*, *Fusarium spp* and *Verticillium spp*. Nematodes are less important and weeds are in general adequately controlled by the plastic mulch that farmers use most of the season.

Steam was initially chosen because of a preference for promoting non-chemical alternatives. However, the practical application of soil steaming in field-grown strawberries revealed various technical and economic limitations: high fuel consumption, constant increases in fuel prices, long application time when covering large areas, field access difficulties, high labour requirements, difficult and expensive transport conditions, tractor dependence and high rental costs of tractors, water and fuel replenishment difficulties, work delays due to labour limitations, difficult payment facilities for farmers, eventual machine breakdown delays in the particular type of equipment chosen by the project.

Many of these limitations are specific to the Lebanese agricultural situation and were considered difficult to predict in advance. Although a demonstration project had already been carried out in Lebanon from 1999 to 2001, it was not possible to test the soil steaming technology during the course of that project. Technical and economic limitations as mentioned above made soil steaming for this crop difficult to sustain under Lebanese conditions and this obviously reduced its acceptance on the part of farmers. These facts, together with the inherent flexibility of project components which allow changes to better meet the phase out commitments, led the Government of Lebanon to propose a re-orientation of the project and the adoption of more suited alternatives.

The new alternatives proposed were: crop rotation, soil solarisation and chemical fumigation (Metham sodium-MNa combined with 1,3-D/pic) applied or a combination of both. These alternatives have been tailored according to pest pressure and cropping practices in each of the main strawberry production regions. They allow for satisfactory control of soilborne pathogens, are technically and economically feasible, and environment-friendly to the largest extent possible. Most important, they enjoy a high level of acceptance from growers.

Figure 10.4. Crop rotation scheme for crops in Lebanon



Crop rotation and solarisation have been mainly applied in the northern Bekaa and Akkar valleys where land is inexpensive and generally present low to medium pest pressure. In these regions, farmers own large areas of land and can apply crop rotation within a frame of 2 to 3 years; the main rotation crops are wheat, barley and pastures, which are used to break the strawberry disease cycle. Farmers can afford solarising moderately infested soils for an average period of 6 weeks during which production stops. In many cases, farmers combine soil solarisation with crop rotation to obtain better results.

Drip-applied chemical fumigants have been mostly adopted in Beirut and the southern coastal areas where due to different reasons solarisation and crop rotation are not feasible. There, land is more expensive and interrupting production for 6 to 8 weeks is not possible. Further, soils around Beirut and in the southern coast are heavily cultivated and pest pressure is much higher, so that solarisation alone is not sufficient and chemical fumigants are needed; best results have been obtained by combining solarisation with chemicals, since the solarisation period can be significantly reduced. Of the two chemical alternatives adopted, the 1,3-D/pic has shown better efficiency for areas with high pest pressure; growers have also found it easier to apply.

Current situation

The alternatives described were satisfactorily adapted to Lebanese conditions by the end of 2005 and led to the phaseout of about 67 tonnes of MB or 83% of the total MB due to be phased out through the project. 70% of strawberry farmers and 177 ha grown with strawberries have now phased-out MB in Lebanon. Aside from farmers, more than 500 additional stakeholders have been trained on MB alternatives.

A summary of the project achievements appears in Table 10.24 below.

Table 10.24. Summary of achievements of the Lebanese project

Alternative	Tonnes phased out	% Tonnes phased out	Area (ha)	Farmers Trained	Other stakeholders trained
Crop rotation	30.1	45.1	59.2	63	189
Soil solarisation	14.5	21.8	32.5	44	132
Metham Sodium	2.6	4.0	6.7	28	84
1,3D+Pic	10.7	16.1	25.4	17	51
Steam	1.02	1.5	1.8	9	27
Reduced rate of MB (transition step, prior to technology change)	7.7	11.5	51.7	13	39
Totals	**66.7**	**100**	**177**	**174**	**522**

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Case Study 15. Turkey - Phasing-out Methyl Bromide in Vegetable and Cut Flower Production

Soil fumigation with MB in Turkey has been almost completely phased-out. Former users are vegetable and cut flower growers who now use solarisation (alone or combined with chemicals), grafting, alternative chemicals and substrates.

Initial situation

Cut flowers and vegetables play an important role in the Turkish agricultural sector. Protected horticulture and cut flower production started in 1940 and 1985 respectively in the region of Antalya; presently, total vegetable production is about 26 million tonnes, which places Turkey as the fourth largest producer in the world after China, India and USA. 87% of the vegetables are produced in open fields and 13% under high and low tunnels made of polyethylene or glass (Yilmaz *et al.*, 2005). The main crops are tomato, comprising about 40% of the horticultural sector, watermelons (15%), onions (9%), peppers (7%), melons (7%) and others (31%). Protected cultivation has grown rapidly and presently there are approximately 50,721 ha of greenhouses, half of which are located around Antalya (Titiz, 2004). Vegetable exports were valued at $225 million USD (274.000 tonnes) in 2006. The cut flower industry has also expanded and exported $40 million USD (405 million stems) in 2006. Flower production comprises of 43 % carnation, 13 % roses, 12 % gladioli, 9 % gerbera and 23% other flowers (Mediterranean Fresh Vegetable and Fruit Exporter Union, 2006, pers. comm.).

Turkish greenhouses are typically small, with an average size of 2-3 da; 90% of the protected areas are less than 3 da. Approximately 150,000 growers produce vegetables and 800-900 produce cut flowers under cover (Anon., 2003).

MB has traditionally been used as a soil fumigant for vegetables, flowers, strawberries and tobacco seedlings and for postharvest treatment of dried figs, apricots and other products as well as various QPS applications. In soils, it was used mainly for controlling soilborne diseases and nematodes, the most important of which appear in Table 10.25.

Table 10.25. Main soilborne pests and pathogens of vegetables and flowers in Turkey

Host plant	Primary pathogens	Secondary pathogens
Tomato	*Meloidogyne* spp., *Fusarium oxysporum.* f.sp. *radicis-lycopersici, Fusarium oxysporum.* f.sp. *lycopersici*	*Sclerotnia sclerotiorum*
Cucumber	*Meloidogyne* spp.	*Verticillium dahliae*
Pepper	*Meloidogyne* spp., *Fusarium solani, Phytophthora capsici*	*Sclerotinia sclerotiorum*
Eggplant	*Meloidogyne* spp. *Fusarium oxysporum.* f. sp. *melonganea, Verticillium dahliae.*	
Cut flowers	*Fusarium* spp., Bacterial diseases	

Nevertheless, MB consumption was almost phased out in all controlled uses in 2006 (Table 10.26) without imposing a major burden for users (Yilmaz *et al.*, 2006).

Table 10. 26. MB phaseout schedule in agricultural sectors in Turkey

Horticulture and Cut-flower Sub-Sectors				Total MB Consumption* for all controlled uses	
Year	Expected Reduction (ODP tonnes)	Consumption (ODP tonnes)	Consumption (tonnes)	Consumption (ODP tonnes)	Consumption (tonnes)
2000	0.0	292.2	487.6	342.6	571.0
2001	0.0	292.2	487.6	332.6	554.3
2002	29.3	263.6	439.3	293.4	489.0
2003	58.6	204.7	341.1	225.4	375.7
2004	58.6	146.1	243.5	167.4	279.0
2005	87.9	58.2	97.0	78.4	130.6
2006	58.6	00.0	00.0	20.4	34.0

*MB consumption for non-controlled uses (QPS) is not included

Actions for replacing methyl bromide

Legislative actions - The Turkish Government ratified the Montreal Protocol in 1987 and the Copenhagen Amendment in 1999. To assist Turkey with the inherent commitments, the MLF approved two investment projects, one with UNIDO as implementing agency in coordination with the Turkish Ozone Office for soils uses and a separate one for postharvest uses which was undertaken by the World Bank. The soils project called for advanced phaseout in 2007 but Turkey is presently a step ahead with the agreed phaseout schedule.

The Ministry of Agriculture coordinates import permits in accordance with the MB phaseout schedule, and enforces regulations for its application, for QPS purposes. MB imports, sales and application are strictly controlled and illegal trade is severely prosecuted. Since Turkey is aiming at membership in the European Union, agricultural practices and chemical uses are being calibrated in conjunction with EU rules and regulations. Thus, the investment project is helping to meet the strict requirements for exporting cut flowers and vegetable crops to the EU.

Actions undertaken through the project – Initially, two MLF demonstration projects on MB alternatives were carried out to determine the options best suited for Turkish conditions (Yilmaz *et al.,* 2006): *"Alternatives to the use of MB as a soil fumigant in protected horticulture (tomatoes and cucumbers) and ornamental crops (carnations)"* implemented by UNIDO (1998-2001) and *"Project for the introduction of alternatives to MB in protected strawberry, pepper and eggplant in the East Mediterranean region and in strawberry in the Aydın province of Turkey"* implemented by The World Bank (1999-2002). Later, two investment or phase out projects were approved, *"Phaseout of MB in protected tomato, cucumber and carnation crops, MP/TUR/01/214"*, implemented by UNIDO (2003-2007) and *"Phase out of Methyl Bromide for Dried Figs (2001-2004)"* implemented by the World Bank.

Research Actions - Through the demonstration projects, extensive trials were undertaken. As a result, solarisation alone or combined with chemical alternatives were selected as good alternatives to MB; steam application proved to be efficient but very expensive; bio-fumigation with chicken manure offered a good solution but gave way to salinity problems in some instances. (Öztürk *et. al*, 2002).

The effectiveness of solarisation, solarisation+chemicals, grafted seedlings, soilless culture, steam, bio-fumigation, cultural techniques and IPM was demonstrated to growers. Further, Good Agricultural Practices (GAP) and traceability of crops were introduced, since these are important for exporters in particular. A very detailed survey of MB users, soilborne pests, grower profiles, and infrastructure of the vegetable and cut flower sectors was conducted to ensure that training efforts were successful (Yılmaz *et. al*., 2006).

Training actions - Intensive training activities were conducted in all relevant sectors; these included workshops, meetings with growers and technical staff, field visits, training sessions in the field, domestic and international training activities and radio and TV programs. 3,100 stakeholders were trained in production techniques, soilless culture, IPM and MB alternatives. About 1,000 growers and technical personnel were reached and nearly 9,000 growers were visited and directly trained. Surveys were conducted. 26 persons were sent to abroad to Italy, Spain, Cuba, Austria, Colombia, Israel, Portugal and Canada to acquire training in IPM, crop production techniques, soilless culture and bio-control. (Yılmaz *et. al*., 2006). 77,000 brochures on 23 different subjects, 1,500 posters on 3 different subjects and 9 reports were published and distributed to different stakeholders.

Good Agricultural Practices - To teach GAP to growers, 2,368 leading growers were identified. They were supported with goods, equipment and technical information through the project budget. Project personnel visited selected greenhouses regularly between 2004 and 2006 and taught growers how to keep records on pests and diseases, conduct climate control and proper soil management, improve growing techniques etc (Yılmaz *et. al*., 2006).

Extension work - Extension services also played a most important role in disseminating results of both the demonstration and phase out projects. Extension personnel were very active in the regions of Antalya, Adana, Mersin, İzmir, Isparta and Mugla creating a firm bridge between researchers and growers, particularly in the course of the investment project (Yılmaz *et. al.*, 2006).

Description of alternatives implemented

Both chemical and non-chemical alternatives were adopted. Table 10.27 below summarises the economic feasibility of MB and its alternatives in Turkey, their registration status, application methods, and key target pests to be controlled. Among the chemical alternatives, only metham sodium proved more costly than other chemical alternatives.

Solarisation has become widely adopted for horticulture since climatic conditions of the Mediterranean Region are very favourable. Combined with low doses of chemicals, it is particularly effective for controlling soilborne pathogens and weeds of vegetables. This alternative has not been as widely adopted by flower growers because time between growing cycles (4 to 6 weeks) is generally not sufficient to achieve effective results. In cooler production areas (e.g. Isparta), solarisation is not feasible because production only stops during the winter months. Solarisation is thus best suited for vegetable sectors in the coast of Mediterranean and Aegean Regions (Öztürk *et. al*, 2002; Yılmaz *et. al.*, 2006).

Table 10. 27. Applicability and economic feasibility of MB alternatives in 2005-2006

Sector	Alternatives	Registration Status	Application Method	Cost USD$/ha	Target Pest
Cut-Flower	MB	Registered	Dripping	3.350	SBP,N,W*
	Chloropicrin + 1.3D	Not Registered	Dripping	2.380	SBP, N.
	MS	Registered	Dripping	3.180	SBP, N
	1.3D	Registered	Dripping	1.430	N
	Dazomet	Registered	By hand	2.240	SBP, (W),
	Steam application	-	Steam machine	23.000	SBP, N, W
	Soilless Culture	-	-	13.159** (inc. initial inv. cost)	SBP, N, W
Vegetables	MB	Registered	Dripping	3.350	SBP,N,W
	Chloropicrin + 1.3D	Not Registered	Dripping	2.380	SBP, N
	MS	Registered	Dripping	3.180	SBP, N
	1.3D	Registered	Dripping	1.430	N
	Dazomet	Registered	By hand	2.240	SBP, W
	Solarisation	-	-	80	SBP, N, W
	Soilless culture	-	-	27.000 (inc. initial inv. cost)	SBP, N, W
	Grafted seedling	-	-	2.680**	SBP, N
	Biofumigation	-	-	2.500	SBP, N,W

Soilborne Pathogens (SBP), Nematode (N), Weed (W), Added cost for grafted seedling

Steam proved too costly for horticulture production due to high fuel prices and currently is not a viable alternative in most circumstances in Turkey. Steaming is however feasible for flower seedling or cutting production in Antalya and for strawberry runner production in the Adana and Mersin provinces (Yılmaz *et. al.*, 2006).

Soilless culture can be a viable alternative for both the vegetable and cut flower sectors. However, Turkish growers need to acquire further expertise to establish and operate this system extensively (Yılmaz *et. al.*, 2006).

Grafting is expanding rapidly in the vegetable sector and is a viable alternative to MB. Grafted seedling technology (GST) is especially suitable for watermelon, eggplant and tomato, where high quality and yields are obtained. GST has also been used for peppers and melons, however affinity problem between rootstocks and scions have arisen and further trialling is needed (Yılmaz *et. al.*, 2006).

Bio-fumigation combined with solarisation is successful but availability and cost of fresh manure generally limit its use (Öztürk *et. al*, 2002; Yılmaz *et. al.*, 2006).

Lessons learned

MB was phased- out from the vegetable and cut flower sectors of Turkey without a major impact for growers and companies. MB has been left over from previous years and may be used in 2007, however amounts will be very small as complete phaseout is due by the end of 2007. New technologies like soilless culture, grafting, steam, compost and some novel growing techniques were introduced and accepted by Turkish growers.

Among the alternatives introduced, solarisation is the cheapest and very effective, and can be successfully combined with chemicals targeted at controlling specific soilborne pests. In addition, soilless culture and grafting are rapidly growing and appear as promising alternatives for Turkish conditions.

The importance of monitoring and crop traceability was evident. IPM and GAP were shown in model greenhouses to growers, consultants, and extension personnel. Very strong coordination and collaboration between academicians, researchers, extension staff, growers, companies, consultants, dealers and policymakers was achieved during the course of the investment project.

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10.4.2. Alternatives for postharvest uses

Case Study 16. Cyprus - Alternatives to MB for grain protection and storage

Experts in Cyprus have concluded that storing grains in structures such as hermetic bins, bunkers and platforms in combination with fumigation systems (phosphine, CO_2) and aeration provide effective and viable alternatives to MB,.

Initial situation

MB was widely used in Cyprus for treating grains until 2003 when MB imports were stopped for grain. Prior to that, between 1991-2002 imports of MB were on average 81 tonnes per year (Varnava, 2007). Grain – mainly barley, maize and wheat - is stored in all regions of Cyprus for varying periods of time. The climate is Mediterranean, with hot, long and dry summers and mild winters. In summer insects can multiply rapidly on stored grain and conditions for insect survival remain favourable for most of the year (Varnava, 2002).

Even before joining the EU the grain industry in Cyprus abided by the EU legislation (as well as Cyprus legislation) with respect to import, trade, storage protection and quality of grain for animal and human consumption. Quality parameters are strict and under the control of official authorities.

Mindful of the need to implement environment friendly practices, the Cyprus Grain Commission – (CGC) a state authority that deals with import of cereals, collection of local grain production and grain storage and sale - started requiring international grain suppliers to exclude MB from the list of chemicals they used for disinfesting grain imported into Cyprus as early as 1990. An average of 600 tonnes of grain are imported per year. In addition, the CGC itself never used MB for grain disinfestation or other postharvest uses (Varnava, 2002; 2007). The main alternatives implemented for stored grain protection are described below.

Description of alternatives implemented

Cyprus was the second country in the world to adopt the Eco2Fume®/Siroflo® technologies (2%PH_3 + 98%CO_2) for grain fumigation following their adoption in

Australia in 1996. These technologies have been successfully implemented both for metal and concrete silos, achieving effective grain disinfestations, products without chemical residues and improved safety in the working environment. MB is no longer needed for silos. Fumigation mixtures PhosFume®/Eco2Fume® were registered in Cyprus by the CGC as early as 1997 (Varnava 2001; 2002).

Wide adoption of Eco2Fume®/Siroflo® technologies have also made it possible to minimise or even avoid the use of liquid insecticides for treating grain, which further enhances procedural safety and avoids chemical residues in grain. Liquid insecticides are only used for store disinfestations now (Varnava, 2001).

The above techniques, combined with hermetic grain storage in bunkers successfully protects grain against insects, rodent contamination, bird attack and losses, and allows access to international markets for bulk grain. Hermetic and semi-hermetic storage and the extensive use of aeration technology have also led to less use of chemicals and allow the successful protection of grain, even for long-term storage. Hermetic storage is also used efficiently for QPS uses. The increase of semi-hermetic storage capacity by introducing the "Bunker" technology under UV PVC, has further reduced the use of fumigants. When phosphine tablets are used any phosphine dust remaining in the grain mass is removed by using a special "fumigation device" (Varnava, 2002).

Aeration is extensively used for controlling the temperature of stored grain. This is an efficient way of minimizing development of fungi and mycotoxins, grain deterioration and use of insecticides (Varnava, 2006).

Table 10. 28. Types of Fumigants used for grain disinfestation in various types of Storage Facilities by the Cyprus Grain Commission, 2005

Fumigants used for grain disinfestation in 2005	Metal and Concrete Silos (unsealed)	Metal and Concrete Silos (hermetic)	Metal and Concrete Silos (semi-hermetic)	Platforms and Bunkers under UV PVC*	Flat Stores (unsealed)	Total storage capacity
Storage capacity (tonnes)	100,000	6,000	6,000	60,000	28,000	200,000
% storage capacity	50%	3%	3%	30%	14%	100%
Methyl bromide	No	No	No	No	No	0%
Phosphine tablets	No	No	Yes	Yes	Yes	47%
Eco2Fume®/Siroflo®	Yes	Yes	No	No	No	53%

* Hermetic and semi-hermetic, special cases

Source: Varnava, A. Cyprus Grain Commission

Table 10. 29. Grain protection methods and technologies used by the Cyprus Grain Commission as alternatives to Methyl Bromide (1985-2005)

	1985	1995	2005
MB in CGC activities			
MB (kg) used for grain protection and store desinfection	0	0	0
MB in imported grain cargoes	4 out of 35 received, m.v.	None out of 50 received, m.v.	None, out of 38 received, m.v.
Grain fumigation with phosphine tablets			
Fumigated grain, tonnes	60,000	60,000	60,000
Phosphine in tablets, kg/ yr	700	700	700
Cost □ / ton	0,16	0,16	0,16
Grain fumigation with ECO2FUME®/SIROFLO®			
Fumigated grain, tonnes	0	2,000	26,300
2% PH3+ 98% CO2 kg/yr	0	96	825
Cost □ / ton	0	0,48	0,31
Liquid insecticides			
Used for grain protection, L/yr	350	250	10
Used for store desinfection, L/yr	650	600	200
Aeration of stored grain			
Aerated grain, tonnes/yr			31,000
Energy used for aeration, Kw.h			33,300
Energy used for aeration, Kw. h/ton			1,1
Cost of aeration, □ /ton			017

1986* = average for 1984-1986
2005* = average for 2004-2006
Source: Varnava, A. Cyprus Grain Commission

Current situation

Cyprus stopped importing MB and was in full compliance with the January 2005 phaseout date. Tables 10.28 and 10.29 describe technologies and products presently used in Cyprus for disinfestations and protection of stored grain.

Based on information provided by Dr. Andreas Varnava, Cyprus Grain Commission, e-mail: a.varnava@cgc.com.cy

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Case Study 17. Israel - Biogenerated atmospheres in vacuum-hermetic systems for disinfestation of narcissus bulbs as a quarantine treatment

Since 2003 biogenerated atmospheres have entirely replaced MB for eliminating the narcissus fly from narcissus bulbs exported from Israel. The narcissus fly is a quarantine pest in the US. Bulbs are placed in a chamber made of a flexible liner that can hold vacuum or modified atmospheric gas compositions.

Initial situation

The large narcissus fly, *Merodon eques*, is a quarantine insect species that attacks narcissus bulbs as well as bulbs of other geophytes. It has not been reported in the US – where a significant proportion of narcissus bulbs produced in Israel are exported - and is included within quarantine requirements that demand total mortality prior to export to the USA (Donahaye *et al.* 1997). Until recently, fumigation with methyl bromide (MB) was used to eliminate infestation from this fly in flower bulbs due to its rapid killing time (4 hours). However, as a result of the Montreal Protocol and also because of the phytotoxic effects of MB, developing new disinfestation methods was strongly encouraged. Pilot commercial experiments were initiated in Israel in 1997 using a newly developed vacuum-hermetic fumigation system. Initial progress was reported in the MBTOC 2002 Assessment Report (MBTOC, 2002).

Description of alternative

During laboratory and field trials, researchers (Navarro *et al.*, 1997) found that when recently harvested bulbs were stored in sealed hermetic conditions, their respiration caused a rapid decrease in O_2 and increase in CO_2 which has a marked toxic effect on the flies. This led to laboratory studies with three kinds of modified atmospheres: high CO_2 concentration (95%), vacuum (low pressure of about 50 mm Hg), and storage under hermetic conditions alone (Finkelman, 2003). It was found that 99% mortality was achieved in 24 h with the first two options and in 34 h under hermetic conditions alone. The possibility of obtaining a bio-generated modified atmosphere utilizing the bulb respiration was further studied and developed.

The vacuum-hermetic system consists of a chamber made of a flexible liner that can hold vacuum or modified atmospheric gas compositions. The bulbs are placed in the chamber on their original shipping pallets using a forklift. The desired modified atmosphere is achieved by taking advantage of the respiration of the narcissus bulbs, which under hermetic sealed conditions results in a rapid reduction in oxygen to 0.1% within 18 hours at 30°C, while the carbon dioxide concentration increases up to 21%. The system is sealed for about 48 hours to ensure a successful treatment. Laboratory and field trials were conducted for several years to ensure that the narcissus bulbs are capable of creating such atmospheres in the vacuum-hermetic system, and that the large narcissus fly can be controlled as a result of this atmosphere (Finkelman *et al.* 2002, Finkelman, 2003; Navarro *et al.* 1997ab). No phytotoxic effects were observed and mortality meets the stringent quarantine standards (Finkelman, 2003)

Commercial adoption

The vacuum-hermetic system was introduced for disinfestation of narcissus bulbs in Israel in 2000. Since 2003 biogenerated atmospheres have been adopted, to the point that they have completely replaced MB for eliminating the narcissus fly from narcissus bulbs exported from Israel (Navarro, pers. comm., 2007). Growers operate units at their own packing stations. Pre-shipment inspections show total insect mortality inside the bulbs and all consignments are approved for export (Finkelman *et al.*, 2004). Studies report that growers using this treatment recovered their investment in three years of use (Finkelman *et al.*, 2004)

Registration is not needed for vacuum-hermetic treatments in Israel. Further, this treatment does not leave pesticide residues, poses no safety risks like fumigation, and is environmentally safe. The system is transportable and can be assembled by a team of three labourers. The main drawback to this treatment is the longer exposure time needed compared to MB fumigation. This drawback is corrected by increasing the number of transportable vacuum-hermetic systems as needed.

Hermetic disinfestation is likely to be suitable for many commodities. Treatment conditions within the vacuum-hermetic system can be adapted to the application of modified atmospheres, vacuum or heat treatment, according to the special needs of the treated commodity (Navarro, pers. comm., 2007).

Based on information provided by Dr Shlomo Navarro, Professor Emeritus, Israel snavarro@013.net

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Case Study 18. Israel - Heat disinfestation of dates

Madjoul dates represent 40% of date production in Israel. Field infestations of nitidulid beetles pose a serious contamination problem that may put exports at risk.

Necessary disinfestation, which used to be performed with MB is now successfully achieved with heat. Application of this alternative is being studied on other date varieties.

Initial situation

In Israel, the date variety Madjoul is very popular because of its large size, texture, and particular taste and its cultivation is increasing. Presently about 40% of all dates produced in Israel are of the Madjoul type. A number of other dry varieties are also grown such as Amery, Deglet-Noor, Hadrawi, Halawi, Deri, and Zehidi. Some of these mature on the tree, but may require drying after harvest.

Field infestations of nitidulid beetles in all date varieties pose a serious contamination problem which can put exports at risk. In the past, this problem has been addressed successfully by fumigation with MB. Fumigation of dried fruits with methyl bromide (MB) upon arrival at the packing plant effectively controls infestation and causes a high proportion of larvae and adults to emigrate from the fruit before they succumb. This is important since minimum tolerances are set for both dead and live insects in the dried fruit.

Several options to replace MB have been analysed by researchers in Israel. Phosphine, although effective, is very slow-acting, and does not force insects to emigrate from fruit (Finkelman *et al*., 2006). Other treatments such as high CO_2 concentrations, low oxygen and low pressures are efficient but pose other problems, mainly due to the fact that they are unsuitable for application at points of entry of the date packing houses (Finkelman *et al.*, 2006). For these reasons, heat treatment has been studied and found to be a feasible and efficient alternative to MB at least for Madjoul dates. Other date varieties still pose problems and are included in CUNs put forward by Israel to the MOP (Government of Israel, 2007)

Description of alternatives adopted

In view of urgent need to develop an alternative to MB for the treatment of dates, work was undertaken to investigate the effectiveness of heat treatment with the aim of removing insects, preventing insect development on the dates, and preserving fruit quality.

Insect pests of stored products survive and multiply over narrow ranges of temperatures. For each species there is a minimum and maximum temperature at which it is able to develop. At certain low temperatures, oviposition and larval growth cease and at specific high temperatures egg sterility occurs and mortality increases. The lower and upper limits and optimal temperatures of most of the important stored-product species are well known (Navarro *et al*., 2004a, b; Finkelman *et al*., 2006).

In laboratory studies, the influence of 40°, 45°, 50° and 55°C on the levels of disinfestation and mortality of *Carpophilus hemipterus* larvae was examined over a 2 h exposure period. Temperatures used for drying the Madjoul variety in Israel should be kept within the range of 45° to 55° C to avoid discoloration and a blistering effect that separates the skin from the flesh of the fruit. The ratio of the number of larvae found outside the feeding sites to the total number of insects was used to describe the term "percent disinfestation". At 50° and 55° C complete mortality was obtained. The conventional drying temperatures for most date varieties are in the range of 50° to 55°

C, so heat treatment appeared as a feasible solution for the treatment of dates as a replacement to MB.

The laboratory findings served as a basis for field trials carried out at a date drying station (Finkelman *et al*., 2006). This consisted of a greenhouse converted into a solar drier for holding pallets of stacked crates of dates arranged in rows and covered by plastic liners to form drying ducts. One extremity of each duct was connected to a thermostatically controlled chamber supplying solar heated air, and the other end appended to large fans set to extract air from the ducts. Crates with artificially infested dates were positioned at strategic sites and the drying phase of 45°C was preceded by a 2 hour phase at a target temperature of 50°C during which disinfestations was achieved. Results showed that although mortality after 2 h was incomplete at some sites, disinfestation was very high, and over the normal drying period of up to 72 h mortality would have been complete (Finkelman *et al*., 2006; Government of Israel, 2007). The approach was shown to be feasible using a commercial drying installation, with no modification required (Finkelman *et al*., 2006)

Actions taken - Results

Commercial scale trials have shown that the use of heat for insect disinfestations and control is even more effective than MB (Finkelman *et. al*., 2006). Since its development in 2003, thermal disinfestation has been increasingly adopted with support and encouragement from Ministry for Protection of the Environment (MPE) of Israel (Government of Israel, 2007). During the harvest season of 2006, about 30% of Madjoul date variety growers used thermal disinfestation.

The successful treatment has convinced growers to the point that almost 90% of the production plans to use the thermal disinfestation technology in the season of 2007 (August-October) (Navarro, 2007). About 8700 tonnes of Madjoul dates are produced per year, which amounts to about 40 % of all dates grown in Israel. (Government of Israel, 2007)

Continuing efforts have been made by the MPE to expand the use of thermal disinfestation into all packing houses that need to disinfest Medjool variety dates in the season of 2007 and 2008. This will probably lead to treatment of more than 10,000 tonnes of Madjoul dates (Government of Israel, 2007). Presently, research is being conducted on application of this technology to other date varieties (Finkelman *et al*., 2006).

Based on information provided by Dr Shlomo Navarro, Professor Emeritus, Israel snavarro@013.net

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10.5 Alternatives to MB Adopted in Latin America

Within Article 5 regions, Latin America presently stands as the higher consumer of MB, with 52% of the total Article 5 consumption, amounting to 4,837 tonnes as described in Chapter 3. Latin American countries phased out 24% of the regional baseline, a percentage which is lower to that of other regions. This is mainly due to high consumption remaining in some sectors such as melons and cut flowers. However, MB phaseout in some sectors, which were previously high consumers such as tobacco, has been very significant and only a small percentage of the consumption is left at present (Brazil, for example, has completely phased out this use and is the world's largest exporter of tobacco). Sectors where MB phaseout has been slower include melons in Central America, strawberries in South America and cut flowers, but even with these, important progress in the adoption of alternatives has been achieved, both through MLF projects and also through independent efforts from growers.

10.5.1. Alternatives for preharvest uses (soils)

Case Study 19. Argentina - Current status of MB phaseout in the tobacco sector

Until recently one of the largest MB users, the tobacco sector of Argentina has now phased-out over 75% of the quantity used in 1998 for producing tobacco seedlings. The Floating Tray System is the primary alternative adopted. In the process, over 9,000 growers were trained directly in a short time by a MLF project and a further 15,000 growers were trained by technicians who had been trained by the project.

<u>Initial situation</u>

Tobacco production begun at the start of the past century in Argentina, showing substantial expansion in the 1940s and 1950s as a result of the government's import substitution policy of the time. Tobacco remains an economically important crop in seven northern Argentinean provinces: Misiones, Corrientes and Chaco in the Northeast and Jujuy, Salta, Tucumán, and Catamarca in the Northwest. Expansion is still occurring: The production area grew from 58,422 ha in 1994 to 79,015 ha in 1999-2000.

Climate in the producing regions varies significantly: from tropical/sub-tropical Misiones where annual rainfall is 1,500 mm per year to the much drier north western provinces with a mere 400 mm per year, which make irrigation necessary. According to the climate and the type of tobacco grown, the seedbed season will run from April to September. The provinces also show different production and social structures, varying from many thousands of peasant farmers (almost 80% of the tobacco farms), to family farms and larger commercial farms. Most of the tobacco produced is either Virginia type (about 65%) or Burley (about 26%), both of which are blonde types. Lesser amounts of dark types (criollos) are also planted in different areas mainly Corrientes.

MB was used for controlling a wide range of soilborne pests attacking tobacco seedbeds in Argentina. Among the most common were Blue Mold, Damping- off, Red stele, and other root diseases (*Pythium* spp.; *Phytophthora* spp; *Rhizoctonia* sp); several other diseases caused by *Xanthomonas* sp., *Gnomonia comari*, *Diplocarpon earliana* and *Phomopsis obscurans;* and arthropod pests such as ants (*Agromymex* spp), and root and crown feeders (*Agrotis ipsilon* and *Heliothis zea*). The main weed problems were *Cyperus rotundus*, *Sorghum halepense* and *Chenopodiun quinoa.* More than 24,400 registered tobacco farmers used MB in the past, with total consumption reaching 268 tonnes in 2000 (Kryvenki *et al.*, 2001).

Actions for replacing MB

The Argentinean National Institute of Agricultural Technology (INTA), the National Ozone Unit (OPROZ) and UNDP, implemented a demonstration project funded by the MLF in 1998-2000 with the aim of trialing different alternatives. Three options were selected for the ensuing phasing-out phase: metham sodium, floating trays and plastic trays (Kryvenki *et al.*, 2001). The phaseout or investment project started in 2002 with a clause for 100% replacement of MB by 2007.

The following actions were taken:

- Regular information sessions with stakeholders were held in all regions. Commissions were created for every province and were in charge of taking the main project decisions;
- Agreements were signed with the governments of the 7 provinces included in the project;
- The majority of tobacco organizations signed a firm commitment to phase out MB by 2007.
- Distribution of inputs and technical assistance to 16,000 growers each year.
- Continuous awareness raising activities in rural primary and secondary schools where most students' parents are tobacco growers and farm employees.
- Awareness-raising activities were undertaken with the media.
- 9,055 growers and 189 technicians were directly trained through seminars, field days workshops and others.
- Leaflets, manuals, and other diffusion materials were produced and distributed in each region. The project team participated in several rural fairs and demonstrated the selected alternatives to more than 30,000 persons.
- The project team developed a pine bark substrate that can be successfully used with the trays. Production protocols without MB were also developed including designed trays and seeding machines, fertilization techniques and others, all of which are suited to Argentinean conditions.

Description of alternatives implemented

Three alternatives were selected for phasing-out MB in the Argentinean tobacco sector:

- **Metham Sodium:** this fumigant proved successful during the demonstration project for the specific circumstances of Argentina. It is sufficiently effective for controlling soilborne pests and diseases in certain areas, and does not require large changes in traditional production methods, although more skilled labour is required.
- The **Floating polystyrene tray system (FTS)** provides plants with water and nutrients through a waterbed. This proved to be the best method for tobacco transplant production. Commercially prepared and cleaned substrates can be used or the grower can prepare them. Seedlings are directly germinated in the trays; when seedlings reach the appropriate size they are transplanted to the field. The bed and the floating trays are never in contact with the soil so pests and diseases are entirely avoided. Initially significant investment was necessary to adopt this system, mainly because the trays and substrates had to be imported. 288-cell trays were selected among different sizes. Presently trays are manufactured locally, and an inexpensive pine bark substrate has been made available, which has led to a significant drop in production costs and wide adoption of this alternative (Biaggi *et al.*, 2003).
- The **non-floating plastic trays** are a variation of the floating system. This technique requires a higher degree of management skills since a smaller quantity of water is used in the pools, so there is a risk of evaporation with possible associated changes in salinity. However, this technique creates fewer environmental problems than polystyrene trays as much less solid waste is created. Additionally, plastic trays are easier to clean than polystyrene, which reduces the risk of disease. This method has proven to be most economical in the long-term and may therefore provide the most sustainable option. However, initial investment is even higher than for floating trays and the project team is presently working on the development of a plastic floating tray that will help overcome these disadvantages (Biaggi *et al.*, 2003).

Current situation

Despite substantial expansion in the tobacco cropping area in Argentina (in 1989-2003 the average area was 56,000 ha, but the last three seasons have averaged 84,000 ha) MB consumption has dropped 75 % since the phaseout project started. Put simply, in 2000, each tobacco hectare used an average of 3.6 kg of MB, while in 2005 that figure dropped to 0.79 kg. This is the result of the firm efforts undertaken by an entire sector to achieve complete phaseout and denotes a high grade of sustainability reflected in the change of production technology. Table 10.30 presents the amounts of MB already phased out.

Table 10.30. Aggregated MB committed with MLF and phased-out amounts

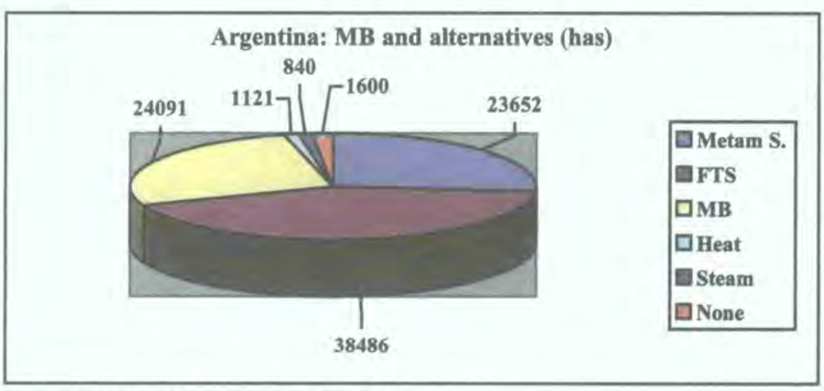
MB phased out per year (tonnes)		
	Committed	**Total phased out per year**
2002	48.3	89.3
2003	35	33.4
2004	26.6	24.0
2005	55.8	35.01
Aggregated Total	**165.8**	**196.7**

The project has made excellent progress in the northeast, where MB is already phased-out. Misiones is the main tobacco- producing province with about 17,000 growers, 100% of which transitioned to the floating tray system by the 2004/2005 season.

The northwest holds larger farms (50 ha per unit on average) so that technological innovation requires much larger capital investment and takes more time. Nevertheless, by 2005 72.9% of the planted area (62,200 ha) had switched to alternatives.

Presently, four of the seven tobacco provinces have prohibited MB use for tobacco production from 2007 onwards. The following chart shows the number of hectares where each alternative has been adopted and the area still using MB.

Figure. 10.5. Use of MB and alternatives in the Argentinean tobacco sector in 2006



Source: PROZONO Project, 2005 Annual Report

Conclusions

The FTS technology was rapidly adopted in non-Article 5 countries during the early 1990s. In Article 5 countries MLF projects offered a good opportunity to demonstrate the system, and then removed the main barriers for widespread adoption: high initial investment and technical and educational requirements for growers.

Stringent requirements are currently imposed on tobacco growers in response to consumer demand for environment-friendly products, a trend that facilitates MB replacement. Implementing adequate extension strategies and institutional alliances are key factors for successful technology transfer. The project described has shown that it is possible to train large numbers of growers in a short period, committing a whole industry to the protection of the ozone layer through methyl bromide replacement.

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Case Study 20. Use of floating tray system as methyl bromide alternative for tobacco in Brazil

After using more than 700 tonnes of MB for tobacco seedling production in 1998, remaining consumption at present is nil in this sector. The main alternative adopted is the Floating Tray system which, although more expensive than traditional ground beds, allows for higher yields and improved quality seedlings compensating for the additional investment.

Initial Situation

Brazil is the first world exporter and the second largest producer of tobacco in the world. Annual harvests are estimated at around 800,000 tonnes of which approximately 75% is exported. The sector involves about 227,000 small growers and their families and is concentrated in the southern region of the country, where 96% of the total production takes place (UNIDO, 2000; 2002).

In 1998, tobacco was the largest MB-consuming sector in Brazil, where it was used for seedbed fumigation. Total MB imports in 1998 were reported at 1,414 tonnes (MB is not manufactured in the country). More than 140,000 farmers used almost 50% of this amount or 703 tonnes to fumigate over 3,000 ha of traditional seedbeds. At the time, the entire seedling production system relied on MB fumigation, which was necessary to control pathogens and weeds (UNIDO, 2000; 2002). In 2005 however, the National Ozone Unit of Brazil reported nil consumption of MB in the tobacco sector (Medeiros, 2006).

Over 90% of the methyl bromide used in the tobacco sector in Brazil was phased out by the end of 2004. This was achieved by replacing the traditional seedling production system in seedbeds with the floating tray system in tunnels. Weed and pest-free substrate is used to fill the trays.

Actions for replacing MB

After identifying the need for testing and implementing alternatives to replace methyl bromide in tobacco, the Government of Brazil presented a proposal to the Executive Committee of the Montreal Protocol, which approved a demonstration project. The project was implemented by UNIDO from 1998 to 2000, in coordination with EMBRAPA the Brazilian Institute for Agricultural Research. Its aim was to test the economic and technical feasibility of different seedling production systems and identify the most appropriate for adoption by tobacco growers (UNIDO, 2000).

During the demonstration project different non-chemical alternatives were trialled, including the floating tray system (FTS), suspended trays, biofumigation and soil solarisation. Metham sodium and dazomet were also evaluated. FTS produced the best results, particularly from a technical standpoint. The system was also tested by AFUBRA - the Association of Tobacco Growers of Brazil - the largest tobacco growers' association in Brazil and SINDIFUMO, the Association of Tobacco Manufacturers. Both institutions were able to confirm the results obtained in the demonstration project. The soilless floating tray system in tunnels was selected by both the tobacco companies and the growers as the alternative of choice to be implemented during the conversion process.

To support this effort and based on this alternative, an investment project was implemented by UNIDO in 2001-2002 in cooperation with the Ministry of Environment. Its main purpose was to transfer the technology and necessary knowledge to farmers and help them eliminate their dependence on MB. UNIDO worked closely with AFUBRA and SINDIFUMO, which acted in representation of the farmers and manufacturers. Both associations co-financed the project. Altogether, the project reached 140,000 tobacco growers, who in addition to training received part of the equipment needed for putting the floating system in place (UNIDO, 2002).

Two training programs were implemented in order to achieve the necessary technology transfer: training of trainers and direct training of about 140,000 farmers. The first stage was directed at the technicians from SINDIFUMO and AFUBRA with the assistance of consultants. Later, these technicians were able to transfer the technology to the farmers using different approaches such as meetings, workshops, training videos and visits to the farms to assist implementation of the new system.

Description of alternative implemented

General layout of the floating system appears in Fig 10.4. Micro-tunnels are formed by metal arches, which are covered with anti- UV polyethylene film. Inside the tunnel a small pool (12 cm high) made of ceramic bricks and black polyethylene film is filled with a solution of water and fertilizer. Expanded polystyrene trays filled with substrate are then sowed with palletised seeds and placed in the pool.

The quality and homogeneity of seedlings, the greater resistance of undamaged roots to transplant stress, and the ease of transplant found when carrying the plants in trays, were the main factors influencing the decision of using FTS as an alternative. Additionally, the tray system has the advantage of requiring extremely low doses of chemicals to control pests and diseases. On the other hand, the adoption of FTS required substantial financial investment, new know-how, and significant changes in practices relating to seedling production and planting.

In general terms, the floating tray system allows for the production of uniform seedlings, and a higher percentage of useful seedlings that are suitable for transplanting (in the range of 95%) when compared to MB and other alternatives.

Overall, the tray system is about 28% more expensive than methyl bromide (Table 10.1). This is mainly due to the initial investment required to set it in place. This difference becomes small in absolute values however (US$ 32.59 per hectare), and is compensated quickly over time by the quality of seedlings.

Table 10.31 – Production cost of tobacco seedlings (per hectare) with the floating tray system and in methyl bromide treated seedbeds (in USD)

Options	Capital costs	Operational costs	Total
Floating tray system	56.22	91.43	147.65
Methyl bromide	19.20	95.86	115.06

Current situation

Imports and consumption of MB in Brazil have dropped dramatically in recent years, particularly after 2000, as a result of converting the tobacco seedling production system to floating trays. The technique has now been adopted by a high percentage of growers. MB consumption in the tobacco sector was reduced from 700 tonnes in 1998 to about 130 tonnes in 2004. In 2005 consumption was reported at zero and MB use was banned in the tobacco sector (Medeiros, 2006).

Brazil still imports around 400 tonnes of MB per year, which are used in other sectors. The Ministry of Agriculture issued an administrative rule in September of 2002 establishing a phaseout schedule for remaining uses of methyl bromide uses by type of crop/use as shown in Table 10.2.

Table 10.32 – Phaseout schedule for methyl bromide in Brazil

Crops / uses	Deadline
Tobacco	December 31, 2004
Vegetable seedbeds of vegetables, flowers and for killing ants	December 31, 2006
Quarantine and pre-shipment treatment including treatment of wood used in packing for importing/exporting	December 31, 2015

Provided by Carlos Medeiros, EMBRAPA, Brazil, MBTOC Member

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Case Study 21. Colombia - Producing cut-flowers without MB

Colombia is the second flower exporter in the world after Holland with exports valued at over $900 million USD. Yet, Colombian flower growers have never used MB extensively. Initial trials proved it to be phytotoxic in some instances and growers adopted alternatives more than thirty years ago. Substrates, steam, biocontrols and fumigants within an IPM approach are the main options used for controlling soilborne pests and pathogens in this industry.

Initial situation

Commercial floriculture worldwide is characterized by high investment and stringent quality demands which often imply high pesticide usage. Consumers want perfect flowers – completely free of damage caused by pests and diseases. Increasing international trade of flowers has led to the establishment of stringent phytosanitary measures at ports of entry, in an effort made by government authorities to limit and avoid the spread of pests in their countries. Generally, this means that exporters are required to send flowers that are disease and pest free.

Most importantly though, floriculture is generally a non-stop intensive activity that can be greatly affected by severe pests and diseases which, if left unchecked, build up in the soil leading to tremendously high losses in yield and quality. Among these, root knot nematodes (*Meloidogyne* sp.) can be particularly troublesome, as well as fungi (*Fusarium, Verticillium)* and some bacteria, (*Agrobacterium tumefaciens, Erwinia* spp*)*. Eradicating these noxious organisms from the soil can be difficult; they may even render whole areas unsuitable for the production of susceptible flowers, and make soil disinfestation mandatory. Traditionally, the treatment of choice has been fumigating with methyl bromide given its wide spectrum of action, its efficiency and its cost, which is usually lower than that of other fumigants in Article 5 countries (Pizano, 2001).

Upon learning about the methyl bromide phase out, many flower growers around the world have expressed deep concern, arguing that there exist no truly efficient alternatives to this fumigant and that, given the strict quality demands imposed on their products, they will go out of business.

However, producing flowers of excellent quality without methyl bromide is clearly possible and is already being done. The best example is Colombia, where initial trials with methyl bromide failed, forcing growers to look for alternatives thirty years ago because MB fumigation was phytotoxic to some flowers such as carnation due to bromine fixation and accumulation in soil high in organic matter (Pizano, 2001; 2004). Still, for many years Colombia has been the second flower exporter in the world after Holland, its export production valued at over US$900 million in 2006 (ASOCOLFLORES, 2006).

Description of the alternatives implemented

Substituting MB usually requires growers to adopt new production approaches. Although effective alternatives are available, there is no single replacement for MB. Rather, an integrated programme, involving different measures which together lead to disease reduction, has been put in place. Depending on the pests to be controlled, environmental conditions, supplies, infrastructure available and others, a particular programme might be more suited for a certain situation (Pizano, 2001).
The following alternatives are presently used by Colombian flower growers:

Steam sterilisation (Pasteurisation) – Pasteurisation or steam sterilization of the soil is a process by which pests, diseases and weeds present in the soil at a given time are killed by heat. Many variables influence the success and cost effectiveness of steam, for example, the boiler and diffusers used, soil type and structure and soil preparation. The depth or volume of soil or substrate to be treated directly influences costs of this alternative. Thus, steam can be made economically feasible when disease incidence is maintained at a low level when it is part of an integrated management system.

Very careful growers can even perform strip treatment (growing beds only) saving 40% of the costs (Carulla, 2006). Just like fumigants, steam is a biocide, killing all living organisms within the soil. To correct this problem, compost and/or beneficial organisms such as *Trichoderma* and beneficial bacterial cultures are added immediately after steaming. Steam has other benefits when compared to fumigants, as these usually require a waiting period – sometimes at least thirty days - before replanting can occur, while steamed soils can be replanted immediately. This sole fact adds one whole month of flower production to steamed areas, representing for example about 135,000 exportable carnation flowers per hectare (Carulla, 2006).

Compost – Compost is not only an excellent fertiliser but also can contain high amounts of beneficial organisms that prevent and help control soilborne diseases. Further, it contributes to restoring natural soil flora and increases water retention capacity. Compost amended or enriched with beneficial organisms such as *Trichoderma* provides very good control of soil fungi such as *Phoma* and *Pythium,* in *Dendranthema* and *Alstroemeria* ranges. Growers incorporating compost to the soil and following a strict IPM programme have been able to produce highly profitable yields without any soil sterilisation being necessary (Jaramillo, 2005) (Table 10. 33).

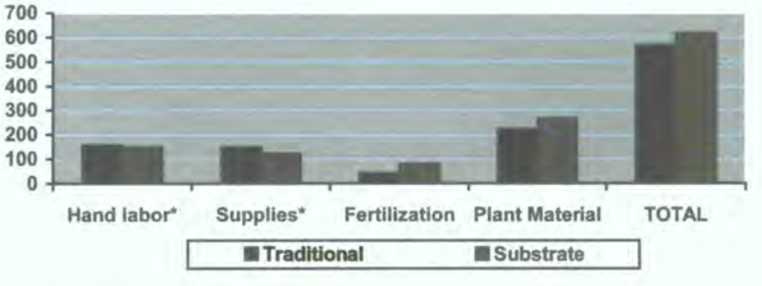
Table 10.33. Plant health and nutrition management with compost in *Dendranthema*

• **Amount of compost applied**:	20 - 30 Tonnes/ha
• **Frequency of application**:	Pre-plant (every 16 weeks)
• **Beneficial organisms (suspension)**:	50 L/ 30m^2 bed
• **% Substitution of chemical fertilizer**	(in growing cycle): 50%
• **Water retention capacity:**	Increased by 30 - 40%
• **Soil sterilization:**	None, except for sporadic spot treatments
• **Overall cost reduction**:	15 - 20%
• **Estimated cost per ha**:	USD $4950

Source: Valcárcel, F. and Jaramillo, F. 2002, 2004, Jardines de los Andes, Bogotá, Colombia

Substrates - Production of cut flowers and propagation materials in substrates has rapidly expanded in Colombia, especially since growers started to find and successfully adapt locally available, cheap substrates such as rice hulls, coir, sand and composted bark. An estimated 50% of all carnations produced in Colombia (around 600 to 700 ha) are presently produced in substrates (Calderón, 2001; Pizano, 2005). Although setting up a soilless production system is expensive – more expensive than traditional ground beds - growers are able to compensate the extra cost through significantly better yields (20-25%) and improved quality that result from higher planting density, optimum plant nutrition and better pest and disease control (Figs. 10.4 and 10.5 below)

Figure 10.6. Carnation production costs: traditional vs. substrate (rice hulls). 2 year cycle (USD/ha).

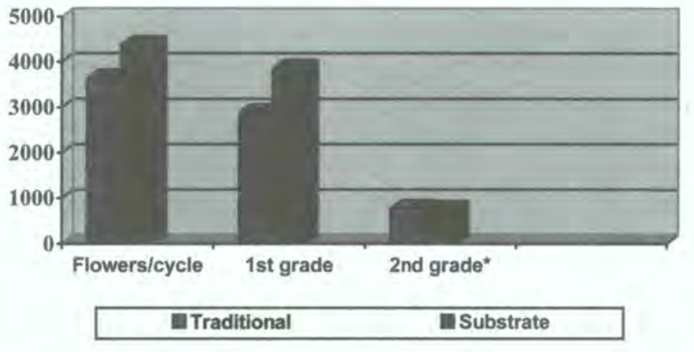


Source: La Gaitana Flowers, 2004.

*Includes herbicide application and fumigation with Telone C-17 in traditional system

Production costs are about 8% higher when grown in substrates compared to traditional production in ground beds where the soil is fumigated with Telone C-17. However, when yields and quality are considered (Figure 10.5), it is clear that more and better quality flowers are harvested, and the higher investment pays off.

Figure 10.7. Carnation yield and quality: traditional vs. substrate (rice hulls)



(USD/ha). Two year cycle. *Includes non/exportable flowers
Source: La Gaitana Flowers, 2004

The same general principle has been observed with respect to rose production in substrates. Whilst investment for substrate production is substantially higher, so are yields and quality of flowers obtained. Even though the production cycle is shortened this is not considered a drawback by growers since the market is constantly requiring new varieties (Valderrama and Larrota, 2006) .

Fumigants - Where losses caused by soilborne pests surpass the economic threshold set by growers soil fumigation may be needed. Trials and experience with soil fumigants in floriculture have shown that their effectiveness varies with factors like the pathogens to be controlled, soil characteristics and crop species. The best results are obtained with metham sodium, dazomet and 1,3-dichloropropene + chloropicrin (Carulla, 2006).

The FLORVERDE Program

The Colombian Association of Flower Exporters - ASOCOLFLORES launched a social and environmental certification program in 1996. Participation in this program is entirely voluntary. Participating growers are evaluated with respect to their performance in two general areas – sustainability of production/ environment friendly practices and social welfare. They are also benchmarked on their performance with respect to other participating growers. A group of advisors, experts in different areas covered in the program's Code of Conduct- e.g. IPM, water and soil management, occupational health – visits each farm periodically and after evaluating performance also makes suggestions for improvement. Methyl Bromide use is not permitted to members of FLORVERDE and in fact this chemical has been banned in Colombia for all uses except QPS since 1995.

Presently, FLORVERDE has more than 160 members which amount to about 60% of the flower production area in Colombia. Farms are certified by the Societé Générale de Surveillance or SGS, a Swiss auditing company with expertise in agricultural eco-labels. Although growers must pay a fee to be members of FLORVERDE and often need to make substantial investments to comply with the Code of Conduct, they are generally in agreement that membership is beneficial since importing markets are increasingly requiring flowers that have been produced within adequate environmental and social standards (ASOCOLFLORES, 2006).

Provided by Marta Pizano, Consultant. MBTOC Co-chair

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Case Study 22. Costa Rica - Progress in phasing out MB in melon and flower production

The banana, tobacco and vegetable sectors of Costa Rica have already phased- out MB and the flower sector is very close to achieving complete elimination. The melon sector, traditionally the largest MB consumer in the country, has made significant progress and presently only 30% of the cultivated area is treated with MB. Solarisation, combined with biocontrols or chemicals is one of the leading alternatives for this sector.

Initial situation

Methyl bromide consumption increased significantly in Costa Rica during the 1990s due to the expansion of the horticulture sector. In 1999 MB consumption reached its maximum historical level at nearly 1,000 tonnes. Consumption decreased temporarily in 2000 to 650 tonnes because melons lost value and this decreased the number of hectares in production but quantities picked up in the following years.

MB has traditionally been used in Costa Rica for melon production followed by cut flowers, with some lesser usage for bananas, vegetable nurseries and tobacco seedbeds as shown in Table 10.34. MB is not used for stored products. In 2000, the melon sector accounted for about 83% (590 tonnes) of MB use.

The melon sector was valued at $62.6 million in 2005. Melons are mostly exported to Europe and the USA. Growers face severe competition from neighbouring countries like Guatemala and Honduras that sell their product in the same market and have lower labour costs.

The cut flower sector expanded in Costa Rica in the late 1960's growing steadily over the following years. In 2005 cut flower exports were valued at over $30 million USD. Some flower growers adopted MB use in the 70s and 80s as the main method of soil desinfestation. The main flowers for which MB was used are chrysanthemums, lilies, tropical flowers and carnations (Pizano, 2005).

Table 10.34. – Breakdown of MB consumption by crop/use (average 1998-2000 and estimated for 2005)

Crops/uses of MB	**MB consumption by crop (average 1998-2000)**		**MB consumption by crop (estimated 2005)**	
	Percentage	**Metric tonnes**	**Percentage**	**Metric tonnes**
Melon	83%	590.0	95%	433.2
Cut flowers	15%	107.0	3,5%	16.0
Banana	1.8%	13.0		
Tobacco seedbeds, nurseries	0.2%	1.5	0,5%	2.3
Sub-total soil	**100%**	**711.5**	**99%**	**451.4**
QPS	-	187.1	1%	4.6
Total including QPS	-	**898.6**		**456.0**

In melons, MB was used to control a broad spectrum of pests, including nematodes (*Meloidogyne* sp), fungi (*Fusarium* sp, *Rhizoctonia* sp, *Phytium* sp, *Phytophthora* sp) and weeds (*Cyperus* sp). Soil types vary greatly from one region to another, and even within the same field. Different microclimates may also be present in different fields. Presently, melon production is concentrated in three main regions of Costa Rica:

- Guanacaste (North Pacific), the main area comprising 80% of the growers and characterized by a long dry season that allows two crops per year.
- Orotina and Parrita in the Central Pacific region, where 20% of the melon production takes place and which are typically rainy regions.

MB is normally applied between October and February in open fields. It is injected into rows using equipment attached to the front of a tractor, that lays plastic mulch over the treated soil. Application rates are typically is 250 kg ha^{-1} although many growers achieve good results with 180 kg ha^{-1}. Dose reduction has enabled growers to comply with MB phaseout reduction steps agreed. The MLF investment project calls for accelerated phaseout by 2010.

There are many small melon producers and about 30-40 medium and large producers. About 5 of the larger farms accounted for more than half of the MB consumption at the end of the 90s. Farms sizes range from less than one ha to more than 100 ha. All fruit production takes place in open fields. Larger farms tend to have a higher technical level and often produce melon seedlings in greenhouses. Smaller farms generally do not have access to such facilities.

Actions for replacing MB

In 1999 the Costa Rican government initiated a National Program for MB phase- out with two MLF demonstration projects (melon and cut flowers) implemented by UNDP. The government, the main agriculture research departments of public universities, melon and cut flowers growers and an environmental NGO, formed a steering group to trial alternative technologies such as solarisation (melons), steam (cut flowers), cover crops, organic amendments and soil fumigants (Metham sodium, 1,3-D/ Pic, Dazomet and non- fumigant pesticides) in combination with IPM. In 2002 a MLF investment project was begun also under UNDP, with an accelerated phase-out clause for 2010.

Description of the alternatives implemented

At the onset of the investment project validations of alternatives were carried out for the different sectors involved, based on experiences gained through the demonstration project. Application methods and timing of application were particularly considered; great success was obtained with the use of biocontrol agents in combination with alternatives and this has lead to significant adoption of IPM practices. Alternatives selected for melons are summarised below:

Fumigants: Metham sodium and 1,3-D/ Pic provided adequate control of most soilborne pests and diseases. Best results were obtained when these were combined with other treatments or practices (using an IPM approach), since a broad spectrum of pests was controlled. Improved soil preparation and appropriate application are essential when using these alternative fumigants.

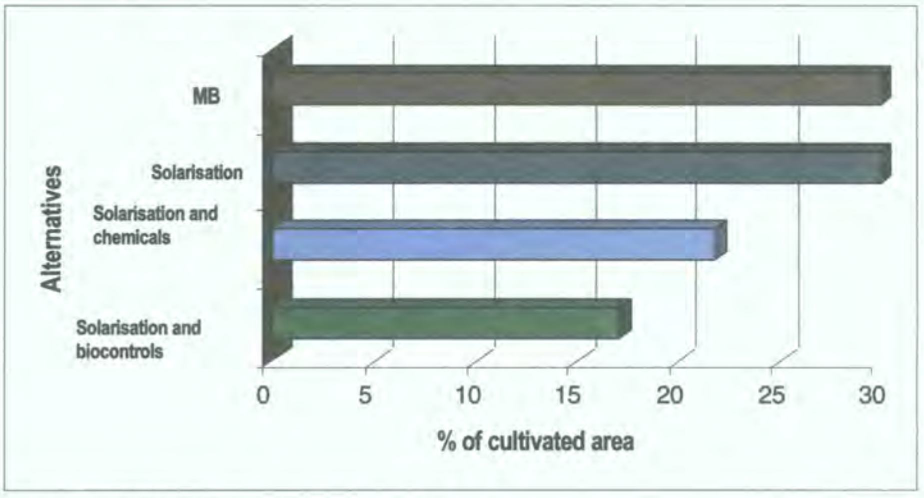
Biofumigation and solarisation: particularly when combined with other treatments such as biocontrol, biofumigation and solarisation provided sufficient control in regions with suitable climate (high solar radiation and low rain during the treatment period), such as Guanacaste where most of the production takes place. Solarisation did not prove suitable for regions like Parrita and Orotina where heavy rainfall occurs. Organic amendments were found to be effective in areas where pest pressure is low.

Current situation

Over 50% of the total MB previously used in Costa Rica has now been phased-out (Chaverri, 2006; Abarca, 2006; 2007). The melon sector still accounts for over 90% of total MB use in Costa Rica, but currently only 30% of the total melon area uses MB for soil desinfestation (Chaverri and Gadea 2002; Abarca, 2006). Adoption of different alternatives has taken place as shown in Fig 10.6 below.

Solarisation alone or in combination with chemicals (Metham Sodium or 1,3-D) and non- chemical alternatives, has replaced MB usage on approximately 2,000 ha of melons since this method ideally suits the crop rotation and climatic conditions. Many growers are opting for non-chemical alternatives in an effort to comply with Good Agricultural Practices included in the EUREP-GAP code of practice, which many importers particularly from the EC are now requiring.

Fig. 10.8. Adoption of alternatives to MB in the melon sector of Costa Rica



Source: MB alternatives investment project in Costa Rica

At present MB use has completely stopped in the banana and tobacco sectors which, although not large users had the potential of increasing use. Flowers presently account for only 3% of the total MB use in Costa Rica (Abarca, 2007). Biocontrol, steaming, and some chemical alternatives like metham sodium and 1,3-D/Pic have been adopted by a large number of growers, most often within an IPM approach. Production in substrates although not yet extensive, is becoming more common. Many of the larger growers - who are usually exporters - have abandoned MB voluntarily, often in response to market demands for environment-friendly flowers imposed through eco-labels such as the Dutch MPS. Small growers selling mostly to the domestic market have needed more assistance and training from the project but have also made progress in adopting alternatives. Remaining MB users are mostly tropical flower growers, and propagation nurseries (Pizano, 2005).

Provided by Fabio Chaverri, IRET, Costa Rica, MBTOC member and Marta Pizano, Consultant, Colombia, MBTOC co-chair.

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10.5.2. Alternatives for postharvest uses

Case Study 23. Phaseout of Methyl Bromide in strawberry and tomato postharvest treatments within the Argentinean domestic market

Argentina implemented an eradication program for Anastrepha fraterculus and Ceratitis capitata at a regional level, establishing a quarantine system to avoid reinfestation. Studies of host status performed at the EEAOC (Experimental Agroindustrial Station Obispo Colombrés) showed that strawberries and tomatoes were not attacked under field conditions by either pest and thus these products did not require fumigation postharvest against these pests. This helped eliminate 1,213 kg of MB, which were used for fumigation every year.

Initial situation

Two commercially important fruit fly pests have been reported in Argentina: *Anastrepha fraterculus* commonly known as the South American fruit fly and which is a native species, and *Ceratitis capitata*, the Mediterranean fruit fly or Medfly, which was introduced. The Medfly is one of the most feared pests in the world, and its presence in Argentina is a major impediment to Argentinean fruit and vegetable exports. To help overcome this situation, the regions of North Patagonia and Cuyo have implemented a fruit fly eradication program based on the Sterile Insect Technique. The program has also helped to ensure that no other fruit flies are introduced to these regions on susceptible hosts, and therefore works as an internal quarantine system. Just as in many parts of the world, the preferred disinfestation method was methyl bromide fumigation since it is fast, effective and relatively cheap. Research was conducted to determine whether preventive fumigation with MB was strictly necessary in all cases.

Actions for replacing MB

The EEAOC located in Tucumán, northern Argentina, is a scientific state Government institution where studies to determine if a postharvest treatment was really necessary for strawberries and tomatoes was carried out. Funding was provided by FUNBAPA (Foundation of Patagonic Barriers), a cooperative association between growers and the Government, and ISCAMEN (Institute for Quality and Health of Mendoza) a state phytosanitary authority. The work was conducted under the supervision of SENASA (Agroalimentary Quality and Health Service) the National Plant Protection Organization.

The studies showed that neither crop is attacked by these two fruit flies in the field conditions characteristically found in Argentina. Following these results SENASA issued two resolutions: the first states that strawberries are not a fruit fly host and thus do not require treatment before entering areas that are subjected to eradication programs (Resolution nº 287/2001); and a second one issued later which states the same for tomatoes (Resolution nº 352/2003).

Current situation

MB was phased-out for postharvest fumigation of strawberries in 2001 and in 2003 for tomatoes. Presently, about 500,000 boxes of tomatoes and strawberries are marketed annually in the regions where eradication programs are conducted. Twenty-two boxes have a volume of $1m^3$; if 60% is considered an average of the MB fumigation chamber coverage (minimum 20% and maximum 80% needed) with a 32g m^{-3} MB dosage, a total of 1,213 kg of MB per year is no longer required. Research on host pest status of different commodities is considered as a priority for the EEAOC; this has helped reduce commercialisation costs, enhanced trade opportunities, improve commodity quality and eliminate MB from quarantine treatments.

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10.6 Adoption of Alternatives to MB in Africa

In 2005 African countries phased out 42% of the regional baseline. African countries accounted for 28% of the total Article 5 consumption in 2005. Large users still remain in the region but significant progress has nevertheless been achieved in replacing MB in many sectors and countries, as illustrated by the examples below.

10.6.1. Alternatives for preharvest uses (soils)

Case Study 24. Kenya - Use of MB alternatives systems in vegetable and flower sectors

Kenya produces large volumes of cut flowers and vegetables for export, and many growers depended on MB during the 1990s. Most have now adopted alternatives, such as substrates, steaming, metham sodium and IPM practices, as a result of MLF projects and the efforts made by farmers themselves. By the end of 2005 Kenya had phased out 78% of the national MB consumption baseline.

Initial situation

The horticultural industry is the fastest growing economic sector in Kenya, ranking third in foreign exchange earnings after tea and tourism. Total foreign exchange earnings derived from horticulture are approximately US$150 million; about 60% is derived from flowers and the remaining 40% from fruits and vegetables. Flower crops include perennials (e.g. roses, carnations). Vegetables produced for exports include sweet peppers, eggplant, courgette, French beans, sugar snaps, snow peas and others (Mutitu *et al.*, 2006). MB consumption reached 394 tonnes in the late 1990s. Kenya's MB consumption baseline (average for years 1995-1998) was 336 metric tonnes (Vos and Bridge, 2006). Following several MLF demonstration projects implemented by UNIDO< UNEP and FAO, an investment project funded by the MLF was initiated in 2003 by the Government of Kenya with UNDP and GTZ aiming to achieve the complete phaseout of 161 tonnes of MB used for soil fumigation in the cut flower sector (105 tonnes), vegetables, fruit, seedbeds and nurseries (56 tonnes). The majority of MB is used by large, medium and small-scale growers. At the request of the Government, some small-scale growers where also included in the project because, although they use little MB at present they contribute to the export market and increasingly face problems with soilborne soilborne pests (Mutitu *et al.*, 2006). There was concern that a number of small-scale growers would start to use MB unless they were assisted with the adoption of alternatives.

The target pests are fungi (*Fusarium spp., Pythium spp., Rhizoctonia* spp., *Verticillium app., Phythopthora* spp. and others), weeds (*Cyperus* spp. and others) nematodes (*Meloidogyne* spp., *Prtatylenchus* spp) and soilborne insects. MB controls all of these pests and has therefore been the method of choice for soil sterilisation especially where high value crops are produced (Mutitu *et al.*, 2006a). The climate is tropical, and various different soil types occur in Kenya including heavy clay soils.

Actions for replacing MB

Work was undertaken to demonstrate and pilot various types of alternatives for flowers and vegetables. The MB Alternatives Project adapted the techniques, making them more convenient to use, particularly for smaller growers. Local companies were encouraged to start supplying alternative products and services. Potential local sources of materials (e.g. substrates) were investigated in order to avoid expensive imports and make the alternatives more economically-sustainable.

The training of growers undertaken by the project typically consisted of 3-day workshops, practical sessions in the field and workshops held at the project Training Centre attached to the University of Nairobi. Small-scale vegetable farmers were organised into 'clusters' of farms, and 40 small-scale farmers were trained from each cluster. On-farm pilots and demonstrations took place, as well as follow-up farm visits. The trained 'contact farmers' then acted as extension farmers and each one will train an average of about 30 other farmers in growing sugar snaps, sweet peas, French beans and other vegetables without using MB (Mutitu et al. 2006a). By 2006 about 100 farmers had learned from the trained contact farmers and had installed and used their own gravity drip irrigation units for substrates, application of metham and better management of water to reduce the spread of pathogens.

This 'cluster' method is not used for the medium and large-scale growers who use MB. Instead, they are provided directly with training and/or technical assistance. The project starts by visiting each farmer that uses MB to discuss in detail the specific pest problems, farm circumstances, and options for alternatives. When the farmer has decided which alternatives best suit his situation, the project makes a written agreement with the farmer about training and other activities that will be undertaken. The project provides materials for pilots and assists farms in installing alternatives on a proportion of the crop, as well as providing relevant technical assistance and training. Growers' organisations have been actively involved in the project.

Several agricultural certification programmes (such as the Kenya Flower Council (KFC), MPS, EUREP-GAP, and Flower Label Program (FLP)) do not permit MB for soil fumigation in flower production, and this has had a significant impact in reducing the use of MB in the flower sector (Mutitu et al., 2006a; Vos and Bridge, 2006).

Description of the alternatives implemented

The main alternatives promoted and adopted in the vegetable sector include substrates for higher value crops in open fields and greenhouses, metham sodium applied by rotating-spading injection (RSI) equipment or by drip irrigation, and various IPM components such as organic amendments, *Trichoderma* spp., improved water management, seed dressings that prevent the introduction of soilborne pathogens into clean substrates, and nematode cyst filters in irrigation systems. Vydate and Nemacur are also sometimes used (Mutitu et al. 2006ac; Mukunya et al. 2006).
In perennial cut flowers (rose, carnation) adopted alternatives include various substrate systems combined with nematode cyst filters and water cleaning treatments. For annual cut flowers alternatives include negative pressure steaming, recyclable substrates, metham sodium applied by spading equipment followed by *Trichoderma* inoculation where appropriate. For nurseries and seedbeds, alternatives include steaming or negative pressure steaming for mother plant production (e.g. chrysanthemum, carnation and geranium cuttings), and substrates combined with nematode filters and water treatment (Mutitu et al. 2006c). Several of these techniques are described below.

Substrate culture of vegetables
Substrates have been adopted for high value export vegetables such as sweet pepper, sugar snaps and tomatoes produced in open fields or plastic greenhouses (Mutitu et al., 2006bc). In simple terms, the growing system includes a drip irrigation unit, substrate-filled containers and a nutrient solution. Smaller farms do not have an electricity supply, so the project developed affordable gravity-fed irrigation units in the form of simple, ready-to-use kits for farmers. Gravity-fed drip irrigation is supplied from a polyethylene tank mounted on a water tower 4 m high, which passes through a screen filter and is then delivered to plants with an ordinary drip irrigation system (Mutitu *et al.*, 2006a).

Substrate filled containers such as troughs, pots or bags are arranged on growing beds according to the recommended crop spacing. The choice between troughs and bags/pots depends on the crop's susceptibility to root infesting pathogens (pots/ bags are best for highly susceptible crops) and on the recommended intra-row spacing (crops needing wide intra-row spacing are best grown in pots/ bags) (Mutitu *et al.*, 2006a).

Nutrient solution is prepared using commercial soluble fertilizers (greenhouse grade), which are premixed and dissolved in 5-10L buckets and placed in the irrigation tank. The solution is fed to the plants using gravity-fed drip irrigation in cycles, whose number and duration vary according to the substrate used and the plant's particular requirements.

Sugar snaps (*Pisum sativum*) for example, are grown in 5L black polyethylene bags generally filled with 30% coco peat and 70% pumice (Mutitu *et al.*, 2006b). The bags are placed on graded growing beds lined with plastic to collect any overflow solution for re-use. Farms report that this system provides a higher yield than MB fumigation. Typical marketable yields using substrate culture ranged from 10,000 to 20,000 kg per ha in sugar snaps, compared to 10,000 kg per ha using MB on soils (Mutitu et al., 2006b; Vos and Bridge, 2006).

Comparative costs and revenue are presented in Table 10.35:

Table 10. 35. Comparing the cost of soil system using MB, and substrate system for vegetables. Costs in Kenya shillings per 1,250 m^2

Inputs	Soil system using MB (Ksh)	Alternative system Substrate (Ksh)	Comments
Drip irrigation system	3,600	3,600	
Bags or pots		639	
Polythene sheeting	10,000	24,000	Used for 4-5 cycles
Fumigant/fumigation	26,250 *		
Substrates		16,880	Used for 2 cycles
Fungicides/insecticides	200	200	
Fertilizers	8563	8,563	
Labour	22,800 +25,000 (application cost)	28,800	
Seed	1,440	1,440	
Support system (cedar posts+manila strap)	9,300	9,300	Used for 6 cycles
Total in 1st year(set up and running costs)	107,153	93,422	
Gross Revenue	100,800	130,230	
Net revenue	-6,353	36,808	

Source, Mutitu *et al.*, 2006b

* The cost of MB, based on recent costs, is Kenya Shilling (Ksh) 400 per kilogram. The typical application rate of 700kg/ha gives a fumigation cost of Ksh 26,250 plus Ksh 10,000 for plastic sheeting, for 1,250m2.

Metham sodium applied by RSI equipment

Metham sodium is applied by drip irrigation or by rotating-spading injection (RSI) equipment. The RSI equipment injects the fumigant in soil and mixes it by rotovation to a working depth of about 20-35cm. A roller then seals the soil to retain the fumigant, and the soil may be covered with plastic after fumigation (Mutitu et al. 2006d).

The efficacy of the RSI treatment in nematode control was monitored in three different farms (Mutitu et al. 2006d). On farm A, nematode counts were initially up to 290 per 100ml of soil before fumigation and were below 25 per 100ml in all soil samples three weeks after fumigation. On farm B the nematodes counts were up to 500 per 100 ml before fumigation and less than 30 when examined 4 weeks after fumigation. On farm C the counts were up to 170 per 100 ml before fumigation and less than 18 four weeks after fumigation (Mutitu et al. 2006d).

The project also studied the effect on yellow nutsedge (*Cyperus rotundus*) when metham sodium was applied at various rates by RSI equipment. The average number of nutsedge was 4 per m^2 following application of metham sodium at 1000 L/ha compared with 48 per m^2 in the control plots, as shown in Table 10.20. When the soil was covered with plastic following the metham RSI treatment (1000 L/ha), the nutsedge count was 2 per m^2 compared with 33 per m^2 in the control plots (Mutitu et al. 2006e).

Table 10.36. Average counts of nut grass on area fumigated with metham sodium, not covered with plastic

Application Rate (litres/Ha)	Control	600	800	1000	1200
Average number of nutsedge/ m^2	48	14	7	4	3

Source: Mutitu et al. 2006e.

Current situation

Alternatives have now been adopted by many large, medium and small-scale growers who produce vegetables, nursery plants and cut flowers in Kenya. By August 2006 the project had assisted growers to phase-out more than 81 tonnes of MB. Other growers also eliminated the use of MB by their own efforts. As a result Kenya's MB consumption was reduced from 394 tonnes in the late 1990s to 73 tonnes in 2005.

Table 10.37. Average counts of nut grass on area fumigated with metham sodium, not covered with plastic

APPLICATION RATE (L/HA)	Control	600	800	1000	1200
Average number of nutsedge/ m^2	48	14	7	4	3

Source: Mutitu et al. 2006e.

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Based on information provided by Prof. E.W Mutitu (UNDP/GTZ Project Manager; assisted by Reuben Waswa; Joseph Chepsoi and Josphine Mutero

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Case Study 25. Methyl Bromide phaseout in the tobacco sector of Malawi.

Malawi is one of the ten largest tobacco growers in the world with over 100,000 ha in production and 400,000 growers. In spite of technical and economic constraints for the adoption of some alternatives, Malawi reported zero imports of MB in 2004 and 2005 and the sector is well on the way to complete phaseout.

Initial situation

Tobacco is the most important economic sector of Malawi. Given the predominance of agriculture, the limited resource base, and the slow growth of the national economy, tobacco plays a major role in domestic economic growth, employment and income.

Malawi has a long history of tobacco production but steady, rapid expansion occurred in the late 70s when production climbed from 29,000 tonnes reaching nearly 160,000 tonnes in 2000. The increase in production is a consequence of the increased production area but also of much augmented yields, both of which tripled between 1960 and 2000. Presently Malawi is one of the ten largest tobacco producers in the world. Burley tobacco leaves comprise about 89% of total production.

In early 1995, Malawi embarked on a structural adjustment programme. In the agricultural sector, reforms included allowing small farmers to produce cash crops, and liberalising commerce of agricultural goods and inputs. These measures contributed greatly to the rapid expansion of the tobacco sector as hundreds of thousands of smallholder farmers started growing this crop. Further, the introduction of tobacco dealers facilitated the marketing process. Today almost 400,000 growers take part in the industry.

Table 10.38. Malawi, tobacco sector: planted area and MB consumption, 1998-2005

Year	MB imports (mt) *	Tobacco area (ha)
1994	104.4	79,207
1995	85.6	105,738
1996	97.2	113,823
1997	128.1	122,300
1998	84.2	104,200
1999	93.2	100,200
2000	131.4	100,200
2001	111.8	100,200
2002	43.4	100,200
2003	68.5	n/a
2004	0	n/a
2005	0	n/a

Source: * USDA; Foreign Agricultural Service; Malawian Pesticides Control Board; and Ozone Secretariat database

Actions for replacing MB

Like many Article 5 countries, Malawi submitted a phase out project to the MLF, which was implemented from 2002 to 2005 by UNDP, the Ministry of Natural Resources and Environmental Affairs of Malawi and the Agricultural Research and Extension Trust (ARET, 2003). The project entailed an advanced phaseout schedule for MB, with complete elimination of imports due by December 2004.

The first phase of the project involved demonstrating alternatives to growers, namely metham sodium, basamid, and the floating trays system (FTS). The second phase comprised the following activities:

- Distribution of subsidized inputs to the growers
- Training of growers on the use of alternatives
- Awareness raising activities directed to the general population
- Banning of MB imports as of 1st January 2005 (Banda, 2003).

Description of alternatives implemented

Although the FTS offers clear advantages over chemical alternatives, the early phaseout agreed through the project led the technical team to encourage adoption of chemical alternatives, as these are easier to implement. Further, all inputs necessary for the widespread adoption of FTS have to be imported to Malawi, which makes them significantly more expensive than other options. It will take time for the local industry to develop production of trays, chemicals, substrates, and seeds but the size of the tobacco sector certainly offers an interesting option for many manufacturers. Presently, most of the inputs for the FTS are imported from South Africa or Zimbabwe (Valeiro, 2005).

These reasons explain why the growers have preferred alternative chemicals to the FTS. Table 10.38 shows a detailed cost comparison for the three alternatives being transferred in Malawi. Without considering depreciation of the different inputs, FTS costs for the first year are 6.6 and 5.3 times higher than those of basamid and metham sodium respectively. Even if depreciation rates are included costs are still 5.2 and 3.6 times higher that the fumigants (Valeiro, 2005).

Table 10.39. General costs per hectare for MB alternatives for tobacco in Malawi

Item	Quantity	Unit Cost USD	Item cost/ investment USD	Annual cost inc. depreciation* USD
1) Floating trays system (FTS)				
Float trays	99	2.1	207.9	41.58
Pine bark substrate	15 bags	5.9	88.5	88.5
Plastic sheets	1	32.7	32.7	10.9
Fertilizer	3 kg	2.18	6.5	6.5
Ammonium Nitrate	1 kg	0.36	0.36	0.36
Cement	1 bag	8.5	8.5	0.85
Bricks	450	0.018	8.18	0.81
Labour	5M/days	0.72	3.6	3.6
Total			**355.85**	**153.1**
2) Basamid				
Basamid	4.5 kg	6.7	10.05	10.05
Fumigation sheets	1	36.36	36.36	12.12
Labour	10M/days	0.72	7.2	7.2
Total			**53.68**	**29.37**
3) Metham sodium				
Metham sodium	10.8 L	2.1	22.67	22.67
Fumigation sheets	1	36.36	36.36	12.12
Labour	10M/days	0.72	7.2	7.2
Total			**66.3**	**41.99**

Source: 15th Steering Committee Meeting for the Phaseout of Methyl Bromide

* Depreciation rates: trays, 5 years; plastic and fumigation sheets,3 years; bricks and cement 10 years.

Current situation:

The MB phaseout project was successful in transferring alternatives to a substantial number of growers. Chemical alternatives are more widely adopted than the FTS:

- The Floating Tray System replaced 1,218 seedbeds.
- Basamid was adopted on 16,039 seedbeds
- Metham sodium was adopted on 2,027 seedbeds

Zero MB imports were reported to the Ozone secretariat for 2004 or 2005, which is outstanding in light of the large number of growers that used MB and constraints to adoption of the FTS technology. One of the main factors influencing this achievement is the legal framework (Banda, 2003) adopted from an early stage to prohibit ODS imports.

At the same time, the biggest tobacco buying companies in the world have started imposing "Good Agriculture Practices Guidelines" (GAP) on their suppliers (Philip Morris Int., 2004). GAP guidelines were designed to "...promote practices which ensure that quality tobaccos are grown under conditions that protect the environment, ensure worker safety and ensure a sustainable national crop". The crop management GAP referring to seedbeds specifically exclude fumigants which are harmful to the environment; require using renewable substrates and recyclable or long-lasting trays and plastic covers; and implementing measures for the adequate disposal of seedbed materials (plastic and water used for floating). Buyers conduct annual assessments, to check on the compliance with these guidelines. Since the Malawi tobacco sector is increasingly producing all tobacco under the contract system, the pressure on the growers to implement GAPs will also increase in the future.

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Case Study 26. Morocco - Phase out of methyl bromide in the strawberry, banana and cut flower sectors

Although Morocco is still listed amongst the largest MB users within the Article 5 regions, significant progress has been made in replacing this fumigant in the various sectors involved. This case study describes alternatives adopted in the strawberry, banana and flower sectors.

Initial situation

In Morocco, strawberries are generally grown in small plastic tunnels known as "Nantais tunnels", which are suited for cold weather. There is also open field production. Bananas are grown in plastic greenhouses, 6m in height, with an average area of 1ha under cover. Cut flowers are normally grown in plastic greenhouses.

The key pests affecting the sectors in this case study appear below:

- **Strawberries:** Fungi (*Rhizoctonia solani, Verticillium dahliae, Phytophthora cactorum)* and Weeds (more than 40 species e.g. *Cynodon dactylon, Chenopodium* sp, *Amaranthus* sp.)

- **Banana:** nematodes (*Meloidogyne javanica, Helicotylenchus multicincthus*)
- **Cut flowers (Carnation, Gerbera, etc):** Fungi (*Fusarium oxysporum* , *Rhizoctonia* sp., *Pythium* sp., *Phytophthora* sp.*)*, nematode (*Heterodera* sp., *Meloidogyne* sp.).

In accordance with Montreal Protocol decisions, the government of Morocco agreed to phase out methyl bromide in the strawberry, banana and cut flower sectors where it has been used for many years. To support these efforts two investment projects were developed with funding from the MLF and managed by UNIDO as implementing agency:

- A ***Strawberry project*** was started in 2002 to achieve phase out of 259 tonnes of MB in the strawberry sector by the end of 2006 (Chtaina, 2005; Chtaina, 2006a).
- A ***Banana and cut flower project,*** was started in 2003 and is aimed at phasing out a total of 102 tonnes of MB, 60 tonnes in the banana sector and 42 tonnes in the cut flower sector by the end of 2007 (Chtaina 2006b).

MB alternatives were tested in experimental trials and commercial fields for each crop. Trials were conducted at the Department of Plant Pathology of the Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco. Selection of the most promising alternatives was based on the following criteria: efficacy against the key pests; economic feasibility of alternatives compared to MB; and consistency of results over consecutive growing seasons.

Description of commercially adopted alternatives

Strawberry sector - Drip applied soil fumigation with metham sodium has increased significantly between 2002 and 2006 in terms of the treated acreages and the number of users. The area treated with metham sodium increased from 6 ha in 2002 to 820 ha in 2006; at the same time, the area treated with MB decreased from 1090 ha in 2003 to 140 ha in 2006. The yield and fruit quality obtained with metham sodium were equivalent to those achieved with MB. (Chtaina, 2006a)

In addition, the combination of metham sodium with other chemical alternatives is under study and offers a good option according to pest population. The main combinations are with metham potassium, 1,3-D/ pic or metham sodium +1,3-D. Drip applied metham sodium does not require any modifications to the cropping system. Some simple recommendations to ensure proper efficiency include good preparation of the soil, moistening the soil before treatment to initiate weed seed germination, building raised beds (40 cm high x 50 cm wide), laying the drip tape in the centre of the bed, using plastic mulch, ensuring uniform water distribution from the drip system. Metham sodium is injected at a dosage of 200 to 250 g m^{-2}. The pipes should be flushed after treatment and planting can take place after 2 to 3 weeks.

Banana sector - Between 2002 and 2004, no economically and technically feasible alternatives to MB had been identified for banana. Farmers were using post plant nematicides such as fenamiphos and cadusafos in granular or liquid formulations; only in a few cases MB was used as a pre-plant treatment for bananas.

The price of MB has steadily increased in Morocco due to supply shortage. This has led to a reduction of 46 % in MB consumption between 2002 and 2004 (63 MB users were reported in 2002 and only 13 in 2004).

In 2004 an alternative combining soil solarisation and drip fumigation with 1,3-D EC as a broadcast or row treatment was developed. Results achieved with this alternative over two production seasons were similar to those obtained with MB in terms of nematode control, however the yield was 10 % lower when compared with MB. MB stimulates plant growth, for this reason when using 1,3-D it is recommended to fertilize directly after planting to stimulate plant root growth from an early stage (Chtaina, 2005, 2006b).

In 2006, 4.6 ha (3 methyl bromide users) were fumigated with MB while 25 ha were treated with solarisation + 1,3-D. 15 of these hectares were financed by the UNIDO project. It was found that for this alternative to work properly as a broadcast or row treatment, drip tapes should be added and connected to the main pipeline independently of the existing sprinkler irrigation system used in the greenhouse. Drip tapes need to be removed just after treatment, before they are used in another greenhouse.

During the hot season (end of July) some recommendations apply: Remove residues of the previous crop; pre- irrigate with water; apply organic manure along the plantation line; lay and connect drip tapes the to pipeline in the entire greenhouse (broadcast treatment) or in bands 6 m long (row treatment); mulch with clear, transparent plastic 40 µm thick; inject the 1,3-D EC to the main pipeline. Plastic should be removed after 4 weeks, when transplants can be brought in, preferably from in vitro-plants (Chtaina, 2005, 2006b).

Cut flower sector - Solarisation plus 1,3-D/Pic (drip-applied) has been shown to be effective for controlling soilborne pathogens but requires adequate soil preparation and a properly designed drip irrigation system. This method does not require any modifications to the cropping system since the existing drip irrigation system can be used to apply the fumigant.

Recommendations to enhance effectiveness include good soil preparation, moistening the soil before treatment, making raised beds (20 cm high x 65 cm wide), laying two drip tapes on each bed, mulching with transparent, clear plastic 40 µm thick, and injecting 1,3-D/pic EC in the main pipeline. The plastic can be removed after 3 weeks prior to planting (Chtaina 2006 b).

Costs of the alternatives described appear in Table 10.39 below

Table 10. 40. Costs of MB and alternatives adopted in strawberry, banana and cut flower sectors

MB and alternatives	Crop	Total application cost US$/ 1000 m^2
MB	All	640 (1)
Metham sodium at high dosage (127, 5 g m^{-2} of active ingredient) or 250 ml m^{-2} of commercial product of 510g L^{-1} ai.	Strawberries	260
Solarisation +1,3-D (200 L ha^{-1}) of commercial product (93% ai)	Banana	270
Solarisation + 1,3-D 65%+ chloropicrin 35% at. 450 kg ha^{-1}	Cut flowers	332

(1) Broad acre application
Source: (Chtaina 2005, 2006 a, b)

Regulatory agency acceptance - All chemical alternatives are registered in Morocco

Lessons learned
Research was carried out in close collaboration with the farmers and with the help of regional extension services to implement the alternatives. Visits to the demonstration plots were organized. These activities clearly facilitated adoption of the described alternatives by previous MB users.

Solarisation +1,3-D as used for bananas is also now used on a large scale by cucurbit growers to control nematodes. The combination of 1,3-D/pic applied by drip irrigation is being widely adopted by tomato growers.

provided by Mohamed Besri, MBTOC co-chair. Professor of Plant Pathology, Hassan II Institute of Agronomy and Veterinary medicine . Email: m.besri@iav.ac.ma. Based on information provided by Noureddine Chtaina, Project Manager ,UNIDO methyl bromide project- Hassan II Institute of Agronomy and Veterinary medicine, Rabat Morocco : Email : n.chtaina@iav.ac.ma

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Appendix

1

Methyl Bromide Technical Options Committee - Committee Structure

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MBTOC structure as at 31 December 2006

Co chairs

Dr Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II Morocco
Ms Michelle Marcotte	Consultant Canada
Ms Marta Pizano	Consultant Colombia
Dr Ian Porter	Department of Primary Industries Australia

Subcommittee chairs, chapter lead authors for this Assessment

Chapter 1 - Executive summary

Chapter 2 - Introduction to the Assessment - lead author, Ms Marta Pizano.

Chapter 3 - Methyl Bromide production, consumption and limitations on use - lead authors, Dr Melanie Miller and Ms Marta Pizano.

Chapter 4 - Reducing Methyl Bromide emissions. Lead authors Dr Jonathan Banks and Dr Ian Porter

Chapter 5 -Alternatives to Methyl Bromide for soil treatment - Chair of 'soils' chapter subcommittee and lead authors, Dr Ian Porter, Dr Mohamed Besri, Dr George Lazarovits, Ms Marta Pizano.

Chapter 6 - Alternatives for Treatment of Post-Harvest Commodities, Food Processing Facilities and Other Structures, Wood Products and Other Durables - co chairs of 'durables' chapter subcommittee and lead authors - Ms Michelle Marcotte, Dr Jonathan Banks.

Chapter 7 – Progress in Methyl Bromide phase-out. Lead authors, Ms Marta Pizano and Dr Melanie Miller.

Chapter 8 - Economic Issues Related to Methyl Bromide Phaseout. Lead authors Dr Jim Schaub, Dr Nick Vink, Ms Ariane Saade
Chapter 9 – Quarantine and Pre-shipment - chair of the 'QPS' subcommittee and lead authors, Dr Jonathan Banks, Ms Michelle Marcotte.
Chapter 10 – Case studies on commercial adoption of alternatives to Methyl Bromide - lead authors, Ms Marta Pizano, Dr Melanie Miller, Mr Alejandro Valeiro,.

Committee contact details and Disclosure of Interest

To assure public confidence in the objectivity and competence of TEAP, TOC, and TSB members who guide the Montreal Protocol, Parties to the Protocol have asked that each member to disclose proprietary, financial, and other interests. TEAP members have published such information for several years in the TEAP annual report.

As a result, Decision XVIII/19 was issued during the 18th Meeting of Parties to the Montreal Protocol held in New Delhi, India from 28 October to 3 November 2006. All MBTOC members are presently required to complete a disclosure of interest form and these are presented in summarized form below.

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Prof. Mohamed Besri, is a full time Professor of Plant Pathology and Integrated Disease Management at the Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco (HII IAVM). The HII IAVM has an interest in the topics of the Montreal Protocol because it houses specialists in Soil-borne Plant Pathogens and MLF projects (strawberries, bananas, cut flowers). It advises the Ministry of Agriculture on all aspects of alternatives to Methyl Bromide. Dr Besri has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs . Dr Besri works occasionally as a consultant to UNEP on matters related to the Montreal Protocol. Neither Dr Besri's spouse, business partner or dependant children living at same home work for or consults for any organization which has an interest in the topics of the Montreal Protocol, nor do any of them have any proprietary interest in alternatives or substitutes to ODSs, nor do any of them own stock in companies producing ODS or alternatives or substitutes to ODSs or consult for organizations seeking to phaseout ODSs. Costs associated to travel, communication, and others related to participation in the TEAP, MBTOC, and relevant Montreal Protocol meetings, are paid by UNEP's Ozone Secretariat.

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Ms Michelle Marcotte, was a member of the 1992 Methyl Bromide Assessment and subsequently a member of the Methyl Bromide Technical Options Committee; she was confirmed as Co-Chair in 2005. Ms Marcotte is a consultant through Marcotte Consulting to governments and agri-food companies in agri-environmental issues, food technology, regulatory affairs and radiation processing. Marcotte Consulting has an interest in the topics of the Montreal Protocol because of its long time market development work in food irradiation, an alternative to some methyl bromide uses. In the field of methyl bromide alternatives, Ms Marcotte has published case studies in pest control in food processing, in stored commodities, in alternatives for quarantine and in greenhouse use. Ms Marcotte has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Marcotte receives a consulting contract from Government of Canada, Environment Canada, a Party to the Montreal Protocol that is committed to the phase out of methyl bromide. Marcotte has also prepared consulting reports summarizing research in methyl bromide alternatives and case studies on food processing for US Environmental Protection Agency. She has consulted to the International Atomic Energy Agency and US AID on irradiation as a methyl bromide alternative in food processing, quarantine and trade. Ms Marcotte's spouse works for United States Department of Agriculture managing research in methyl bromide alternatives and is a member of MBTOC. He does not have proprietary interest in alternatives or substitutes to ODS and does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Ms Marcotte pays for travel to TEAP, MBTOC and Montreal Protocol meetings out of funds provided by the Canadian government, Environment Canada, to support her work on MBTOC.

Ms Marta Pizano **Article 5 co-chair**
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Ms Marta Pizano is a consultant on methyl bromide alternatives, particularly for cut flower production, and has actively promoted methyl bromide alternatives among growers in many countries. She is a regular consultant for the Montreal Protocol Multilateral Fund (MLF) and its implementing agencies. In this capacity, she has contributed to the methyl bromide phase-out programs in nearly twenty Article 5 countries around the world, assisting growers with the adoption of sustainable alternatives and the implementation of IPM programs. She is a frequent speaker at national and international methyl bromide conferences and has authored numerous articles and publications on alternatives to this fumigant. She has been a member of MBTOC since 1998 and a co-chair since 2005. Neither Ms Pizano nor her husband or their children own stock or have proprietary interest in companies producing ODS or their alternatives or substitutes. Costs associated to travel, communication, and others related to participation in the TEAP, MBTOC, and relevant Montreal Protocol meetings, are paid by UNEP's Ozone Secretariat.

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Dr Ian Porter is the Statewide Leader of Plant Pathology with the Victorian Department of Primary Industries (DPI). DPI has an interest in developing sustainable control measures for plant pathogens and biosecurity. He is a member of a number of National Committees regulating ODS, has led the Australian research program on methyl bromide alternatives for soils and has 26 years experience in researching sustainable methods for soil disinfestation of plant pathogens with over 200 research publications. He has been a member of MBTOC since 1997, Soils sub committee chair since 2001 and MBTOC Cochair since 2005. Neither, Dr Ian Porter, wife or children have any proprietary interest in alternatives or substitutes to ODSs, nor own stock in companies producing ODS or alternatives or substitutes to ODSs. Dr Porter is presently assisting National research agencies in Australia develop national priorities for IPM and soil health. He has acted occasionally as a key consultant for UNEP and UNIDO in developing programmes to assist China, Mexico and CEIT countries to replace methyl bromide. The Victorian DPI has in the past made in-kind contributions to attend MBTOC and UNEP meetings, but provides no present support. The Australian Federal Government Research Funds and funds obtained through the Ozone Secretariat have provided funds to support travel and expenses for MBTOC activities.

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Dr. Jonathan Banks, Chair of TEAP's QPS Task Force, is a private consultant. He was a member of the 1992 Methyl Bromide Assessment and from 1993 to 1998 and

2001 to 2005 co-chaired the Methyl Bromide TOC. He worked as a Research Scientist with the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) from1972 to 1999 on grain storage technologies, including use of improved use of fumigants. He is coinventor of carbonyl sulfide, an alternative fumigant to methyl bromide in some applications. Patent rights have been assigned to his employer, CSIRO. Dr Banks has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs. He has stock in Brambles Ltd, a company that *inter alia* leases wooden pallets for freight. The pallets may or may not be treated with methyl bromide or alternatives. His spouse is co-owner of their commercial organic apple orchard. She has no financial interests relating to ozone-depleting substances. He has served on some national committees concerned with ODS and their control, and within the last 4 years has received contracts from UNEP, and other institutions and public companies related to methyl bromide alternatives and grain storage technology--including training in fumigation (methyl bromide and alternatives) and fumigation technology and recapture systems for methyl bromide. In 2005 and 2006 he received some support from UNEP for TEAP and MBTOC activities. Other funding for his MBTOC activities has been through grants or contracts from the Department of Environment and Heritage, Australia or from personal contributions.

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Marten Barel, a member of MBTOC since 2002, is a consultant. He has no proprietary interest in alternatives or substitutes to ODSs, and does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Since 1999 he has worked as a consultant and trainer in MLF methyl bromide projects for GTZ, UNDP and UNIDO. For more than 30 years he has provided growers, fumigators and companies with specialist technical advice and training in methods of controlling soilborne pests and soil pasteurisation/ disinfestation techniques in nurseries and horticultural crop production. For 40 years (until 1999) he owned a fumigation / soil disinfestation company that used methyl bromide until it was phased-out in the early 1980s, and then developed alternatives to methyl bromide e.g. negative pressure steaming techniques. His social partner and children do not work for organisations which have an interest in the topics of the Montreal Protocol, and have no proprietary interest in alternatives or substitutes to ODSs, and do not own stock in companies producing ODS or alternatives or substitutes to ODSs. Travel to MBTOC meetings is currently funded by the Ministry of VROM in the Netherlands.

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Dr Christopher Hugh Bell, is a Fellow at the Central Science Laboratory (CSL), Department of Environment, Food and Rural Affairs, at York, UK, where he led research into fumigation technology, including studies on methyl bromide and potential alternatives which were sponsored by UK government agencies and private companies, until his retirement in 2004. He is also a Regional Editor for the Journal of Stored Products Research for Europe and Africa, an Elsevier journal publishing original research addressing problems encountered in the storage of durable commodities. Dr Bell has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs, and does not represent organizations seeking to phase out ODSs. He works occasionally as a consultant to governments and companies on matters related to methyl bromide use or replacement, or the Montreal Protocol. Travel and subsistence to attend MBTOC meetings has been paid by the UK Department of Environment, Food and Rural Affairs (DEFRA), or by UNEP.

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Dr Antonio Bello Pérez is a full time Research Professor at the Consejo Superior de Investigaciones Cientificas, Madrid, Spain. The institute has an interest in the topics of the Montreal Protocol because of the environmental impact of methyl bromide. Dr Bello Pérez has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. He works occasionally as a consultant for UNEP, Implementing Agencies and Governments, on matters related to the Montreal Protocol. Travel to MBTOC meetings is paid by his institution, which in turn receives contributions for this travel from national projects.

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Dr. Aocheng Cao is a Research Professor at the Institute of Plant Protection, Chinese Academy of Agricultural Sciences focusing on research in pesticide sciences. The Chinese Academy of Agricultural Sciences, a non-profit organization, is interested in the topics of the Montreal Protocol because soil pathogens and nematodes are important pests in China and alternatives to methyl bromide are urgently needed. Dr Cao has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or their alternatives or substitutes and does not consult for organizations seeking to phase-out ODSs. His spouse also works for the Chinese Academy of Agricultural Sciences, which has an interest in the topics of the Montreal Protocol as it conducts research on pest control, but has no proprietary interest in alternatives or substitutes to ODSs, nor does she own stock in companies producing ODS or their alternatives or substitutes or perform consultancy for organizations seeking to phase out ODSs. Expenses related to Dr Cao's attendance to MBTOC meetings are paid by UNEP.

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Dr Peter Caulkins is the Associate Director in the Special Review and Reregistration Division in the Office of Pesticide Programs in the U.S.EPA. The U.S. EPA has sole authority for the regulation of all pesticide use in the U.S. and therefore has a strong interest in the Montreal Protocol's phase-out of methyl bromide. Neither Dr Caulkins nor his wife or their son have any proprietary interests in ODSs or their alternatives, own no stock in either ODS companies or companies providing alternatives and do not do any consulting for organizations seeking to phase-out ODSs. Travel to MBTOC meetings is paid for by EPA.

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Mr Fabio Chaverri is a professor at the Universidad Nacional de Costa Rica where he works as a full time researcher on pesticide alternatives at the IRET (Central American Research Centre on Toxic Substances). The IRET has an interest in the topics of the Montreal Protocol since its main objective is to implement alternatives for toxic substances with a strong environmental or human health impact, such as ODSs. Mr Chaverri has no proprietary interest on alternatives or substitutes to ODSs, does not own stock in companies producing ODS or their alternatives or substitutes and does not consult for organizations seeking to phaseout ODSs. He occasionally works as a consultant for UNDP and UNEP, governments and companies on matters related to the Montreal Protocol. His spouse does not work for or consult for any organization with has an interest in the topics of the Montreal Protocol and has no proprietary interest on alternatives or substitutes to ODSs, nor does she own stock in companies producing ODS or their alternatives or substitutes or consult for organizations seeking to phaseout ODSs . Mr Chaverri's travel expenses to cover attendance to MBTOC meetings is paid by UNEP.

Dr Kathy Dalip

Dr Kathy M Dalip is an Entomologist at the Caribbean Agriculture Research and Development Institute (CARDI), which has headquarters in Trinidad and offices in twelve member countries. Kathy works full-time at the CARDI Belize Unit, Central Farm, Western Highway, Cayo District, Belize, Central America. Between 2000 and 2005, Kathy was stationed at the CARDI Jamaica Unit where she was a member of the Jamaica Methyl Bromide Working Group. Her work at CARDI is focused in the areas of integrated pest management (IPM) and organic agriculture. Hence, her emphasis is on finding non-chemical pest control options to improve production and economic feasibility for farmers. Kathy has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and has not done consulting for organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by for by the Ozone Secretariat of UNEP.

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Dr Ricardo Deang is a retired Deputy Administrator for Pesticides of the Fertilizer and Pesticide Authority (FPA) – a government regulatory office for fertilizers and pesticides – since April 1996. He was responsible for registration, restriction, and banning of pesticides when imminent hazards are posed; and certification of pesticide applicators and fumigators. FPA has an interest in the topics of the Montreal Protocol because the Philippines is a signatory to the Montreal Protocol and the office restricts/monitors methyl bromide importation and use. Prior to this position Mr. Deang worked as a research entomologist on biological control. Currently Mr Deang is Chairman of the Board of a consultancy firm, Management and Executive Network, Inc. He has no proprietary interest on alternatives or substitute to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs and does not engage in consulting for organizations seeking to phase out ODSs. His wife and their children have no proprietary interest on alternatives or substitutes to ODSs, do not own stock in companies producing ODSs or alternatives or substitutes to ODSs and do not engage in consulting for organizations seeking to phase out ODSs. They have no interest in the topics of the Montreal Protocol. Travel to MBTOC meetings is paid by UNEP.

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Jacques François Patrick Ducom, Agronomy Engineer, is a long standing MBTOC member and head of the Laboratoire National Denrées Stockées (LNDS), Plant Protection Service, Ministry of Agriculture, France. Dr Ducom is a full time researcher in fumigation LNDS. He works occasionally as a consultant for Implementing Agencies of the Multilateral Fund on matters related to the Montreal Protocol. Dr Ducom has no proprietary interest on alternatives or substitute to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs and does not engage in consulting for organizations seeking to phase out ODSs. Travel to MBTOC meetings is paid from the LNDS budget

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Ms Ariane Elmas was formerly the project manager of a "Trade and Environment" project funded by UNEP, managed by UNDP and implemented by the Ministry of Environment in Lebanon. This project published a report on the effects of trade liberalization in Lebanon with special focus on products where methyl bromide is used and includes an annual profitability analysis and a cost benefit analysis comparing the Methyl Bromide alternatives used for each crop. Ms Elmas, is an economist and is currently the Project Manager at the UNDP in Lebanon. The UNDP has an interest in the topics of the Montreal Protocol because it is one of its implementing agencies and as such manages the MB phase out project implemented in Lebanon under the coordination of the Ministry of the Environment. Neither Ms Elmas, nor her spouse or their dependant children have any proprietary interest in alternatives or substitutes to ODSs, own stock in companies producing ODS or their alternatives or substitutes or consult for organizations seeking to phaseout ODSs. Expenses related to Ms Elmas' attendance to MBTOC meetings is paid by UNEP.

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Dr Abraham Gamliel is a full time senior researcher on methods and technologies for pest control and pesticide application at the Ministry of Agriculture, Agricultural Research Organization, Volcani Center, Bet Dagan, Israel .He is also an adjunct professor at the Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, Israel. ARO Volcani Center has an interest in the topics of the Montreal Protocol because it is the research and development institute for solving the farmer's problem and for developing environmentally safe crop production. Dr Gamliel has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs, and does not consult for organizations seeking to phaseout ODSs. He works occasionally as a consultant for the Government, on matters related to the Montreal Protocol. Neither his spouse nor their children work for or consult for organizations having an interest in the topics of the Montreal Protocol nor do they have a proprietary interest in alternatives or substitutes to ODS, own stock in companies producing ODS or their alternatives or substitutes. Dr Gamliel's travel expenses to attend MBTOC meetings are paid by the Ministry of Agriculture of Israel.

Mr Kenneth Glassey
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Mr Kenneth Logan Glassey is a Senior Biosecurity Adviser at the Ministry of Agriculture and Forestry (MAF). Ken Glassey is a full time adviser on Phytosanitary Treatments and Treatment Operators at the Ministry of Agriculture and Forestry Head Office, Wellington, New Zealand. MAF has an interest in the topics of the Montreal Protocol because quarantine and preshipment treatments uses a significant amount of methyl bromide (218 tonnes in 2004). Current responsibilities cover researching, developing and reviewing New Zealand's import standards including operational standards such as treatments for imported commodities. This also involves monitoring quality and adequacy, initiating remedial action as necessary, and the provision of advice on the practical application and implications of such standards. Mr Glassey has been involved in QPS inspection and treatments for 20 years with particular expertise with forest produce, and worked in forest management for 11 years prior to that. Mr Glassey has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. He does not work as a consultant to implementing agencies on matters related to the Montreal Protocol. Mr Glassey's partner living in same home does not work for or consults for any organization which has an interest in the topics of the Montreal Protocol. She has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. Travel to TEAP/TOC/TSB meetings is paid by MAF.

Mr Alfredo T. Gonzalez **Article 5 Member**
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Mr Gonzalez is president of Pestcon Pest Management and General Services, a company with an interest in the Montreal Protocol because it uses methyl bromide in the for Quarantine and pre-shipment treatments as well as ISPM 15 treatments for wood packaging materials. Mr Gonzalez, has no proprietary interest in alternatives or substitutes to ODSs, and does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Presently he is the general consultant for the implementation of the Methyl Bromide Phase-out program in the Philippines for the Government of his country, under the Department of Natural Resources- Philippine Ozone Desk (DENR-POD) in cooperation with the Fertilizer and Pesticide Authority (FPA), which is directly related to the Montreal Protocol. Neither Mr Gonzalez's wife or their children have any proprietary interest in alternatives or substitutes in ODSs. Expenses related to Mr Gonzalez's attendance to MBTOC meetings are paid by UNEP.

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Dr. Saad L. Hafez is a full Professor of Nematology at the University of Idaho, working at the Parma Research and Extension Center. The University of Idaho has an interest in the topics of the Montreal Protocol as it conducts research on methyl bromide alternatives for nematode control. Dr Hafez has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or their alternatives or substitutes and does not consult for organizations seeking to phaseout ODSs. Dr. Hafez occasionally works as a consultant for UNDP, UNEP, and UNIDO, Governments, companies and others on projects relating to Methyl Bromide alternatives. Dr. Hafez's spouse children do not work for or consult for any organization with an interest in the topics of the Montreal Protocol. His spouse and their dependant children have no proprietary interest in alternatives or substitutes to ODSs, do not own stock in companies producing ODS or alternatives or substitutes to ODSs and do not consult for organizations seeking to phaseout ODSs. Costs of travel to enable Dr Hafez to attend MBTOC meetings are paid by the University of Idaho.

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Dr Darka Hamel is an entomologist responsible the protection of stored products. Dr Hamel is a full time executive manager at the Institute for Plant Protection in Agriculture and Forestry of the Republic Croatia (PPI). The PPI has an interest in the topics of the Montreal Protocol because companies using methyl bromide for treatment in accordance with ISPM 15 are authorized to do so in accordance with the PPI recommendation. Dr Hamel has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consulting for organizations seeking to phaseout ODSs. Dr Hamel works occasionally as a consultant to the Croatian Ministry of Agriculture, Forestry and Water Management or the Ministry for Environmental Protection and Physical Planning regarding legislation on matters related to the Montreal Protocol. Travel to MBTOC meetings is paid by UNEP.

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Dr George Lazarovits is a research scientist at the Southern Crop Protection and Food Research Center of Agriculture and Agrifood Canada (AAFC). He is employed as a fulltime research scientist to investigate aspects of plant pathology involved with management of soilborne plant pathogens. AAFC has an interest in the topics of the Montreal Protocol because Canada has a vested interest in eliminating ozone-depleting substances such as methyl bromide, which are still being used by Canadian growers and Industries. AAFC, in collaboration with Environment Canada, is charged with overseeing the phase-out of ozone depleting products. Dr Lazarovits has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or those manufacturing alternatives or substitutes to ODSs and does not act as consultant for organizations seeking to phase-out ODSs, other than non profit government agencies charged with enforcing the regulations of the Montreal Protocol. He is involved in advising as a consultant to Environment Canada (EC) on matters related to the Montreal Protocol, including evaluation of critical use nominations submitted to them by Canadian growers or Industries seeking exemptions for use of MB under CUE. Such nominations, if approved by EC, are eventually adjudicated by members of MBTOC. Dr Lazarovits' spouse has no involvement whatsoever with any issues or has any interest in the topics of the Montreal Protocol or any proprietary interest in alternatives or substitutes to ODSs. She does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phase-out ODSs. They have no dependent children living with them and their children have no involvement in any businesses dealing with issues that are in any way related to the Montreal Protocol. Travel to MBTOC meetings is paid for by AACF, and occasionally Environment Canada, from A Base budgets.

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Dr Nahum Marbán-Mendoza is a full-time professor of Integrated Pest Management and Plant Nematology at the Universidad Autónoma de Chapingo in the graduate programme of crop protection. He has over 25 years experience in the research and development of non-chemical alternatives to control plant parasitic nematodes associated with different crops in Central America and Mexico. Dr Marbán-Mendoza was MBTOC co-chair from 2002 to 2005. He has also assisted implementing agencies of the Montreal Protocol (UNEP, UNIDO) with methyl bromide phase-out programs in Mexico and Guatemala; occasionally he receives funds for wages and travel. Neither Dr Marbán nor his spouse or their daughter have ever had proprietary interest or owned stocks in a company producing ODS or their alternatives or substitutes, nor have they ever consulted for organizations seeking to phase out ODSs Costs related to Dr Marbán's participation in MBTOC activities are paid by UNEP.

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Carlos Alberto Barbosa Medeiros is a full time researcher at the Brazilian Institute of Agricultural Research - EMBRAPA, leading the Experimental Station of Cascata – EMBRAPA Temperate Climate, Pelotas-RS, where all research activities are related to agro ecology. EMBRAPA has an interest in the topics of the Montreal Protocol because of the environmental impact of methyl bromide. Dr Medeiros has assisted UNIDO with methyl bromide phase-out programs in Brazil and works occasionally as a consultant to UNIDO on matters related to the Montreal Protocol. Dr. Medeiros has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Neither his spouse or children work for or consult for any organization which has an interest in the topics of the Montreal Protocol, nor do any of them have any proprietary interest in alternatives or substitutes to ODSs, or own stock in companies producing ODS or their alternatives or substitutes. Travel to MBTOC meetings is paid by UNEP.

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Dr Melanie Miller, a member of MBTOC since 1993, is a consultant on methyl bromide and alternative technologies. She has no proprietary interest in alternatives or substitutes to ODSs, and does not own stock in companies producing ODS or alternatives. She has authored a large number of papers and publications about methyl bromide alternatives for UNEP and other government bodies. She is a reviewer of project proposals for MLF and GEF methyl bromide projects, and has provided technical assistance to many methyl bromide projects in Article 5 countries. She was a sector expert in the World Bank's Ozone Operations Review Group

(OORG) from 1999, member/adviser of the TEAP Economic Options Committee (EOC) Task Force on Methyl Bromide in 1996-1998, and analysed data for the TEAP Task Force reports on MLF replenishment in 2002 and 2005. Her spouse is an international expert on technical and legal aspects of the Montreal Protocol and currently works as a consultant. Her spouse has no proprietary interest in alternatives or substitutes to ODSs, and does not own stock in companies producing ODS or alternatives. The cost of travel to MBTOC meetings is paid from her own personal funds and sometimes by UNEP, at least in part.

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Dr Andrea Minuto is a full time assistant professor at the University of Torino (c/o Agroinnova) in Italy. Agroinnova has an interest in the topics of the Montreal Protocol because of the research conducted on soilborne pest and disease management. Dr Minuto has no proprietary interest in alternatives or substitutes to ODSs, and does not own stock in companies producing ODS or their alternatives or substitutes. He does consulting (as Agroinnova) for organizations seeking to phaseout ODSs and also works occasionally as a consultant for Implementing Agencies and Governments on matters related to the Montreal Protocol. His spouse does not work or consul for organizations which have an interest in the topics of the Montreal Protocol or organizations seeking phase-out of ODS, nor does she have any proprietary interest in alternatives or substitutes to ODSs, or own stock in companies producing ODS or their alternatives or substitutes. Travel to MBTOC meetings is paid by Agroinnova, which receives contributions from the Italian Ministry of Environment, Territory and Sea.

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Mr. Takashi Misumi, member of MBTOC since 2005 is a senior researcher at the Yokohama Plant Protection Station (YPPS). Mr. Misumi is a full time Researcher at the Quarantine Disinfestation Technology Section, Research Division of YPPS. He has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. Neither his spouse nor their children work for organizations with has an interest in the topics of the Montreal Protocol. Expenses related to the attendance of MBTOC meetings are paid by International department of MAFF.

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Dr Kazufumi Nishi is a Chief Researcher at the National Institute of Vegetable and Tea Science of Japan (NIVTS). He conducts research on plant disease control techniques, particularly physical control methods. Dr. Nishi has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by the International Department at MAFF.

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Dr. David Okioga is a founding member of MBTOC, joining in 1992. He was MBTOC co-chair between 1997 and 2002. Dr Okioga was the Director, National Plant Quarantine Services of Kenya for sixteen years. He also served as the Coordinator in Agricultural Botany under the Kenya Agricultural Research Institute, Secretary to the Ministry of Agriculture on Plant Breeder's Rights, Member of the National Agricultural Research Centre, National Horticultural Research Centre, National Potato Research Centre, and the National Committee for the National Genebank. Dr. Okioga has undertaken a number of contracts from the African Unity (then Organization of the African Unity), FAO and UNEP. Some of these consultancies were related to crop protection, where methyl bromide was considered as the chemical of choice for soil fumigation, whereas others were on strengthening the Montreal Protocol policies on ODS phase out in the African region (including methyl bromide). In 1995, Dr Okioga was appointed Coordinator, of the National Ozone Unit (NOU) of Kenya by the Ministry of Environment and Natural Resources, Kenya, in consultation with UNDP, a post that he still holds at present. Dr. Okioga's main responsibility is strengthening the government of Kenya in meeting the requirements of the Montreal Protocol and in phasing out of ODS in the country. Travel and expenses related to his attendance to MBTOC meetings are paid by UNEP.

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Dr Jordi Riudavets is a Researcher at the Institute for Agrifood Research and Technology (IRTA) of Spain. He is a full time entomologist at the Crop Protection Division, with experience in the development and transfer of integrated pest management (IPM) programs for stored products and horticultural crops. The IRTA has an interest in the topics of the Montreal Protocol because is a state-owned company of the Catalan Government, and its activities are concerned with scientific research and technology transfer in the areas of agriculture, aquaculture and the agrifood industry. Dr Riudavets has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. He occasionally works as a consultant to the Spanish Government, food companies, pest control companies and private companies with interest in matters related to the Montreal Protocol. Travel to MBTOC meetings is paid by the Spanish Ministry of the Environment.

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Prof. Dr. Christoph Reichmuth is chemist and responsible for stored product protection. Dr Reichmuth is a full time director of the Institute for Stored Product Protection of the Federal Biological Research Centre for Agriculture and Forestry in Berlin, Germany, of the German Ministry for Nutrition, Agriculture and Consumer Protection, Germany.
The Federal Ministry for Nutrition, Agriculture and Consumer Protection together with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has a pronounced interest to replace methyl bromide as quickly as possible, due to the strongly expressed political interest and public opinion in Germany. Dr Reichmuth has no proprietary interest, patent for production of phosphine from

magnesium phosphide in a generator with the company Degesch Detia, Germany, patent for the treatment of stored products and organic materials (wood) with inert atmospheres with the company Buse, Germany, patent for pheromone traps for Lepidopteran pests with the Max-Planck-Society, Germany, at present there are no royalties paid from the patents to Dr Reichmuth. He gave and gives advice to private companies in Germany to obtain critical use exemptions for methyl bromide in helping to understand the English forms of UNEP/TEAP, he works occasionally as a consultant to UNIDO, supporting projects or parties to replace methyl bromide. Travel to MBTOC meetings or related meetings concerning the phaseout of methyl bromide are paid by the German Ministry for Nutrition, Agriculture and Consumer Protection or by the German Ministry for the Environment, Nature Conservation and Nuclear Safety.

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Mr John Sansone is the President and General Manager for SCC Products. He is employed in a full time capacity with responsibilities for sales, training, stewardship and as a consultant for end users in the residential, commodity, quarantine and port fumigation industries. SCC Products has a commercial relationship with several fumigant/pesticide manufacturers/registrants, some of which offer products which are considered alternatives to MB. SCC Products has been involved in research trials in the food processing and stored commodities sectors. The firm was instrumental in the transition to alternatives for the residential fumigation marketplace and currently is transitioning alternatives into the commodity fumigation market. It is also involved in the implementation of recapture equipment for commodity fumigation companies in California. SCC Products has an interest in the topics of the Montreal Protocol because of its relationship and expertise in many fumigation areas. Mr Sansone has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. He does not work as a consultant to the UN, UNEP, MLF, Implementing Agencies, Governments, companies, etc. on matters related to the Montreal Protocol. Mr Sansone has no relatives or business partners that work for or consult for any organization with an interest in the topics of the Montreal Protocol nor does he have relatives or business partner having a proprietary interests in alternatives or substitutes to ODSs, or who own stock in companies producing ODS or alternatives or substitutes to ODSs or consult for organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by SCC Products, which receives no contribution for this travel from anyone.

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Dr. James D. Schaub is an economist and Director of the Office of Risk Assessment and Cost-benefit Analysis, Office of the Chief Economist, United States Department of Agriculture (USDA). Dr. Schaub is employed full time within the Office of the Chief Economist, USDA in Washington D.C. The USDA has an interest in the topics of the Montreal Protocol because of its interest in environmentally sound agricultural production systems and the protection stored commodities. Further, USDA is responsible for protection of animal and plant health from quarantine pests. Dr. Schaub has no proprietary interests in alternatives or substitute ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phase out ODSs. He does not work as a consultant to any organization on matters related to the Montreal Protocol. Neither his spouse nor dependant children living at same home work for or consult for any organization which has an interest in the topics of the Montreal Protocol, nor do any of them have any proprietary interest in alternatives or substitutes to ODSs, nor do any of them own stock in companies producing ODS or alternatives or substitutes to ODSs or consult for organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by Office of the Chief Economist, USDA.

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Dr Sally Schneider is a National Program Leader at the United States Department of Agriculture. Dr. Schneider is a full time National Program Leader for Horticulture, Pathogens, and Germplasm at the Agricultural Research Service, Beltsville, Maryland, U.S.A. The Agricultural Research Service has an interest in the topics of the Montreal Protocol because they are the in-house research agency for the U.S. Department of Agriculture. Dr. Schneider has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. Dr. Schneider does not work, occasionally or otherwise, as a consultant to UN, UNEP, MLF, Implementing Agencies, Governments, companies, etc. on matters related to the Montreal Protocol. Dr. Schneider does not have a spouse, business partner, social partner, or dependant children living in same home. Travel to MBTOC meetings is paid by United States Department of Agriculture.

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Dr JL (Stappies) Staphorst is a soil microbiologist at the Plant Protection Research Institute of the Agricultural Research Council of South Africa. Dr Staphorst is a full time senior researcher, advisor and mentor in the Plant Pathology and Microbiology Division of the Institute in Pretoria, South Africa. The Plant Protection Research Institute has an interest in the topics of the Montreal Protocol because it houses the specialist Soil-borne Plant Diseases Unit and forms part of the Public Support Services Division that advises the Department of Agriculture on all aspects of plant diseases, pests and pesticides. Dr Staphorst has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does no consulting for organizations seeking to phaseout ODSs. Dr Staphorst works occasionally as a consultant to UNEP on matters related to the Montreal Protocol. His spouse has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does no consulting for organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by UNEP with logistical support from the Plant Protection Research Institute.

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Mr. Akio Tateya is a Technical Adviser at Syngenta Japan K.K. a pesticide producing company, which does not produce substitutes to methyl bromide. He also a technical adviser for the Japan Fumigation Technology Association, a non-profit body that is financially supported by the Japanese Government and companies producing methyl bromide and its substitutes. He conducts work for Syngenta Japan K.K. on a contract basis for a consultancy fee; he acts as a nominal member and adviser of the Japan Fumigation Technology Association, for which he is not paid. He is also a member of the Japanese delegation attending the Meeting of the Parties and Open-ended Working Groups, acting as technical adviser on matters related to the Protocol. He has been occasionally asked to attend panels or meetings at the Ministry of Agriculture, Forestry and Fisheries. He has no proprietary or any other kind of interest in alternatives or substitutes to ODS, nor does he own any stocks in companies producing either ODS or their alternatives or substitutes and does not work for any organization seeking to phase-out ODS. His spouse and children do not work for organizations with an interest in the Montreal Protocol. Travel expenses to enable attendance to MBTOC meetings and other meetings related to the Montreal Protocol are paid by the Japan Fumigation Technology Association. He receives no funding from the Japanese Government.

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Mr Robert Taylor retired from the Natural Resources Institute (NRI) of the United Kingdom in 2001. The NRI was a government establishment involved in biological/agricultural research, development and training, primarily in relation to developing countries. In recent years the NRI has become part of the University of Greenwich. Crop protection in both the pre- and post-harvest stages has always been a major feature of NRI's research and development programmes. Pest management, including the use of fumigants, has always features strongly in such programmes. Mr Taylor has no proprietary interest in alternatives or substitutes to methyl bromide and does not own stock in companies consulting for organizations seeking to phase out the chemical. He works occasionally as a consultant to UN agencies including UNIDO and UNEP on matters relating to the Montreal Protocol. Mr Taylor has no relatives or business partners who work or consult for organizations which have an interest in the topics of the Montreal Protocol, nor does he have relatives or business partners having proprietary interests in alternatives or substitutes to methyl bromide, or who own stock in companies producing alternatives or substitutes to methyl bromide, or who consult for companies seeking to phase out methyl bromide. Travel and subsistence for MBTOC meetings is paid for by the UK government and most recently by the Department for the Environment Farming and Rural Affairs and UNEP.

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Mr Alejandro Valeiro is the National Coordinator of the PROZONO Project (MLF/UNDP project ARG/02/G61) at the National Institute for Agricultural Technology (INTA) of Argentina, based at the Famaillá INTA´s Experimental Station in Tucumán Province, Argentina. The INTA has an interest in the topics of the Montreal Protocol because it is the national counterpart for implementing MLF methyl bromide phase-out projects, which are coordinated by the National Ozone Unit. Mr Valeiro has no proprietary interest on alternatives or substitutes to ODSs, does not own stock in companies producing ODS or their alternatives or substitutes and does not perform permanent consulting for organizations seeking to phaseout ODSs. He works occasionally as a consultant to the MLF, Implementing Agencies, on matters related to the Montreal Protocol. Mr Valeiro's spouse consults for UNDP, which has an interest in the topics of the Montreal Protocol because it implements MLF projects in Argentina. Neither Mr Valeiro, nor his spouse or dependant children have proprietary interest in ODS or their alternatives or substitutes, and do not own stock in companies producing ODS alternatives or substitutes to ODSs. Travel to MBTOC meetings is paid by UNEP.

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Dr Kenneth W. Vick is a Senior National Program Leader for methyl bromide alternatives research at the Agricultural Research Service (ARS), United States Department of Agriculture (USDA). As National Program Leader he helps lead the almost $20 million ARS research program to develop alternatives to the use of methyl bromide for soil and post-harvest applications. ARS has an interest in the topics of the Montreal Protocol because it was assigned lead responsibility for developing alternatives as the primary research arm of the USDA and because it was deemed to be of high priority by the United States Government. Dr Vick has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for any organization. His spouse, a MBTOC co-chair, consults for governments, NGOs and companies that have an interest in the phase out of methyl bromide because they are Parties to the Protocol or because they are investigating or developing food irradiation a methyl bromide alternative for some commodities and in some quarantine situation. She has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does consult for organizations seeking to phaseout ODSs. Dr Vick's travel to MBTOC and Montreal Protocol meetings is paid by the USDA Agriculture Research Service.

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Dr Nick Vink is Chair of the Department of Agricultural Economics at the University of Stellenbosch, South Africa. He is a full time Professor at the University of Stellenbosch. The University has no interest in the topics of the Montreal Protocol. Dr Vink has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult for organizations seeking to phaseout ODSs. He does not work as a consultant to any organisation on matters related to the Montreal Protocol. Neither his spouse or dependant children work for or consult for any organization which has an interest in the topics of the Montreal Protocol, nor do they have any proprietary interest in alternatives or substitutes to ODSs, or own stock in companies producing ODS or their alternatives or substitutes. Travel to MBTOC meetings is paid by UNEP.

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Mr.Christopher Russell Watson is a MBTOC member since 1992. He works for Igrox Ltd in the UK as Chairman a part-time position since he is presently semi-retired. Mr Watson has been involved in the fumigation industry using both methyl bromide and other fumigants for 40 years. Together with his wife he formed Igrox Ltd in 1976, which is now one of the largest fumigation and pest control servicing companies in the UK. For the past 20 years he has been involved in working closely with government agencies in the UK to develop safe and efficient fumigation practices and procedures. Igrox Ltd has an interest in the topics of the Montreal Protocol because it supplies services and products that are alternatives to methyl bromide, as well as continuing to provide services using methyl bromide in situations where it is still necessary. Mr Watson owns stock in Igrox Ltd, and occasionally carries out consultancy work for agencies seeking to phase out ODS's which have included the UK government agencies as well as private companies. His spouse doesn't not own stocks in Igrox Ltd and has no proprietary interests in alternatives or substitutes for ODS's and does not consult for companies seeking to phase out ODS's. Travel to MBTOC meetings was subsidised by Igrox Ltd and the British Pest Control Association until 2005. Presently, Mr Watson covers travel expenses from his own personal funds with some assistance from the UK Government(DEFRA)

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James Wells is the President of Environmental Solutions Group, LLC (ESG), a regulatory consulting firm in Sacramento, California. He was invited to join MBTOC in 1993 primarily because of his experience in pesticide regulatory programs, especially with methyl bromide and methyl bromide alternatives. He worked for the State of California pesticide regulatory program for 27 years and was the Director of the California Department of Pesticide Regulation from 1991 to 1999. Dr. Wells has no proprietary interest in alternatives or substitutes to ODSs and does not own stock in companies producing ODS or alternatives or substitutes to ODSs. He does not consult for organizations seeking to phaseout ODSs. However, ESG consults with several agricultural organizations seeking Critical Use Exemptions for the use of methyl bromide. These organizations are; the California Strawberry Commission (CSC), the California Strawberry Nursery Association (CSNA), the Garden Rose Council (GRC) and the California Association of Garden and Nursery Centers (CANGC). Together with his staff he prepares and submits CUEs for the CSNA, GRC and CANGC to the USEPA. His spouse works for the California Department of Justice which has no interest in the topics of the Montreal Protocol. She has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consult with organizations seeking to phaseout ODSs. Travel to MBTOC meetings is paid by ESG.

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Mr Eduardo Willink is Director of Special Disciplines and Head of the Agricultural Zoology Department of the Estación Experimental Agroindustrial Obispo Colombrés Tucumán, Argentina. He is a full time researcher in entomology who leads a team of researchers working on quarantine treatments, systems approach and pest host status, and is a member of the Technical Panel on Phytosanitary Treatments within IPPC, FAO. The organization has an interest in the topics of the Montreal Protocol because its mission is to resolve regional agro industrial problems with the least impact on the environment. Mr Willink has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs and does not consulting for organizations seeking to phaseout ODSs. Neither his spouse or dependant children work for or consult for organizations with an interest in the topics of the Montreal Protocol, nor do they have any proprietary interest in alternatives or substitutes to ODSs, own stock in companies producing ODS or their alternatives or substitutes or consult for organizations seeking to phaseout ODSs. Travel to TOC is paid by UNEP.

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