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Case Studies on Alternatives to Methyl Bromide Volume 2

Technologies with low environmental impact in countries with economies in transition

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CONTENTS

MESSAGE FROM THE ASSISTANT EXECUTIVE DIRECTOR, DIRECTOR UNEP DTIE

Methyl Bromide is a toxic chemical used to control a broad spectrum of pests in soil, commodities and structures. In the early 1990s, scientists identified methyl bromide as one of the substances contributing to ozone depletion. In response, the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer agreed in 1992 to a global phase-out schedule, with the passing of the Copenhagen Amendment. Achieving this phase out is one of the last remaining challenges for ozone layer protection.

Fortunately, the methyl bromide phase out offers multiple benefits for agriculture, the environment, and human health, since carefully chosen alternative techniques can be cost-effective, protect the ozone layer and improve worker safety simulataneously.

UNEP's Methyl Bromide Technical Options Committee (MBTOC) has identified effective alternatives for the vast majority of methyl bromide uses and many of these are in commercial use around the world. Global efforts are now underway to implement these alternatives. Yet, there is the potential for methyl bromide to be replaced by other toxic pesticides that will continue to pose risks to human heamth and the environment.

Methyl bromide phase out will require a shift towards more environmentally sustainable agricultural practices. Such behavioural changes will come through sustained awareness-raising, training and capacity-building activities to provide farmers with the knowledge and tools needed to adopt alternatives successfully. It will only occur if farmers and policymakers have practical examples of successful alternatives to methyl bromide.

UNEP in 1999 sought GEF funding for a regional project "Initiating Early Phase Out of Methyl Bromide in Countries with Economies in Transition (CEITs) through Awareness Raising, Policy Development and Demonstration/Training Activities", with the participation of 8 CEITs (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia). It was felt that this step was necessary since, having ratified the Montreal Protocol, CEITs have found it very difficult to comply with their ODS phase out schedules under the Protocol, due to the economic and political transformations of their countries.

In 2000, with US$663,000 in funding from the Global Environment Facility (GEF), the OzonAction Programme of UNEP DTIE, began in earnest with assisting Countries with Economies in Transition (CEITs) in their bid to phase out methyl bromide by 2005, as is mandated for these countries under the Montreal Protocol. In early 2001, the Government of Canada provided a further US $ 120,000 to facilitate the participation of Georgia and Moldova in the activities of the regional project. The project represents the first step towards:

- gathering comprehensive regional data on methyl bromide use;
- raising awareness on methyl bromide alternatives;
- developing policy to support methyl bromide phase out;
- identifying areas of use which might be targetted for phase out;
- presenting countries, with examples of viable, environmentally sustainable, effective alternatives for major uses of methyl bromide; and
- developing training strategies for the implementation of alternatives.

Whilst working with the countries, and evaluating their needs as well as the results of the demonstration projects carried out under the larger regional initiative, it was clear that the CEITs are unique in their climate, culture and socio-economic conditions. UNEP therefore sought to support compiling a document to encourage farmers, extension agencies, researchers, policy-makers and other stakeholders from the region to examine environmentally sustainable techniques when considering the replacement of methyl bromide. The document before you, *Case Studies on alternatives to Methyl Bromide, Volume 2: Technologies with low environmental impact in countries with economies in transition* is the result of our efforts.

These case studies demonstrate alternatives, both chemical and non-chemical, across the spectrum of uses in CEITs. It includes analyses of associated costs and the applicability of technologies to the region. It is hoped that this document, along with UNEP's other technical resources, will help the National Ozone Units in the CEITs successfully meet the phase out measures required of them under the Montreal Protocol, in an economically and environmentally sustainable fashion.

Jacqueline Aloisi de Larderel, Assistant Executive Direcor, Director
UNEP DTIE

INTRODUCTION

Protection of the ozone layer

The Montreal Protocol is an international agreement that aims to protect the Earth's fragile ozone layer from the damage caused by chemicals such as CFCs, halons and methyl bromide. The ozone layer is important to life on earth because it screens us from harmful ultraviolet radiation emitted by the sun.

Methyl bromide (MB) was added to the international official list of ozone depleting substances in 1992. Under the Montreal Protocol, governments have agreed to phase-out MB in industrialised countries by 2005 and in developing countries (called 'Article 5 countries') by 2015. In the interim the national supplies of MB will also be reduced.

MB is an agricultural fumigant which is used to control a broad spectrum of pests in soil, commodities and structures. Globally, MB is mainly used as a soil treatment prior to planting crops such as tomatoes, peppers, cucumbers, melons, strawberries, cut flowers and tobacco seedbeds. Post-harvest treatments are mainly applied to grains and traded commodities.

Use of MB in CEITs

MB is used for a very wide range of crops and commodities in Countries with Economies in Transition (CEIT) in Central and Eastern Europe. A UNEP survey carried out in eight CEIT countries showed that approximately 39% of MB was used for quarantine and pre-shipment, while 61% was used for soil, storage and other uses that are controlled by the Montreal Protocol. Of the controlled uses, the majority was consumed for soil disinfection (53%), followed by durable commodities (34%) and structures (12%) (Porter 2001).

The crops grown on MB-treated soil in CEIT countries include vegetables (eg. tomato, pepper, cucumber, cabbage, celeriac), strawberries, cut flowers (eg. gerbera, carnations), ornamental plants, fruit tree nurseries, orchard replant, tobacco seedbeds and others. Target soil-borne pests include nematodes (such as root-knot nematodes *Meloidogyne*) and a range of fungal pathogens (such as *Fusarium*, *Sclerotinia*, *Pythium*, *Rhizoctonia*, *Verticillium* and *Phytophthora*).

The main commodities treated with MB are durable products such as grains, herbs, dried fruit, other dried food products, cocoa, tobacco, cotton, timber, artefacts and museum items. Relatively little MB is used for perishable commodities. Treated structures include grain stores, silos, mills, historical buildings, ships and barges. The pest targets in commodities include a wide array of weevils and other beetles, moths, other insects and mites (Porter 2001).

The consumption of MB in CEIT countries was reported by the Ozone Secretariat as follows for the year 2000 (the given tonnages do not include quarantine and pre-shipment): Poland (65 tonnes), Hungary (40 t), Macedonia (39 t), Romania (33 t), Bulgaria (22 t), Georgia (22 t), Croatia (18 t), Lithuania (16 t), Bosnia and Herzegovina (10 t) and Latvia (1 t). The majority of countries in the CEIT region also use MB for quarantine and pre-shipment (QPS) treatments.

Controls at national level

Most CEIT countries already control imports of ozone depleting substances by a licensing or permit system. Quotas on MB have been introduced in Bulgaria, Croatia, Hungary, Latvia and Lithuania, for example. Restrictions on the use of MB are also in place in some countries. Permits, for example, are required for the use of MB in Bulgaria, Hungary, Latvia, Lithuania and Poland. Estonia has prohibited imports and use of ozone-depleting substances including MB (Porter 2001).

Candidate countries for the European Union are bringing their legislation into harmony with the EU regulation (EC 2037/00) on ozone depleting substances, which requires phase-out of MB imports by 2005. The regulations also introduced a limit on the quantity of MB that can be used for QPS.

Measures to assist MB phase-out

Agricultural producers are starting to avoid broad-spectrum treatments like MB because of concerns about adverse effects on beneficial organisms and the environment, as well as risks to human health. European supermarkets, for example, increasingly require producers to adopt Integrated Pest Management (IPM) in order to reduce the negative impacts of pesticides. IPM programmes will increasingly be required on farms as a matter of good agricultural practice. A few countries are experimenting with environmental labels for fruit and vegetables produced without MB to enable consumers to choose environmentally-friendly products.

Several countries around the world have introduced import taxes or voluntary duties on MB which act as disincentives and make the price of alternatives more attractive. Slovakia and the Czech Republic, for example, have placed duties or licence fees on MB imports.

The Montreal Protocol has established a Multilateral Fund to provide technical and financial assistance for countries classified as 'Article 5 countries' to phase-out MB. Article 5 CEIT countries include: Bosnia and Herzegovina, Croatia, Georgia, Kyrgyzstan, Macedonia, Moldova, Romania and Yugoslavia. Albania is also temporarily classified as Article 5, pending receipt of complete data on consumption of ozone-depleting substances.

Other CEIT countries are classified as industrialised countries (non-Article 5) and are not eligible for financial assistance from the Multilateral Fund. However, some technical assistance is available from the Global Environment Facility (GEF) to assist phase-out of ozone depleting substances. GEF provided assistance recently to a CEIT project implemented by UNEP DTIE which initiates early phase-out of MB by raising awareness, policy development and training. This project included a regional demonstration project which evaluated alternatives for tomato, cabbage, pepper, celeriac and strawberries. The project covered nine countries: Bulgaria, Estonia, Georgia, Hungary, Latvia, Lithuania, Moldova, Poland and Slovakia. The participation of Georgia and Moldova was made possible through bilateral assistance from the Government of Canada.

Alternatives

UNEP's Methyl Bromide Technical Options Committee (MBTOC) has identified alternatives for about 95% of MB use, excluding QPS. Effective alternatives for soil-borne pests include Solarisation, substrates (soil substitutes), steam, soil amendments, alternative fumigants, selected pesticides and crop rotation, used within integrated pest management systems. Alternatives for grain and durable commodities include phosphine, modified atmospheres, heat, cold, vacuum-hermetic and other treatments. Alternatives transferred from other countries generally need to be adapted to suit the local conditions. Training will be important in ensuring that farmers and other MB users will be able to apply alternatives effectively in future.

Purpose of case studies

Some farmers and MB users have already adopted MB alternatives for a wide variety of reasons, such as commercial advantages or international trends towards IPM and pest control methods that do not depend on toxic pesticides. The 1998 report of MBTOC lists countries where alternatives are in commercial use (MBTOC 1998), highlighting the desirability of detailed case studies to illustrate these examples. UNEP therefore compiled a volume of detailed Case Studies relevant to Article 5 countries, particularly Latin America, Asia and Africa. This second volume of Case Studies provides additional examples of alternatives relevant to CEIT countries. The document aims to encourage farmers, extension agencies, researchers, policy-makers and others involved in the MB phase-out process to examine environmentally sustainable techniques when considering their options for replacing MB.

Importance of safe alternatives

It is important to increase awareness about the successful use of biological and non-chemical alternative techniques so that farmers can make informed choices about MB alternatives. This booklet aims to reduce the risk that MB could be replaced by chemicals which are not ozone depleting substances but give rise to other environmental problems such as health risks or the pollution of air, soil or water.

This compilation focuses on alternatives which are safer for human health and the environment. Such techniques will meet the increasing demands of retailers and the public for food without pesticide residues, reduced pollution from agriculture, and safer working conditions for the farming community. Indeed, phasing out MB provides an opportunity for MB users to adopt (and further develop) environmentally sound pest control methods.

How to use the case studies

The case studies in this book are arranged by crop and commodity type, as follows:

- Tomatoes, peppers
- Cucumbers
- Tobacco seedbeds
- Strawberries
- Food processing facilities
- Archives, museum artefacts and cultural treasures

The case studies describe a variety of alternatives in commercial use and relevant to CEITs. Each study provides information on the following:

- Economic significance of crop or commodity
- Climate
- Use of MB
- Target pests
- Description of alternative
- Yields and performance
- Costs
- Acceptability to regulators and consumers
- Applicability to CEITs and other regions
- Sources of further information

A discussion and conclusions are provided in the final section of this book.

Data collection

Information for the case studies was compiled by six experts, with additional assistance from other specialists. For each case study experts were asked to provide detailed data on the alternative, a description of the technique, data on yields, a comparison of the performance and costs, regulatory information, and applicability to other regions. The data were put into a standardised format, edited and peer-reviewed by international experts.

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Case Study 1

Substrates for greenhouse tomatoes and peppers

SUMMARY

Crop/use: Tomatoes and peppers in greenhouses and tunnels

Country: Hungary

Pests: Root knot nematodes and fungal diseases eg. *Fusarium* spp. *Pyrenochaeta lycopersici*, weeds

Alternative: Growing plants in containers of substrate (eg. volcanic limestone), grafted plants and integrated pest management

Yields: Alternatives give much higher yields than MB

Costs: System costs slightly more than MB, but gives higher profits

Regulatory approval: None required

Comments: These cultivation techniques address the needs of greenhouses which have highly infected soil

Examples of use in other CEIT countries: Poland has more than 800 ha of substrates for tomato, cucumber and paprika production. Lithuania uses a wide range of substrate materials.

Examples of use in other regions: Substrates are used for greenhouse crops in many countries, including Australia, Belgium, Canada, Denmark, France, Netherlands, New Zealand, South Africa and Turkey.

Economic significance

Vegetable production is a very important part of Hungarian horticulture. It not only covers the country's needs for fresh market vegetables, but also provides significant exports, particularly to Western Europe (Germany, Switzerland and Austria). Protected (glasshouse and tunnel) crops are grown on approximately 40% of the total vegetable production area. The value of protected crops far exceeds that of open field vegetable cultivation.

Protected crops are the main source of employment for several thousands of families in Hungary.

Protected pepper is grown on about 2,250 hectares (ha) while protected tomato is grown on about 1,200 ha (1999 data). This represents about 64% of the total greenhouse area of 5400 ha in Hungary.

Climate

Production is mostly in the South-Eastern part of the country where the annual number of sunshine hours is highest (more than 2100 hours per year). Horticulture is traditionally significant in this area; production of open field tomato, pepper and cucumber has been carried out for many years. The soil is sandy in most parts of this region, favouring root-knot nematode pests. Typical temperatures in the greenhouses and tunnels are 25–30°C during the day and 18–22°C at night.

Production characteristics

There are two main types of protected vegetable production: (a) heated greenhouses, which are mainly heated by geothermal energy (thermal water) and (b) unheated conditions, mainly plastic tunnels. There are both large and small greenhouse units; the average size is 500 m^2.

The planting periods vary as follows. In unheated tunnels, Spring-Summer tomato production is the most common, starting in April. In heated greenhouses, planting is done earlier, in January, providing a long growing season. The tomato varieties and the production technology come from the Netherlands predominantly.

Use of methyl bromide

MB was first registered for use in horticulture in 1984 in Hungary. About 40 t MB is used for treating soil in about 100 ha of protected crops, primarily for controlling pathogens and nematodes in early-fruiting varieties. The recommended MB dose is 50 g/m^2, but

Table 1. **National production area of protected tomato and vegetables**

	Production area (ha)			
Crops	**1995**	**1996**	**1997**	**1998**
Protected tomato	1040	1080	1150	1180
Protected pepper	2050	2100	2200	2250
Protected cucumber	720	650	680	640
Other early crops	1635	1670	1420	1330
Total	**5445**	**5500**	**5450**	**5400**

Source: Vegetable and Fruits Product Council, 1999

***Table 2.* MB consumption in Hungary (excluding QPS)**

Year	MB (tonnes)
1992	45
1994	74
1998	53
2000	40

sometimes higher doses of 75 g/m^2 and 100 g/m^2 are required. The national consumption of MB is shown in Table 2, excluding the amounts used for quarantine and pre-shipment.

Key soil-borne pests include the following:

- Root knot nematodes, *Meloidogyne* spp. (*M. hapla*, *M. incognita*, *M. arenaria*, *M. javanica*, *M. thameesi*)
- Fungal diseases, eg. Pyrenochaeta lycopersici, Sclerotinia spp., Botrytis spp., Fusarium spp.
- Weeds
- Other pests, eg. Noctuidae (Lepidoptera), Gryllotalpidae (Saltatoria).

Due to the very narrow range of crops grown on the same area for many years, and due to particular microclimatic conditions, the soil pests and pathogens and some species of weeds have increased to very high levels. Under the conditions found in the South-Eastern part of Hungary, and particularly in sandy soils, *Meloidogyne* spp. (mainly *M. hapla*) is the most important pathogen of tomato. The conditions of soil-heated greenhouses encourage the reproduction of nematodes, but even in air-heated greenhouses (18–21°C) there are many generations per year. In infected tomato crops the yield losses can exceed 30–40%. High levels of infestation cause significant losses, so soil sterilisation has to be performed on a routine basis.

Soil-borne fungal diseases are generally considered more damaging than airborne fungal diseases. Continuous cropping leads to a build-up of fungal resting stages in the soil, resulting in substantial disease problems. In tomato crops, for example, *Fusarium oxysporum* f. *lycopersici* (wilt) and sclerotia-forming fungi (eg. *Sclerotinia* spp., *Botrytis* spp.) pose a permanent threat of reduced yields.

Weeds also need to be controlled because they compete with crop plants for nutrients, water and light, and can also provide favourable conditions for harmful plant pathogens and nematodes.

Commercial use of alternatives – substrates, resistant varieties, grafted plants

Use of substrates is gaining popularity in Hungary and is the most common alternative to MB in glasshouses. Various different substrate methods and materials are used.

Árpád-Agrár Co, for example, is the largest vegetable producer in Hungary and has 46 ha of heated glasshouses and plastic tunnels. Due to severe nematode and disease problems Árpád was one of the first companies in Hungary to use MB for soil disinfestation in the 1980s. After becoming aware of the Montreal Protocol's MB phase-out requirements the company trialled tomato on rockwool slabs in 1998. The results were good so the area was increased to 1 ha in 1999. In 2000, they converted 2 ha of pepper production to rockwool. Following successful projects with the Netherlands, the company converted further glasshouses, giving a total of 11 ha rockwool (comprising 8 ha pepper, 2 ha tomato and 1 ha cucumber). As a result of their successful experience, the company aims to convert all their glasshouses to rockwool by about 2005.

For many smaller farms and plastic tunnels rockwool slabs are not appropriate. Small farmers do not have the investment capital necessary for rockwool, and plastic tunnels have insufficient airspace, uneven heating and problems with irrigation water. So other substrate systems have been introduced in such situations. For example, 50–60 small family farms now grow crops in containers of various substrates (eg. volcanic limestone) on a total area of about 15–20 ha. The container system was introduced about ten years ago and is used mainly for the production of tomato and occasionally for melon or cucumber.

Some growers have adopted grafted plants and integrated pest management. Grafted plants are used increasingly in plastic tunnels following the successful results of commercial trials.

Alternative techniques

Producing tomatoes and peppers in clean substrates, instead of the soil, makes soil disinfection unnecessary. The substrates are made from materials that are free from nematodes and other soil-borne organisms that cause diseases in plants. Materials can include peat, coconut waste, treated pine bark, mature compost, volcanic limestone (perlite), small stones, rockwool, and many others. Substrates are often made from mixtures of materials, to allow the movement of water, nutrients and air in ways that suit the needs of each crop.

Dutch tomato varieties are commonly used in protected production in Hungary because most are resistant to pathogens. For cucumber and white sweet pepper, nematode-resistant grafted plants are sometimes used instead of MB fumigation. Where non-resistant varieties are grown, pest control can also be achieved by alternative soil fumigants and certain nematicides.

Substrates in containers – small producers

The group of small family farms mentioned above plants young tomato plants in 10 litre pots (two plants per pot) which have been filled with peat and/or perlite substrate. The pots are placed in rows on plastic sheets on the floors of greenhouses and tunnels. The sheet acts as a barrier, preventing pests entering pots from the soil below. The density of tomato plants is about 40,000 per ha (two plants per container). Drip irrigation lines are placed along the top of the pots to provide water and nutrients. IPM technology is used. After the crop is finished, the substrate material can be used again in forestry nurseries.

Rockwool slabs in large glasshouses

The largest producer, Árpád-Agrár Co., has many old greenhouses built in the 1960s and 70s. Before installing the rockwool systems they carried out a lot of additional work to upgrade the old glasshouses. Broken glass panes and old insulation were replaced. They removed large amounts of surplus soil that had accumulated in the houses, increasing the available height for crops. Glasshouses were installed with computer-controlled equipment, new heating systems, drip irrigation and water filtering-cleaning equipment. Pepper, tomato and cucumber are now grown on rockwool slabs in the converted glasshouses, using Dutch technologies.

Grafted plants and IPM in plastic tunnels

Árpád found that heated plastic tunnels were unsuitable for rockwool. They had insufficient airspace, uneven heating and problems with irrigation. Following trials in 2000, grafted plants are now used commercially in several heated plastic tunnels. Traditional local varieties of pepper are grafted onto Snooker rootstock. Un-heated plastic tunnels can use grafted pepper combined with selected chemicals or IPM techniques.

Yields and performance

In small farms, substrates in pots provide higher yields of tomatoes and peppers than conventional production in soil disinfected with MB. Substrates also provide higher quality vegetables. In small family farms the tomato yield is 10 kg/m^2 when using MB, compared to 15 kg/m^2 using substrates in pots. The number of tomato clusters is 7 per plant when using MB and 12 per plant when using substrates.

Larger and better-resourced farms have substantially higher yields than small farms. Conventional production using MB provides tomato yields of about 22 kg/m^2 (two crops, spring and autumn). However, rockwool slabs and similar intensive substrate systems produce yields which are almost double, at about 40 kg/m^2. The picture for pepper is similar. The yield using MB is 12–13 kg/m^2 (spring crop), while the yield on substrates is 22–23 kg/m^2. Substrate systems provide more uniform fruit and less fruit wastage than MB systems.

The yield of grafted pepper is about 16.5 kg/m^2, compared to 12–13 kg/m^2 from conventional MB systems. The grafted rootstock has a larger root mass to supply the growing plant and fruit with more water and nutrients. It is stronger and more resistant to stress, diseases, viruses and bacteria. The larger root is also more tolerant of nematodes and consequently it develops a larger leaf mass and higher yields. The larger root allows two stems to be grown on each plant, increasing the density of production so that grafting becomes economically viable.

Acceptability to regulators and markets

Substrate systems and grafted plants do not require registration or approval from the authorities responsible for pest control products, because they do not pose the safety risks of fumigants. Tomatoes and peppers grown in substrates are often of higher quality than products grown in MB-treated soil. Substrate production is well-accepted by supermarkets and consumers alike.

Costs

Production on rockwool slabs requires a high initial investment. Árpád, for example, spent about $ 19.50 per m^2 installing rockwool systems in old glasshouses. But this price included a lot of work that might not be necessary in other situations: it included new greenhouse insulation, repair of broken glass,

Greenhouse tomatoes produced on substrates in large plastic pots, Hungary

Csaba Budai

Table 3. **Cost of rockwool and MB in glasshouse tomato and pepper (average of 2 years)**

	Tomato (US$/m²)		Pepper (US$/m²)	
Items	**MB soil**	**Rockwool**	**MB soil**	**Rockwool**
Investment cost	–	19.52	–	19.52
Operating cost	0.74	–	0.74	–
Income (gross)	14.84	23.43	10.93	23.43

Source: L. Kovács, Árpád-Agrár Co. Conversion rate: 1 Hungarian Forint = US$ 0.0039

Table 4. **Costs of soil disinfection technologies in Hungary**

Active ingredient	Dose	Costs (US$/ha)
MB 98%	500 kg/ha	8,700–10,050 (contracted service)
Dazomet 98%	500 kg/ha	2,800
Metam-ammonium 40%	1500 l/ha	2,800 (contracted service)
Oxamil 10%	30 kg/ha	490

new heating systems, drip irrigation and water cleaning systems. Removing a layer of soil to increase the effective height inside the greenhouses accounted for about 25% of the cost. But even with this additional work, the investment cost can be recovered in a maximum of 4–5 years based on the experience of this producer.

The gross income from rockwool systems is about $ 23 per m^2 while the gross income from MB systems is about $ 11–15 per m^2 (Table 3).

Substrates in pots require substantially less investment than rockwool, and cost slightly more than MB. In Hungary, substrates in pots cost about $ 10,500 per ha compared to $ 8,700–10,050 per ha for MB. However, the substrates are more profitable than MB.

Grafted plants used in plastic tunnels also give a higher gross income of about $ 14.5 per m^2 compared to about $ 11 per m^2 for MB.

For tomatoes grown in soil, the doses and costs of various pesticides for the control of soil-borne pests are shown in Table 4.

Applicability to other regions

Substrates can be used in all CEIT countries. Commercial use of substrates in Poland has increased to more than 800 ha. MB is not used to treat soil in Lithuania; growers use a wide range of substrate materials, such as coconut, clay, rockwool, perlite and pumice (Porter 2001).

Examples of other countries where substrates are used for tomatoes and vegetables include: Australia, Belgium, Canada, Denmark, Finland, France, Netherlands, New Zealand, South Africa and Turkey (Miller 2001). Substrates are used in all climates, from cool temperate to tropical.

Technical information provided by:

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Case Study 2

Solarisation and biofumigation for tomatoes and cucumbers

SUMMARY

Crop/use: Tomatoes and cucumbers in greenhouses

Country: Republic of Macedonia

Pests: Fungal diseases eg. *Fusarium*, root knot nematodes, weeds

Alternative: Solarisation + biofumigation

Yields: Similar yields to methyl bromide

Costs: Costs are lower than MB, consequently the profit is higher

Regulatory approval: None needed

Comments: Important to select appropriate types of organic matter

Examples of use in other CEIT countries: None known

Examples of use in other regions: Biofumigation + solarisation is used commercially on about 35 ha of sweet pepper in Murcia, Spain, and for pepper and tomato production in Uruguay

Economic significance

Production of vegetables contributes significantly to the agricultural economy of the Republic of Macedonia. The climate is suitable for production of a wide range of vegetables.

Vegetables are produced on a total area of 56,000 ha. Agricultural enterprises (state-owned farms) own approximately 200–250 ha of heated greenhouses and approximately 100 to 1000 ha of open field production. Private farms own the remaining vegetable production area (about 55,000 ha) consisting of both plastic tunnels and open fields.

Greenhouse vegetable production is important for fresh vegetable exports such as tomatoes and cucumbers, although greenhouses comprise only 0.2 % of the total arable land. About 19,000 t of vegetables are produced in greenhouses annually. The majority of vegetable exports go to the Federal Republic of Yugoslavia (28,072 t), Bosnia and Herzegovina (9,195 t), Croatia (4,722 t), Slovenia (3,650 t) and Russia (992 t). Table 1 shows the volume of exports of major vegetables in 1998 and 1999. The most significant crops are tomatoes, cucumbers, peppers, watermelons and melons.

Greenhouse cropping is considered to be a profitable activity provided it is responsive to changes in the market. The export of vegetables is highly successful, mainly due to greenhouse production. However, in certain periods there are problems such as over-production, leading to over-supply on the market.

Climate

The location of vegetable production is mainly in Strumica, Gevgelija, Kumanovo and Skopje. In the five most important vegetable production regions the annual average temperature lies between 11 and 14°C. The maximum temperature is 41–43°C, and the minimum is -14 to -29°C. The annual rainfall varies from 520 to 610 mm per year, and average relative humidity is 68–73%.

Crop production characteristics

Two production cycles take place each year so that crops are ready for harvest when market prices are highest. The first cycle starts in mid-January (or in February to avoid high fuel costs) and ends in mid to end June, or later. The second cycle starts at the end of July and finishes in November or December. The typical yield of tomato ranges from 100 to 130 t/ha, while cucumber yields are in the range of 160–200 t/ha.

The majority of seed used in greenhouses is imported, mainly from the Netherlands. The main F1 hybrids and cultivars are shown in Table 2.

Table 1. **Exports of main fresh vegetables from Macedonia**

Crop	1998 (tonnes)	1999 (tonnes)
Tomatoes	12,900	14,649
Cucumbers and gherkins	13,122	6,686
Sweet peppers	22,670	22,902
Total	**48,692**	**44,237**

Source: Horticulture Marketing Study, MAFWE – Private Farmers Support Project, 2000

Table 2. **Common F_1 hybrids and cultivars used in greenhouses in Macedonia**

Crop	F_1 hybrids	Cultivars
Tomatoes	Marfa	Balca
	Carmello	Arletta
	Monica	Prisca
	Amati	Calibra
	Lucy Cronos	Big Beef
Cucumbers	Sandra	Darina
	Monitor	Rambo
	Jazer	Kalunga
	Dalibor	Sonchev potok
	Nevada	Dolga zelena

Use of methyl bromide

From 1994 the Republic of Macedonia officially banned the use of MB in horticulture, permitting its use in tobacco seedbeds only. The reported use of MB in 1999 was 21 t, but a survey carried out by the Faculty of Agriculture during 2000 indicated that the real use of MB was probably twice that figure. Around 10% of MB is probably used in vegetable production, although it is not officially permitted. Vegetable growers use the small 454 ml cans intended for tobacco seedbeds because the 50 litre MB cylinders are not permitted now. The typical MB application rate is about 50 g/m^2.

MB is used for common soil-borne problems such as the following:

- Weed control
- Damping off (*Phytophthora*, *Pythium* and *Rhizoctonia*)
- wilt (*Fusarium oxysporum*)
- Verticillium wilt (*Verticillium dahliae*)
- Bacterial canker (*Corynebacterium* spp.)
- Alternaria stem canker (*Alternaria alternata*)
- Late blight (*Phytophthora infestans*)
- Root knot nematodes (*Meloidogyne* spp.)

Commercial use of alternative – biofumigation and solarisation

In the past decade the most frequently used MB alternative was dazomet granules, applied at the rate of 90 g/m^2. Biofumigation combined with solarisation was evaluated in 1999–2000 in a large greenhouse complex of 36 ha in the area of Valandovo, in the South Eastern region. Biofumigation is now used commercially on a small number of farms and it is expected that this technique will be widely adopted in the horticultural regions of Macedonia.

Alternative technique

The combination of biofumigation + solarisation substantially reduces the time normally required for a solarisation treatment. The process consists of mixing moist soil with organic material (eg. manure) and covering it with a transparent polyethylene sheet. The soil temperature increases to a level that is lethal to many soil-borne pests and diseases. At the same time, the raised temperature favours the fermentation of the organic material, generating gases which are trapped beneath the plastic and lethal to many undesirable micro-organisms in the soil. Solarisation is important in providing the heat for decomposing the organic material which in turn generates high temperatures necessary for a successful treatment. For this reason the technique can only be used in seasons and climates where solarisation can generate sufficient temperatures.

In Macedonia, organic matter such as cow manure with straw is applied at 5–7 kg/m^2, well distributed and incorporated into the soil to a depth of 20 cm. Before covering with plastic sheets, the soil is irrigated with 30 mm of water which enables intensive decomposition of the manure. The process of decomposition is considered to be finished when the temperature starts decreasing down to 25°C. In Macedonia's climatic conditions (summer time) it takes two to three weeks to complete this procedure.

This treatment raises the soil temperature to 45–50°C for long periods in Macedonian conditions. While the organic matter is decomposing, the temperature can be even higher, up to 70°C, depending on the outside temperature and the amount of organic matter. The more intensive the decomposition, the higher the temperatures obtained and the shorter the period of solarisation that is needed (two to three weeks).

The type of organic matter is very important. Cow manure can contain weed seeds that

Plastic sheets laid on soil during solarisation treatment

Volkmar Hasse GTZ

require relatively high temperatures during the biofumigation + solarisation treatment. So it may be preferable to use other organic materials that release isothiocyanates, such as plant residues from the cabbage family. Both sheep manure and cabbage family residues were found to give better results than cow manure with respect to weeds.

Performance and yields

Growers find solarisation + biofumigation very acceptable because it gives good pest control, is relatively easy to handle, and provides fertiliser. The successful results on farms have been corroborated by controlled trials. A demonstration project funded by the Multilateral Fund (implemented by the Faculty of Agriculture in Skopje and UNIDO) compared MB, solarisation + biofumigation (cow manure + straw applied at about 5–7 kg/m^2 as described above) and dazomet. All treatments reduced the indicator pathogen *Fusarium* to acceptable levels. Similar results were obtained on root knot nematodes (Table 3). The heat of solarisation controls most pathogens in the upper 20 cm of soil.

Technical know-how is required in selecting appropriate types of organic matter because their effects on pests will differ greatly according to the soil type and other conditions.

In the comparative trials, solarisation + biofumigation (cow manure as described above) gave tomato yields of 126 t/ha, which was by far the highest of the three treatments. The control gave the lowest yield of 101 t/ha. In the trials where cucumber was grown as the second vegetable crop, solarisation + biofumigation again gave the highest yield of 235 t/ha. The results are shown in Table 4.

Costs and profitability

In the tomato sector, MB is the most expensive method. The total production costs using MB are $ 65,280 per ha, compared to $ 59,514 per ha for solarisation + biofumigation with cow manure. Likewise, MB is less profitable, giving gross profits of only $ 48,720 per ha compared to $ 66,486 per ha from solarisation + biofumigation (Table 5). The market price of tomatoes was the same for all treatments (about

Table 3. **Effect of treatments on root knot nematodes in tomato and cucumber. Total nematode density per m^2 of soil**

Time of sampling	Control	MB	Dazomet	Solarisation + biofumigation
Tomato				
Before treatment	79,848	55,213	59,824	62,384
After treatment	155,487	3,359	6,686	8,900
During growth	175,763	6,422	7,727	9,132
Cucumber				
Before treatment	64,212	58,712	61,236	63,520
After treatment	68,427	6,595	4,434	3,255
During growth	69,276	7,843	8,721	5,515

Table 4. **Yield of greenhouse tomato and cucumber**

	Average yield (t/ha)	
Treatment	Tomato	Cucumber
Control	101.4	158.8
MB 50 g/m^2	114.0	202.0
Solarisation + biofumigation (about 5 kg/m^2 cow manure + straw)	126.0	235.6
Dazomet 50 g/m^2	113.0	222.2

Table 5. **Cost of production and gross profit in greenhouse tomato. Yields are shown in Table 4**

Treatment	Total production cost (US$/ha)	Gross income (US$/ha)	Gross profit (US$/ha)
Control	58,350	101,400	43,050
MB 50 g/m^2	65,280	114,000	48,720
Solarisation + biofumigation (about 5 kg/m^2 cow manure + straw)	59,514	126,000	66,486
Dazomet 50 g/m^2	62,148	113,000	50,852

$ 1 per kg). The increased profitability of the alternative is largely due to its higher yield, and partly due to its lower production cost.

For cucumber, the total production costs using MB are about $ 42,250 per ha, while production costs for solarisation + biofumigation (cow manure) are about $ 41,520 per ha. As with tomato, in cucumber production MB gives a lower gross profit than alternatives. The gross profits using MB were found to be $ 78,952 per ha compared to $ 99,844 per ha when using solarisation + biofumigation (Table 6). The market price was about $ 0.60 per kg. As before, the higher profit from solarisation + biofumigation is largely due to its higher yield.

The only capital or set-up costs for both MB and solarisation + biofumigation are the plastic sheets which are used for 2–3 years. The operating or recurrent costs for tomato are given in Table 7, while costs for cucumber are shown in Table 8.

Acceptability to regulators and markets

Solarisation and biofumigation do not require regulatory approval. The vegetable products are very acceptable to markets and consumers.

Applicability to other regions

Biofumigation with solarisation can be used in regions that have sufficient sunshine hours and temperature in the treatment period prior to planting, as well as a large local supply of suitable organic waste material. Biofumigation with solarisation is used for the commercial production of greenhouse pepper on more than 40 ha in Spain (López *et al.* 2002), and for the production of tomato and melon in Uruguay (de Léon 2002).

***Table 6.* Cost of production and gross profit in greenhouse cucumber. Yields are shown in Table 4. Application rates are shown in Table 5**

Treatment	Total production cost (US$/ha)	Gross income (US$/ha)	Gross profit (US$/ha)
Control	39,023	95,280	56,257
MB	42,248	121,200	78,952
Solarisation + biofumigation (cow manure)	41,516	141,360	99,844
Dazomet	42,972	133,320	90,348

***Table 7.* Operating costs of tomato production**

Item	Cost of MB system (US$/ha)	Cost of solarisation + biofumigation system (US$/ha)
Plastic sheets (a)	836 (= 2508 x 2/6)	836 (= 2508 x 2/6)
Fumigant chemical	7,000	0
Organic matter	5,351 manure	7,015 manure + fresh cow manure
Other items which differ	1,570 fungicide + insecticide	0
All other materials (b)	36,591	36,591
Labour and contracted services	11,361	12,237
Total cost	**62,709**	**56,679**

(a) Sheets are used for 2–3 years.
(b) All other recurrent costs, including seed, manure, fertiliser, chemicals, fuel.

***Table 8.* Operating costs of cucumber production**

Item	Cost of MB system (US$/ha)	Cost of solarisation + biofumigation system (US$/ha)
Plastic sheets (a)	836 (= 2508 x 2/6)	836 (= 2508 x 2/6)
Fumigant chemical	7,000	0
Organic matter	2,778 manure	4,422 manure + fresh manure
Other items which differ	6.9 straw	94.4 tilt
All other materials (b)	22,751	22,751
Labour and contacted services	8,101	10,945
Total operating cost	**41,473**	**39,069**

(a) Sheets are used for 2–3 years.
(b) All other recurrent costs including seed, manure, fertiliser, chemicals, fuel.

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Case Study 3

Floating seedtrays for tobacco seedlings

SUMMARY

Crop/use: Tobacco seedbeds

Country: Croatia

Pests: Nematodes such as *Aphelenchoides*, *Ditylenchus*, *Meloidogyne*, fungi such as *Pythium*, *Rhizoctonia*, weeds and soil-borne insects

Alternative: Substrates in floating seedtrays

Yields: Higher yield of seedlings than MB system

Costs: Higher investment cost

Regulatory approval: None required

Comments: Increasingly adopted in many countries

Examples of use in other CEIT countries: Tobacco seedbeds in Macedonia and Hungary

Examples of use in other regions: The float system is being adopted for tobacco in many countries, such as Argentina, Australia, China, Cuba, Brazil, Malawi, Spain and Zimbabwe

Economic significance

Tobacco is economically important in Croatia. More than 10,000 t tobacco leaves are produced each year. About 8% of tobacco leaves and 48% of tobacco products are exported to industrialised countries. Growing tobacco provides direct employment for more than 2,000 farming families in Croatia.

Climate

The tobacco-growing regions are found mainly in northern Croatia, in areas such as Podravina and Slavonija. Climate and soil type are very important for tobacco production, affecting both yield and quality. The climate in the tobacco production areas of Croatia is moderate continental. In recent years the annual precipitation was found to be about 708 mm average, although it fluctuates substantially. The average annual air temperature was 10 or 11°C. Frost can be found in most months, except May to September. Soil types in tobacco seedbeds include loam, sandy loam and silty loam.

Crop production characteristics

The main type of tobacco is Virginia for flue-cured tobacco. Tobacco is grown on about 6,500 ha, including about 52 ha for the production of tobacco seedlings. In northern Croatia around 2,000 farmers are involved in tobacco production. The average size of the family farms is about 3.5 ha.

The preparation of tobacco beds normally starts in March, transplanting is in May, and the harvest is completed in September. Tobacco is often produced in rotation with another crop such as winter wheat. However, on smaller farms it is produced in monoculture, leading to a higher incidence of viruses such as tobacco mosaic virus (TMV) and the development of *Orobanche* spp., a parasitic weed.

Use of methyl bromide

MB has been used in Croatia for more than forty years. Producers of tobacco seedlings in Croatia used about 30 t MB in 1998 before work was done to identify suitable alternatives. Today MB is being reduced steadily and will decrease to zero by 2005. MB is imported mainly from the USA and Israel. MB is normally applied to well-prepared seedbeds, at the rate of 45.5 g/m^2. The soil is covered with a plastic sheet and the MB fumigation is completed in approximately 48 hours. The sheet remains on the soil for about seven days to raise the soil temperature before seeds are planted.

Tobacco seedling production in floating trays, Croatia

Zagreb Tobacco Institute

Case Study 3

FLOATING SEEDTRAYS FOR TOBACCO SEEDLINGS

The main pest problems in tobacco seedling production are:

- Nematodes such as *Aphelenchoides*, *Ditylenchus*, *Meloidogyne*
- Fungi such as *Pythium*, *Rhizoctonia*
- Weeds
- Soil-borne insects

Commercial use of alternative – substrates in floating trays

MB alternatives, primarily floating trays, are now used commercially in several regions. In 2001 about 20% of the tobacco seedlings were produced in floating trays systems. Floating trays are expected to be adopted as the major alternative for tobacco, allowing Croatia to meet its commitment to phase-out MB under the Montreal Protocol.

Alternative technique

The floating tray system avoids the need for soil fumigation by using clean substrates (also called growing media) placed in seedtrays. Substrates can either be made from materials that are inherently free from pests, or they can be treated with solarisation or steam to kill pests. In Croatia, tobacco producers started using a commercial mixture of peat and perlite or vermiculite. Other substrate materials can be used, provided they allow appropriate proportions of water, nutrients and air for the roots of tobacco seedlings.

When setting up the floating tray system, farmers level the seedbed area and build sides to make a small shallow pool (approx. 0.15 m high x 0.92 m wide x 10.35 m long). The pool base and sides are covered with a double black plastic sheet, and it is filled with water to a depth of 0.12 m. Fertilisers (1.2 litres of N-P-K-Mg (10:5:10:2) and micronutrients) are added as well as potassium permanganate to prevent the development of algae. Substrates are placed in seedtrays with 209 cells, and pelleted seeds are sown. Sixty trays are then placed in each pool, and covered with thermo selective sheets.

Good aeration is necessary for the plastic tunnels during germination and seedling development. The electro-conductivity (EC) of the water is monitored regularly to determine how much fertiliser should be added. The seedlings are clipped several times before being transplanted to the fields.

Yield and performance of alternative

Farmers have found that the floating tray system produces the most uniform seedlings, and the highest percentage of useful seedlings. These results have also been confirmed in trials which compared MB and the float system in Croatia in a project funded by the Multilateral Fund and implemented by the Tobacco Institute of Zagreb and UNIDO. When seedlings produced in the float system are planted out in the field, they recover faster than MB seedlings. This is because the plug of substrate around the root protects it from dehydration stress. In some recent seasons the weather in Croatia has been drier than normal and it was found that the float tray system provided a significant advantage over MB-produced seedlings in these dry years.

Table 1. **Yield of harvested tobacco leaf from float tray seedlings and MB seedlings, eight locations 1999–2000**

	Yield of tobacco leaves (kg/ha)	
Control	**MB**	**Floating tray (peat/ vermiculite substrate)**
1,630	2,050	2,296
1,710	2,021	2,295
1,480	1,960	2,208
1,430	1,680	1,930
1,670	1,730	1,863
1,760	1,810	1,960
1,730	1,690	2,030
1,360	1,480	1,603
1,596 average	**1,803 average**	**2,023 average**

Table 2. **Quality index of tobacco leaves at harvest**

Quality index	Control	MB	Float tray system (peat/vermiculite substrate)
Range		118 –121	124 – 126
Average	100	120	125

The float system uses less land than MB seedbeds: 25 m^2 of float tray beds will produce as many seedlings as 60 m^2 of MB seedbeds.

At harvest the yield of tobacco leaves from float tray seedlings is higher than MB seedlings. Comparative trials on six locations (five commercial farms and the tobacco research institute) found that seedlings from float tray systems produced a final harvest of about 2,020 kg/ha compared to only 1,800 kg/ha from MB seedlings (average figures from Table 1). Tobacco leaves grown from float tray seedlings are also of better quality, being longer and wider than tobacco leaves grown from normal MB seedlings. Table 2 shows the quality index of harvested tobacco leaves.

Acceptability to regulators and markets

The float tray system does not require regulatory approval. Tobacco produced from float tray seedlings is more acceptable to markets because it is of higher quality.

Costs and profitability

The cost of the float system is higher than MB but it brings other commercial advantages, such as a smaller seedbed area and a higher grade of tobacco leaf. The set-up cost of the float system is about $ 246 for sufficient seedbed area to produce seedlings for 1 ha of final crop. However in the second and third year the tobacco float system is slightly cheaper than MB. Typically, the operating cost of the float system is about $ 184 per ha of final crop compared to $ 180 for MB. The seed trays for the float system need to be replaced from time to time, so the production cost increases to about $ 200 every 4–5 years or so, before falling back to the normal level. Therefore the average annual cost over 3 years (including set-up costs) is about $ 200 for the float system and about $ 186 for MB per hectare of tobacco crop.

Applicability to other regions

The float tray system is suitable for virtually all tobacco growing regions. In areas where night temperatures are very low during the seedbed stage, the float system needs additional insulation to keep the pool temperature moderate. The float system is being adopted as the main MB alternative in many tobacco growing regions of the world, including Argentina, Brazil, China, Cuba, Malawi and Zimbabwe.

***Table 3*. Cost of producing seedlings for one hectare of tobacco crop**

Inputs	MB (US$ per 60 m^2)	Float tray system (US$ per 25 m^2)
Capital and set-up costs:		
Metal arches for seedbed cover	22.70	9.46
Construction of pool	0	30.26
Black polyethylene sheets	0	22.70
Seed trays	0	21.79
Seeder	0	6.05
Operating costs:		
Methyl bromide	17.40	0
Seed	39.72	25.22
Polyethylene sheet	30.26	12.61
Substrate	0	45.90
Fungicide	6.56	6.56
Insecticide	2.27	2.27
Fertilizer	5.30	13.87
Water analysis	0	6.31
Labour	79.00	42.88
Total in year 1	203.21	245.88
Total in year 2	180.51	178.32 (a)
Total in year 3	180.51	178.32 (a)
Total in year 4	180.51	200.11 (a,b)
Average for 4 years (c)	186.19	200.67

(a) Replacement of black plastic every year
(b) Assumes replacement of seedtrays every 4th year
(c) Including initial investment cost
(d) Currency conversion rate: 1 Croatian kuna HRn = US$ 0.126

Case Study 3

FLOATING SEEDTRAYS FOR TOBACCO SEEDLINGS

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Case Study 4

Integrated fruit production for strawberries

SUMMARY

Crop/use: Strawberries grown in open fields
Country: Poland
Pests: Strawberry root weevil, European cockchafer, wireworms, root lesion nematode, Verticillium wilt, crown rot
Alternative: Integrated Fruit Production (IFP)
Yields: IFP gives yields much higher than the average in Poland
Costs: IFP cost is much lower than using MB
Regulatory approval: This IFP system does not require regulatory approval because it uses pesticides that are already approved
Comments: IFP is used on a small scale at present, and is increasing
Examples of use in other CEIT countries: No significant examples
Examples of use in other regions: Italy, Germany, Switzerland, Belgium and other countries. IFP is also used in temperate climates for apples, pears and stone fruits, blackcurrants and raspberries

Economic significance

Strawberry production and marketing has been of great importance in Poland for many years. About 200,000 t strawberries are currently produced on an area of about 50,000 ha. About 60% of the fruit is exported, primarily to Germany. While some fruit are sold fresh, the majority of strawberries are frozen or processed. In total about 75% of strawberries produced in Poland are frozen, accounting for about 21% of the worldwide supply of frozen strawberries. However, the processed fruit sector has suffered low prices in the last two years so more farmers are now growing strawberries for the fresh fruit market.

Climate

Strawberry production is dispersed all over Poland but is concentrated in the central area. The climate in this part of the country is temperate. The mean temperature is -3.5°C in January and 18.5°C in July. Annual precipitation is 500–600 mm and the prevailing winds come from the west. The soil is moderately fertile (mainly in the fertility classes III – IV on a scale where I is most fertile and VI is least fertile).

Production characteristics

Strawberry production has a long history in Poland. Berries were traditionally produced in the open field as part of a crop rotation with cereals, seed rape, root crops, some legumes (on light soils) and potatoes. The main cultivar is Senga Sengana, which is most suitable for processing and relatively tolerant of soil-borne pathogens in Polish conditions. It is also frost resistant. The most common planting time is September and the first part of October or early spring. For this reason the yield is zero or very low during the first growing season. Beds are maintained for several years, typically 3–4 years, giving 2 or 3 fruit crops in total. Recently the fruit quality and marketable yield have been improved by irrigation and laying straw between the rows.

In the past, the average quality and yield was usually low. However, strawberry production was more profitable than other agricultural crops, particularly on light sandy soils. But the situation has changed dramatically in the last two years because strawberries for processing received low prices. So growers have increasingly turned to production of strawberries for the fresh market because it gives a higher income. But the production of fresh fruit requires more inputs and effort, and the suitable cultivars (eg. Elsanta, Kent) are more susceptible to soil-borne pathogens than cultivars for processed fruit. So this change has placed more pressure on growers to control soil-borne pests.

Use of methyl bromide

Soil fumigants including MB were never used in commercial strawberry production in Poland in the past because of the very high cost of fumigants in relation to other production costs and fruit prices. However, recently MB has been adopted in strawberry fruit production. It has also been adopted in strawberry plant (runner) propagation on an area of about 68 ha at the request of Spanish importers of runner plantlets. MB is typically applied at the rate of about 600 kg/ha, each time before planting.

Strawberry producers face a wide spectrum of soil-borne pests:

- Root lesion nematode (*Pratylenchus penetrans*) which feeds on the roots and destroys critical plant tissue. It is the main cause of strawberry black root rot.

Strawberry production using integrated pest management in Poland

Adam Szczygiel

- Needle and dagger nematodes (*Longidorus* spp. and *Xiphinema* spp.) which stunt root growth and can act as vector for viruses.
- Fungal pathogens such as verticillium wilt (*Verticillium dahliae*, *V. alboatrum*), crown rot (*Phytophthora cactorum*), *Phytophthora fragariae* and *Colletotrichum acutatum*.
- Wireworms, strawberry root weevil (*Othiorhynchus ovatus*), larvae of European cockchafer (*Melolontha melolontha*) and larvae of click beetles (particularly *Agriotes linealus*).

Commercial use of alternative – Integrated fruit production

In Poland the most useful and effective alternative to MB and other fumigants is Integrated Fruit Production (IFP). The programme is based on guidelines prepared for soft fruits in Europe by the Joint Group for Integrated Fruit Production Guidelines of the International Organisation for Biological Control (IOBC/WPRS) and International Society for Horticultural Science (ISHS). This programme combines biological, cultural, physical, mechanical and some chemical methods, and does not use soil fumigants such as MB or metam sodium. Strawberry production using IFP can be certified, thus enabling better marketing.

In Poland, IFP was started in strawberry in 1996 on an experimental scale. In 2001 IFP was used commercially on about 240 ha, producing about 2,895 t of certified fruits.

There are about 65 IFP strawberry producers organised in six groups, located in different parts of the country but mainly in the central region. They produce fruits primarily for the fresh domestic market. The key varieties are Honeyoe, Elkat, Dukat and Kent. One IFP group produces certified fruits of Senga Sengana for processing and export.

Most fruits are harvested in the standard open field production period of June and July. Small amounts are produced under plastic covers for earlier picking. Only a few producers try to obtain a delayed crop, either from 'frigo' plants or from day neutral cultivars (Selva).

Alternative technique

Key elements of the IFP programme include:

- Crop rotation and planting of appropriate crops prior to planting strawberries
- Application of animal manure and sometimes green manure
- Use of healthy plantlets free of pests and diseases

The standard planting time is September, but in the event of a cold autumn or early winter, planting may be delayed to spring of the following year. Runner plantlets always come from the farm's own propagating field established with certified 'elite' plants (see description below). The strawberry plants stay in the ground usually for two, or occasionally for three, full crops.

After a strawberry crop is removed, strawberries are not re-planted in the same field for at least 3 years. During this period cereals are commonly grown, and other agricultural crops such as beet, seed rape or certain annual legumes, alone or mixed with cereals. The crop that directly precedes strawberries is always cereal or mustard. The latter has pest-suppressive properties and can be used as green manure after chopping and ploughing. The main nutrients are provided by animal manure applied some months before planting the strawberries. An analysis of nutrient levels in the soil is always made before planting, and if results indicate it is necessary, some additional nutrients are applied.

Nematodes populations are controlled by a well-selected crop rotation: cereals, seed rape, mustard or *Tagetes*, a type of marigold. Tagetes spp. can reduce nematode populations to non-harmful levels after about four months and can then be used as green manure (chopped and ploughed into the soil). No chemical treatments are necessary against Verticillium wilt and crown rot. Key fungal pathogens, particularly *Verticillium* spp., *Phytophthora* spp. and *Colletotrichum* spp. can be spread by infected runner plantlets, so healthy and disease-free planting material is of prime importance and a standard requirement in IFP.

The plantlets are obtained according to the following scheme approved in Poland. The starting material is obtained by micro-propagation from tested virus-free plants which, after reproduction in the field, give 'super-elite' strawberry plantlets. Super-elite plantlets are then used for producing 'elite' plantlets. These can be used for establishing fruiting plantations or for single reproduction to produce normal certified plantlets. Super-elite propagation fields are certified by a committee appointed by the Ministry of Agriculture, while propagation fields of elite and normal plantlets are certified by regional committees. Soil-less culture of strawberry runners has been introduced recently in Poland with good results.

Some weeks before planting, the perennial weeds are controlled if necessary with systemic herbicides such as Roundup or others (glyphosates). To protect strawberries from injury by some soil-borne arthropods, the IFP programme recommends avoiding planting the crop in infested fields. Alternatively, if any problem species are detected, growers can apply certain insecticides such as chlorpyrifos or diazinon before planting. In the IFP programme the use of pesticides is avoided wherever possible. Pesticides can only be used if pest monitoring or analysis shows that it is necessary. They are applied at the lowest effective doses.

Most of the IFP farms are certified, because this helps the farmers to sell fruits more easily or even to get higher prices. Producers who want certification are obliged to follow very closely the principles and recommendations of the IFP system based on guidelines prepared by the Joint Group of IOBC/WPRS and ISHS (1999), adapted to Polish conditions and described in detail by Bielenin *et al.* (1995).

During the first two years of establishing IFP production, groups are trained and advised closely by specialists of the Advisory Service. Monitoring for pests and diseases is carried out usually every two or three weeks over two seasons but it depends on the kind of pests and diseases. Later when farmers are trained and experienced they make all the pest observations themselves, recording them in a special notebook which is checked by the committees that provide certification. At that stage the Advisory Service gives assistance only when needed.

Yield and performance of IFP

Open field strawberries give relatively low yields in Poland due to the cold climate. In addition the first year gives no production, reducing the average. The average strawberry yield in Poland is about 4–5 t/ha per year, but it is at least double (10–12 t/ha) in fields where IFP is used. The IFP system produces high quality fruit, and is profitable. Marketing is easier, and prices can be higher in some cases. In addition, the IFP system uses lower levels of pesticides and fertiliser, so reducing the environmental impact.

The price for fresh strawberries from the IFP system was on average $ 0.5 per kg when harvested at the usual time, and more than $ 1.0 per kg when produced under plastic sheets and harvested about two weeks earlier than normal. Prices of conventional strawberry fruit can be similar if they have a high standard of appearance. However, it is generally easier to sell IFP fruit, and demand for such fruit is increasing.

Costs

The costs of establishing and maintaining an IFP crop is shown in Tables 1 and 2. This example comes from a producers' group called Sanniki in the northern part of central Poland. The group consists of 19 producers with a total strawberry production area of 25 ha. The size of planted areas varies from 0.7 up to 5.5 ha. The mean annual yield in this group is 11.6 t/ha. The cost of establishing the IFP strawberry crop is about $ 2,750 per ha. The subsequent operating cost in one year is about $ 4,582 per ha on average.

Acceptability to regulators and markets

IFP does not require regulatory approval. Consumers in Germany and other markets like to buy strawberry fruit from IFP farms because they prefer fruit grown with fewer pesticides. Knowledge of IFP technology and its positive effect on fruit quality is increasing slowly among consumers in Poland.

Applicability to other regions

IFP in the form described above can be used almost anywhere in Poland, and also in neighbouring countries which have temperate climates. IFP programmes for strawberries have been introduced in Germany, Switzerland, Italy, Belgium and other countries. IFP is also used in temperate climates for apples, pears and stone fruits, blackcurrants and raspberries.

***Table 1.* Cost of establishing one hectare of IFP strawberry crop**

Items	Set-up costs (US$/ha)	Percent of total
Plantlets	2,000	72.7%
Fertilisers	135	4.9%
Herbicides	35	1.3%
Use of machines (tractors)	380	13.8%
Contracted workers	200	7.3%
Total	**2,750**	**100%**

***Table 2.* Cost of maintaining one hectare of IFP fruiting strawberry crop for one year**

Item	Operating cost (US$/ha)	Percent of total
Establishing crop (1/3 of the total cost from table 1)	917	20.0%
Fertilisers	100	2.2%
Pesticides and herbicides	425	9.2%
Containers	900	19.9%
Plastic sheets for covering plants	485	10.5%
Straw	75	1.6%
Contract workers for maintaining crop	450	9.8%
Use of tractor	210	4.6%
Contract workers for picking fruit	1,020	22.2%
Total	**4,582**	**100%**

Case Study 4

INTEGRATED FRUIT PRODUCTION FOR STRAWBERRIES

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Case Study 5

IPM systems in food processing facilities

SUMMARY

Crop/use:	Food processing plants
Country:	USA
Pests:	Stored product pests, flying insects, ants, rats, mice
Alternative:	Integrated pest management (IPM) system based on pest monitoring, inspection, regular cleaning, re-design to exclude pests, spot treatments with heat or low-toxicity pesticides
Performance:	More effective long-term results than MB
Costs:	Cost-effective
Regulatory approval:	IPM systems often use technologies that do not require regulatory approval. If pesticide treatments are necessary, they can use pesticides that are already registered.
Comments:	Increasing consumer concern about toxic pesticides is leading more food companies to adopt IPM
Examples of use in CEIT countries:	No known use of this IPM system. However, some parts of the system, such as cleaning, inspection and use of less toxic chemicals, are used in many CEIT countries
Examples of use in other countries:	Australia, Canada, Denmark, UK, USA, Brazil, Argentina, Mexico, Japan and SE Asia

Economic significance

The processing and storage of food and feed is an important aspect of the food chain, and often has a high economic value.

Climate

The climate found within food processing factories and facilities is frequently warm and moist, providing ideal conditions for insects and other pests to multiply. They are shielded from the harsher conditions of the exterior climate.

Use of methyl bromide

MB is often used for pest control in food processing plants and flour mills because the gas is able to penetrate into difficult-to-reach parts of equipment and crevices in the building or floors. MB fumigation is also relatively rapid so it minimises the time for which a plant must be shut down, losing valuable production time. The typical MB application rate for food processing facilities in the USA is about 16–24 g/m^3, depending on pests, temperature, commodity and air pressure.

Many pest species can cause problems in food processing plants. Examples include:

- Beetles such as warehouse beetle (*Trogoderma* spp.), rust-red grain beetle (*Cryptolestes* sp.), rust red flour beetle and confused flour beetle (*Tribolium* spp.) and saw-toothed grain beetle (*Oryzaephilus* sp.)
- Weevils such as granary weevil, rice weevil and maize weevil (*Sitophilus* spp.)
- Moths such as Indianmeal moth (*Plodia interpunctella*), tobacco moth and Mediterranean flour moth (*Ephestia* spp.)
- Ants
- Rats and mice
- Birds.

Eliminating and controlling pests within and around cereal and grain processing plants (including warehouses) is challenging. Incoming raw ingredients and thousands of different supplies can deliver pests to the facilities or warehouse. Additionally, the food odours, heat, moisture and shelter also attract insects, rodents and birds in the locality of the processing plant. Commercial food plants are usually well lit at night, attracting still more flying and crawling insects.

Commercial use of alternatives – Integrated Pest Management

In the USA a number of grain mills and food processing plants avoid the use of MB, making use of the following techniques instead:

- Heat treatments + integrated pest management (IPM), or
- Fumigation with phosphine + carbon dioxide + raised temperature,
- IPM systems strongly based on inspection, pest prevention and localised treatments.

As an illustration of the latter, this case study focuses on a food plant which makes cereal based products in the midwest USA. It mills and processes raw grains and similar durable food ingredients, producing a range of packaged goods. The factory size is about 27,870 m^2. It receives 8–10 different grain products in bulk via rail and trailer-car shipments, and receives many minor ingredients, flavourings, salts and sugars in various sizes of bags and totes. The plant has approximately 10 grain elevators and storage silos for each of the raw bulk grains and flour. It also has a warehouse on the premises for storing finished goods and shipping.

Case Study 5

IPM SYSTEMS IN FOOD PROCESSING FACILITIES

Frequent cleaning, part of the integrated pest management programme in a large food processing facility

Robert Corrigan

Alternative technique

IPM programmes in the food industry need to be based on a solid foundation of 'Good Manufacturing Practice' (GMP), with emphasis on cleaning, making structures pest-proof to exclude pests, monitoring and inspection programmes. Data from inspection and monitoring form the basis of decision-making. For food plants in particular, emphasis is placed on the non-chemical practices of pest exclusion and plant sanitation because these methods address consumer concerns about pesticides. These methods have been found to produce good long term, cost-effective results. Low-impact pesticides and trapping programmes are used for controlling or eliminating any pests that, despite non-chemical efforts, may manage to enter or exist within or around the plant.

In addition to general pest control, US food producers have to meet standards (called filth standards) that limit the quantity of insect fragments, rodent hairs etc. allowed in products such as flour. In the European region producers often have to implement HACCP and 'due diligence' programmes. IPM systems such as the one described below enable food facilities to achieve high standards of pest control.

In this processing plant, the pest management programme is carried out partly by in-house staff and partly by a local contracted pest management company. A contracted pest management professional visits the site twice each month. Parts of the plant are shut down each week for cleaning (Friday night to Sunday afternoon). For pest control purposes the complete plant is shut down twice a year for total cleaning of all areas.

The components of the IPM programme for this processing plant are as follows:

a) Pest inspections
b) Pest monitoring
c) Pest exclusion
d) Cleaning programme
e) Non-chemical pest management
f) Tactical use of chemical pesticides when necessary
g) Insecticide fogging
h) Exterior perimeter treatments

a) Pest inspection

Pest management inspections are intended to uncover problems that might cause or permit contamination of food items by pests. Where possible the plant and equipment are re-designed or changed to discourage pests and allow easier access for inspectors. The grain processing plant utilises a three fold approach for pest management inspections: (i) daily, weekly, and monthly in-house inspections by quality assurance managers and staff; (ii) outside consultants and/or inspection service companies (eg. accredited personnel of American Institute of Baking); and (iii) inspection and recommendations by a contracted pest management professional.

Inspection procedures follow inspection guidelines such as those provided by the American Institute of Baking (2001). All interior and exterior areas are inspected visually, from the incoming raw ingredients to the shipping of finished products. Check-off sheets list each separate room and area of the plant and warehouse to prevent any area from being overlooked. A general floor level inspection is made of all areas, using a flashlight and tools to access factory equipment. The following areas are given special attention:

- Hard-to-reach areas. When an area is difficult to clean, food residues and various types of debris tend to accumulate, so pests often proliferate in these areas.
- Areas of previous equipment malfunction. Processing equipment malfunction, blowouts, back-ups, spillovers, and various other types of processing malfunction typically result in food accumulation in various nooks and crannies and structural voids in buildings or equipment.
- Previously infested areas. Pests repeatedly seek out the same harbourages and micro-environments because they provide ideal cover, and/or the best temperature, moisture, and food for the pests to breed. A pest activity log book (i.e. pest history) records all the *specific locations* of all previous and new pest activity, to assist in ensuring these areas are managed and re-inspected regularly.

b) Pest monitoring

The monitoring programme provides an early detection system for any newly-introduced pests, an opportunity to identify the pest species and pinpoint the location of the infestation. Two types of monitoring programmes are used in the processing plant:

- General pest monitoring; and
- Pheromone trap monitoring for stored product (grain) pests.

General pest monitoring: General pest monitoring is accomplished using floor-level sticky traps designed to simply capture any insects that crawl or land on the sticky surfaces. The sticky boards are installed within protective plastic boxes and inserted in multiple-catch mouse traps. The monitor traps are located in places subject to pest activity such as near doorways, near clutter, and within or near various nooks that tend to collect food from processing operations. Insect electrocution light traps, (ILTs) serve as monitoring tools for various flying insects.

Pheromone traps / biomonitoring for grain pests: Pheromone traps for Indianmeal moth and warehouse beetle are installed at densities that provide general monitoring (one trap per 850–2830 m^3 depending on the area). Occasionally, pheromone traps are used to ‘zero in’ on possible infestation sites, and/or for mass trapping programmes (at rates of one trap per 85–283 m^3).

The location of all traps (including monitoring traps, pheromone traps, mouse traps and exterior bait stations) is drawn on a plan. Each trap is numbered and dated, and corresponding records maintained for the trap monitoring. Detailed records of pest species and numbers are made during inspections. Data are analysed according to monthly, quarterly, and annual trends and pest management decisions are made accordingly. This might result in intensive cleaning of certain equipment, for example.

c) Pest exclusion

Physical aspects of the facility are changed to exclude pests by installing closures or screens to windows and entry points, closing up holes and gaps in the walls and fabric of the building, and making other changes to the plant to eliminate pest access and harbourages. Air doors and rodent barriers may also be used in some cases. While it is highly desirable to deny entry to all pests, this goal is not feasible in practice. Therefore, the aim is to keep as low as possible the numbers of pests entering the plant on a daily basis. This is accomplished by a constant vigil of closing entries, scheduled inspections of all entry points, doors, vents, screens, fascia, roof and other vulnerable areas. Also, employees are reminded repeatedly at meetings and during daily inspections about the importance of keeping doors closed when not in use.

d) Cleaning programme

In addition to food, most pests require protected, isolated areas and micro-habitats. The goal at the plant is to control or eliminate the pest’s resources in such areas by ‘micro-sanitation’ ie. thorough cleaning to limit or eliminate pest populations entirely. An important theme that is repeatedly encouraged among all plant employees is: *sanitation is pest control*.

Inside the plant, the small nooks, crannies and internal voids within the processing equipment and utility lines are very frequently inspected, disassembled and cleaned to remove accumulating food residues. Overhead areas such as utility lines, walls, windows, ceilings, structural beams, conduits and similar areas are kept free of food residues. Pest populations erupt periodically in these hard-to-reach areas if cleaning is overlooked or incomplete.

Inspection aisles of 40–60 cm width (also referred to as sanitation lines) have been created along all interior walls and between rows of pallets. These aisles are kept free from stored products and debris. The aisles provide access for inspections, cleaning up spilled food, repairs to damaged walls or equipment, for installing rodent traps and, if necessary, for applying spot or crevice applications of pesticides. The perimeter wall inspection aisles are painted white and well lit from above to assist in detecting pests.

In the exterior areas, vegetation is regulated to avoid attracting or harbouring pests. All lawns surrounding the food facility are mowed regularly and weeds and other uncontrolled plant growth are not permitted close to the exterior walls. All trees and shrubbery are kept about 10 m away from the buildings. A vegetation-free, gravel perimeter 1 m wide around the buildings is maintained to discourage rodent and insect activity, as well as serving as an inspection pathway and area for installation of bait stations or other rodent control devices. Exterior debris (e.g. rubbish piles, empty containers, old machinery, construction materials) is not allowed to accumulate because clutter provides attractive harbourage sites for rodents, wildlife and insects.

e) Non-chemical pest management

Wherever possible, non-chemical methods are chosen in preference to chemical methods (pesticides), and non-chemical methods are used to supplement chemical approaches.

Rodent control: Rodent management at the plant comprises three lines of defence. The first line consists of exterior rodenticide bait (or trap) stations along the property fence (if one exists). The second defence consists of a line of bait or trap stations along the entire exterior perimeter wall of the plant. The third line consists of trap door multiple-catch mouse traps spaced at 7 m intervals, as well as traps flanking all doors leading to the exterior. Record keeping of all mouse trap activity, similar to the insect monitoring system, is maintained to evaluate the rodent control programme in the long term.

Flying insect control: Insect light traps are located in several areas around the interior of the plant where maximum fly activity is noted by employees and from inspections. In most cases, the light traps are placed within 4–5 m inside doorways. The centres of the traps are positioned 1–2 m off the floor to maximise the attraction of foraging filth flies. The bulbs of the traps are changed once each year in early spring to maintain the UV-output and remain attractive to pests.

f) Chemicals and pesticides

Because of the nature of food manufacturing, and the intense amount of pest pressure on many food processing plants, it is difficult to eliminate pests entirely without the occasional use of insecticides and rodenticides. Rodenticide baits are placed along outside fence lines due to the particularly damaging nature of rodent pests. Insecticide applications are not made on a ‘preventative’ calendar schedule. Inside the plant, pesticide applications are dictated by trap monitoring data, inspection results, and the history of specific pests in any particular area of the food plant. In other words, if inspections and monitoring data reveal no presence of pests, no insecticides are applied. Moreover, when insecticide applications are made, every attempt is made to direct the pesticides into the very specific locations where insects are hiding.

In this processing plant, the two most commonly employed insecticidal treatments are: (i) targeted ultra-low-volume (ULV) space treatments using non-residual chemicals; and (ii) exterior perimeter residual insecticidal treatments in areas exhibiting pest activity from any of the various common crawling insect pests such as ants, ground beetles and spiders.

g) Insecticide fogging

Space treatments of food plants with insecticides (also known as fogging) can be a useful, occasional supplement to an IPM programme. Fogging is occasionally used to knock down flies and reduce the reproductive potential of certain stored product pests, such as warehouse beetle, red flour beetle, merchant grain beetle and Indianmeal moth, at certain times of the year. But fogging is most effective when applied in a targeted manner into structural or equipment voids that are relatively inaccessible to cleaning personnel, and to hard-to-reach or inaccessible ledges within the plant until these areas can be properly cleaned.

It must be stressed that in this IPM system the fogging treatments are not ‘mini-fumigations’ but minor supplements to other much more effective components of the total IPM package. Insecticide fogs do not penetrate areas where air currents do not normally flow. Nor do fogs penetrate packages, equipment, walls, beneath slip-sheets, or between boxes and jutes stored close together. Fogging efforts do not control deeply hidden insect populations nor prevent outbreaks of important stored product pests if the essential elements of good sanitation are not maintained.

Deciding whether or not a food plant should receive a fogging treatment is entirely dictated by pheromone trap data and the results of detailed pest management inspections and specific pest occurrences. Fogging as a ‘preventative’ approach to general insect control provides little benefit or protection to a plant.

h) Exterior perimeter treatments

During the peak insect activity months of spring and summer, residual perimeter insecticide treatments are used very judiciously along outside and some inside walls to help suppress insect populations and their ingress into the facility. Only insecticides with low toxicity ratings are used. In most cases, micro-encapsulated (ME) pyrethroid insecticides are used to provide a residual killing effect for as long as 45–60 days after treatment.

Exterior perimeter wall treatments are applied using relatively low pressures (below 50 psi) using either hand held sprayers or backpack sprayers. Power sprayers are never used for foundation treatments due to the risk of pesticide drift.

If an expansion joint exists at the foundation wall and exterior slab, this crevice is treated using targeted crack and crevice applications (low pressures of 15 psi and less, using a pin stream nozzle opening directed into the expansion joint). This application requires more time than a higher-pressure fan treatment at the junction of the foundation wall and ground (ie. a 'band treatment'), but provides better pest elimination. Depending on the particular pest, both a band treatment and low-pressure crevice treatment of the expansion joint may be employed.

Several species of ants have become important pests of food plants. New ant baits are now available which are highly effective against many ant species found in commercial structures built on large slabs, such as pavement ants, fire ants and pharaoh ants.

Costs

The estimated cost of this IPM programme is about $ 80,000 per year in a processing facility of about 27,900 m^2 in size. Costs fluctuate from year to year depending on the need for occasional small phosphine fumigations for specific bins or trailer cars, or other special pest management operations.

If the same plant used MB once or twice per year the cost would be about $ 90.000 or 114,000 respectively in addition to the high cost of shutting the plant for several days.

Acceptability to regulators and markets

The pesticides used in this IPM system are registered products. Preference is given to products with very low toxicity. Consumers are increasingly concerned about the use of pesticides in processing and warehousing of all types of food. Many food facilities are reducing reliance on pesticides in response to consumer and regulatory pressures. IPM programmes which rely on monitoring, inspection, cleaning and non-chemical methods are very acceptable to the public.

Applicability to other regions

As the IPM approach provides a collection of management tools, rather than one method, IPM systems can be adapted to a wide range of climates, pests and facilities. IPM programmes of various kinds are used in food facilities from the humid tropics of Hawaii (Pierce 2000) to cool temperate areas of Scandinavia (Nielsen 2000). In the UK, for example, a large international snack food processing facility uses a cost-effective IPM system based largely on preventive cleaning and inspection as an alternative to MB (Raynaud 2002). IPM practices are increasingly demanded by supermarkets and food purchasing companies, so IPM has been adopted in certain food processing facilities in countries as diverse as Australia, Brazil, Italy, Japan, Malaysia and Mexico.

***Table 1.* Estimated annual cost of IPM system compared to MB fumigation in a US grain processing facility (size approx. 27,900 m^2) (a)**

Items	MB system (US$ per year)	IPM system (US$ per year)
MB contracted plant fumigation (1 fumigation per year) (b)	23,000 – 26,000	0
Trailer, rail car, bin spot fumigations as needed	8,000	8,000
Pheromone monitors (18 monitors)	720	720
Interior repeating mouse traps (65 traps) (c)	780 initial, 540 annual replacement	780 initial, 540 annual replacement
Exterior rodent bait stations (63 stations) (c)	820 initial, 160 annual replacement	820 initial, 160 annual replacement
Insect light trap installation (12)	2,700	2,700
Contracted pest management specialists	10,800	10,800
Pesticide fogging interior space treatments in warm weather (8 treatments)	2,600	0
Interior residual pesticide spot treatments and labor	1,800	630
Exterior residual applications in months when insects active (7)	395	395
Labour for monitoring, inspections, detailed cleaning	36,000	54,000
Total	**88,315 – 91,315**	**79,545**

(a) Costs can vary significantly from one region to another
(b) Assumes only 1 MB fumigation per year. Cost will double if plant carries out 2 MB fumigations per year.
(c) Includes initial installation and annual replacements

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Case Study 6

Nitrogen treatments for heritage items and archives

SUMMARY

Crop/use:	Museum collections, artefacts, archives and other heritage items of organic origin
Country:	Nitrogen is widely used for the control of pests in museum artefacts in Germany, including provinces of the former German Democratic Republic
Pests:	Furniture beetles, borers, powder post beetle, clothes moths, silverfish and many other pests
Alternative:	Nitrogen treatments
Performance:	Control of pests is as effective and complete as when MB is used
Costs:	Operating costs are often lower than MB because nitrogen needs fewer safety measures than MB
Regulatory approval:	Some countries (eg. Germany) require approval of nitrogen as a pest control agent, while others (eg. UK) do not require approval
Comments:	Nitrogen requires few safety precautions and safety costs compared to MB. Curators generally prefer nitrogen because it is inert and does not change or damage the artefacts
Examples of use in CEIT countries:	Treatment of icons in Romania
Examples of use in other regions:	Nitrogen is used in Australia, Germany, the UK and USA for control of museum pests. Nitrogen + IPM is used as a grain treatment in Australia

Economic significance

Museums, ancient buildings, national collections and archives hold many artefacts and historical treasures. These items are an important part of our rich cultural heritage and have substantial social, historical and scientific value. Many of the items are literally priceless because they are so rare or so old. They are generally made from organic materials such as wood, skin, fur, feathers, wool or paper. The maintenance and safe-keeping of this heritage is the task of curators and archivists. But insects like carpet beetles, powder post beetles, furniture beetles and clothes moths destroy these materials and pose a severe threat to historical artefacts. Museums and archives hold rare pieces which can be partially or completely destroyed if pest monitoring and control does not function adequately.

Climate

In warm and moist conditions insects tend to grow and multiply quickly. If the temperature increases from 20°C to 30°C the speed of development from egg to adult almost doubles, with corresponding consequences for the magnitude and extent of insect damage.

Use of methyl bromide

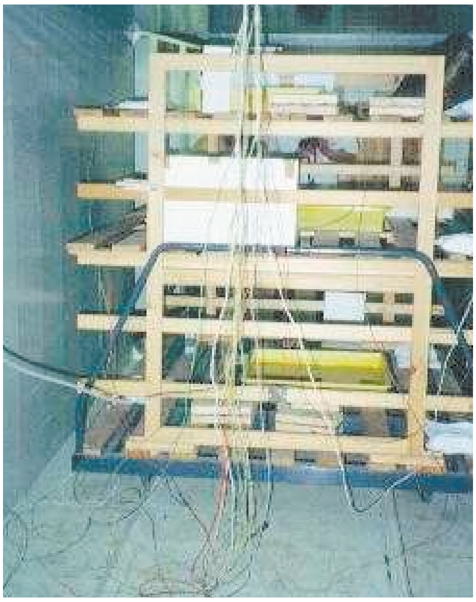
Until recently, nearly all museums in Germany and many other countries fumigated artefacts exclusively with MB or other toxic chemicals in gas-tight steel chambers to control the pests. Typical museum chambers in Germany have a volume of about 10 m^3 and are used weekly or about once a month. The application rate of MB is 50 g/m^3.

Commercial use of alternative – nitrogen

In a number of countries there is a strong tendency to change from MB fumigation to treatments with inert gases and other methods such as the following:

- Mixtures of more than 97 vol.-% nitrogen gas (the remainder is oxygen)
- More than 90 vol.-% carbon dioxide gas (remainder is oxygen and nitrogen)
- More than 98% argon gas (remainder is nitrogen)
- Heat treatment (more than 50°C) with controlled level of humidity (55% relative humidity)
- Solarisation (more than 50°C)
- Freezing (eg. -18°C, wrapped to hold humidity)

Nitrogen is one of the preferred options because this gas is totally inert and does not have adverse effects on the artefacts. Argon gas is also inert but has the disadvantage of being very expensive. MB can react with certain components of artefacts, causing damage.



Museum artefacts on racks undergoing nitrogen treatment in a fumigation chamber

Christoph Reichmuth

Case Study 6

NITROGEN TREATMENTS FOR HERITAGE ITEMS AND ARCHIVES

As a result, a number of museum fumigation chambers in Germany have been discarded and replaced by a nitrogen system called nitrogen flow fumigation. About 30 chambers installed in Germany can be used for controlled disinfestations using the nitrogen flow system as described by Reichmuth *et al*. 1994.

Alternative techniques

Normal air contains 21% oxygen which insects need to survive, like all animals. Nitrogen also forms a large proportion – 78% – of the air around us. The nitrogen flow technique replaces normal air, in a sealed chamber or container, with a very high proportion of nitrogen, leaving very little oxygen (down to about 0.1 vol.-% of oxygen). All the oxygen-dependent organisms like insects (beetles, moths, booklice, silverfish) and mites are damaged by the lack of oxygen and die within weeks, depending on the temperature and humidity. Permanent or diapausing stages of insects, mites and fungi may survive for longer periods but will eventually perish in the nitrogen atmosphere.

The nitrogen gas can be obtained from several sources:

(a) Steel cylinders of nitrogen gas purchased from a commercial supplier;
(b) Membrane apparatus which takes nitrogen from pressurised air by separating oxygen and nitrogen using semi- permeable membranes;
(c) Pressure swing absorption (psa) machines which take nitrogen from ambient air using sorptive chemicals in separating columns;
(d) For individually-wrapped artefacts where the airspace is small: sachets of oxygen absorber (made of iron + activator) which absorb and remove oxygen from the airspace, thereby providing a high-nitrogen atmosphere.

Various types of structures or containers are used for nitrogen treatments – the publications list at the end of the chapter provides several examples. Artefacts are commonly loaded into fixed, gas-tight chambers which are then filled with nitrogen gas. In other cases, the nitrogen treatment is carried out in fairly gastight re-usable containers made of flexible plastic or PVC, sometimes called 'bubbles' or 'cocoons'. These can be useful in situations where large artefacts cannot be transported to a fixed chamber, for example.

Another method involves wrapping artefacts individually in barrier plastic film – like the sheets used for wrapping vacuum-packaged meat and cheese in the food industry. (These sheets have an oxygen permeability of less than 6 ml/m^2/24hr/1atm.) Disinfestation in this case is achieved by sachets of iron + activator placed in the package, and afterwards the artefacts can be left wrapped for protection during long-term storage (Brokerhof 1998). Each method has certain advantages for particular situations.

In the nitrogen flow fumigation method, a gas-tight chamber is built from thin sheets of aluminium. The chamber size (volume) is in the range of 4, 12 or 16 m^3. The aluminium walls are stabilised by a frame made of 4 cm x 4 cm

***Table 1.* Examples of pest insects found in artefacts in museums**

Insect English Name	Latin Name	Infested material
Common furniture beetle	*Anobium punctatum*	Wood
House longhorn beetle	*Hylotrupes bajulus*	Wood
Powder post beetle	*Lyctus brunneus*	Wood
Carpet beetle	*Anthrenus* sp.	Fur, feathers, leather, carpets, wool, insect collections and seeds
Museum beetle	*Attagenus* spp.	Fur, wool, carpets, feathers and insect collections
(Common) clothes moth	*Tineola bisselliella*	Wool, carpets, fur
Silverfish	*Lepisma saccharina*	Books, pictures, paintings, drawings
Hide beetles	*Dermestes* spp.	Fur, carpets, pelts
Booklice, Psocids	*Liposceles divinatorius*, *Trogium pulsatorium*, *Lepinotus* spec., *Psyllipsocus ramburi*	Books, paintings, drawings
Tobacco beetle	*Lasioderma serricorne*	Artefacts of organic material of plant origin, except wood, like grain containing exponates
Drugstore beetle	*Stegobium paniceum*	Artefacts of organic material of plant origin, except wood, like grain containing exponates
Golden spider beetle	*Niptus hololeucus*	Seeds, wool, dead insects
Case-bearing clothes moth	*Tinea pellionella*	Wool, carpets, fur
Museum beetle	*Trogoderma angustum*	Collections of insects, dried plants, seeds

wooden struts. Artefacts are placed in the chamber and the door is sealed. The nitrogen flow fumigation is controlled by an electronic unit which carries out the following automated steps:

(a) The normal air in the chamber is pushed out (purged) by an influx of nitrogen gas, a process that takes about one week;
(b) The oxygen is maintained at a very low level of 0.1 vol.-% of oxygen for a further three weeks, by adding nitrogen gas into the chamber as necessary;
(c) Humidity inside the chamber is kept constant by humidifying (ie. adding water to) the nitrogen gas. A relative humidity of 55% throughout the treatment prevents artefacts being damaged by drying or cracking;
(d) In addition, the unit may contain a regulator for a heating unit which raises the chamber interior to a temperature in the range of 20–25°C, providing a shorter treatment time.

This system gives complete control of pests within four weeks or less for any artefact made of organic materials. The precise treatment time depends on various factors such as the time necessary for nitrogen to displace oxygen inside the artefact, so that thin items generally require less time than thick items. The time also varies according to the target pest species, life stages and temperature. In general, a raised temperature makes insects more sensitive to the lack of oxygen and reduces the necessary treatment time.

In warmer climates insect pests breed faster, but the warmth also has a positive aspect because the oxygen-deficient atmospheres act faster against insects. Lethal exposure times are therefore reduced, along with the cost of gas and electricity for the treatment.

Yield and performance of alternative

The nitrogen flow system controls pests as completely as MB, with the advantage of leaving no residues from the fumigant and causing no chemical damage to the artefacts. Curators generally prefer the nitrogen treatment because it is gentle and keeps the artefacts in the same condition and quality.

One disadvantage is the longer exposure period of up to 4 weeks, compared to 3 days for MB (at 20°C). However this is rarely a constraint in museums where artefacts are normally stored for long periods anyway. Longer treatment times can be accommodated by better management and earlier planning.

Licensed fumigators are required for MB treatments, whereas nitrogen treatments can be carried out by normal museum technicians. The safety precautions for nitrogen are considerably less onerous than for MB. Minor safety precautions must be taken to ensure that the air mixture always contains more than 17 vol.-% of oxygen in the room or location where the chamber stands and operators may work. If nitrogen diffuses out of the chamber it dissolves easily in the ambient air. In a room of about 100 m^3 at a distance of 1 m from a 10 m^3 chamber the oxygen content will not fall below 17 vol.-%. After opening the chamber door, the oxygen level in the chamber adjusts within seconds back to the normal 21 vol.-% of oxygen.

Costs

Table 2 compares the capital cost of MB, nitrogen produced on-site by a nitrogen generator, and nitrogen gas purchased in cylinders in Germany. The capital cost of a MB fumigation chamber is approximately $ 100,000, with additional safety costs. The capital cost of

***Table 2.* Capital cost of MB and nitrogen treatments**

Item	MB (US$)	Nitrogen from on-site generator (US$)	Nitrogen from gas cylinders (US$)	Comments
Cost of 12 m^3 fumigation chamber	100,000	5,000–6,500 (a)	5,000–6,500 (a)	(a) Basic cost is 5,000, but if heating is required, extra insulation and an electric heater brings it to $ 6,500
Nitrogen generator	0	5,000–7,500 (b)	0	(b) depending on the size/output (3–8 litre/min).
Nitrogen-regulator	0	50	50	
Computer controlled unit	Approx. 50,000	4,500 (c)	4,500 (c)	(c) Including a humidifying unit
Safety precautions including filters, gas sensors and alarm	very high (d)	very little	very little	(d) MB needs installation of special safety structures and special training of workers, required for working with highly toxic fumigants
Total	Approx. 150,000 + high safety costs	Approx. 14,550 to 18,550 + small safety costs	Approx. 9,550–11,050 + small safety costs	

Table 3. **Operating costs of MB and nitrogen for one treatment in 10 m^3 chamber**

Item	MB (US$)	Nitrogen from on-site generator (US$)	Nitrogen from gas cylinders	Comments
Cost of gas for one treatment of 10 m^3	25 (a)	Approx. 5 (b)	100–800 (c)	(a) approx. $5 per 100 g. (b) electricity for nitrogen generator – about 200 Watts for 4 weeks. (c) 10 x 50 litre cylinders of nitrogen under pressure. Cost of $1–80 per m^3 depending on supplier.
Specialist staff	Licensed fumigator	Normal technician (d)	Normal technician (d)	(d) The nitrogen treatment can be carried out by any museum technician
Total	25 + cost of licensed fumigator	Approx. 5 + cost of normal technician	100–800 + cost of normal technician	

nitrogen is between about $ 9,500 and 11,000 for a system that uses nitrogen gas ready-made in cylinders. If nitrogen gas is produced on-site, the total capital cost is about $ 14,500 to 18,500 plus small safety costs (Table 2).

The operating costs are compared in Table 3. While MB gas is relatively cheap, the total operating cost of MB is higher than nitrogen because licensed fumigators are expensive. Purchase of nitrogen gas in cylinders can be expensive unless a cheap supplier is found. The cheapest method is the production of nitrogen on-site by pressure swing absorption equipment – this requires an initial capital cost that can be recouped over several years.

When flexible plastic or PVC liners (containers) are used, more nitrogen gas is generally needed because some leakage may occur from seams and zippers. So they tend to have higher gas costs than gastight fixed chambers.

Acceptability to regulators and markets

Registration is necessary for the use of nitrogen as a pesticide or biocide in some countries (eg. Germany), but registration is not required for nitrogen in many other countries.

Museums and curators prefer nitrogen over MB because the gentleness of the treatment keeps the artefacts in the same condition.

Applicability to other regions

The nitrogen technique described above can be used in any region of the world. It needs a reliable supply of electricity which can be provided by a battery or small generator if the public electricity supply is unreliable. Without doubt, this is the case in many museums around the world. Initial training is required, but no specialist knowledge is necessary for performing the treatment successfully.

Very few constraints exist for museums in adopting nitrogen methods. The only constraint is in circumstances where a faster treatment may be necessary. But in many such situations a heat treatment with controlled humidity provides rapid and effective control.

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CONCLUSIONS

The studies in this book highlight the need to combine several techniques in order to control the wide range of pests that MB can control. An integrated pest management (IPM) approach is very useful in this respect. IPM is based on pest monitoring, establishment of pest injury levels, and a combination of strategies and tactics designed to prevent or manage pest problems in an environmentally sound and cost-effective manner (MBTOC 1998). Increasingly, IPM is being promoted by governments, farming organisations and supermarkets as a means to reduce the environmental impact of agriculture. The adoption of IPM to phase-out a broad-spectrum and toxic chemical like MB fits well with this trend.

The case studies have provided examples of the following soil techniques that are in commercial use today in certain CEIT countries:

- IPM techniques such as hygienic practices, removal of pests hosts and havens, practices that inhibit pest numbers increasing to problem levels
- Solarisation and biofumigation
- Various types of substrates
- Crop rotation
- Grafted plants and resistant varieties
- Certified disease-free plants
- Biological controls such as *Trichoderma*
- Green manure and trap crops such as *Tagetes*
- Seedtray systems

For commodities and structures the examples of alternatives were:

- Nitrogen treatments
- Integrated pest management, including removal of pest havens, measures to exclude pests from buildings, intensive cleaning, regular monitoring, and spot treatments with low-toxicity pesticides if necessary

Most of the alternatives described in these case studies produce crop yields equal to MB, and in some cases they produce higher yields. They provide the necessary level of pest control for users – and in some cases provide more effective control than MB. MB kills pests present at the time of fumigation but does not prevent the soil or commodities from becoming re-infested with pests. Many alternatives in these case studies have the advantage of providing continuous and on-going management of pests, preventing the build-up of pests to economically damaging levels.

The establishment of alternatives normally requires an initial investment in training, technical advice, and materials or capital equipment. The costs vary greatly, depending on the technique. The operating costs of some alternatives are less than MB, while some cost more and others cost the same as MB. All of the techniques described in these case studies are used in commercial practice and are cost-effective for their users. Export producers find that the alternatives allow them to be competitive in international markets.

Growers and other users of these alternatives in CEITs are satisfied with their efficacy, performance and profitability. Purchasing companies such as supermarkets find that the quality of the products is the same as, and in some cases better than, those produced with MB.

Advantages of non-chemical alternatives

The case studies also show that non-chemical alternatives offer CEITs a number of advantages over chemical methods for the following reasons:

- Non-chemical treatments are generally non-toxic and safer for operators, farm families and rural communities
- In general they do not leave undesirable residues in soil, plants, food and water
- Consumers strongly prefer products grown with non-chemical methods
- Many supermarkets and food manufacturers are encouraging farmers and suppliers to reduce their reliance on pesticides
- Most non-chemical treatments do not require expensive and time-consuming registration by pesticide authorities because they do not pose the same safety risks as pesticides

These case studies show that biological and non-chemical techniques can be as cost-effective and viable as MB while being substantially better for the environment and the health of users and farming communities.

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UNEP/GEF 2001. *UNEP Regional Demonstration Project: Identification and Evaluation of Environmentally Sustainable Alternatives for Methyl Bromide Used on Horticultural Crops in Eastern and Central Europe*. Website: www.uneptie.org/ozonaction.html

UNEP/GEF 2001. *Report on the Regional Policy Development Workshop to Assist Methyl Bromide Phase-out in Eastern and Central Europe*. 25-27 October 2000, Warsaw, Poland. Website: www.uneptie.org/ozonaction.html

UNEP/GEF 2001. Report on Regional Workshop on Methyl Bromide Alternatives for Soil Uses in Eastern and Central Europe. 23-25 April 2001, Szeged, Hungary. UNEP DTIE, Paris. Website: www.uneptie.org/ozonaction.html

UNEP 2002. *Floriculture and the Environment – Growing Flowers without Methyl Bromide*. UNEP DTIE, Paris. Website: http://www.uneptie.org/ozonaction/library/tech/main.html#guide. Available in English, French and Spanish.

UNEP/GEF 2002. Report on Regional Training Workshop on Methyl Bromide Alternatives for Post Harvest Treatments in Central and Eastern Europe. 28-30 May 2002, Sofia, Bulgaria. UNEP DTIE, Paris. Website: www.uneptie.org/ozonaction.html

UNEP websites

OzonAction Programme: www.uneptie.org/ozonaction.html

UNEP website for demonstration project reports: www.uneptie.org/ozonaction/unido-harvest/

Regular Update on Methyl Bromide Alternatives (RUMBA): www.uneptie.org/ozat/pub/rumba/main.html; subscribe to RUMBA at www.uneptie.org/ozat/forum/rumba.html

Other useful websites

Agriculture and Agri-Food Canada and Environment Canada, Ottawa, Canada: www.agr.ca/policy/environment and www.ec.gc.ca/ozone/mbrfact.htm

Appropriate Technology Transfer for Rural Areas (ATTRA), extension materials on IPM and sustainable agriculture: www.attra.org

Centro de Ciencias Medioambientales (CSIC), Madrid, Spain: www.ccma.csic.es

Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg: http://res2.agr.ca/winnipeg/home.html

Department of Stored Products, Agricultural Research Organization, Bet Dagan, Israel: www.agri.gov.il/depts/storedprod/envfriend.html

European Commission, Brussels, Belgium: www.europa.eu.int/comm/environment/ozone/conference

Food and Agriculture Organisation (FAO), Rome, Italy, methyl bromide information: www.fao.org/waicent/faoinfo/agricult/agp/agpp/ipm/web_brom; sustainable agriculture: www.fao.org/sd/index_en.htm; FAO library: www.fao.org/library; and the FAO Global IPM Facility: www.fao.org/ipm

Fruit Research Centre (FPO), the Netherlands: www.agro.nl/fpo

GTZ Proklima, bilateral technical cooperation agency of Germany: www.gtz.de/proklima, and www.gtz.de/home/english/index.html

MBAO proceedings of annual MB alternatives conference, USA: www.epa.gov/ozone/mbr

MBTOC reports on methyl bromide and alternatives: www.teap.org

Natural Resources Institute, England – stored products information: www.nri.org

Plant Pathology Internet Guide Book, Universities of Bonn and Hannover, Germany: www.ifgb.uni-hannover.de/extern/ppigb/

Research Station for Floriculture and Glasshouse Vegetables (PBG), the Netherlands: ww.agro.nl/pbg

Stored Products Research Group, CSIRO Entomology Division, Canberra, Australia: www.ento.csiro.au

TEAP reports on ozone-depleting substances: www.teap.org

University of California, Statewide IPM Project, California, USA: www.ipm.ucdavis.edu

US Environmental Protection Agency (EPA), Washington DC, USA: www.epa.gov/ozone/mbr

Videos

Methyl Bromide Public Service Announcement. UNEP DTIE, Paris, 1999.

Healthy Harvest: Alternatives to Methyl Bromide. UNEP DTIE, Paris, 1999.

Good Grounds for Healthy Growth. Video about substrates and alternatives in Holland. Ministry of Environment, Netherlands. Available from Department for Information, VROM, PO Box 20951, The Hague, Netherlands.

Soil Solarization. Video no. 6127, Ministry of Agriculture Extension Service, Israel. Available in English, French, Spanish, Italian, Portugese, Hebrew, Arabic. Available from Mr A Tzafrir, Ministry of Agriculture, fax +972 3 6971 649.

CD-ROMs and audio-visual material

Canadian Grain Storage CD-ROM. 195 Dafoe Rd, Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, Manitoba, Canada, R3T 2M9, email: CanStore@em.agr.ca, website: http://res2.agr.ca/winnipeg

Ecogen alternative for methyl bromide and phosphine. CD-ROM. Modified atmosphere systems for commodity treatments. Ecogen BV, PO Box 7488, 3280 AG Numansdorp, the Netherlands, tel +31 186 651 010, fax +31 186 657 844, email: info@ecogen.nl, website: www.ecogen.nl

Sanitation, GMPs and Team Work as an Alternative to Methyl Bromide in Food Facilities. Powerpoint presentation. Dean M Stanbridge, Technical Director, Steritech, Box 246 Stn Main, Milton, Ontario, Canada L9T, 4N9, tel +1 905 878 8468, fax +1 905 878 9223, email: dstanbridge@steritech.com, website: www.steritech.com

ANNEX I: ABOUT THE UNEP DTIE OZONACTION PROGRAMME

Nations around the world are taking concrete actions to reduce and eliminate production and consumption of CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide and HCFCs. When released into the atmosphere these substances damage the stratospheric ozone layer. Nearly every country in the world -currently 183 – has committed to phase out the consumption and production of ozone depleting substances (ODS) under the Montreal Protocol. Recognizing that developing countries ("Article 5 countries") require special technical and financial assistance to meet their commitments under the treaty, the Parties established the Multilateral Fund and requested UNEP, along with UNDP, UNIDO and the World Bank to provide the necessary support. UNEP also supports ozone protection activities in Countries with Economies in Transition (CEITs) as an implementing agency of the Global Environment Facility (GEF).

Since its inception in 1991, the UNEP DTIE OzonAction Programme has strengthened the capacity of government National Ozone Units (NOUs) and industry in developing countries to make informed decisions about technologies and policies required to implement the Montreal Protocol. The Programme has supported ODS phase-out at national, regional and international levels by delivering the following need-based services:

Information Exchange Clearinghouse
Provides information tools and services to encourage and enable decision makers to make informed decisions on policies and investments required to phase out ODS. The Programme has developed and disseminated to NOUs over 100 publications, videos, and databases that include public awareness materials, a quarterly newsletter, a web site, sector-specific technical publications as well as guidelines to help governments establish policies and regulations.

Training
Builds the capacity of policy makers, customs officials and local industry to implement national ODS phase out activities. The Programme promotes the involvement of local experts from industry and academia in training workshops and brings together local stakeholders with experts from the global ozone protection community. UNEP has conducted 39 training activities at the regional level and 71 at the national level.

Networking
Provides a regular forum for officers in NOUs to meet to exchange experiences, develop skills, and share knowledge and ideas with counterparts from both developing and developed countries. Networking helps ensure that NOUs have the information, skills and contacts required for managing national ODS phase out activities successfully. UNEP currently operates 8 regional/sub-regional Networks involving 114 developing and 9 developed countries.

Refrigerant Management Plans (RMPs)
Provide countries with an integrated, cost-effective strategy for ODS phase out in the refrigeration and air conditioning sectors. RMPs assist developing to overcome the numerous obstacles to phase out ODS in the critical refrigeration sector. UNEP DTIE is currently providing specific expertise, information and guidance to support the development of RMPs in 62 countries.

Country Programmes (CPs) and Institutional Strengthening (IS)
Support the development and implementation of national ODS phase out strategies especially for low-volume ODS-consuming countries. The Programme has assisted 100 countries to develop their CPs and 96 countries to implement their IS projects.

In 2002, UNEP restructured its programme in order to better respond to the evolving needs of developing countries during the compliance period. Its overall vision and work strategy was reoriented into the Compliance Assistance Programme (CAP). A major feature of the CAP strategy is to move away from a disparate project management approach towards integrated and direct implementation of the programme using a team of professionals with appropriate skills and expertise. UNEP has now regionalised the delivery of the programme and services by placing its regional offices at the forefront to assist the countries in the region.

UNEP

For more information about these services please contact:

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About the UNEP Division of Technology, Industry and Economics

The mission of the UNEP Division of Technology, Industry and Economics is to help decision-makers in government, local authorities, and industry develop and adopt policies and practices that:

- are cleaner and safer;
- make efficient use of natural resources;
- ensure adequate management of chemicals;
- incorporate environmental costs;
- reduce pollution and risks for humans and the environment.

The UNEP Division of Technology, Industry and Economics (UNEP DTIE), with the Division Office in Paris, is **composed of one centre and five branches**:

- **The International Environmental Technology Centre (Osaka)**, which promotes the adoption and use of environmentally sound technologies with a focus on the environmental management of cities and freshwater basins, in developing countries and countries in transition.
- **Production and Consumption (Paris)**, which fosters the development of cleaner and safer production and consumption patterns that lead to increased efficiency in the use of natural resources and reductions in pollution.
- **Chemicals (Geneva)**, which promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide, with a priority on Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC, jointly with FAO).
- **Energy and OzonAction (Paris)**, which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition, and promotes good management practices and use of energy, with a focus on atmospheric impacts. The UNEP/RISØ Collaborating Centre on Energy and Environment supports the work of the Branch.
- **Economics and Trade (Geneva)**, which promotes the use and application of assessment and incentive tools for environmental policy and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development.
- **Coordination of Regional Activities Branch (Paris)**, which coordinates regional delivery of UNEP DTIE's activities and ensures coordination of DTIE's activities funded by the Global Environment Facility (GEF).

UNEP DTIE activities focus on raising awareness, improving the transfer of information, building capacity, fostering technology cooperation, partnerships and transfer, improving understanding of environmental impacts of trade issues, promoting integration of environmental considerations into economic policies, and catalysing global chemical safety.

For more information contact:

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ANNEX II: CONTACTS

The Multilateral fund of the Montreal Protocol has been established to provide technical and financial assistance for developing countries to phase-out ozone depleting substances such as methyl bromide.

Although some countries of Central and Eastern Europe are categorised under the Montreal Protocol as industrialized, and are therefore ineligible for funding from the Multilateral Fund, they are eligible for funding from the Global Environment Facility (GEF) under the focal area of Protection of the Ozone Layer, in light of the criteria set out in Article 9, Paragraph (b) of the Instrument for the Establishment of a Restructured Global Environment Facility.

It was with GEF funding, as well as contributions from Environment Canada, that the regional project 'Initiating Early Phase Out of Methyl Bromide in Countries with Economies in Transition (CEITs) through Awareness-Raising, Policy Development and Demonstration/Training Activities' , and this document, was made possible.

For further information, please contact the Implementing Agencies and Secretariats listed below.

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ANNEX III: GLOSSARY AND UNITS

Acronym/Term	Meaning
Biofumigation	Soil treatment in which organic matter, added to the soil, decomposes and releases gases that eliminate or control pests
Biological controls	Living organisms used to control pests and diseases
CEITs	Countries with Economies in Transition
Compost	Decomposed waste plant or animal materials
Cultivar	variety of a plant that was produced from a natural species and is maintained by cultivation
Durables	Commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods
EC	European Community
EU	European Union
F_1 hybrid	Plants or seeds bred from two parent plants selected for special characteristics eg. resistance to certain diseases. F_1 means first generation of cross-breeding
GEF	Global Environmental Facility
GMP	Good Manufacturing Practice
Grafting	Use of resistant rootstocks to protect susceptible annual and perennial crops against soil-borne pathogens
Heat treatment	Use of heat to kill insect and/or other pests
Hermetic storage	Large, sealed storage areas where insects perish from lack of oxygen
IFP	Integrated Fruit Production
IPM	Integrated Pest Management: Pest monitoring techniques, establishment of pest injury levels and a combination of strategies and tactics to prevent or manage pest problems in an environmentally sound and cost-effective manner
ICM	Integrated Commodity Management: Management of commodities to minimise environmental and health impacts. It includes the use of Integrated Pest Management
ILTs	insect electrocution light traps
IOBC/WPRS	Joint Group for Integrated Fruit Production Guidelines of the International Organisation for Biological Control
ISHS	International Society for Horticultural Sciences
Insectocutor	Ultra-violet (UV) bulb device that attracts and kill insects
MA(s)	Modified atmosphere(s): Modification of the normal composition of air by decreasing oxygen and increasing carbon dioxide or nitrogen levels
MB	Methyl bromide
MBTOC	Methyl Bromide Technical Options Committee under the United Nations Environment Programme
MF	Multilateral Fund
Monoculture	Production of one crop in a field; often the same crop grown year after year at a particular site. This contrasts with crop rotation, where the crop in a particular field is changed each year
Nematodes	Microscopic 'worms' that live in soil; some are pests while others are beneficial in agriculture
ODS	Ozone depleting substance
Pathogen	Organisms that cause damage or disease
pH	Degree of acidity or alkalinity, log scale
Pheromone	Chemical substance externally transmitted by members of a species and influencing the behaviour or physiology of others in the same species
Phosphine	Phosphorus trihydride (hydrogen phosphide), a fumigant gas
Phytotoxic, phytotoxicity	A substance or activity that is toxic to plants
PVC	Polyvinylchloride, a type of plastic
Psa	Pressure Swing Absorption – a process where an absorption bed is alternately pressurised and has the pressure released. Different gases are sorbed (taken up) and desorbed (released) at different rates, and as a result gases such as nitrogen or oxygen can be separated from other gases in the air
Pyrethroid	any of various chemical compounds of similar insecticidal properties to pyrethrin, an oily, water-insoluble compound (formula $C_{21}H_{28}O_3$ or $C_{22}H_{28}O_5$), which is often derived from the dried flowers of certain cultivated Eurasian chrysanthemums.
QPS	Quarantine and pre-shipment
Resistant varieties	Plant varieties that are able to resist attack by specific pests
Rockwool	also known as mineral wool; a fibrous material made by blowing steam or air through molten slag, and originally used for packing and insulation

Acronym/Term	Meaning
Sanitation	Avoidance or elimination of pathogen inoculum or pest sources, such as infected plant residues, before planting
Soil amendments	Organic materials added to the soil to improve texture, nutrition and/or assist in controlling pests
Solarisation	When heat from solar radiation is trapped under clear plastic sheeting to elevate the temperature of moist soil to a level lethal to soil-borne pests including pathogens, weeds, insects and mites
Steam treatment	Use of steam (water vapour) to kill pests
Substrates	A method in which plant growth substrates provide an anchoring medium that allows nutrients and water to be absorbed by plant roots
Trichoderma	A beneficial soil fungus used as a biological control agent
ULV	ultra-low-volume
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP DTIE	United Nations Environment Programme, Division of Technology, Industry and Economics
UNIDO	United Nations Industrial Development Organisation
Vermiculite	any of a group of micaceous minerals, consisting mainly of hydrated silicate of magnesium, aluminium and iron: on heating they expand and exfoliate, and in this form are used in heat and sound insulation, fireproofing, and as a bedding medium for plants.

UNITS USED IN THIS REPORT

Unit	Meaning
Hectare, ha	area of 10,000 square metres or 2.47 acres
Metre, m	length of 100 centimetres or 39.37 inches or 3.28 feet
Square metre, m^2	area measuring 1 metre long by 1 metre wide or 1.19 square yards or 10.76 square feet
Cubic metre, m^3	volume measuring 1 metre long by 1 metre wide by 1 metre high or 1 kilolitre or 264.17 US gallons (219.97 UK gallons)
Litre, l	capacity (volume) of 0.035 cubic feet or 2.11 US pints (1.76 UK pints) or 0.26 US gallons (0.22 UK gallons)
Millilitre, ml	capacity (volume) of 0.001 litre
Gram, g	weight of 0.032 ounces
Kilogram, kg	weight of 1000 grams or 2.21 pounds or 32.15 ounces
Tonne, t	weight of 1000 kilograms
°C	temperature measured in degrees Celsius or degrees centigrade 0°C equals 32°F (degrees Fahrenheit) 15°C equals 59°F 37°C equals 98.6°F
Pounds per square inch, psi	unit of pressure exerted per square inch of surface (1 pound (lb) = 0.4525 kilos; 1 square inch = 0.0006454 m^2
Atmosphere, atm.	a unit of pressure, where 1 atm is the pressure that will support a column of mercury 760 mm high at 0°C at sea level.

ANNEX IV: INDEX

A WORD FROM THE CHIEF OF UNEP DTIE'S ENERGY AND OZONACTION UNIT

Much of the Montreal Protocol's success can be attributed to its ability to evolve over time to transform the latest environmental information and technological and scientific developments into actions. Through this dynamic process, significant progress has been achieved globally in protecting the ozone layer.

As one of the agencies involved in the implementation of the Montreal Protocol, UNEP DTIE's OzonAction Programme promotes knowledge management in ozone layer protection through collective learning. There is much that we can learn from one another in adopting effective alternatives to methyl bromide.

In publishing our first volume of *Case Studies on Alternatives to Methyl Bromide: technologies with low environmental impact*, we presented a range of technologies suitable for the developing country situation in general. We promised to make information available as technologies were further developed and countries gained more experience as they moved ahead with their phase out of this substance.

We have made good on that promise by highlighting the specific experience of the CEIT countries, which, by virtue of their specific climate and socio-economic conditions, agreed that there was a need to share information on suitable available alternatives across the range of applications for methyl bromide in their region. *Case Studies on alternatives to Methyl Bromide, Volume 2: Technologies with low environmental impact in countries with economies in transition* is the result of our efforts.

I therefore, wish to renew my invitation at this time, to encourage you to share your experiences with the OzonAction Programme, so that we can continue to inform others involved in this issue about the lessons you have learned. You can send us, by e-mail, fax or letter, your experiences and successes in phasing out methyl bromide. Your feedback is crucial to the collective learning process, and we cannot compile documents such as this without your input!

With your feedback and information, UNEP can update the Case Studies series on a periodic basis, to reflect the very latest of developments. We will also disseminate experiences and stories through a variety of channels, including the OzonAction Newsletter and the OzonAction Programme's website (www.uneptie.org/ozonaction). If we use the information you provide, we will send you a free copy of one of our videos, publications, posters or CD-ROMs as thanks for your cooperation.

So take up a pen (or pull up to a computer keyboard!) and write us. Let us continue to collectively learn and protect the ozone layer!

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Due to the unique economic and political transformations experienced by countries with economies in transition (CEITs), most have found it difficult to comply with the measures established under the Montreal Protocol. One of the substances covered by the Protocol is methyl bromide which contributes to the depletion of the stratospheric ozone layer. As an effective but toxic chemical used to control a broad spectrum of pests in soil, commodities and structures, it is widely used in CEITs – and worldwide. In 1999, UNEP sought GEF funding for a regional project "Initiating Early Phase Out of Methyl Bromide in Countries with Economies in Transition (CEITs) through Awareness Raising, Policy Development and Demonstration/Training Activities", which aimed to assist CEITs in their bid to phase out methyl bromide by 2005, as required under the Protocol. It initially had the participation of 8 CEITs – Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, with Georgia and Moldova joining in the project activities assisted by bilateral funding from the Government of Canada.

One of the key targets of this project was to present countries with examples of cost-effective, viable, environmentally sustainable alternatives for major uses of methyl bromide. It included a component where demonstration projects were set up in the region to explore alternatives suited to the unique climate, culture and socio-economic conditions of CEITs. Based on the results of these demonstration projects, as well as the implementation successes of other initiatives taken in the region (or in countries of similar climate), six case studies were compiled to produce this document. The case studies cover uses ranging from soil fumigation, to the fumigation of storage structures and the treatment of heritage items and archives.

This document encourages farmers, extension agencies, researchers, policy-makers and other stakeholders from the region to examine environmentally sustainable techniques when considering the replacement of methyl bromide. It addresses both chemical and non-chemical alternatives across the spectrum of uses in CEITs, and it includes analyses of associated costs and the applicability of technologies to the region. While targeted specifically at CEITs, this document can help any National Ozone Unit successfully meet their country's methyl bromide phase out obligations under the Montreal Protocol.

This project was funded under the Global Environment Facility and through bilateral resources provided by the Government of Canada.

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