

Case Studies on Alternatives to Methyl Bromide

Technologies with low environmental impact



United Nations Environment Programme
Division of Technology, Industry and Economics
OzonAction Programme



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A Message from UNEP's Executive Director

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 and in response, the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer agreed in 1997 to a global phase-out schedule. Achieving this phase out is one of the last remaining challenges for ozone layer protection.

Fortunately, the methyl bromide phase out offers a win-win-win situation for agriculture, the environment and human health: carefully-chosen alternative techniques can be cost-effective, protect the ozone layer and improve worker safety at the same time.

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 with other toxic pesticides that will continue to pose risks to human health and the environment.

Methyl bromide phase out will require a shift towards more environmentally sustainable agricultural practices. Such behavioral 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 occur only if farmers and policymakers have practical examples of successful alternatives to methyl bromide.

UNEP's *Case Studies on Alternatives to Methyl Bromide* comprises 18 case studies that illustrate non-chemical alternative techniques successfully used for the major crops/commodities using methyl bromide. Based on data collected by more than 30 experts from around the world, each case study contains information on the alternative technique, comparison of yields and performance, comparison of costs, acceptability to regulators and consumers and applicability to other regions and uses. Sources of further information are also provided so that readers can contact organisations and technical experts to obtain more detailed information.

These case studies demonstrate that non-chemical alternatives are not only cost-effective but are also safer for farm workers, local communities and the environment. They show that export producers using these techniques can compete in the international marketplace, where consumers are becoming increasingly concerned about pesticide use.

It is hoped that this document, along with UNEP's other technical resources, will help National Ozone Units in developing countries successfully meet the first methyl bromide control measure required by the Montreal Protocol – the 2002 freeze on methyl bromide consumption and production. Farmers, extension agencies, researchers and other stakeholders can also use these case studies to identify and adopt alternatives to methyl bromide that will maintain agricultural productivity while protecting the global environment.



– Klaus Töpfer
United Nations Under-Secretary-General and
Executive Director of UNEP

Introduction

PROTECTING THE OZONE LAYER

The Montreal Protocol is an international agreement that aims to protect the Earth's fragile ozone layer from 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 official list of ozone depleting substances in 1992. Under the Montreal Protocol, governments have agreed to phase out MB in developed countries by 2005 and in developing countries (Article 5 countries) by 2015. In the interim the national supply of MB will also be reduced. In developing countries production and consumption will be frozen (at average 1995–98 levels) by 2002 and reduced 20% by 2005. Quarantine and pre-shipment applications of MB are currently exempt from these controls.

MB is an agricultural fumigant which is used to control a broad spectrum of pests in soil, commodities and structures. Developing countries used about 17,323 t in 1996, accounting for approximately one-fourth of global use. These uses are primarily for soil fumigation (70%) and stored durable products. Most MB is used as a soil treatment prior to planting crops such as tomatoes, peppers, cucumbers, melons, strawberries, cut flowers and tobacco seed-beds. Post-harvest treatments are mainly applied to grains such as wheat, maize (corn) and rice.

The Multilateral Fund of the Montreal Protocol provides financial and technical assistance for Article 5 countries to phase out ozone depleting substances. The Fund has approved more than 60 MB phase out projects, primarily demonstrations of alternatives. Increasingly the Fund is providing support for projects to train farmers and other MB users in alternative techniques, so that Article 5 countries can meet their commitments to reduce and phase out MB consumption.

PURPOSE OF CASE STUDIES

Some farmers and other MB users have already adopted alternatives to MB, for a wide variety of reasons, such as commercial advantages or international trends towards pest control methods that do not rely on toxic pesticides. The 1998 Report of the Methyl Bromide Technical Options Committee (MBTOC) *Assessment of Alternatives to Methyl Bromide* lists many examples where alternatives are in commercial use (MBTOC 1998). UNEP has compiled this book of Case Studies to provide additional, detailed information on such alternatives. This document aims to encourage farmers, extension agencies, researchers, policy-makers and others involved in the MB phase out process to explore environmentally sustainable techniques when considering their options for replacing MB.

IMPORTANCE OF SAFE ALTERNATIVES

In choosing alternatives to MB, it is important to increase awareness about the successful use of biological and non-chemical alternative techniques in order for farmers to make informed choices. This is to minimise the risk that MB could be replaced by other chemicals which may not be ozone-depleters, but lead to other environmental problems in the form of health risks and pollution.

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 environmental 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 (see Contents list for page numbers):

- ▶ Peppers and eggplant (aubergine)
- ▶ Tomatoes
- ▶ Melons and cucumbers (cucurbits)
- ▶ Strawberries
- ▶ Tobacco seed-beds
- ▶ Cut flowers
- ▶ Stored and export grains

-
- ▶ Storage structures for grains and food products
 - ▶ Quarantine treatment for fresh fruit

The Case Studies describe a variety of alternatives used commercially in diverse climatic regions. Each study provides information on the following:

- ▶ Economic significance of crop or commodity
- ▶ Climate
- ▶ Target pests
- ▶ Use of MB
- ▶ Description of alternative technique
- ▶ Comparison of yields and performance
- ▶ Comparison of costs
- ▶ Acceptability to regulators and consumers
- ▶ Applicability to other regions and uses
- ▶ Sources of further information

The **Contents** list and **Index** will assist you in identifying uses and techniques of particular interest. The **Annex** provides a glossary of terms and explanation of units used.

DATA COLLECTION

Information for the Case Studies was compiled by more than 30 experts globally, with additional assistance from other specialists. For each 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 of MB and the alternative, regulatory information, and applicability to other regions. The data were put into a standardised format, edited and circulated for peer review.

CONCLUSIONS

In order to control the full range of pests controlled by MB, the alternatives described in these Case Studies often combine several techniques using an integrated pest management (IPM) approach. 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. Increasingly, IPM is being promoted by governments, farming organisations and supermarkets to reduce the environmental impact of agriculture in general (MBTOC 1998). The use of IPM to phase out a broad-spectrum and toxic chemical like MB fits well with this trend.

The Case Studies provide illustrations of the following soil techniques that are in commercial use (often as combined treatments):

- ▶ IPM techniques such as hygienic practices, seeds free from disease, removal of pest hosts and havens, practices to prevent pest numbers building-up to problem levels
- ▶ Grafted plants and resistant varieties
- ▶ Solarisation
- ▶ Natural substrates, such as coconut fibres and sawdust
- ▶ Biological controls, such as *Trichoderma* applied via irrigation systems, *Tagetes*, *Gliocladium* and *Paecilomyces lilacinus*
- ▶ Soil amendments such as compost, worm humus and animal manure
- ▶ Steam treatments
- ▶ Mulches, ie. soil covers that inhibit weeds and in some cases raise soil temperature
- ▶ Certified organic and biodynamic production methods

For commodities and structures the treatments covered are:

- ▶ Nitrogen with integrated commodity management
- ▶ Hermetic storage

-
- ▶ Diatomaceous earth slurry
 - ▶ Heat treatment
 - ▶ Pest trapping, monitoring and repellent barriers

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

Alternatives normally require an initial investment in training, technical advice and materials or capital equipment. The costs vary greatly from one technique to another. Some alternatives cost less than MB, some cost more, while others cost the same as MB. All of the techniques described in these Case Studies 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 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 have a number of advantages over chemical methods for the following reasons:

- ▶ Non-chemical treatments are generally non-toxic and safer for farm workers and local communities
- ▶ They do not leave undesirable residues in soil, plants, food and water
- ▶ Consumers strongly prefer products grown through non-chemical methods
- ▶ Many supermarkets and food manufacturers are encouraging farmers to reduce reliance on pesticides because of the commercial risks
- ▶ 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 clearly show that biological and non-chemical techniques can be as cost-effective and viable as MB, while being substantially better for the environment and health of farming communities.

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MBTOC 1998. *Assessment of Alternatives to Methyl Bromide*. Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi. pages 38–56, 71–88, 224–226 and 271–291.

Case Study 1

Peppers and eggplant in Israel: solarisation

REPORT CARD

Crop: Peppers and eggplant (aubergine)

Soil pests: Nematodes, weeds, fungi, bacteria and parasitic plants

Alternative: Strip solarisation (plus nematode control when necessary)

Yields: Solarisation provides the same yields as MB

Costs: Solarisation costs substantially less than MB

Regulatory approval: None required

Comments: Solarisation is used on approximately 1,500 hectares each year in Israel. It is suitable for regions with sufficient sunshine and crop cycles that allow a 4–6 week treatment between crops

Examples of

commercial use: Solarisation is used commercially for greenhouse tomatoes, vegetables and/or nurseries in Italy, Greece, Mexico, South America, Japan

Economic significance of crop

In Israel's Jordan Valley, peppers and eggplant (aubergine) are grown primarily for the local market during the winter months. These crops, together with flowers, grapes, and other horticultural crops, support many small and medium-sized farms in the region.

It is estimated that 200 families produce peppers and eggplant in the valley. The total production value of pepper and eggplant winter crops is approximately US\$ 15 million per year.

Region

The Jordan Valley of Israel is isolated from urban areas of the country. It is a hot, dry, arid region with less than 200 mm rainfall per year. Summer high temperatures usually range from 35–42°C; winter temperatures are mild ranging from 15–25°C with a small risk of frost. The region is 250–400 m below sea level and the predominant soils are of medium to heavy clay texture.

Crop production characteristics

The productive area in the Jordan Valley in Israel comprises:

- ▶ 400 ha of peppers and eggplant
- ▶ 200 ha other vegetables
- ▶ 800 ha table grapes
- ▶ 300 ha dates
- ▶ 200 ha flowers

There are approximately 200 small and medium-size farms involved with growing peppers and eggplant. These farms also grow other crops such as flowers and grapes. The crops are generally grown on small (2 ha) open field farm plots, but many farmers also use greenhouses, walk-in tunnels and low plastic tunnels.

Cropping takes place during the winter months to take advantage of the milder seasonal temperatures. Normally one crop is grown each year. Rotation is limited, but in certain cases

crops such as onions, corn or zucchini (courgette) are rotated with pepper and eggplant.

Use of methyl bromide

MB was first introduced into Israel about 35 years ago and until the 1980s most vegetables were grown using MB in Jordan Valley. In the past, 150–200 t MB per year was used in this region. Today, about 50–70 t MB are applied to about 200–280 ha, primarily for melon and some flower crops.

The MB application rate for peppers and eggplant was 50 g/m² or 250 kg/ha using strip fumigation techniques. In the valley, MB was used to control weeds and various soil-borne pathogens such as:

- ▶ Fungal wilts due to *Verticillium* spp. (mainly in eggplant)
- ▶ Damping off diseases mainly caused by *Rhizoctonia*
- ▶ Root knot nematodes, *Meloidogyne* spp.
- ▶ Parasitic plant broomrape, *Orobanche* sp.

Commercial use of alternative – solarisation

Solarisation has been used extensively in Israel especially in the Jordan Valley and the southern Arava region for over 20 years with good results. It is the preferred choice of many farmers in the Jordan Valley because it is cheaper and more convenient to use than MB. As a result, strip solarisation is used for most peppers and eggplant grown in open fields in the region. Most winter crops of peppers grown in greenhouses are also grown on solarised soil. About 400 ha of peppers and eggplant in Israel's Jordan Valley are solarised each year.

In Israel, it is estimated that at least 1,500 ha are treated with solarisation each year for a variety of crops such as winter vegetables grown in greenhouses (eg. tomatoes, peppers, cucumbers) and greenhouse flower crops, in addition to open field crops such as onions.

Case Study 1

PEPPERS AND EGGPLANT IN ISRAEL: SOLARISATION

Techniques

Soil solarisation is a non-chemical method of soil disinfestation or pasteurisation, using solar energy to heat the soil. It is best used as part of an IPM system. After preparing and irrigating the soil, it is covered with transparent polyethylene sheets during the hot, dry, non-growing season. Moisture is important for transferring heat within the soil. Solarisation in Israel typically raises soil temperatures to 47, 43 and 39°C at depths of 10, 20 and 30 cm respectively. Prolonged exposure to raised soil temperatures controls key soil-borne pests, pathogens and weeds. Solarisation can also promote beneficial soil organisms, providing biological control of plant pathogens after the treatment has finished.

In the Jordan Valley region of Israel, strip solarisation is used for pepper and eggplant and the sheets are generally left on the soil for about 4–7 weeks.

Yield and performance of alternative

Solarisation controls most pests and diseases that are controlled by MB except for the root knot nematode *Meloidogyne* sp. against which it is only partially effective. Additional techniques (such as nematicides at reduced dosages) can be combined with solarisation to control *Meloidogyne* sp. Organic amendments such as poultry manure are being used in experimental trials and may also be effective against root knot nematode.

Solarisation is particularly effective in controlling soil-borne pathogens such as *Verticillium* spp. and the parasitic plant *Orobanche* sp. in the area, with farmers reporting that these pests have become either very rare or insignificant.

In this region, the alternative system gives similar crop yields to those obtained using MB (Table 1).

Table 1 Crop yields from MB and solarisation in Jordan Valley of Israel

Crop	Yield using solarisation (t / ha)	Yield using MB (t / ha)
Pepper, open field	40–50	40–50
Pepper, greenhouse	120–150	120–150
Eggplant, open field	60–80	60–80
Eggplant, greenhouse	100–120	100–120

Source: Katan 1999

Table 2 compares the performance and benefits of strip solarisation and MB. Farmers favour the solarisation pest control method for peppers and eggplants in this region because it provides the same level of control as MB, is cheaper and easier to implement.

Acceptability to regulators and markets

Solarisation is a non-chemical treatment and does not require any regulatory approval.

The harvested vegetables are more acceptable to supermarkets and purchasing companies than those grown using MB because solarisation does not involve the use of toxic materials and reduces the companies' risk of criticism by consumers and the media.

Costs

In this region, the use of solarisation costs approximately 60–67% less than MB fumigation, depending on the technique used and on local prices for materials (Table 3). Since yields are similar, solarisation is more profitable for peppers and eggplant.

Table 2 Performance and benefits of solarisation and MB

Solarisation	MB system
Good growth rates	Good growth rates, but sometimes growth is retarded
Pest re-invasion is rare	Pest re-invasion more frequent than with alternative
Effective against all soil pests and pathogens except <i>Meloidogyne</i> spp. nematodes	Effective against all soil pests and pathogens including <i>Meloidogyne</i> spp, nematodes but its effectiveness against certain bacteria is low.
Safe for farmers to implement	Farmer concern about using fumigant; best used by trained farmers or contractors
Suitable for regions where there is sufficient sunshine and cropping systems that can accommodate a 4–6 week treatment	Suitable for a wider range of climates and cropping systems

Table 3 Cost estimates for strip solarisation and MB for pepper and eggplant

Item	Cost of using solarisation (US\$ / ha)	Cost of using MB (US\$ / ha)
Chemicals for treating soil	0	1,000
Plastic sheets for soil	400–600	400–600
Other purchased items (related to soil treatment)	–	–
Labour for soil treatment	200	400
Total	600–800	1,800–2,000

Source: Katan 1999

Table 3 provides only estimates of costs because local prices fluctuate. In addition there is an initial investment in learning correct techniques of solarisation. The main on-going cost of the alternative lies in the plastic sheets. Solarisation uses standard polyethylene sheets, made locally from imported raw materials and readily available from most agricultural suppliers. In the Jordan Valley farmers do not lose growing time due to solarisation because the treatment is carried out during the summer when crops are not grown.

Applicability to other regions

Solarisation is being used with success in other parts of Israel, for example in the southern desert Arava valley to control pink root disease of onions. It is also used commercially in the countries and crops listed in Table 4.

Solarisation can be used in areas that have high temperatures and sufficient cloud-free days to allow the soil to reach approximately 40°C at depths below the root area, and where the treatment can be applied for a 4–6 week period without disrupting the cropping cycle.

Where root knot nematodes are a problem, or where the temperature or other conditions for solarisation are not optimal, solarisation can be combined with other methods of control. Solarisation is best used as part of an IPM system.

Table 4 Examples of the commercial use of solarisation

Countries	Crops utilising solarisation
Mexico	Many vegetables
Central America	Nurseries
Caribbean countries	
South America	
Southern Italy	Greenhouse tomatoes
Greece	Vegetables
Jordan	
Florida	Open field tomatoes (early stages)
Japan	Greenhouses

Source: Katan 1999

Technical information provided by:

Prof Jaacov Katan, Department of Plant Pathology and Microbiology, Hebrew University of Jerusalem; Mr David Silverman, Extension Service, Ministry of Agriculture and Rural Development, Israel.

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A video about solarisation has been produced by the Extension Service, Ministry of Agriculture, Israel, and is available in several different languages including: English, Spanish, Portuguese, Arabic, Hebrew, French and Italian. Information available from Mr Tzafir Betzer fax +972 3 697 1649.

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Solarisation has been used for more than 20 years in parts of Israel

(Jaacov Katan)



Case Study 2

Tomatoes in Morocco: IPM and grafted plants

REPORT CARD

Crop: Greenhouse and tunnel tomatoes

Soil pests: Mainly root knot nematodes and fungal diseases eg. *Fusarium*

Alternative: Integrated pest management including grafted plants and hygiene

Yields: Grafted plants give much higher yields than MB (due to double stem)

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

Regulatory approval: None required for grafting and hygienic practices

Comments: This IPM system is used mainly by export farmers who are aware that MB will be phased out. The system can be adapted to other regions

Examples of

commercial use: IPM is used for cucurbits in Morocco, Egypt, Jordan and Lebanon; and for open field tomatoes or peppers in Japan

Economic significance of crop

The horticultural sector is well developed and has played an important role in modernising Moroccan agriculture. Most new agricultural technologies were first developed or introduced in the country because of horticultural demand including greenhouses, certified seed, new hybrids and varieties, grafting and tissue culture.

Tomato production and marketing is of great economic importance to Morocco. About 540,000 t tomatoes were produced in 1997/8, representing about 63% of vegetable production (Table 1). More than 220,000 t of tomatoes are exported, primarily to France (74%), other European Union countries (8%), Russia (6%), the USA, Canada, Poland and other countries (10%).

Horticultural crops, particularly tomatoes, generate about 90 million working days, representing 22% of agricultural employment in Morocco. Horticulture provides an additional 3 million working days in packing houses and canning industries.

Regions

The climate is primarily Mediterranean. Tomatoes are grown in most parts of Morocco, although the export crops are produced mainly along the Atlantic coast. Agadir is the most important region for both covered and open field tomatoes, producing 441,000 tonnes in 1997/8.

Tomato production characteristics

Tomatoes are grown from July to May. Early tomatoes for export are mainly grown in plastic tunnels and plastic greenhouses. The main varieties are Daniella and Gabriella.

Plastic tunnels and plastic greenhouse were introduced in 1971 to advance the harvests, mainly because European countries introduced regulations requiring exports to be made three months earlier (before the end of March). The greenhouse area for tomatoes increased from 3 ha in 1971 to 3,600 ha in 1998. In the same period there has been a revolution in greenhouse production technology, requiring a substantial investment (Table 3).

Use of methyl bromide

The use of MB to control soil-borne pathogens is considered to be a major reason for the success of greenhouse tomato production. MB soil fumigation has increased 40-fold in Morocco, rising from 30.4 t in 1989 to 1224 t in 1998. Tomato production uses approximately 700 t MB.

MB is used for export crops because it is considered by many growers to be a universal solution for controlling soil-borne pathogens, nematodes, bacteria and weeds. In Morocco, MB has a low cost relative to total production costs (Table 3) and controls pests effectively. As a result, tomatoes represent 58% of the total area fumigated with MB (Table 2). The application rate varies from 750 kg/ha to 1000 kg/ha. The majority of MB (68%) is used in the Agadir area, because it is the main vegetable production region and its sandy soils favour nematodes.

Table 1 Production area, volume and export of tomatoes and other early vegetables

Crop	Production area (ha)		Production volume (t)		Export (t)	
	1996/7	1997/8	1996/7	1997/8	1996/7	1997/8
Tomato						
greenhouse	3,700	3,600	410,000	461,000	150,730	207,070
open field	1,500	1,500	80,000	79,000	14,820	13,440
Others	15,300	14,400	285,000	315,000	91,450	78,490
Total	20,500	19,500	775,000	855,000	257,000	299,000

Source: Besri 1999

Table 2 Area of covered crops fumigated with MB in Morocco (1996)

Crops	Area fumigated (%)
Tomato	57.85
Melon	13.66
Strawberry	10.96
Banana	6.78
Others	10.75

Source: Besri 1999

Tomato plants are attacked by many soil-borne pathogens, but most of them such as *Alternaria solani* (early blight), *Didymella lycopersici* (Didymella stem rot), *Clavibacter michiganense* (bacterial canker), *Pseudomonas syringae p.v tomato* (bacterial speck) and *Orobanche* (*Orobanche crenata*), can be controlled easily by farmers without using MB. However, the key soil-borne diseases controlled with MB in the Agadir area are:

- ▶ Root knot nematodes, *Meloidogyne* spp.
- ▶ Fungal pathogens, *Verticillium* and *Fusarium* wilts (*Verticillium dahliae*, race 1 and *Fusarium oxysporum* f.sp.*lycopersici*, race 1 and race 2)

These pathogens are particularly severe in the sandy soils of the Agadir region.

As a broad spectrum biocide, MB kills a full range of pests and pathogens as well as beneficial organisms. It leaves a biological “vacuum” suitable for re-infestation by plant pathogens. It has been observed that when a pathogen such as *Fusarium oxysporum* f.sp.*melonis* is introduced into the soil (by seeds, or nematodes introduced by workers or the wind), the incidence of the disease is higher in fumigated soils than in non-fumigated soils. In such cases, MB could increase the incidence and severity of some diseases.

Commercial use of alternative – grafted plants and integrated pest management

Alternatives to MB for tomato production are available in Morocco. To decrease the use of MB, an integrated pest management (IPM) programme was introduced in some tomato farms in 1992. It was based mainly on local research results obtained since 1972 by the Department of Plant Pathology of the Hassan II Institute of Agronomy and Veterinary Medicine (Rabat, Morocco). The IPM programme integrates suitable practices in compatible ways to keep key soil pest populations below economic threshold levels.

The IPM programme is now used by many export farmers who are aware that MB will be phased out. Generally such farmers are technically more advanced and watch for new technologies that could improve long-term production.

Techniques

The IPM programme is implemented at various stages of tomato production and comprises:

- ▶ Measures to avoid or reduce pathogen populations eg. sanitation, selection of sites, rotations, soil preparation, organic amendments, and if necessary, soil sterilisation with metam sodium
- ▶ Selection of appropriate cultivars, quality seeds and plants
- ▶ Grafting

The precise practices vary from one farm to the next, according to the local pathogens, farmers’ cultural practices and prevailing environmental conditions.

Controlling Fusarium and Verticillium wilts

Most of the cultivars available in Morocco are resistant to *Fusarium* and *Verticillium* wilt diseases. The most popular cultivars (Daniella and Gabriella) have a high level of resistance to these two pathogens. Daniella is also resistant to Tobacco mosaic virus. Non-chemical methods are used in addition to resistant cultivars and include:

- ▶ Sanitation
- ▶ Crop rotation with pepper or hot pepper, as these are not infected by the two pathogens
- ▶ Seeds certified free of these pathogens
- ▶ Use of non-saline water (saline water increases plant susceptibility to the two pathogens)
- ▶ Weed control (weeds can be hosts to *Fusarium* and *Verticillium*)

Controlling root knot nematodes

Under Moroccan conditions, and particularly in sandy soils, *Meloidogyne* spp is the most important pathogen of tomato and MB is mainly used for this purpose. The appropriate alternative varies according to the cultivar, Daniella or Gabriella.

- ▶ Nematode control for Daniella: Daniella is very susceptible to nematodes, particularly in sandy soils. However it can be grown without MB by adopting the same cultural practices reported above for *Fusarium* and *Verticillium* wilts: grafting on resistant rootstocks or disinfecting soil with metam sodium. Grafting, which at one time was too expensive, is now

Case Study 2

TOMATOES IN MOROCCO: IPM AND GRAFTED PLANTS

widely used in commercial practice.

- Nematode control for Gabriella: This cultivar has the same horticultural characteristics as Daniella when grown in Agadir and is resistant to the same pathogens. It is also resistant to nematodes, but the resistance breaks down under the high temperatures found in Morocco. However, metam sodium applied through the drip irrigation system provides an effective control for nematodes.

Yield and performance of alternatives

The IPM system provides sufficient control of soil-borne pests and is a viable alternative to MB for tomato production in Morocco. Tomato yields using MB can be as high as 200 t/ha. In an IPM system using grafted plants, the yield almost doubles because each plant has two stems.

Acceptability to regulators and markets

IPM components such as grafted plants and other non-chemical techniques do not require safety approval. Metam sodium is an approved pesticide in Morocco and other countries, although it does pose certain risks for health and the environment. Tomatoes produced under the alternative system are very acceptable to purchasers.

Costs

Tomato is a high value cash crop, but it requires an investment of about US\$ 61,585/ha. The cost of MB is US\$ 1,250, representing only about 2% of the production cost (Table 3).

The costs of the IPM systems for Daniella and Gabriella cultivars are similar. For Daniella, for example, the costs are similar to the costs for MB shown in Table 3, with the addition of US\$ 3,240/ha for grafted plants purchased from specialised nurseries (Tables 4 and 5). Initially, there is also the cost of training farmers and farm workers in IPM practices. However, once training has been completed, farmers can almost double their tomato yield (per ha) for a relatively small additional cost of 5%. This explains why grafting and IPM are increasingly popular with farmers.

Applicability to other regions

The IPM systems described above can be adapted and further developed for other regions which have a similar range of soil-borne pathogens and conditions. Grafting is widely used in Japan for open field tomatoes (MBTOC 1998). The entire watermelon crop in Almeria (Spain) is raised from grafted plants, a practice that assisted in eliminating the use of MB in this region (Tello 1998). Grafting is currently used for cucurbits in Morocco, Egypt, Lebanon and Jordan. It is also in widespread use for nursery crops (vegetables and fruit) (MBTOC 1998).

Table 3 Costs of plastic covered tomato production in Morocco

Production items	Costs (US\$ / ha)	% of total
Agricultural machinery	4,580	7.4
Irrigation	6,040	9.8
Plastic green house	30,930	50.2
Wind break	1,450	2.4
Methyl bromide	1,250	2.0
Nursery	1,710	2.7
Crop maintenance	5,940	9.7
Energy	270	0.4
Labour	5,100	8.2
Land rental	520	0.9
Boxes	625	1.1
Financial expenses	3,170	5.2
Total	61,585	100.0

Source: Besri 1999

Table 4 Production costs using MB and alternative IPM system

Production costs	Costs using grafted plants with IPM (US\$ / ha)	Costs using MB (US\$ / ha)
All inputs and labour	64,825	61,585

Breakdown shown in Tables 3 and 5

Source: Besri 1999

Table 5 Material costs for grafted and non-grafted plants

Material costs	Non-grafted plants (US\$ / ha)	Grafted plants (US\$ / ha)
Seeds	1,170	0
Grafted plants ^(a)	0	4,950
Peat	270	0
Alveolar plates	230	0
Black plastic	20	0
Watering cans	20	0
Total	1,710	4,950

^(a) 9000 grafted plants @ US\$ 0.55 each = US\$ 4,950 purchased from specialised nurseries

Source: Besri 1999

Technical information provided by:

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Production of grafted tomato seedlings in Morocco

(Hans Kaack)

Case Study 3

Tomatoes in New Zealand: substrates and *Trichoderma*

REPORT CARD

Crop: Greenhouse tomatoes

Soil pests: Pathogenic fungi, nematodes, weeds

Alternative: Sawdust substrate with *Trichoderma* biological control via irrigation

Yields: Substrate + *Trichoderma* give equal yields to MB

Costs: Alternative costs less than MB

Regulatory approval: None required for substrates. *Trichoderma* is registered in many countries

Comments: Substrates are used by many New Zealand tomato producers; a small proportion have introduced *Trichoderma*. This system is suitable for most climates

Examples of commercial use: Substrates + *Trichoderma* are used for wide variety of horticultural crops in Australia, Denmark, Netherlands, New Zealand, South Africa, Turkey and other countries

Economic significance of crop

New Zealand produced about 29,796 t tomatoes during 1997/8. The market value was about US\$ 48 million in 1998. Production has been increasing, and is expected to continue increasing in the next decade.

Most tomatoes are for the domestic market, although 91 t fresh tomatoes were exported in 1998 (value US\$ 150,000). The main export destinations are Australia and the Pacific Islands.

In 1999 there were 593 tomato producers, some of which have large production units. The number of people employed in the sector is not known.

Region

The climate in New Zealand is predominantly temperate. Greenhouse tomatoes are grown in most regions, and humidity promotes fungal problems in particular. Field tomatoes are grown for processing in two main regions, Gisborne and Hawkes Bay, which together produce 35,000 t on about 450 ha. The total area of greenhouse tomato production was more than 1.7 million m² in 1997/8, and the regional breakdown is presented in Table 1.

GDW Gargiulo and Sons, the greenhouse producer that is the subject of this case study, is in the Christchurch metropolitan area (Canterbury). The temperature varies from a daily average of about 6.4°C in winter (June to August) to 15.5°C in summer (November to February). The greenhouses are heated in winter, like many other tomato greenhouses in New Zealand. The average relative humidity in Canterbury is 70% in summer and 85–90% in winter.

Table 1 Regional breakdown of greenhouse tomato production in New Zealand in 1996

Region	Greenhouse production area (m ²)	Region total (m ²)
North Island		1,200,000
Auckland	785,000	
Wellington	27,000	
Others	388,000	
South Island		336,000
Tasman	50,000	
Nelson	58,000	
Others	228,000	
Total		1,536,000

Source: VegFed New Zealand 1999

Crop production characteristics

The production area for greenhouse tomatoes in New Zealand was 1,550 ha in 1996, increasing to 1,707 ha in 1998.

Gargiulo and Sons grow 55,000 plants in glasshouses covering 4 ha. Seedlings are transplanted in April, grown through winter, spring and summer, and pulled out in February/March the following year. Plant density is 2.5 plants/m².

Use of methyl bromide

New Zealand used about 94 t MB for soil fumigation in 1996, mainly for strawberry production, and about 14% for greenhouse crops. MB was widely used for greenhouse tomatoes in the past, but less than 5% of tomato producers use it now because most have adopted alternative systems.

The following soil pests can affect tomatoes grown in greenhouse soil:

- ▶ Pathogenic fungi such as *Phytophthora* spp., *Pythium* sp. and *Fusarium* sp
- ▶ Nematodes
- ▶ Weeds

Gargiulo and Sons no longer use MB for their greenhouse tomatoes, and so they provide a useful case study of a commercial operation that does not rely on this fumigant.

Commercial use of alternative – sawdust substrate with *Trichoderma* via irrigation

Many growers in New Zealand introduced sawdust as a substrate (soil substitute) for greenhouse tomato production, starting a decade ago, because it offers greater convenience and improvements in crop management compared to growing in soil. Sawdust or other soil-less substrates are now used for tomato production for about 95% of the glasshouse crop grown in New Zealand. Tomatoes for processing are usually grown in open fields and rotated with other crops.

A formulation of *Trichoderma* that can be applied via irrigation systems (called Trichoflow™) was introduced into 5–6 tomato greenhouses in 1998 in Canterbury and is now being used by more than 30 greenhouses nationally. Adoption of this treatment is expected to increase.

Technique

Gargiulo and Sons use a combination of sawdust substrate and *Trichoderma* applied regularly via the irrigation system. The substrate avoids many soil-borne pest problems such as weeds.

Trichoderma is a biological control, a beneficial fungus that can control or suppress certain pathogenic fungi such as *Fusarium*, *Pythium* and *Rhizoctonia*. The system comprises the following components:

- ▶ Fresh sawdust from pine trees (*Pinus radiata*) – a waste product from the forest timber industry in New Zealand
- ▶ Containers for the substrate and tomato plants – in this case black plastic bags
- ▶ A *Trichoderma* formulation called Trichoflow™ – a wettable powder containing selected strains of the beneficial fungus *Trichoderma harzianum* and nutrients to feed the fungus

The plastic bags are filled with new sawdust each year. Tomato seedlings are placed (in their growing-on pots) on top of the sawdust-filled plastic bags. There are two plants per bag, giving a density of 2.5 plants/m². The normal irrigation (fertigation) system is set up. The *Trichoderma* powder is mixed with water and dispensed into the irrigation water from a 200 l stirred tank. The Trichoflow is applied monthly through the irrigation pipes, at application rates of 2 kg per 5–6,000 l water. This is doubled to 4 kg per 5–6,000 l during the traditional periods of high crop stress (September to November in New Zealand).

The sawdust provides cellulose and other carbon-based food sources for the *Trichoderma* to grow on. The Trichoflow formulation contains water dispersable nutrients that are designed to feed and support the beneficial fungus while it gets established in the growing media. Water use, electrical conductivity (EC), temperature and nutrient levels are monitored regularly.

Yield and performance of alternative

The substrate and *Trichoderma* system provides highly effective prevention of disease caused by soil/water borne pathogens. When the sawdust was used without *Trichoderma*, Gargiulo and Sons had widespread problems with *Phytophthora*, a fungal root rot that caused average crop losses of 10–20% or considerably more in bad years. Chemical pesticides did not adequately control this disease problem.

Since using the *Trichoderma* formulation the production manager reports that the company has had excellent results in combating the root rot problem. In the 1998 season they did not lose a single plant through root disease. He also noted that the plant root systems were substantially better when this biological control was used: roots were twice the normal length and developed a highly dense fibrous system. Adding the *Trichoderma* has significantly improved crop performance and increased yield (per m²) by about 10%. Yields from the substrate and *Trichoderma* system were about 50 kg/m² in 1998.

Soil fumigation rarely controls fungal disease indefinitely and usually results in unfilled biological niches which can easily be filled with disease-causing fungi coming from below the fumigation zone or brought in the water supply. Soil fumigation kills most of the beneficial microorganisms along with soil pathogens. *Trichoderma* and similar beneficial soil organisms help to protect plant roots from disease.

Table 2 Costs of soil-borne pest control using sawdust substrate and *Trichoderma* compared with MB, for greenhouse tomatoes (prices in 1998)

Item	Costs using substrate and <i>Trichoderma</i> ^a (US\$ / m ² per year)	Costs using MB (US\$ / m ² per year)
Soil fumigation (contracted service)	0	1.48
Plastic bags and sawdust	0.33	0
<i>Trichoderma</i>	0.12–0.18	0
Labour (estimated) for setting up substrate bags etc.	0.40	0
Total	0.85–0.91	1.48

^a Plant density is 2.5 plants/m²
Source: Hunt 1999, Marsden 1999

Case Study 3

TOMATOES IN NEW ZEALAND: SUBSTRATES AND *TRICHODERMA*

Acceptability to regulators and markets

This *Trichoderma* formulation is sold as a soil/media bio-inoculant without specific disease claims and as such does not require regulatory approval in New Zealand or Australia. Other formulations sold as bio-pesticides with specific disease claims require registration in New Zealand and most other countries. For example, *Trichoderma* products for prevention and control of silverleaf and *Armillaria* root rot in orchard trees and vines (Trichodowels® and Trichoject® by Agrimm Technologies) are registered in New Zealand and are likely to be registered in other countries in the near future.

The substrate and biological control system is very acceptable to wholesale purchasers of tomatoes because the *Trichoderma* formulations are safe natural products manufactured with food grade components and nutrients. They are acceptable for use by certified organic producers.

Costs

The cost of the sawdust substrate and *Trichoderma* is shown in Table 2. In New Zealand MB is applied by a licensed fumigator as a contracted service. If the farmer were licensed to apply the MB himself, the MB cost would be slightly lower.

Normally, Gargiulo and Sons would have used three applications of pesticides (fungicides) to try to control the *Phytophthora* problem. The *Trichoderma* is much cheaper – it costs only one-quarter of the amount previously spent on fungicides. The fungicides cost US\$ 7,155/ha, while the *Trichoderma* formulation costs about US\$ 1,800/ha per year.

The alternative system probably requires more labour than MB fumigation for setting up the substrate bags. Adding a biological control via the irrigation system adds only a small amount of labour.

Applicability to other regions

Table 3 gives examples of countries where substrates and *Trichoderma* are used commercially.

The system does not rely on climatic conditions or soil types and can therefore be used in any world region where there are suitable materials. The system could be utilised for most horticultural crops grown under glass.

Table 3 Examples of countries and crops using substrates and *Trichoderma*

Country	Horticultural crops
Australia	Greenhouse tomatoes, cucurbits, peppers, flowers Commercial nurseries Open field melons, peppers, cucurbits
Denmark	Greenhouse vegetables and flowers
Netherlands	Greenhouse crops
New Zealand	Greenhouse tomatoes, cucurbits, peppers, flowers Commercial nurseries Open field melons, tomatoes, flowers, strawberries
South Africa	Greenhouse crops
Turkey	Greenhouse tomatoes, cucurbits, flowers

Compiled from: Hunt 1999; Prospect 1997; Gyldenkaerne *et al.* 1997

Technical information was provided by:

Dr John S Hunt, Technical Director, Agrimm Technologies Ltd, Christchurch; and VegFed New Zealand.

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Tomato production using sawdust substrate and biological control in New Zealand

(FruitFed New Zealand)



Case Study 4

Tomatoes in Brazil: substrates in seed-trays

REPORT CARD

Crop: Tomato seedlings

Soil pests: Nematodes, weeds, fungal diseases

Alternative: Substrates in seed-trays

Yields: Substrate seedlings give equal yields to MB

Costs: Alternative system costs substantially more than MB, but saves labour

Regulatory approval: None required

Comments: Suitable for all regions and many types of seedlings

Examples of

commercial use: Natural substrates are widely used for seedlings in Europe

Economic significance of crop

Brazil is the largest producer of tomatoes in South America, growing more than 2.8 million t in 1998. This comprised almost 1.6 million t fresh tomatoes and 1.3 million t tomatoes for processing. Tomato production has increased substantially since the 1980s and is expected to reach 4 million t in the next decade (Table 1). The value of the tomato sector in 1998 was US\$ 560 million for fresh tomatoes and US\$ 100 million for tomatoes for processing, making a total of US\$ 660 million.

Most of the tomatoes are sold on the domestic market, but about 10,000 t are exported to Argentina, Paraguay and other countries. Exports are expected to increase to around 100,000 t/yr primarily as a result of Mercosul, the common market agreement in Latin America. The tomato production sector provides direct employment for about 60,000 people in Brazil.

Region

About 60% of the fresh tomatoes are produced in São Paulo state. The remainder are grown in the other states of Brazil, primarily around major cities. Industrial tomatoes for processing are grown primarily in the states of Pernambuco, Minas Gerais, São Paulo and Goiás. Most of the greenhouse production occurs in São Paulo state. The climate in these diverse regions varies from temperate to tropical.

Crop production characteristics

The production area is about 65,000 ha. Fresh tomatoes grown in open fields account for more than half this area. Santa Cruz and Carmen are important tomato varieties.

About 5,000 producers grow open-field fresh tomatoes, known as staked tomatoes, while an additional 5,000 produce greenhouse tomatoes. About 850–900 produce industrial tomatoes.

Table 1 Trends in tomato production in Brazil, 1987–2007

Type	Tomato production ('000 t)				
	1987	1992	1997	1998	2007 predicted
Fresh tomatoes – open field	1,100	1,200	1,200	1,400	1,600
Tomatoes for processing – open field	680	707	1,200	1,300	2,000
Greenhouse tomatoes	–	–	100	150	400
Total	1,780	1,907	2,500	2,850	4,000

Source: Minami 1999

For staked tomatoes, farm sizes vary from small to very large, although the average farm size is about 2 ha. An average farm produces or purchases about 30,000 tomato sets (seedlings) per year, and transplants them in the field at the rate of about 15,000 plants for each ha. Seeds are planted from February to as late as August in some cases.

Use of methyl bromide

Brazil imported about 1,748 t MB in 1997, primarily for tobacco seed-beds. It is used for various horticultural crops, greenhouses and seed-beds. This case study focuses on tomato seedlings, where MB has traditionally been used by farmers who produce their own 'paper pot' seedlings for open field, staked tomatoes. In this system, the farmer makes small heaps of soil and manure mixture, covers them with plastic sheets and applies MB from small cans. The sterilised soil is put into paper pots made by rolling old newspaper around a wooden mould. Seeds are planted in the pots and the seedlings are later transplanted to the open field. The procedure is time-consuming for farmers and their families, but small farmers in particular have traditionally preferred this system because the material costs are cheap.

The main soil pests and pathogens for tomatoes vary from region to region, and include the following:

Case Study 4

TOMATOES IN BRAZIL: SUBSTRATES IN SEED-TRAYS

- ▶ Nematodes
- ▶ Fungal diseases caused by *Phytophthora* spp., *Fusarium* spp. and *Verticillium* spp.
- ▶ Weeds

Commercial use of alternative – substrates in seed-trays

In some areas growers have stopped using MB for staked tomato seedlings because the paper pot system was time-consuming. Large growers were probably the first to adopt an alternative utilising substrates and seed-trays.

Technique

The principle of this alternative is that clean substrates are used in place of soil. Clean substrates are free from soil-borne pests and pathogens and do not need to be treated with MB. Farmers can either grow their own seedlings or purchase them from specialist producers. Typically, the following materials are required:

- ▶ Seed-trays (typically 128 cells per tray)
- ▶ Substrate
- ▶ Pelletised seeds
- ▶ Wooden tray to assist in planting seeds accurately, and gadget to help release mature seedlings from seed-tray
- ▶ Structure and plastic cover for trays

Commercial substrates are produced from composted pine bark mixed with vermiculite (expanded mica), although the composition varies and a wide range of materials could be used. Farmers could make their own substrates (sterilised with solarisation or steam) if they wished to do so. The seed tray cells are filled with clean substrate, and a seed is planted in each cell. The trays are covered and watered regularly until the seedlings are mature.

Yield and performance of alternatives

Provided that the substrate is of adequate quality (ie. from a material that is free from pathogens), substrates provide results equal to those obtained from MB. Typical yields are 80 t/ha for open field (staked) tomato crops, and can be expected to be the same whether the seedlings are produced in substrates or MB-treated soil (Table 2). Substrates have now been used successfully for several years by some growers. A large 25 ha farm in São Paulo state, for example, has used substrate seedlings for several years and achieves yields of 90–100 t/ha.

The MB system requires more labour for making paper pots, although small farmers have preferred to do this rather than purchase inputs. Substrates can produce more uniform seedlings.

Table 2 Tomato crop yields using MB or substrates for seedling production

Tomato yield	Using MB (t / ha)	Using substrates (t / ha)
Typical yields in open fields ^a	80	80

^a In São Paulo state, the main fresh (staked) tomato production region

Source: Minami 1998

In certain instances, quality control in the production of commercial substrates has not been sufficient, giving lower germination rates than expected. This problem can be resolved by introducing adequate quality control procedures in facilities that make substrates.

Costs

Purchased inputs for the substrate system cost substantially more than the MB system (Table 4), and an initial investment in training and technical advice is required for their proper use. However, the substrate system requires less labour. Seed-trays can be used for several years if they are handled with care. Substrates have to be purchased each year.

Acceptability to regulators and markets

No regulatory approval is needed for the substrate system. The establishment of national quality control standards for manufactured substrates would help to ensure their consistent performance.

Tomatoes produced from this alternative are very acceptable to retailers and customers – there is no difference in quality or other characteristics.

Applicability to other regions

Growing seedlings in substrates – or purchasing seedlings produced this way – could be used successfully by tomato farmers in other regions and climates. The alternative is suitable for controlling all soil-borne pests traditionally controlled by MB. It is applicable for seedling production for a wide range of horticultural crops.

Substrates are widely used for vegetable and fruit nurseries (protected cultivation) in countries such as Canada, Denmark, Germany, Israel, Mexico, Morocco, Netherlands, Spain, Switzerland, UK, USA and Zimbabwe (MBTOC 1998).

Case Study 4

TOMATOES IN BRAZIL: SUBSTRATES IN SEED-TRAYS

Tomato seedlings produced in natural substrates in seed-trays

(Melanie Miller)



Table 3 Performance and benefits of substrates and MB

Substrates in Seed-trays	MB system
Seedlings are often more uniform	Seedlings can vary in size and maturity
Seedlings develop and are ready for planting earlier than MB systems	Seedlings develop more slowly
Seedlings recover quickly after transplantation because roots are protected by substrate plug	Seedlings can take longer to recover after transplantation
Farmers save labour either by purchasing seedlings, or spend less time filling seed-trays and planting seeds than they would using the MB system	Farmers spend 10 days on average making paper pots, in addition to time spent mixing and sterilising soil, filling pots and planting seeds

Table 4 Comparison of costs of seedlings produced with substrates and with MB

Item	Cost of MB paper pot system (US\$ for seedlings for 1 ha) ^a	Cost of substrates and seed-trays (US\$ for seedlings for 1 ha)
MB fumigant	60	0
Plastic sheets and covers	100	202
Paper	8	0
Seed-trays	0	80
Substrates	30	46
Structure for cover	0	100
Total	198	428

^a Approx. 15,000 seedlings

Source: Minami 1999

Technical information provided by:

Prof Keigo Minami, University of São Paulo, Brazil; Dr Melanie Miller, MBTOC Member, Touchdown International, Australia.

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Case Study 5

Tomatoes and cucurbits in Egypt: certified organic methods

REPORT CARD

Crop: Open field tomatoes, greenhouse tomatoes and cucumbers

Soil pests: Nematodes, fungi, weeds, soil insects

Alternative: Certified organic and biodynamic production methods, using mature compost and biological controls

Yields: System gives lower yields than MB

Costs: Organic production costs are lower than MB, and farmers get higher prices for their products

Regulatory approval: None required

Comments: Organic production is carried out on more than 2,000 hectares in Egypt. International demand for organic products is increasing. Suitable for many regions.

Examples of commercial use: Organic and biodynamic horticultural production in Europe, North America, Africa, the Middle East, Asia and Latin America

Economic significance of crops

Vegetable crops such as cucumbers, tomatoes and bell peppers have a high economic importance for growers. Prices vary greatly according to supply and demand. The highest prices are available for winter production and Ramadan. Some tomatoes and cucurbits are exported but most are produced for the domestic market.

Tomatoes and cucurbits accounted for more than 80% of the cultivated horticultural area during two cropping seasons (field and protected production) in 1996 (Table 1). Data are not available for the number of farming families and farm workers employed in these sectors.

Table 1 Horticultural production area in Egypt (1996)

Crop	Production area (ha)	Percent of total
Tomatoes	70,500	55%
Cucurbits	38,600	30%
Bell peppers	16,800	13%
Strawberries	2,900	2%
Total	128,800^a	100%

^aTotal excludes french beans

Source: GTZ 1998

Region

Egypt has Mediterranean and desert climates. Temperatures in the main horticultural areas vary from 15°C to 45°C, while rainfall ranges from 0 to 85 mm/yr. Soil types are mainly sandy to sandy loams in desert areas and fluvial sediment, to heavy clay soils in the Nile valley and delta.

Crop production characteristics

Commercial protected cultivation is carried out from autumn (October) till spring (April). The majority of tomatoes are produced under small holder conditions in open fields throughout the entire year. There are two main systems:

- ▶ Greenhouses: Steel construction covered with plastic, average area about 500 m², drip irrigation, sandy soils, single cropping. Producer sizes: small producers have a few greenhouse units, medium producers have up to 80 units, and large producers have up to about 500 units. Most grow only one crop per year and leave land fallow from spring to autumn.
- ▶ Low tunnels (cloches): Semi-protected system because the plastic is removed during days with sunshine. Crop rotation is standard. Seedlings for field production are produced in on-farm nursery beds.

Sekem farm, the subject of this case study, produces and sells organic products in Egypt as well as exporting to northern Europe. Sekem produces a range of crops, including greenhouse tomatoes and cucumber, and open field tomatoes. It grows tomato varieties such as Florida, BTU, Castle Rock, TY Jacal, Marmand and Super Marmand, producing winter, early summer and late summer crops.

Use of methyl bromide

Egypt used about 74 t MB for soil fumigation in 1996. It is mainly used for greenhouse production of tomatoes, cucurbits, peppers and other vegetables. It tends to be used by larger producers who grow only cash crops like vegetables. Soil fumigation is used to control the following soil-borne pests:

- ▶ Nematodes such as *Meloidogyne* spp., *Pratylenchus* spp.
- ▶ Fungi such as *Fusarium* spp., *Verticillium* spp., *Pythium* spp., *Rhizoctonia* spp., *Sclerotinia* spp. and *Phytophthora* spp.
- ▶ Weeds such as sand grasses, nutsedge

Commercial use of alternative – certified organic methods

Organic and biodynamic production methods are used on more than 2,000 ha in Egypt. The

Egyptian Biodynamic Association (EBDA) has adapted biologically based 'Biodynamic' agricultural methods for arid zones. The Association includes a group of more than 150 farms covering about 2,000 ha. They produce certified organic and biodynamic crops, including tomatoes and cucumbers. One of these farms, Sekem, has a production area of about 70 ha.

Agricultural consultants from the Egyptian Biodynamic Association work with farmers while they learn and adopt the alternative methods. Research is carried out with Egyptian and international research scientists.

Techniques

International and regional standards for organic and biodynamic agricultural production methods have been established by the International Federation of Organic Agriculture Movements (IFOAM), the international biodynamic association (Demeter Guild) and the EU regulation on organic methods (EC 1991). The UN Food and Agriculture Organisation (FAO) has recently published a report about the increasing importance of organic agriculture around the world (FAO 1999).

The WHO/FAO Codex draft guidelines on organically produced foods provide the following draft definition: "Organic agriculture is a holistic production and management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biodiversity activity. It emphasises the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system." (Codex 1997).

At Sekem farm in Egypt, crops are produced according to the methods required by the EU regulation on organic production and the international 'Demeter' biodynamic standards. These emphasise practices that improve soil health and nutrition, and preclude the use of synthetic pesticides and fertilisers. The main methods used by Sekem to control soil-borne pests are:

- ▶ Careful management of technical aspects
- ▶ Selection of varieties that are appropriate to specific sites, local climates and commercial needs
- ▶ Use of seedlings that are free of viruses – large numbers of seedlings are grown on-farm

- ▶ Application of mature compost (75% plant residues and 25% animal manure)
- ▶ Biological controls such as *Trichoderma* and *Bacillus subtilis*
- ▶ Solarisation when necessary

The site for a compost heap is carefully selected so that it will be shaded from sunlight and close to a source of water. The compost heap is normally 3m wide and 2m high; its length depends on the available residues and the required quantity of compost. The heap is built up in several layers: the first layer is composed of plant residues (10cm deep), and the second layer is composed of animal manure (5cm deep). These layers are repeated until the heap reaches the desired height. Six compost preparations made from plants are added, which add beneficial microorganisms and substances to promote effective composting. The heap is covered by a thin layer of mud. Water is added once a week in winter and twice a week in summer. The entire heap is turned once each month.

The mature compost is added to the soil after ploughing. Before cultivation, a biodynamic preparation consisting mainly of microorganisms and micronutrients is sprayed on the soil at the rate of about 500g in 50 l water/ha. Seedlings are planted out, and irrigation is carefully managed to avoid excess water which promotes diseases. The soil is dug every 2 weeks to remove grass weeds.

The compost is used in open fields as well as greenhouses. Solarisation is mainly used in greenhouses. When solarisation is used, the wet soil (moisture above 70%) is ploughed and covered with a layer of UV-resistant polyethylene for 4–6 weeks during the summer months (May–August). This raises the soil temperature, suppressing certain pests and increasing the biological activity of some beneficial soil organisms. Cultivation is started one week after removing the plastic sheets.

Yield and performance of alternative

Conventional tomato production typically gives yields of about 35 kg/m², while yields from Sekem farms are lower. However, organic

Table 2 Performance and benefits of organic system and MB fumigation

Organic system	MB system
Toxic substances are not used	Concerns about worker safety, food residues, soil and water pollution
Desert sand is turned into fertile soil	Sand and soil are not improved
Plant roots are healthy and better able to resist pest attacks and diseases	Plant roots have no on-going protection
Farmers' skills and confidence are increased substantially	Farmers remain dependent on purchased inputs
Low cost system	High cost system

Case Study 5

TOMATOES AND CUCURBITS IN EGYPT: CERTIFIED ORGANIC METHODS

farmers have much lower production costs and obtain higher prices for their products. The organic system controls soil-borne pests successfully. In addition, the compost turns infertile desert sand into fertile soil.

Sekem's philosophy is to build up human capacity and capital, not just the agricultural capacity. The skills of farmers, farming communities and agricultural engineers are increased by training in seminars and workshops held regularly.

Acceptability to regulators and markets

The organic and biodynamic agricultural methods used by Sekem avoid the use of toxic substances, so no regulatory approval is required for the inputs. Sekem's tomatoes and cucumbers are very acceptable to purchasers – a major UK purchaser of organic products has selected Sekem as a high quality producer of intensive vegetables.

The FAO's report on the importance of organic agriculture notes the export opportunities it offers to developing countries in particular (FAO 1999). The market for organic products is expanding in Japan, the USA and especially in northern Europe. In the USA, sales of organic products have reportedly increased by more than 20% per year in the last seven years, reaching US\$ 3.5 billion in 1996. In Europe, annual sales of organic produce are expected to increase from the current level of about US\$ 11 billion to approximately US\$ 100 billion in 2005.

Costs

The costs for controlling soil-borne pests in greenhouse tomato and cucumber production are shown in Table 3. Total production costs for open field organic tomatoes are typically US\$ 352 compared to US\$ 387 (per 1,000 m²) for conventional chemical methods (EBDA 1999). Certified organic products receive premium prices, which are generally 30–40% higher than tomatoes grown conventionally in Egypt. So the organic farmers get higher prices and profits for their tomatoes.

Table 3 Costs of using organic methods for controlling soil-borne pests in greenhouses

Items	Cost of organic methods (US\$ / 1,000 m ²)
Purchased inputs eg. biological controls	107
Labour	533
Total	640^a

^a Compost also provides nutrients, saving fertiliser costs

Source: EBDA 1999

Applicability to other regions

These agricultural methods can be applied to other horticultural crops and regions. Organic and biodynamic horticultural production occurs commercially in all regions, including Europe, North America, Africa, the Middle East, Asia and Latin America. The demand for organically grown products is increasing steadily in Europe, North America and other regions.

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Dr Werner Gassert, GTZ, Cairo.

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Organic vegetables are now produced in many countries – this photo shows organic tomato plants in Brazil

(Melanie Miller)



Case Study 6

Watermelons in Mexico: mulch and soil amendments

REPORT CARD

Crop: Watermelon

Soil pests: Nematodes, weeds, fungi eg. *Pythium*, *Fusarium*

Alternative: Soil amendments (manure), plastic mulch, direct sowing

Yields: Alternative system gives much higher yields than MB

Costs: Initial investment is higher, but over three years the alternative costs less than MB

Regulatory approval: None required

Comments: System is used by about 80 growers in Mexico. Suitable for other regions

Examples of

commercial use: Soil amendments (eg. compost) are used for horticultural crops such as strawberry, tomato and pepper

Economic significance of crop

The total production value of watermelons in Mexico was more than US\$ 100 million in 1997. In 1996, 390,180 t watermelon were produced, mainly for Mexico City and the domestic market. About 31% is exported, bringing a return of US\$ 46.1 million in 1996. The main export market is the United States.

Region

The main melon production states in Mexico are Sonora, Chihuahua, Jalisco, Nayarit, Veracruz, Guerrero, Tabasco and Oaxaca. It is estimated that 53% of the production is irrigated, while the rest is rain fed. Watermelon is grown in tropical humid and sub-tropical dry climates.

This case study focuses on production in the Mixtec region located in the southeast of the state of Puebla. It is an area of almost 824,000 ha, and includes 46 municipalities with 326 rural communities. The rural communities are poor and migration of workers to areas with more jobs is common.

The Mixtec region is characterised by rivers, river basins, hills and mountains, and slight to steep slopes with gradients from 20 to 60%. Altitude varies from 700 to 1900 m above sea level.

Crop production characteristics

Generally in Mexico, watermelon seedlings are produced in greenhouses or covered areas before being transplanted into the fields. The growing season is between the months of November and May and all watermelon production is irrigated. During the rainy season from July to September double cropping with maize or sesame, squash and beans takes place, while during the drier months watermelon is grown as the major income-earning crop.

In the south part of the Mixtec, watermelon is a traditional crop of small irrigated areas located around the rivers and land with small-scale

irrigation infrastructure, wheels and reservoir dams. Watermelon is grown on 400 ha, mostly sandy soils. There are more than 350 farms producing watermelons in the Puebla Mixtec region. Farms range in size, from 1.5–4.5 ha family farms to large commercial enterprises of more than 20 ha.

Use of methyl bromide

The important soil-borne pests in Mexico's watermelon production are:

- ▶ Nematodes, especially *Meloidogyne* spp.
- ▶ Soil-borne fungi – *Pythium* spp. and especially *Fusarium* spp.
- ▶ Weeds

MB has been used for watermelon production in Mexico since 1989. In the past, many small growers who experienced difficulty controlling soil-borne pests and pathogens with pesticides, turned to MB because they found it more effective. MB is primarily used to fumigate soil for seedlings in greenhouses and may also be used for partially protected seed-beds in the fields. Application rates for watermelon are generally 454 g/m² in field seed-beds.

Commercial use of alternative – soil amendments, mulches and direct sowing

Since 1997 in the Puebla Mixtec region, some growers have started to use plastic mulches and soil amendments in a drip irrigation system for watermelon. This allows direct sowing of seeds in the field, avoiding the need for seed-beds and MB fumigation. The system was adopted because it has advantages such as earlier harvests and higher cash returns.

This alternative method is used by about 80 growers from 20 communities. This represents about 40% of a total of 50 communities producing watermelon in the Mixtec region.

Case Study 6

WATERMELONS IN MEXICO: MULCH AND SOIL AMENDMENTS

Technique

In the Puebla Mixtec region, the alternative is primarily used in open field conditions. The main inputs and equipment are:

- ▶ Manure from chickens, cows or goats
- ▶ Black plastic sheets (mulch) in strips
- ▶ Plastic tubes and a small gasoline pump to set up a drip irrigation system
- ▶ Seeds coated with an anti-fungal agent

The main steps or activities by farmers using the system in open fields:

- ▶ The soil is ploughed with a mechanised plough
- ▶ Chicken, cow or goat manure is added to soil
- ▶ Irrigation system is laid in field
- ▶ Soil is covered with strips of black plastic mulch
- ▶ Holes are made in plastic mulch so that seeds can be planted in the soil

Seeds are imported (generally from the USA) and have already been coated with an anti-fungal treatment. No chemical treatments are needed to control soil pests after the plastic is laid. Conventional insecticides are used to control aerial (above-ground) insects if necessary. The manure is added just once at the beginning of the cycle. Later, one application of chemical fertiliser is applied via the drip irrigation system during the flowering period.

Yield and performance of alternative

The alternative system was adopted because, compared to using MB, it gives:

- ▶ More efficiency in open field conditions
- ▶ Increased yield
- ▶ Earlier harvest
- ▶ Higher and faster cash returns

The conventional MB system used for watermelon in the Mixtec Puebla region gives average yields of 25 t/ha. This yield is lower than 20 years ago, due to accumulated levels of pathogens and insects and depleted soil

nutrients. Using the alternative system, the yield increases to 45 t/ha, regaining the lost productivity. Comparisons of the yields using MB and the alternative are given in Table 2.

The alternative system maintains 95% effective weed control, 80% nematode control and about 85% control of soil-borne pathogens. The harvest date is advanced by about 27 days due to faster growth mainly because the black plastic mulch raises the soil temperature.

Table 2 Comparison of watermelon yields using MB and alternative system

Farm size	Yield using alternative system (t / ha)	Yield using MB (t / ha)
1.5–4.5 ha	45	25

Source: Mendoza and Bejarano 1999

The limitation of the alternative system is the investment needed in the first year to set up the infrastructure for drip irrigation and plastic mulch. However this initial investment is recuperated in subsequent years. Agricultural officials in the Mixtec region have decided to look for a source of regional credit in the state of Puebla to help small farmers with the initial investment.

Acceptability to regulators and markets

This alternative system for controlling soil-borne pests does not require regulatory approval because it does not use toxic materials.

Markets have responded favorably to the increase in production yields and quality. The yield increase and shorter growing period opens up the possibility of growers capturing new markets and increasing the supply to existing ones. As a result, growers in the region are planning to export watermelons in the near future.

Costs

An initial investment is required in the alternative system for technical advice, training and setting up the drip irrigation system and plastic mulches. The drip irrigation materials can be used for 10 years, while the plastic mulch has a life of 2 years because the materials are handled carefully on small family farms. The alternative saves costs associated with the use of machinery, fertilisers, water and pest control. The extra yield leads to slightly higher labour costs for harvesting. The costs are summarised in Table 3.

In Year 1, the alternative system costs US\$ 1,643/ha (including the investment), whereas MB application costs US\$ 1,416. However, in Year

Table 1 Comparison of performance and benefits of alternative system and MB

Mulch, amendments and drip irrigation	MB system
Plants grow stronger and more uniform	Plants tend to be weaker and less uniform
High quality watermelons	Lower quality plants
Earlier harvest date	Requires an extra month growing period
Uses less water because mulch reduces evaporation by 10–50%	Requires more water
Yield of 45 t/ha	Lower yield of 25 t/ha
No significant worker safety issues	Worker safety concerns because MB is a toxic gas
Operation cost is cheaper over 3 years, but needs an initial investment to set up the system	Operation cost is higher, but initial capital investment is not required

2 the alternative system costs US\$ 878, while the MB application costs US\$ 1,416. In Year 3 the cost of the alternative system rises to US\$ 1,178 due to installation of new mulch. Over a three year period the alternative costs about 13% less than MB (Table 3).

Growers are changing to the alternative system because of benefits such as increased yields, earlier harvest, higher prices for fruit and export opportunities in the future.

Table 3 Costs of using MB and alternative system (mulch and soil amendments) for watermelon production in Mixtec region

Item	Alternative system (US\$ / ha)	MB system (US\$ / ha)
Machinery	52	108
Labour	142	112
Seeds	32	32
Fertilisers	51	230
Chemical pest control	510	674
Watering (labour)	26	130
Fuel for water pump	65	130
Sub-total	878	1,416
Initial investment to purchase equipment to set up mulches and drip irrigation	765	0
Total for year 1	1,643	1,416
Total for year 2	878	1,416
Total for year 3	1,178	1,416
Average over 3 years	1,233	1,416

Sources: Mendoza and Bejarano 1999

Applicability to other regions

The alternative system could be used by more cucurbit growers in Mexico and many countries

with similar growing conditions. The materials required are readily available in other regions.

Soil amendments such as compost are used for strawberries and cut flowers in many countries, and for tomato and pepper to a limited extent (MBTOC 1998).

Technical information provided by:

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Watermelon production using mulch and soil amendments in Mexico

(Fernando Bejarano)

Strawberries in Jordan: solarisation with IPM

REPORT CARD

Crop: Greenhouse and open-field strawberries and vegetables

Soil pests: Nematodes, fungi, insects, weeds, parasitic plant

Alternative: Solarisation with integrated pest management

Yields: Alternative gives equal or higher yields than MB

Costs: Solarisation costs substantially less than MB

Regulatory approval: None required

Comments: Increasingly replacing MB in Jordan. Suitable for sunny regions and crop systems that allow a 4–6 week treatment

Examples of commercial use: Used by some farmers for strawberries in Spain; used for vegetables in Japan, southern Italy, Greece, Mexico and other parts of Latin America

Economic significance of crop

In 1997, the Jordanian greenhouse production of tomatoes, cucumbers, peppers, eggplants, beans, strawberries and other horticultural crops reached more than 155,000 t. This was about 11% of the total vegetable production of 1,388,000 t. Of this 327,000 t were exported, mainly to Europe. The total value of exports was US\$ 78.9 million.

Jordan has approximately 1,000 greenhouse farms, employing more than 6,000 labourers during the growing season. This figure increases greatly during the harvesting period.

Region

The Jordan Valley is one of the main irrigated horticultural areas in Jordan. It is a hot, arid region with rainfall of less than 200 mm. Summer temperatures range from 35–42°C, sometimes reaching 45°C; winter temperatures are mild ranging from 15–25°C with the occasional frost at night. The region is 200 to 300 m below sea level with arable land that has predominantly clay loam soils. The main growing season is in the temperate winter months (October to May) in the valley. The upland growing season lasts from March to October.

Crop production characteristics

The total horticultural production area (including tomatoes and peppers) is 30,000 ha in Jordan. In the Jordan Valley in 1997, about 20 ha of strawberries were grown in plastic greenhouses. The main varieties of strawberries are Oso-Grande and Camarosa.

There are approximately 1,000 small, medium and large greenhouse farmers with a total of about 1600 ha. There are about 31,000 greenhouses, each typically 500 m² in size. The majority of farmers grow the same crop each year. However, a few farmers are starting to rotate crops between the seasons.

Use of methyl bromide

MB is used in Jordan to control weeds and soil-borne diseases:

- ▶ Damping off diseases mainly caused by *Rhizoctonia* and *Fusarium* spp.
- ▶ Wilts caused by *Verticillium* spp.
- ▶ Root knot nematodes, *Meloidogyne* spp.
- ▶ Parasitic plant broomrape (*Orobanche* sp.)
- ▶ Weeds
- ▶ Insects such as white grub

The main problems for strawberries are *Botrytis* and white grub. MB has been widely used in intensive horticultural production in Jordan since the middle of the 1980s, mainly because of its relatively convenient application method. MB is used by small, medium and large-scale farms, and is usually applied once a year. The application rate varies from 26 to 50 g/m² (average 40 g/m²).

In 1997, the seasonal price of MB almost doubled because of supply shortages, and as a result many farmers began trying soil solarisation, even if they had only heard about the technology and did not know how to apply it correctly. MB consumption fell from 285 t in 1996 to 150 t in 1997, representing a 53% decrease.

Commercial use of alternative – solarisation and integrated pest management

Soil solarisation in Jordan is mainly used for intensive horticultural production in plastic houses, by small, medium and large farms. Some farmers have completely adopted solarisation, most use both MB and solarisation concurrently, and some are alternating the use of MB and solarisation from year to year.

Use of solarisation has increased mainly because it is cheaper than MB. The technique has been promoted since the late 1980s by the University

of Jordan, and since 1995 by an Integrated Pest Management (IPM) programme of the Jordanian-German Technical Cooperation Program implemented by GTZ. The project has provided technical assistance for 'pioneer farmers' to trial the technique on small parts of their farms in a participatory manner. Other farmers are invited to learn from the experiences of pioneer farmers at field days and via extension activities.

Techniques

The key requirement of solarisation is to achieve soil temperatures that increase biological processes to a level that suppresses pests. Typically, the farmers in Jordan cover the soil with clear plastic for four to six weeks during the hot summer months when crops are not grown. The soil is kept moist via irrigation pipes. In some cases the beneficial fungus *Trichoderma harzianum* is also applied as a biological control to suppress pathogens.

The following steps illustrate a solarisation technique used successfully for the commercial production of strawberries and vegetables in Jordan:

- ▶ Remove residues from the previous crop and deep plough the soil
- ▶ Apply unfermented manure at a rate of 4 m³ for each 500 m² greenhouse (80 m³/ha)
- ▶ Rotovate soil to incorporate the manure
- ▶ Divide area into 100 m² plots with dykes around each
- ▶ Moisten soil with water (500–600 m³ water/ha)
- ▶ Moisten again two weeks later (with 400–500 m³ water/ha)
- ▶ After 10–12 days plough and rotovate to prepare soil for solarisation
- ▶ Lay irrigation pipes
- ▶ Cover the soil with clear polyethylene plastic (2% UV, 100 microns thick) and cover edges with soil to make a tight seal
- ▶ Add water (3 m³ per 500 m²) and continue to water every five days for 45–50 days (2 m³ per 500 m²)

Farmers need to control the application of water because too much water will cool the soil and reduce the effect of solarisation.

Yield and performance of alternative

Soil solarisation controls many soil pests effectively when soil temperatures are raised to approximately 40°C or more, at depths below the root area. The required temperature and treatment time depends on the specific pests and root depth. Studies in Jordan have found that the

Table 1 Crop yields of solarisation/IPM compared to MB – results from several farms

Crop/technique	Yields at farm 1 (t/ha)		Yields at farm 2 (t/ha)		Yields at farm 3 (t/ha)	
	Solarisation	MB	Solarisation	MB	Solarisation	MB
Strawberry	35–40	35–40	–	–	–	–
Tomato	184	176	184	147	144	144
Cucumber	170	170	170	162	153	145

Source: GTZ 1999

Table 2 Performance and benefits of solarisation and MB

Solarisation with IPM	MB system
Costs about 50% less than MB	Expensive inputs
Normal plant form and growth rates	Normal plant form and growth rates
Fits into the off-season in the Jordan Valley	Can be done shortly before planting
Time required 4–6 weeks	Time required 4 days
Labour required during the hottest part of the year	Labour required at cooler time before planting
Effective against soil pests and pathogens	Effective against soil pests and pathogens
Safe for health of farmers and farm workers	Highly toxic- considerable health risks on and off the farm (fumigant drift)

maximum soil temperatures achieved at noon during solarisation were more than 55°C at a depth of 15 cm, and reached 51°C at 20 cm. Studies by GTZ in two Jordanian farms found that solarisation reduced fungal pathogens such as *Fusarium* to zero or barely detectable levels.

In areas where optimum temperatures are difficult to reach, *Trichoderma harzianum* is also applied. Soil temperatures need to be kept lower to prevent the beneficial fungus being killed, although it appears to be somewhat heat resistant: the number of *Trichoderma* propagules increased under solarisation while soil pathogens and other microorganisms decreased. A GTZ study tentatively concluded that raised but not hot soil temperatures increase the efficiency of *Trichoderma* against pathogenic fungi. The *Trichoderma* is produced and sold locally in Jordan. As use of MB decreases in the future, the demand for alternatives such as this will also increase, providing additional business and employment opportunities in Jordan.

Solarisation provides crop yields that are the same or higher than provided by MB (Table 1 provides examples). Farmers express satisfaction with the results. Table 2 compares the performance and benefits of the alternative and MB. The IPM programme reduces environmental contamination and prevents cases of ill-health due to farm-workers handling MB and other toxic pesticides.

Case Study 7

STRAWBERRIES IN JORDAN: SOLARISATION WITH IPM

Acceptability to regulators and markets

Soil solarisation does not require regulatory approval. The beneficial fungus *Trichoderma harzianum* has been registered with the pesticide registration authority of the Ministry of Agriculture in Jordan. Customers are very satisfied with the crop quality, as well as the reduction in pesticide use and residues.

Costs

Solarisation, with or without *Trichoderma*, is cheaper than MB. Table 3 provides the cost of material inputs in Jordan in general, and the subsequent section details the costs of materials and labour for a large strawberry producer (Table 5).

Cost example – large strawberry producer

A farm in the main horticultural area of Jordan ceased using MB some time ago, preferring instead to use solarisation for the past seven years. Strawberries are grown in 80 'monospan' greenhouses – an area of 4 ha. Other vegetables (tomatoes, cucumbers, eggplant (aubergine), beans, sweet peppers and nursery onions) are grown in 51 greenhouses covering 7.5 ha. The farm is one of the largest strawberry producers in Jordan, producing 70 to 100 t strawberries for export per year, in addition to 70 t for the domestic market. The farmer practices single cropping on a rotational basis, for example: strawberry – tomato – cucumber – strawberry. Solarisation is used for 100% of the cropping area. The strawberry 'mother plants' are imported from Canada.

Before changing to solarisation, the farmer used MB, fungicides and nematicides to control soil-borne pests and pathogens. The farmer now finds that all the soil pests are controlled by solarisation and he considers the results very satisfactory.

The farmer has found that his crop yields are the same under soil solarisation/IPM techniques as they were when he used MB (Table 4). The main economic benefits arise from the low inputs for

solarisation compared to MB, as shown in Table 5. Since yields are the same, solarisation is substantially more profitable than using MB.

Table 4 Crop yields from solarisation/IPM

Crop	Yields from solarisation/IPM (t / ha)
Strawberry	35–40
Tomato	175–180
Eggplant	162
Cucumber	200

Source: GTZ 1999

Table 5 Costs of using MB or solarisation for strawberry and vegetable production on a large farm

	Cost of using solarisation (US\$ / ha)	Cost of using MB (US\$ / ha)
MB in small canisters	0	2,538.00
Plastic sheets	535.80	493.50
Labour	56.40	56.40
Water	12.69	–
Total	604.89	3,087.90

Source: GTZ 1999

Applicability to other regions

Solarisation can be used in any region where soil temperatures can reach approximately 40°C at depths below the root area, and where the treatment can be carried out for a 4–6 week period without disrupting the cropping cycle. Solarisation can be combined with other treatments such as *Trichoderma*, and is best used as part of an IPM system.

Solarisation is used commercially for strawberries in some other regions. For example, the technique is used by a limited number of strawberry producers in the major production area of Huelva in Spain. Examples of other crops using solarisation are listed in Table 4 of Case Study 1.

Table 3 Material costs of MB and solarisation in Jordan (1997/8)

Material costs	Average cost of solarisation (US\$ / 1000 m ²) ^a	Average cost of MB (US\$ / 1000 m ²) ^a
Fumigant and sheets	0	292
Plastic sheets for solarisation	100	0
<i>Trichoderma</i> (optional)	40	0
Total material cost	140	292

^a 1000 m² is the area of two standard greenhouses

Source: GTZ 1999

Case Study 7

STRAWBERRIES IN JORDAN: SOLARISATION WITH IPM

Technical information provided by:

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Further information and references

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A video about solarisation has been produced by the Extension Service, Ministry of Agriculture, Israel, and is available in several different languages including: English, Spanish, Portuguese, Arabic, Hebrew, French and Italian. Information available from Mr Tzafir Betzer fax +972 3 697 1649.

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Solarization sheets being laid over irrigation pipes in Jordan

(Volkmar Hasse)

Case Study 8

Strawberries in Uruguay: integrated pest management

REPORT CARD

Crop: Open-field and greenhouse strawberries

Soil pests: Nematodes, fungi, weeds

Alternative: Integrated pest management, including hygienic nursery methods, careful site selection and crop rotation

Yields: IPM and MB give similar yields

Costs: Material costs of IPM are lower than MB, but IPM requires training and more labour

Regulatory approval: None required for crop rotation and hygienic practices. Fungicide dip for mother plants is a registered pesticide

Comments: System is used by most of the strawberry producers in Uruguay. Use of IPM is increasing world-wide; it can be adapted for many regions

Examples of

commercial use: IPM is used for strawberries in parts of Italy and Spain, for vegetables in Spain (Almeria) and Morocco, and throughout the Mediterranean for all manner of intensive horticultural crops

Economic significance of crop

Uruguay produces about 2,380 t strawberries each year. In 1998 the commercial value was almost US\$ 2.9 million. The majority of the fruit is sold on the domestic market, while exports in 1996 amounted to more than 52 t. The main export markets are Argentina and Brazil, with smaller volumes going to Germany, Spain, other European countries and Costa Rica.

The sector provides employment for many farming families in the country, typically at the rate of 7 people/ha at harvest time.

Region

Strawberries are primarily grown in the region of Salto (north west of Uruguay) and to a lesser extent San José (the south). The climate is temperate and wet, with some sub-tropical areas principally in the north. Soil types vary from north to south (argisoles to brunosoles). Across the year, temperatures can range from minus 4.5 to 30°C, with the north generally experiencing greater extremes than the coastal zones. The relative humidity in summer and winter is 61% and 76% in the north west (Salto), but 74% and 82% in the south (Canelones). The humidity is beneficial in preventing water stress to plants, but creates problems for disease control. The climatic factors tend to be amplified by greenhouses and have to be moderated to obtain suitable conditions for strawberry production.

Crop production characteristics

The strawberry production area is 138 ha, comprising 132 ha in open fields and 6 ha of greenhouses. The main varieties of strawberry are Selva, Seascape, Chandler, Oso Grande and Camarosa. The latter three are short-day varieties. Mother plants are mainly imported from the USA and Argentina.

There are about 185 strawberry growers, with production areas varying in size from 0.2 to 10 ha. The majority have 0.25 to 0.5 ha of

strawberries in family farms of about 5 ha. There are three large commercial companies, each growing about 10 ha of strawberries.

The growing season varies according to the variety and plant protection. In Salto for example, planting occurs in February and March; harvesting starts mid-June for mulched plants in tunnels, at the end of June for mulched plants that are not in tunnels, and July for plants without protection. The harvest period extends to December. In San José planting occurs from March to July, depending on the variety, and harvesting takes place from July or September to December for short-day varieties, or from September to June for varieties such as Selva and Seascape.

The soil-borne pests and pathogens in strawberry cultivation are:

- ▶ Nematodes such as *Pratylenchus penetrans*, *Meloidogyne hapla*, *Helicotylenchus* sp., *Hoplolaimus* sp. and *Tylenchus* sp.
- ▶ Fungi such as *Phytophthora* spp., *Fusarium* spp., *Alternaria* spp., *Verticillium* spp., *Colletotricum* spp., *Rhizoctonia* spp.
- ▶ Weeds

Use of methyl bromide

Uruguay uses almost 20 t MB per year in protected cultivation, principally for tomatoes, pepper and cucurbits. MB is not normally used for strawberry production. However, a small producer in the south used MB at one time, applying it at the rate of about 40 g/m².

Commercial use of alternative – integrated pest management

Almost the entire strawberry sector, comprising 138 ha, uses alternatives to MB. This includes small, medium and large producers in Uruguay.

Techniques

Strawberries are produced using an IPM approach, which includes the following components:

- ▶ Hygienic production of mother plants in nurseries
- ▶ Nursery installed in new sites, without a history of strawberry cultivation
- ▶ Crop rotation
- ▶ Neck and roots of mother plants immersed in fungal control product, if necessary
- ▶ Organic fertiliser
- ▶ Black plastic mulch
- ▶ Solarisation (starting to be used for some covered crops)

Growers minimise disease problems mainly by rotating crops and changing the nursery area within the farm. Because of concerns about sanitary problems, primarily soil fungi, a formal programme of IPM is beginning to be introduced in the north west region where most strawberries are produced.

Yield and performance of alternative

In Uruguay, yields using the alternative system are about 45 t/ha from Selva and Seascape, and 31.5 t/ha for short-day varieties such as Chandler (Table 1). This compares with typical yields of 45 and 31 t/ha respectively where MB is used in neighbouring Argentina. (There are no comparative figures for Uruguay because MB is not normally used.)

The system controls soil-borne pests effectively. Table 2 compares the performance and benefits of MB and this IPM system.

Acceptability to regulators and markets

Rotation and sanitation do not require any approval because they avoid the use of toxic substances. The fungicide agent used for mother plants has approval as a registered pesticide. Less fungicide is used when applied to mother plants than if sprayed on the entire crop.

Costs

The material cost of using MB is US\$ 3,400/ha (when applied at the rate of 40 g/m²), while the cost of soil pest control in the alternative system is about US\$ 2,236 (Table 3). This represents 11.8% and 7.7% (respectively) of the entire production cost (Table 4).

Applicability to other regions

The IPM system can be adapted for use by growers in other regions. It is also suitable for other crops like peppers, tomatoes (Case Study 2) and cut flowers (Case Study 11).

IPM is used for strawberries in parts of Italy and Spain. It is used for vegetables in Spain (Almeria region), Morocco and throughout the

Table 1 Crop yields using MB and IPM system

Strawberry variety	Yield using IPM system	Yield using MB
	(t / ha)	(t / ha)
Selva	45	40–50
Short-day variety eg. Chandler	31.5	31

Source: INTA 1999; de León and Peyrou 1999

Table 2 Performance and benefits of IPM system and MB

IPM system	MB system
Low cost for farmers	High cost for farmers
Maintains biodiversity of the soil	Eliminates many soil organisms
Does not deplete the ozone layer	Depletes the ozone layer
No pesticide residues in fruit or soil	Bromide ion residues in fruit and soil
Reduced health risks to farm workers and the local community	Health risks to farm workers and local community
Requires sufficient land for rotation. In some countries this is achieved by farmers renting land or swapping fields with neighbours for one year	No need for additional land

Table 3 Material costs of MB and IPM system for strawberry production in Uruguay

All purchased inputs	Costs for IPM system (US\$ / ha)	Costs for MB (US\$ / ha)
Pest control chemicals	1,236	2,400
Plastic for fumigation or mulch	1,000	1,000
Total cost of materials	2,236	3,400

Source: de León and Peyrou 1999

Table 4 Total costs of strawberry production in macro-tunnel, micro-tunnel and burlap

Items	Strawberry production costs (US\$ / ha)		
	Macro tunnel	Micro tunnel	Burlap (sackcloth)
Black plastic mulch	1,000	1,000	1,000
Pest control chemicals	1,236	1,236	1,236
Synthetic fertilisers	1,026	1,026	1,026
Irrigation equipment	1,000	1,000	1,000
Annual depreciation (a)	6,900	3,700	500
Other costs: eg. organic fertiliser, plants, containers	8,600	8,100	7,163
Labour	9,063	9,153	7,163
Total	28,825	25,215	19,088

^a 25% annual depreciation for irrigation equipment (droppers, connectors); 50% for tunnel plastic; 33% for PVC tubes of macro-tunnels; 50% for burlap.

Source: de León and Peyrou 1999

Mediterranean area in all manner of intensive horticultural production (MBTOC 1998). Use of IPM is increasing in many countries to reduce the health risks from pesticides and to meet the commercial demands of retailers and consumers.

Case Study 8

STRAWBERRIES IN URUGUAY: INTEGRATED PEST MANAGEMENT



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Case Study 9

Strawberries in Scotland: natural substrates

REPORT CARD

Crop: Open-field and greenhouse strawberries

Soil pests: Nematodes, weeds, fungi, soil insects

Alternative: Natural substrates

Yields: Substrates give substantially higher yields than MB

Costs: Substrate system costs much more than MB, but gives higher profits

Regulatory approval: None required

Comments: Substrates are used for strawberries on about 28 ha in Scotland. The system is suitable for many regions

Examples of commercial use: Natural substrates are used successfully for diverse horticultural crops in a wide range of climates, from Finland to the tropics

Economic significance of crop

The total production value of strawberries in Scotland was almost US\$ 20 million in 1998. Production continues to increase and it is expected to reach US\$ 25 million in the next decade.

In 1998, about 3,000 t strawberries were produced in Scotland. About 1,000 t valued at US\$ 8 million was exported (mainly to England). The remainder was sold on the domestic market and valued at US\$ 12 million.

The strawberry industry has about 400 people in permanent employment in Scotland. Temporary employment often reaches 20,000.

Region

The main strawberry growing regions in Scotland are around Aberdeen and Perth. Temperatures in these regions range from -5°C to +25°C; the annual average rainfall is 800 mm; and humidity ranges from 40 to 90%. Soils in the strawberry regions are sandy-loam on chalk.

Crop production characteristics

The total area under cultivation for strawberries in Scotland is 4,000 ha in open fields and plastic greenhouses. The main commercial varieties are Elsanta and Symphony grown from mother plants imported from the Netherlands and England.

The growing season is between March and October and double and triple cropping is the normal practice. Some farmers rotate strawberries with other crops such as wheat and oilseed rape.

Strawberry-producing enterprises range from small 2 ha farms to large commercial enterprises of more than 40 ha.

Use of methyl bromide

MB is used to control the following soil-borne pests in strawberries in Scotland:

- ▶ Fungi such as *Verticillium* wilt, *Phytophthora fragariae* (red core), *Phytophthora cactorum* (stem rot)
- ▶ Nematodes: *Meloidogyne hapla*, *Longidorus elongates*, *Pratylenchus penetrans*
- ▶ Weevils such as *Otiorhynchus ovatus* (vine weevil)
- ▶ Weeds of all kinds, particularly thistle

In Scotland, 80 t of MB were used in 1998 for strawberry production and the trend in use is currently stable. About 25 strawberry producers use MB.

MB application rates vary from about 75 g/m² in open fields to 100 g/m² in greenhouses. In order to control pest infestations, MB applications need to be made every 48 months.

Commercial use of alternative – natural substrate

Substrate systems for strawberries were first developed in the Netherlands in 1975 and have been widely used in other countries for more than a decade. Some Scottish growers introduced substrate systems in 1988, receiving technical support from organisations such as the Agricultural Development and Advisory Service (ADAS) and Farm Advisory Service Team (FAST) in England, in addition to the Agricultural Extension Service (Dienst Landbouw Voorlichting, DLV) and consultants in the Netherlands.

Five farms (28 ha) now use substrates for strawberries in Scotland, representing 7% of the strawberry production area. Farms using the alternative include both small and large enterprises, varying from 2 to 40 ha in size.

Technique

The substrates are used primarily in greenhouses but also in open fields in Scotland (and other countries). Normally, substrates are

Case Study 9

STRAWBERRIES IN SCOTLAND: NATURAL SUBSTRATES

completely free from pests, diseases and weeds, so fumigants and other pesticides do not have to be used to control soil-borne diseases. The farmer is able to manage water and fertiliser inputs, providing an opportunity to maximise crop yields and quality.

The substrate comprises 40% white peat and 60% black peat, imported from the Netherlands and Ireland. Over the last two years, coconut fibre imported from India and Bangladesh has been mixed with the peat, usually making up to 20% of the substrate.

The following materials and equipment are used:

- ▶ 40 x 100 cm white plastic bags for holding peat
- ▶ Any sizes of plastic pots for holding peat
- ▶ Table tops or small platforms for holding plants off the ground (made from whatever materials are available)
- ▶ Drip irrigation system for dispensing water and fertiliser
- ▶ Hand-held testers for pH and electrical conductivity (EC) levels. The pH indicates acidity or alkalinity, while the EC level indicates the total amount of nutrient salts (mainly fertilisers)
- ▶ Straw to cover the mud floor (alleyways) between table-tops – to control weeds and prevent mud splashing onto fruit
- ▶ For open field production: polythene covers for the period when the fruit are ripe, to protect them from rain damage

Activities that lead to successful use of substrate systems include the following:

- ▶ Source of good technical advice
- ▶ Level the soil before establishing the system
- ▶ Obtain accurate water analyses; monitor daily the pH and EC levels in the substrate
- ▶ Manage water and fertiliser carefully; ensure that sufficient water is available at all times
- ▶ Ensure that water quality is good
- ▶ Use only top quality plants
- ▶ Use tray-plants instead of bare-rooted plants
- ▶ Cover plants with polyethylene to protect fruits from splashes and prevent cracking

Each pot or bag is a separate compartment so pathogens do not spread from one to the next. The substrate can be used twice for strawberry production, after which it is sold to garden centres and flower growers. It can also be used as a soil improver on other parts of the farm.

Yield and performance of alternative

The substrate systems produce strawberry yields about 20% higher than MB-treated soil. But

substrate systems have a significant commercial advantage over fumigated soil because they allow two crops per year in this climate, producing yields 46% higher per year (Table 1).

Strawberry farmers in Scotland who are using natural substrates are satisfied with the results, particularly because picking costs are lower and fruit size and quality are improved. This is largely due to the fact that the substrate system allows growers to optimise water and fertiliser applications. Table 2 compares the performance and benefits of MB and substrates.

Table 1 Strawberry yields using substrate systems and MB

Yield using substrate systems (kg / ha) ^a	Yield using MB (kg / ha)
22,000	15,000

^a Substrate systems allow two strawberry crops per year to be grown in this climate, while soil fumigated with MB can only produce one crop per year

Source: Nuyten 1999

Acceptability to regulators and markets

The alternative substrate system does not require regulatory approval. The reduced use of pesticides makes the fruit more acceptable to supermarkets because their commercial risks are reduced.

Costs

A comparison of the costs of using the substrate and MB for strawberry production is given in Table 3. The substrate system costs about 61% more than MB, but gives higher yields and better quality fruit. The high costs occur in the first year when the table-top system is set-up. The pay-back period to the grower using the substrate system is two years. The substrate system is more profitable than the MB system from the third year onwards.

Substrates can be introduced at less cost, without the table-top system and using cheaper, local substrate materials. For example, a recent demonstration trial for strawberries in China funded by the Montreal Protocol's Multilateral Fund found that local substrates gave yields 35% higher, and profits 57% higher, than normal MB systems (González Pérez 1998).

Applicability to other regions

Substrate systems are used commercially for strawberry production in some countries, including developing countries (Table 4). Substrate systems do not rely on climatic conditions or soil types and therefore can be

Case Study 9

STRAWBERRIES IN SCOTLAND: NATURAL SUBSTRATES

used in any region of the world where suitable substrate materials are available. The substrate system can also be used for a wide range of horticultural crops as illustrated in Table 4.

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Table 2 Performance and benefits of substrate system and MB

Substrate system	MB system
Better fruit size and quality	Smaller fruit size and lower quality
More uniform plant and fruit form	Less uniform plant growth
Safe for farmers and farm workers	Concern about use of a toxic fumigant
Raised tables make fruit easier for pickers to harvest	Fruit difficult to pick at ground level
More labour to set up the system, but reduced labour costs due to faster picking	Less labour to apply MB, but higher labour costs at harvest due to slower picking
Soil quality is important	Soil quality becomes irrelevant
Requires good knowledge of techniques and more careful management	Needs less knowledge

Table 3 Costs of using substrate and MB for strawberries

Input	Cost of using substrate (US\$ / ha)	Cost of using MB (US\$ / ha)
Chemicals for treating soil	0	6,500
Plastic sheets for soil	350	250
Other purchased items:		
Substrates	5,000	0
Extra fertilisers	2,500	
Drip system	500	
Labour	3,000	300
Total	11,350	7,050

Source: Nuyten 1999

Table 4 Examples of countries using substrates for commercial production

Country	Crops
Argentina	Tobacco seedlings
Belgium	Strawberry, pepper, tomato, cucumber, roses
Brazil	Flowers, tobacco seedlings
Canary Islands	Perennial vines, banana, tomato (open field)
Denmark	Tomato, cucumber, roses
England	Tomato, strawberry
Finland	Tomato, strawberry, other horticultural crops
Indonesia	Strawberry
Norway	Strawberry
Malaysia	Strawberry
Morocco	Tomato, pepper, nurseries
Netherlands	Pepper, tomato, eggplant (aubergine), cucumber, roses

Sources: Nuyten 1999; MBTOC 1998; Prospect 1997

Example of strawberry production using substrates – simpler systems are also available

(Peter van Luijk BV)



Tobacco seed-beds in Argentina: floating seed-trays

REPORT CARD

Crop: Tobacco seed-beds

Soil pests: Nematodes, weeds, fungi, soil insects

Alternative: Natural substrates in floating seed-trays

Yields: Substrates give the same tobacco yields as MB

Costs: Substrate system costs substantially more than MB, but cost could be reduced if substrates were manufactured locally

Regulatory approval: None required

Comments: System was recently introduced in Argentina. Suitable for many tobacco-producing regions

Examples of commercial use: Used for tobacco in Brazil, South Africa and USA

Economic significance of crop

Tobacco has been an economically important crop in Argentina for many years. In 1997, the production value of tobacco was US\$ 295.5 million. The domestic cigarette sector was worth more than US\$ 2,421 million, while tobacco exports to Germany, USA, France and other countries were worth US\$ 191.6 million. There are well over 20,000 tobacco farmers, and many more people are employed in production and cigarette manufacture.

Two major cigarette companies, Nobleza Piccardo and Massalin Particulares, share the Argentine tobacco market, so the dynamics of crop production are closely related to the needs of these companies. The Argentine government plays an important role via the Fondo Especial del Tabaco (FET) which partially determines the prices paid to farmers, controls the internal commerce and exports, provides production loans, and promotes research programmes and alternative crops.

Region

Tobacco is grown in the provinces of Misiones, Corrientes and Chaco in the north east of Argentina; and Jujuy, Salta, Tucumán and Catamarca in the north west. These regions have a variety of soil types from sand to clay. Altitudes range from sea level to 800 m. The climate varies greatly, from Misiones which is tropical with high rainfall (1,500 mm), to warm temperate areas with low rainfall (600 mm) and areas prone to frosts in Salta, Jujuy or Tucumán. The total area under cultivation is given in Table 1.

Table 1 Area of tobacco production in Argentina

Region	Area (ha)			
	1993/94	1994/95	1995/96	1996/97
North west	32,225	33,300	37,218	32,679
North east	23,506	25,122	25,980	21,786
Total	55,731	58,422	63,198	54,465

Source: INTA 1998

Crop production characteristics

Most of the tobacco is Virginia (65%) and Burley (26%). Producers vary from very small family farms to capital-intensive production companies. In the second largest tobacco region, Misiones, there are 16,000–20,000 tobacco producers, 90% of whom are peasant farmers. In contrast, Jujuy state has about 1,000 large producers.

The tobacco area in Argentina was 54,465 ha in 1996/7. The growing season for tobacco is from May to February, with three main stages:

- ▶ Seed-beds are prepared during May and June in soil beds covered with plastic tunnels or covers
- ▶ Seedlings are planted out in the fields about 80 days after seeds are planted
- ▶ Tobacco leaves are usually harvested from December to February

Use of methyl bromide

MB has been used for tobacco seed-beds for many years because it is relatively cheap and provides good control of pests such as weeds, fungi (eg. *Fusarium* spp), nematodes and soil insects. To date, many farmers using MB feel it is perfect for their needs.

About 230 t MB were used for tobacco seed-beds in Argentina in 1996, rising to nearly 283 t in 1997. Almost 100% of the tobacco seed-beds were fumigated with MB in 1997. However, this percentage decreased in 1998/9 as a result of tobacco companies promoting an alternative substrate system and a 'Prozono Tabaco' project demonstrating alternatives by Instituto Nacional de Tecnología Agropecuaria (INTA), the Argentine applied research and extension service and the United Nations Development Programme (UNDP).

MB is used on farms of all sizes. Approximately 80–100 m² of seed-beds are needed for each ha of tobacco crop, and most farmers use a small (454 g) can of MB for each 10 m² seed-bed. Seed-beds are prepared once a year.

Commercial use of alternative – substrates in floating seed-trays

During 1998/9, a small percentage of growers introduced an alternative substrate system for seed-bed preparation. Growers trialling this alternative system range from small peasant farmers growing less than 1 ha to large tobacco farms comprising 120 ha or more.

Technique

This alternative avoids the need for soil treatments by utilising clean substrates (growing media) purchased from a commercial producer or made on the farm. Substrates can either be made from materials that are free from pests, or they can be treated with solarisation or steam to kill pests. In Argentina, tobacco growers have started using a commercial mixture of peat and perlite (or vermiculite). Other substrate components can be used, provided they allow water, nutrients and air to move in the correct manner for tobacco seedlings.

To set up the floating system for tobacco seedlings, a rectangular seed-bed area (1.13 m by 17.7 m) is levelled in the field and a low wall of brick or wood (12 cm high) is erected around the edge of the bed. The bed and wall are covered with black plastic (150 microns thick) and filled with water, making a shallow pool. Polystyrene seed-trays (typically 0.36 m by 0.56 m in size) with about 288 cells are filled with substrate. A tobacco seed is placed in each tray cell and about 98 trays are floated in the shallow pool. The bed is covered with plastic to prevent the water getting too cold at night and slowing the growth of seedlings. Selected substances may be added to the water to control root growth and algae. For example, charcoal can be used to inhibit algal growth. Fertilisers are also added to the water.

Yield and performance of alternative

The alternative system controls all the target soil pests effectively, provided the substrate materials are free from pests and pathogens. This requires the companies manufacturing substrates to have quality control procedures.

The substrate system provides better seedlings than the traditional MB system in several ways: more seeds germinate successfully; a higher percentage of seedlings are strong enough to be planted out; and more survive transplanting to the field. The final crop is much more uniform, and produces higher grade tobacco leaves. Table 2 compares the germination rate and survival of seedlings. For example, a large 120 ha farm found that the failure rate for transplanted seedlings was 14% on average for the traditional

MB system and 1% on average for the alternative. Small farmers often lose up to 20% of seedlings or even more when using MB, but this can be reduced to 5% with the alternative system. Table 3 compares the performance and benefits of the alternative and MB.

Farmers who have tried the alternative substrate system are pleased with the results. They find that, although the alternative requires more initial investment, it is labour-saving and produces better quality plants than when MB is used.

Acceptability to regulators and markets

This alternative does not require regulatory approval.

The harvested tobacco is much more acceptable to purchasing companies than tobacco grown with MB because the leaves are more uniform and of a higher quality grade.

Costs

The substrate system in Argentina is estimated to cost approximately US\$ 350–370 per seed-bed (sufficient for 1 ha tobacco) compared to US\$ 120–170 for MB. Prices vary from one region to another. In addition, an initial investment is required for training and technical advice. The

Table 2 Germination rate, survival and tobacco leaf grade for tobacco grown using MB and the floating substrate system – examples from small and large farms

Characteristic	Size of farm	Using substrate system	Using MB
Germination rate (GP 90%)	120 ha	90%	75%
Survival of transplanted seedlings	120 ha	99%	86%
Germination and survival of seedlings	2 ha	95%	85%
Grade of tobacco leaf	All sizes of farms	Higher	Standard

Source: Miller 1998

Table 3 Performance and benefits of floating substrate system and MB

Floating substrate system	MB system
Less land required for seedling production, giving more land for crop production	Requires more land for seed-beds
High germination rate	Lower germination rate
Trays allow more efficient management when transplanting seedlings. Seedlings more uniform and therefore require much less labour for sorting	Problems with organisation of transplanting operation. Increased labour for sorting out weak seedlings
Roots remain moist and protected within the substrate when seedlings are transplanted	Roots subject to drying and stress because exposed to sun when transplanted
Seedlings transplant better due to less stress. Growth commences within 1–2 days	Seedlings subject to stress through added handling and root exposure. May take up to a week for seedlings to become established and start growing
Plants can be fertilised within 3 or 4 days	Fertilisers must be applied 10 to 12 days after transplant
Higher grade tobacco leaf	Standard grade tobacco leaf

Case Study 10

TOBACCO SEED-BEDS IN ARGENTINA: FLOATING SEED-TRAYS

alternative is more expensive than MB largely because the substrate is imported from countries such as Canada, Germany or the Netherlands. The cost could be reduced if substrates were to be sourced locally. Currently, the imported substrate accounts for more than 50% of the cost of purchased inputs for the alternative system (calculated over a 3 year period).

Growers have found that the MB system uses much more hand labour than the alternative substrate system. For example, a medium-size farm requires about 30 hours labour to prepare seed-beds using the MB system, compared with about 10 hours on a farm using the alternative method. A large farm (120 ha) found that the MB system required 6.13 labour days to plant out seedlings compared to 0.13 labour days for the alternative system.

Cost example – Small farms in Misiones

In Misiones, a large tobacco production area, small farmers report that they lose up to 15–20% of their seedlings in the MB system because the seed fails to germinate or the seedling has to be discarded because it is weak or poorly formed. To get about 18,000 plantlets (for 1 ha of crop) from the MB system a farmer needs to grow at least 21,000 seedlings. When properly applied, the substrate system loses only about 5% of plants, so the farmer needs to grow only 19,000 seedlings. The alternative also requires much less of the farmer's time for sorting and transplanting seedlings.

On small farms the alternative substrate system costs more than MB, especially in the first year. One example of costs is shown in Table 4. Seed trays can be used for 4 years and black plastic for 2 years, so the costs are lower in the subsequent years (years 2 to 4). Note that prices can vary greatly from one area to the next. The 'Prozono Tabaco' project by INTA and UNDP plans to collect detailed production and economic data from the major tobacco regions and different sizes of farms in Argentina.

Applicability to other regions

The alternative floating substrate system can be used by many other tobacco growers. As part of an INTA/UNDP project in Argentina, growers and other stakeholders are developing a plan for phasing out MB in the tobacco sector. Similar alternatives are being adopted widely in Brazil as a result of pressure from tobacco companies and assisted by a demonstration project being carried out by EPAGRI (the national extension service) with United Nations Industrial Development Organisation (UNIDO).

This substrate system is used commercially for tobacco in Brazil, South Africa and USA (MBTOC 1998). It would be equally effective in most regions that grow tobacco, although in areas where the temperature is low at night (eg. mountain areas) it would be necessary to add a layer of insulation when constructing the plastic pool. In many areas substrates could be sourced locally if technical and financial assistance is made available.

Table 4 Material costs of MB and substrate system on farm in Misiones

Items	Seed-bed cost using substrate system (US\$ / crop ha)	Seed-bed cost using MB (US\$ / crop ha)
Fumigant	0.0	17.0
Plastic sheeting	14.4	21.4
Seed trays	136.0	0.0
Substrates	77.0	0.0
Seeds	20.0	11.7
Fertiliser	3.1	1.0
Total in year 1	250.5	51.1
Total in year 2	104.9	51.1

Source: Tabacos Norte SA 1998

Floating seed-trays trialled by a small tobacco grower in Argentina

(Melanie Miller)



Technical information provided by:

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Cut Flowers in Colombia: integrated pest management

REPORT CARD

Crop: Greenhouse cut flowers

Soil pests: Nematodes, fungi, weeds, soil insects and other arthropod pests

Alternative: Integrated pest management, including hygienic management, compost, resistant varieties, substrates and in some cases steam

Yields: IPM gives similar yields to MB

Costs: IPM systems can cost less or more than MB, depending on the techniques used

Regulatory approval: None required for compost, substrates or steam

Comments: Alternative systems are used on more than 4,500 hectares in Colombia. These IPM systems can be adapted to many other regions

Examples of commercial use: For cut flowers, farmers in many countries use resistant varieties and organic amendments (eg. compost). Steam is used in Europe, while substrates are used in Europe and Canada

Economic significance of crop

Internationally, Colombia has 10% of the global cut flower market and is the largest flower producer after the Netherlands. Within Colombia, the cut flower sector is the second most important agricultural sector after coffee.

Floriculture in Colombia started as a commercial export activity during the 1960s, and grew from an export revenue of about US\$ 20 million in 1975 to more than US\$ 556 million in 1998 (Table 1). The sector now exports more than 147,000 t cut flowers, primarily to markets in the USA, but also to Europe, Canada and other countries. Less than 5% of the flowers are produced for the domestic market.

Floriculture has become an important job provider, accounting for about 75,000 direct and 50,000 indirect jobs. It has also stimulated the development of many related sectors such as transport and other service providers.

Table 1 Volume and value of cut flowers exports from Colombia

Year	Export volume (t)	Export value (US\$)
1992	124,627	340,897,000
1996	140,591	509,496,000
1998	147,775	556,179,000

Source: ASOCOLFLORES 1998

Region

Colombia has an equatorial climate with no seasonal variation. The growing areas are at altitudes of 2,200–2,600 m and are located mainly around Bogotá (the capital city in the centre of the country), Medellín and Popayan near the Pacific coast. There is also a small production area of tropical flowers in the coffee growing regions around 1,200 m above sea level.

Crop production characteristics

Cut flowers are produced by approximately 450 enterprises, comprising more than 4,500 ha of polyethylene greenhouses. Plantation size ranges from large corporate enterprises of more than 100 ha to smaller companies of about 10 ha.

More than 40 types of flowers are grown. Carnations, chrysanthemums and roses comprise about 85% of production, while alstroemerias, limonium, gerberas, gypsophyla and tropical flowers make up the remaining 15%.

Cut flowers are produced all year round. Planting cycles may vary from about four months for chrysanthemums to ten years for roses. Multiple cropping or crop rotation are carried out according to marketing and sometimes phytosanitary considerations. Flowers for production are grown directly in soil beds, while mother-plants and cuttings for propagation are grown in raised beds.

Cut flower production can be seriously reduced by soil pests and pathogens, unless they are managed. The pests prevalent in Colombia are listed in Table 2.

Use of methyl bromide

Floriculture developed in Colombia with heavy reliance on pesticides for soil sterilisation and general pest and disease control. However, MB was seldom used. The majority of growers avoided MB for reasons such as unsuitable soils, MB's phytotoxicity (ie. toxicity that damages or delays crop growth) and the human health risks from handling MB. MB use has now been generally abandoned because it is prohibited under a Colombian regulation agreed in 1996, and the Colombian Association of Flower Exporters has helped in enforcing this measure.

Commercial use of alternative – integrated pest management

Integrated pest management (IPM) is a proven technology in Colombia, having been implemented for more than ten years in many nurseries. About 90% of Colombian flower growers use at least some IPM components. Approximately 50% of the growers use IPM systems that completely avoid the use of soil fumigants (such as metam sodium, dazomet, dichloropropene), and this percentage will probably increase with the global trend for more sustainable agricultural production methods.

Techniques

IPM systems prevent and limit the incidence of pests and diseases by making use of cultural, biological and mechanical methods and minimising the use of chemicals. IPM practices for controlling soil-borne pests include the following in Colombia:

- ▶ Monitoring and scouting – trained people check systematically and regularly for pests and diseases, recording results. Soil samples are taken to identify and count nematodes. Results are analysed and used for making management decisions
- ▶ Excluding pests and diseases and eliminating potential hosts – a variety of preventative practices to avoid the spread of diseases, including clean planting material, phytosanitary procedures, restricted access to greenhouses, careful cleaning of equipment, and strict sanitation measures eg. lime wells in greenhouse entrances
- ▶ Selecting crop varieties that are resistant to diseases or nematodes, where available
- ▶ Using biological controls – mature compost helps to suppress pathogens; beneficial micro-organisms are added to soil to control specific pests eg. *Paecilomyces lilacinus* is used against *Pratylenchus* spp.; species of *Trichoderma* and *Gliocladium* are used to suppress *Rhizoctonia* spp. in chrysanthemum
- ▶ Using physical or mechanical treatments – for example, removing soil and plants in a small area as soon as disease is detected; steam treatments are used in some farms
- ▶ Chemical controls – these are mainly spot-treatments, used only when monitoring indicates they are necessary

Table 3 provides an example of an IPM system for controlling Fusarium wilt (*Fusarium oxysporum* f.sp. *dianthi*) in carnations in Colombia.

Substrates and steam

Substrates such as coal slag and volcanic scoria are used in propagation beds. A few growers use peat as a substrate, but this is expensive because it is imported.

Steam is used for sterilising substrates in propagation beds. A limited number of growers also use steam to sterilise soil in production beds. Steam is economically feasible if growers observe stringent IPM practices (monitoring, sanitation, removal of infected plants etc.) to keep disease incidence low. In such cases it is feasible to sterilise only the upper 30 cm or so of soil, and to spot treat disease foci as soon as they occur. Sterilisation (with steam or MB) does not provide on-going protection, so additional IPM measures are essential to keep diseases controlled during the growing period in these intensive production systems.

Table 2 Important soil-borne pests requiring control in flower production in Colombia

Flower	Soil-borne pest or pathogen	Causal agent
Carnation	Vascular wilt	<i>Fusarium oxysporum</i> f.sp. <i>dianthi</i>
	Nematodes, pin nematode, root lesion nematodes	<i>Heterodera</i> spp., <i>Pratylenchus</i> spp.
	Collembola, symphyllans	Class Symphyllidae, Collembola
	Slugs and snails	Class Gastropoda
Rose	Crown gall	<i>Agrobacterium tumefaciens</i>
	Nematodes, root knot, lesion	<i>Meloidogyne</i> spp., <i>Pratylenchus</i> spp.
Chrysanthemum	Phoma root rot	<i>Phoma chrysanthemicola</i>
	<i>Fusarium</i> wilt	<i>Fusarium oxysporum</i> f.sp. <i>chrysanthemi</i>
	Nematodes – foliar, lesion, root knot	<i>Aphelenchoides</i> , <i>Pratylenchus</i> , <i>Meloidogyne</i>
	Root and stem rots	<i>Pythium</i> spp., <i>Sclerotinia sclerotiorum</i> , <i>Rhizoctonia</i> spp., <i>Sclerotium rolfsii</i> , <i>Verticillium</i> spp.
	Crown gall	<i>Agrobacterium tumefaciens</i>
	Collembola, symphyllans	Class Symphyllidae, Collembola
	Slugs and snails	Class Gastropoda

Source: Pizano 1998

Table 3 IPM practices for controlling Fusarium wilt in carnations

A. Monitoring	Trained personnel work as disease scouts Identify pests and affected areas Use historic information for decision making
B. Cultural control	Crop sanitation Manage fertiliser applications (especially nitrogen sources) Control pH (acid inhibits this fungus) Restrict access to greenhouses
C. Physical and mechanical control	Steam soil Remove and destroy diseased plants
D. Biological control	Resistant varieties Antagonist-suppressive soils and composts Allelopathy (to increase plants' own defences against pests)
E. Chemical control	Disinfection of articles entering greenhouses Soil fumigants when necessary eg. metam sodium, dazomet

Source: Pizano 1998

Case Study 11

CUT FLOWERS IN COLOMBIA: INTEGRATED PEST MANAGEMENT

Examples of two more recent developments in Colombian flower production are composting and hydroponic substrates, used as part of IPM systems. These methods have had particularly good results and are described below.

Composting

Plant refuse is constantly produced as a by-product of the cut flower industry. Each day, an average of 2.25 m³ of plant refuse is collected from each cultivated ha, mainly from prunings and discarded plants. In the past this refuse was burnt but some Colombian growers have now introduced sophisticated and successful composting systems. Composting is generally done in the open field. It requires adequate space, well-aerated areas, and careful sorting of residues. The decomposition rate is maximised by cutting plants into smaller pieces and controlling conditions such as temperature, pH, oxygen aeration and humidity. The compost mix sometimes includes a microbial broth made on the farm, to increase the range and number of beneficial soil microorganisms. Depending on the type of plant residues, composting takes 4–5 months and temperatures in the mound may reach 70°C. Such temperatures are lethal to many pathogenic fungi and bacteria. The compost is used as an organic fertiliser. It helps suppress many soil-borne pathogens and improves water retention in the soil.

Some farms feed the resulting compost to earthworms (often *Eisenia foetida*, commonly known as Californian or red earthworms), producing a rich humus. The humus is more uniform than compost, provides nutrients to plants more directly, and has better water retention capacity. Compost, on the other hand, improves soil structure better and is cheaper because it requires less processing. The type of plant residue is another consideration: earthworms do not seem to like dendranthema, while they thrive on rose residues.

Hydroponic substrate system

Recently, several carnation growers have tried a new system offering the advantages of substrates raised above the ground, but without the high costs of constructing raised beds and necessary infrastructure.

The system requires constructing beds lined with heavy polyethylene film directly on the ground, providing a barrier from pests in the soil. The beds are then filled with burnt (sterilised) rice hulls to a depth of 15–20 cm. Substrates could be steamed instead of burnt. Carnation plants are then planted in the beds and grown as usual.

Care needs to be taken to ensure that nutrients and water levels are maintained in the hydroponic beds. Iron deficiency is a potential problem in some cases, but can be overcome by appropriate fertiliser amendments such as iron chelates.

Yield and performance of alternatives

These systems are used very successfully. IPM for the control of pests and diseases in floriculture is now a proven technology in Colombia, having been implemented for more than ten years in many nurseries. Full IPM systems lead to excellent results by improving the efficiency of the business and over time giving significant savings both in natural resources and in money.

In the case of *Fusarium* wilt of carnations, for example, growers using IPM report losses of only 1–2% per year due to this disease, compared with 20–40% and more when relying on soil sterilisation only. This approach is not only environmentally friendly but is also economically feasible and highly successful with studies showing that growers can save up to 50% in pesticide costs.

Some growers using composting techniques use 50% less chemical fertilisers, have less need to apply soil chemicals and achieve higher productivity yields. Plant vigour improves and productivity increases because the humus increases soil biomass, replaces essential plant nutrients and re-introduces beneficial soil microorganisms. For example, a grower found that after many years of growing chrysanthemums as a monoculture he experienced severe soil fungi problems such as *Phoma* spp. and *Pythium* spp.. After adopting the composting technique, this grower managed to virtually eliminate these pathogens without the need for soil steaming or fumigation.

To date, growers using the new hydroponic substrate system report a significant reduction in losses caused by *F. oxysporum*, particularly on varieties that are highly susceptible. Losses as high as 45% were reduced to only 3% in one production cycle.

Many growers using alternative IPM systems report that they are able to sustain strong plant vigour and high production yields even in a monoculture system. This is a very positive result considering the virulence of some pathogenic organisms in Colombian soils and climate.

Table 4 compares typical yields while Table 5 compares the performance and benefits of MB and IPM systems.

Acceptability to regulators and markets

The best practice IPM systems rely on non-chemical practices which do not require regulatory approval because there is no risk of toxicity. In cases where pesticides are used they are registered by the Colombian Institute of Agriculture (an agency of the Ministry of Agriculture) and sometimes by the Ministries of Environment and Health.

The flowers produced using IPM systems are very acceptable to purchasers. In the past Colombian growers were forced to address a variety of environmental issues by local and international NGOs and consumers in export markets. This led to the ECOFLOR Code of Conduct for producing environmentally friendly flowers and later FLORVERDE, the official programme of the Colombian Association of Flower Growers and Exporters (ASOCOLFLORES) and the widespread adoption of IPM.

Costs

A comparison of soil-pest control costs in 1995 found that the IPM + compost system cost US\$ 4,930 compared to US\$ 6,827 for the MB system (including rice hulls) (Rodríguez-Kábana 1998). IPM systems require a significant initial investment in training. Once set up, IPM systems that do not use fumigants tend to be more cost effective than MB, when considering yields, flower quality and productivity time.

Cost example – steam sterilisation

Steam is normally cost-effective when combined with stringent IPM practices to keep disease incidence low. If disease incidence is high, steam is generally too expensive. Table 6 presents costs of treating one ha with steam for the control of *Fusarium* wilt of carnations. In this type of steam application, the fuel costs depend largely on the depth of steam injection which is determined by the disease incidence:

- ▶ Low disease incidence: steam injected at 30 cm
- ▶ Medium severity: steam injected at 30 cm for half the treatment time and at 80 cm for the remainder
- ▶ High disease incidence: treatment to depth of 80 cm

For comparison, the cost of applying MB is estimated to be about US\$ 5,000/ha in Colombia but growers must then wait before they can plant their crops, representing a significant loss of revenue of up to US\$ 15,000/ha. With steam sterilisation, crops can be planted straight away, avoiding revenue losses.

Table 4 Typical yields of IPM systems that do not utilise soil fumigants

Varieties	Yield from IPM system (Bunches / m ²)	Yield from MB system (Bunches / m ²)
Carnations (pompons) ^a	10.5	10.5
Fuji chrysanthemums ^b	5.8	5.8

^a 7 stems per bunch ^b 10 stems per bunch
Source: Gutierrez 1997

Table 5 Comparison of performance and benefits of IPM system and MB

IPM system	MB system
In well-managed farms the quality of cuttings can be higher	Normal quality cuttings
Plants are healthier and grow more uniformly, producing high quality cut flowers	Risk of phytotoxicity can lead to less uniformity and lower quality cut flowers
Worker safety issues reduced	Worker safety concerns
No danger to the ozone layer	Depletes the stratospheric ozone layer
Cheaper after initial investment in training, infrastructure and equipment	More expensive in longer term

Table 6 Steam sterilisation costs for the control of *Fusarium* wilt of carnations

Direct and indirect costs	Cost of using steam treatment (US\$ / ha)		
	Low disease incidence	Medium disease incidence	High disease incidence
Direct costs			
Hand labour	2,003	3,258	8,010
Fuel	3,379	5,491	13,515
Maintenance	109	177	435
Equipment depreciation	318	517	1,270
Other materials ^a	262	429	1,051
Indirect costs			
Steam boiler transport	165	165	165
Energy	742	1,208	2,968
Total	6,980	11,245	27, 415

^a Tents, rakes, pipes and tubing and other
Source: Flexport de Colombia 1998

Cost example – compost and humus

When compost was introduced as a soil amendment and fertiliser in a nursery producing *Dendranthema*, the nursery was able to reduce the purchase of chemical fertiliser by half, reducing costs by 15–20%. Pre-existing problems with *Phoma* and *Pythium* were virtually eliminated, and soil sterilisation is no longer required (Jaramillo and Valcárcel 1998). The main reason for this is better drainage and aeration, and beneficial microorganisms which compete with pathogens.

The use of humus in rose nurseries allows a similar 50% reduction in chemical fertiliser (Valderrama 1998), reducing costs by 10%, and sometimes by 20%. The humus also reduces water consumption and gives higher yields.

Case Study 11

CUT FLOWERS IN COLOMBIA: INTEGRATED PEST MANAGEMENT

Applicability to other regions

All techniques described are feasible for tropical and sub-tropical horticultural production areas around the world. These technologies can be successfully adapted in other regions (including Central and South America, Africa and Asia), utilising local materials and resources. These IPM systems provide the benefit of safer working conditions and stable incomes for farming communities.

Farmers in many countries use resistant varieties and organic amendments (eg. compost) in cut flower production. Steam is used in Europe, while substrates are used in Europe and Canada (MBOC 1998).

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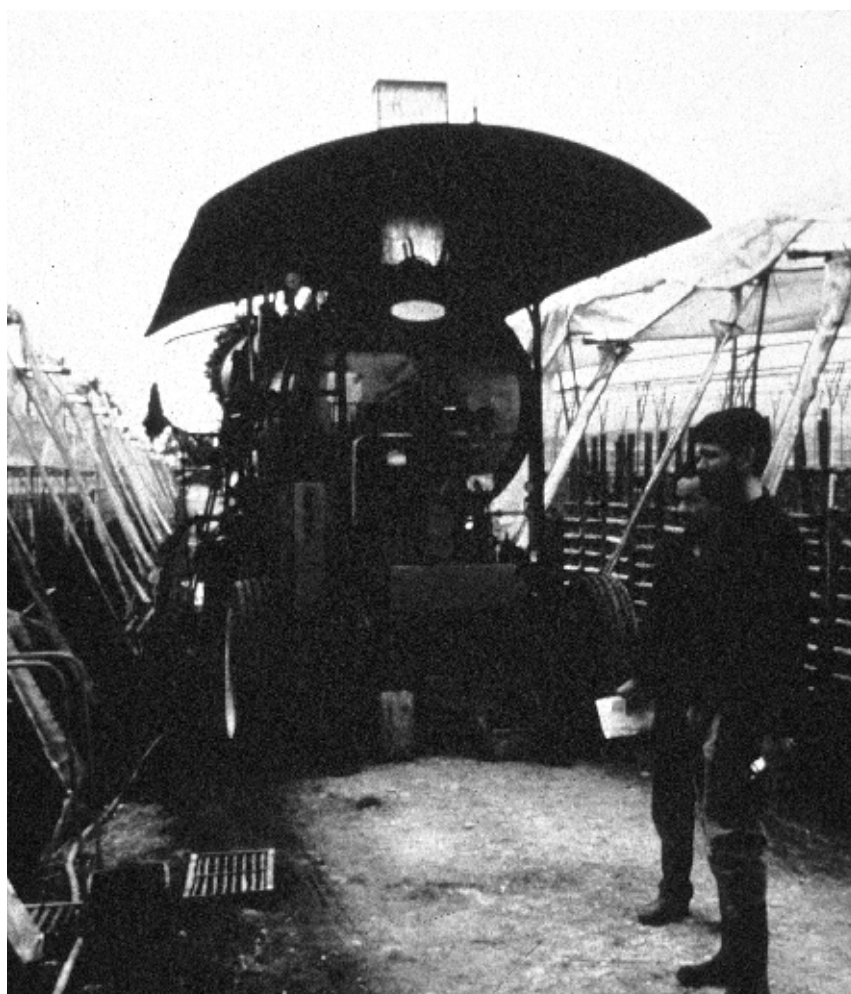
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Steam is used for sterilising propagation beds in the Colombian cut flower industry

(Rodrigo Rodríguez-Kábana)



Cut Flowers in Côte d'Ivoire: natural substrates

REPORT CARD

Crop: Cut flowers and ornamental plants

Soil pests: Mainly nematodes

Alternative: Natural substrates: waste coconut fibres

Yields: Substrate gives same or higher yields than MB

Costs: Coconut substrate costs less than MB

Regulatory approval: None required

Comments: Introduced by one plantation in Côte d'Ivoire. Suitable for many regions

Examples of commercial use: Various substrate materials are used commercially for cut flowers in Canada, Europe, USA and (to a limited extent) in Kenya. Substrates are widely used for greenhouse vegetable production in Europe

Economic significance of crop.

The production value of cut flowers and ornamental plants in Côte d'Ivoire is estimated to be approximately US\$ 1.5 million per year. Cut flowers are produced for the domestic market and ornamental plants are exported to France.

The coconut substrate alternative described in this case study has potential economic importance for Côte d'Ivoire. This country has a large palm oil industry, generating coconut by-product waste that could be developed into a new local and export industry to help replace MB. This would bring employment opportunities to a developing nation currently experiencing high unemployment.

Region

Côte d'Ivoire lies about 200 miles north of the equator and has a predominately equatorial climate. The soils are predominantly sandy. The main regions for growing flowers and ornamental plants are in the western area near lagoons that run along the coast, where fresh water can be pumped to the plantations.

Crop production characteristics

The total area in Côte d'Ivoire producing cut flowers and potted plants is estimated to be more than 100 ha, some of which is under cover.

Plantations range in size from small to large commercial enterprises of at least 60 ha. The plantation that is the subject of this case study has 60 ha of cut flowers and potted ornamental plants. These are grown in greenhouses and open fields.

Use of methyl bromide

Until recently, there was a heavy reliance on MB for soil fumigation to control nematodes in particular. The soils of Western Africa are ancient and nutrient poor having undergone no rejuvenation processes for millions of years. These factors, combined with the equatorial

climate, provide perfect conditions for the development of pathogenic nematodes which can devastate a crop in days. Ornamental plants grown in these soils tend to be stunted and have roots severely damaged by cyst nematodes. This pest causes hundreds of balls or cysts to form on the roots of a plant, deforming and weakening the stem and leaves and destroying any commercial value.

Côte d'Ivoire is estimated to have used approximately 10 t of MB for soil fumigation in the early 1990s. Use of MB for cut flowers and ornamental plants has been reduced substantially since that time. MB application rates were generally about 450–700 kg/ha. Fumigations had to be carried out every 12 months in order to control nematodes.

Commercial use of alternative – coconut substrate

Several years ago the manager of a flower plantation was prompted to look for an alternative to MB fumigation because of concerns for worker safety, the cost of MB (including transportation of cylinders, polyethylene sheeting and labour) and damage to the ozone layer. The manager planted ornamental plants and flowers in coconut fibre substrate as an experiment and found that the plants were healthier and more uniform than those grown in soil. He found that nematodes and other soil diseases were controlled without the need for treatment with MB or other chemicals.

Since 1997, the plantation has successfully used coconut substrate for cut flowers and potted plants instead of fumigating soil with MB.

Technique

The substrate is made from coconut waste, milled or shredded into small strands. There is a ready source of this waste material in Côte d'Ivoire because many hectares of palm trees are

Case Study 12

CUT FLOWERS IN CÔTE D'IVOIRE: NATURAL SUBSTRATES

Table 1 Performance and benefits of using coconut substrate and MB

Coconut substrate system	MB system
Planting can begin immediately	Planting cannot start until 2–3 weeks after fumigation
Plants grow uniformly	Plants grow uniformly
System prevents invasion by nematodes, weed seeds, insects and other pests	Re-invasion of the soil by nematodes and other pests occurs soon after soil fumigation
High quality ornamental plants suitable for meeting the strict standards of the French market, and international export standards	Normal quality plants
No worker safety issues	Worker safety concerns; needs safety equipment
Producing and selling coconut substrate can provide new industry and employment	MB manufacture does not create employment in most developing countries because MB is generally imported
Relatively inexpensive system	Expensive to implement

grown commercially to produce palm oil. Coconut by-products can be sourced from local palm oil refining facilities and fibre mills. The waste may include trunks of dead palm trees, leaves and nut fibres. The most effective substrate mixture for flowers grown in Côte d'Ivoire consists of 10% trunk material and 90% nut and leaf waste. Before use, the substrate is soaked with lagoon water to ensure adequate distribution of moisture and to help condition the mixture before using it for planting.

12 month old healthy plant grown in coconut substrate

(David Mueller)

Each plant is potted in coconut substrate and transplanted as necessary to allow for growth. The pots are placed 10 cm above the soil to



prevent infestation from nematodes and other soil pests. Care is taken to prevent the nematodes from coming into direct contact with the potted plants. Some plants are grown in mounds on coconut substrate mixture.

Yield and performance of alternative

The substrate system controls soil-borne diseases and nematodes very effectively. The coconut substrate gives equal to better flower yields and better plant form than MB.

Table 1 compares the performance and benefits of both techniques. A wide range of cheap substances can be used as substrates, but some need to be combined with biological controls to be as effective as MB, as illustrated in Case Study 3.

Acceptability to regulators and markets

This alternative does not require registration by pesticide authorities.

The quality of the cut flowers and potted plants is very acceptable to purchasers. Reduced production costs also provide a competitive advantage.

Costs

The costs of the coconut substrate are modest where palm plantations exist in the locality. The greatest costs are milling the coconut waste and transporting it to the plantation. MB fumigation used to account for 50% of the production costs. The adoption of coconut substrates has delivered 40–50% cost savings (Table 2).

Table 2 Estimated costs of coconut substrate and MB systems

	Cost of substrates (US\$ / ha)	Cost of MB (US\$ / ha)
Total	900–1,200	1,800–2,000

Source: Anon. 1999

Applicability to other regions

Substrates made from diverse materials have been shown to be effective and available alternatives to MB. Substrate systems are generally independent of climatic conditions or soil type, and can therefore be used in almost any world region. Various types of substrates are used commercially for cut flowers in Canada, Europe, USA (MBTOC 1998) and (to a limited extent) in Kenya (HEWA 1997).

The coconut substrate described in this case study is suitable for producers in other regions where coconut waste is available. Palm trees

(the source of coconut material) are grown across equatorial Africa, Asia and other regions, and some countries are already utilising palm by-products. The Netherlands and other northern European producers, for example, import coconut substrate from Latin America and Asia, while a major flower producer in the USA uses coconut substrate from Asia.

Substrates made of coconut fibre mixed with other materials (such as peat) are used commercially for crops such as roses, gerbera, anthurium, tomatoes, bell peppers, cucumbers and strawberries, in countries such as Mexico, the Netherlands, Belgium, Switzerland, Spain, Eastern Europe, Australia and the USA (Bossers 1999). In some cases substrates need to be combined with biological controls to be fully effective (see Case Study 3).

Technical information provided by:

Jean Marie Pacaud, Côte d'Ivoire; David Mueller, Insects Limited, USA.

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Peter van Luijk BV, Langewateringkade 35b, Kwintsheul, NL-2295 RP, the Netherlands, Tel +31 174 292 662, Fax +31 174 298 443, Email: info@peval.nl, Website: www.peval.nl – suppliers of coconut substrates.

Cut Flowers in Mexico: soil amendments, biological controls

Report card

Crop: Greenhouse cut flower production

Soil pests: Fungi, white grubs, weeds

Alternative: Soil amendments (compost), biological controls (*Trichoderma*) and plant extracts (eg. *Tagetes*)

Yields: Alternative system produces higher yields and more first-grade flowers than MB

Costs: After an initial investment in training, the alternative system costs less than MB and is more profitable

Regulatory approval: None required for compost; *Trichoderma* is registered in a number of countries

Comments: Alternative system has been introduced in three regions of Mexico. It could be adapted for other countries

Examples of commercial use: Organic amendments such as compost are used for cut flowers in many countries

Economic significance of crop

Cut flowers are produced in Mexico for the domestic and export markets. In 1990, 112.5 million stems were exported to the USA. In the month of February alone in 1998, 14 million stems were exported. Flower exports are currently worth about US\$ 30 million per year. The main export market is the USA; other destinations include Canada, Europe and Japan.

It was estimated that 8,000 ha were used for production of cut flowers and ornamentals in 1997/8. In 1992, there were approximately 10,000 flower growers in open field production and about 150 growers producing export flowers in greenhouses.

Regions

Greenhouse flowers are grown mainly in the regions of México state and Morelos, while other important floriculture states are Puebla, Michoacán, México City and Veracruz.

In México state, the areas of flower production are: Villa Guerrero, Coatepec Harinas, Tenancingo and Texcoco. The climate in these areas is temperate and sub-tropical. Temperatures range from -2 degrees to 34°C, while rainfall varies from less than 600 mm to more than 1,100 mm each year. In Texcoco, the growing season is primarily between the months of February and November.

Crop production characteristics

Mexico has 8,000 ha of protected cultivation for cut flowers and ornamentals, comprising 700 ha for export and 7,300 ha for the domestic market. Cut flowers are produced on about 4,200 ha (Table 1).

Table 1 Area of cut flower cultivation in Mexico in 1997/8

Crop	Area (ha)
Cut flowers	4,200
Ornamental plants	3,800
Total	8,000

Source: RAPAM 1999

México state is the main producer region, accounting for 50% of the country's cut flower and ornamental plant production. Greenhouses in the region produce about 24 cut flower species, although the main ones are chrysanthemums, daisies, carnations and roses.

In Texcoco municipality, the area examined in this case study, 150 growers produce flowers in plastic greenhouses which are typically 160, 315 or 500 m² in size. Small producers may have up to five 315 m² greenhouses each. In Texcoco, there is some crop rotation between chrysanthemums and daisies.

Use of methyl bromide

The important pests in Mexico's greenhouse cut flower industry include:

- ▶ Fungi such as *Phytophthora* spp., *Rhizoctonia solani* and *Pythium* spp.
- ▶ White grubs such as *Phyllophaga* spp.

Growers have relied heavily on MB for covered cut flower production. It needs to be applied to the soil or substrate at the beginning of each growing cycle in order to control pests adequately. There is little information on the amount of MB used in Mexico's cut flower industry. However the sector has been identified as a major consumer of MB, along with the strawberry, melon, tomato and tobacco sectors. MB application rates in greenhouses in the Texcoco region are 68 g/m² on average. Small growers normally use small 680 g (1.5 lb) canisters of MB.

Commercial use of alternative – organic soil amendments and biological controls

Some greenhouse flower producers have started to use a combination of organic soil amendments, biological control and plant extracts to control major pests. This alternative system is used by several small and medium-size greenhouse growers in the Texcoco region. It is also used successfully by cut flower producers in two other regions in Mexico.

Technique

The alternative system uses compost, a biological control and plant extracts to suppress soil-borne pests and pathogens. The biological control consists of at least three different species of *Trichoderma*, a beneficial fungus produced by a local company in the Texcoco region. This alternative system is used in greenhouse production in Texcoco, but could also be used in open field production. It requires the following inputs:

- ▶ Composted manure of bovine and lamb residues (not blood and bone) mixed with other organic materials such as crop waste, vegetation and kitchen waste. The compost can be purchased or made by growers themselves
- ▶ Beneficial fungi *Trichoderma* spp. (a mixture of *T. harzianum*, *T. faciculatum* and others)
- ▶ Compound mix of marine algae
- ▶ Botanical insecticides such as *Tagetes* spp.

At the beginning of the planting cycle, composted manure is applied to the seed-bed (often a substrate mixture composed of volcanic soil, peat moss and other materials). Before transplanting seedlings, the beds are treated with the *Trichoderma* mixture. During the growing period botanical insecticides are also used to control pests and pathogens. Throughout the season the soil pH is monitored carefully, and lime or sulphur are added to raise or lower the pH as required.

Yield and performance of alternative

The alternative system controls the same range of pests as MB in the regions where it has been introduced. In addition, greenhouse producers using the alternative no longer suffer 'Roya Blanca' (*Puccinia horiana*), a pathogenic fungus that attacks the foliar area of the flower, preventing growers from achieving high prices in Mexico City.

Greenhouse flower producers have adopted organic soil amendments because:

- ▶ Input costs are reduced

- ▶ Additives are sourced locally
- ▶ Worker safety concerns are reduced
- ▶ Quality of plants is greatly improved

Growers have found that this soil amendments system consistently gives better plant form than MB. It often gives better flower quality as well. A grower in Santa María Nativitas who has used the alternative for four years achieves twice the number of first-class stems, (fewer second-grade flowers) and more stems overall than the traditional MB system (Table 2).

Table 2 Comparison of yield and grades (for one grower) using MB and soil amendment system for greenhouse cut flower production

Flower grade	Yield using soil amendments (Stems / 160 m ²) ^a	Yield using MB (Stems / 160 m ²) ^a
1st Grade	8,400	3,600
2nd Grade	2,400	4,800
Total	10,800	8,400

^a Greenhouse size is 160 m²

Source: RAPAM 1999

In other regions of Mexico, results with the soil amendments are mixed, with some growers reporting the same crop yield, and one instance of lower yield in San Pablo Ixayoc. However, the vast majority of growers reported that the quality and size of the plants is greatly improved when using soil amendments and they are well satisfied with the results. Table 3 compares the performance and benefits of soil amendments and MB.

Acceptability to regulators and markets

NOCON, a Mexican producer and supplier of *Trichoderma* mixtures, is registered as a laboratory for producing beneficial organisms and soil improvement agents.

Markets have responded favorably to cut flowers grown under the alternative system because of improved flower quality.

Table 3 Performance and benefits of soil amendments and MB	
Soil amendment system	MB system
Germination rate of seeds 95%	Germination rate of seeds 95%
Plants grow stronger and are more uniform	Plants tend to be weaker and less uniform
Consistently improved plant form	Lower quality plants than alternative system
Large number of first grade stems	More second grade stems
'Roya Blanca' fungus eliminated	'Roya Blanca' fungus prevalent
No worker safety issues	Worker safety concerns

Case Study 13

CUT FLOWERS IN MEXICO: SOIL AMENDMENTS, BIOLOGICAL CONTROLS

Table 4 Costs of MB and soil amendment systems for a small greenhouse cut flower producer

Inputs	Cost of soil amendment system (US\$ / m ²)	Cost of MB system (US\$ / m ²)
MB fumigant	0	0.33
Plastic fumigation sheets	0	0.16
Chemical fertiliser	0	0.01
Chemical pesticides	0	2.49
Compost	0.18	0
<i>Trichoderma</i>	0.02	0
Botanical and biological inputs ^a	0.21	0
Other purchased fixed costs ^b	1.53	1.53
Labour ^c	1.82	1.82
Total excluding labour	1.94	4.52
Total including labour	3.76	6.34

^a Foliar nutrients, botanical insecticides and virus control ^b Electric light, water service, soil nursery, plastic sheets for greenhouse

^c Most of the labour is provided by families of small growers

Source: RAPAM 1999

Costs

For a typical small grower in Texcoco, the soil amendment system costs about 40% less than the MB system (Table 4). However, different know-how is required, so that farmers have to make an investment in learning the new skills. The alternative is more profitable than using MB because the stems are consistently of higher grades.

Applicability to other regions

Organic soil amendments could be used by more cut flower growers in greenhouses in Mexico, and in other countries that have similar growing conditions. Organic amendments such as compost are used for cut flower production in many regions (MBTOC 1998). Biological controls are used for cut flowers in Colombia (Case Study 11).

The alternative system used in Mexico yields more 1st grade flowers than MB fumigation

(Fernando Bejarano)



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Case Study 14

Grains exported from Australia: IPM and nitrogen

Report card

Commodity: Wheat, oilseeds and pulses for export

Pests: Stored product pests

Alternative: Integrated commodity management and nitrogen treatment

Performance: Intensive sampling of treated grain at export has detected no insects

Costs: Nitrogen can be cheaper than MB depending on the source of gas

Safety issues: Nitrogen is an inert gas

Comments: A major grain export terminal in Australia has treated more than 262,600 tonnes of grain with nitrogen to date. Suitable for dry grain (less than 16% moisture) in many climates

Examples of

commercial use: Nitrogen is used for high-value durable commodities (eg. organic grains) in Australia and Germany

Economic significance of commodity

Australia produced about 33 million t of grain in 1997/8, including wheat, barley, sorghum, oilseeds and pulses. Almost 21 million t (64%) was exported in 1997/8 (Table 1).

The value of export grains was US\$ 3,404 million in 1997/8. There are more than 50,000 grain farms in Australia and the sector provides employment for a substantial number of people.

Region

Wheat is grown in the fairly dry regions of Australia where minimal rainfall is normally about 200 mm each year. Grain is usually harvested in the early part of summer and then stored through the hot summer months when conditions favour pest reproduction. It is moved to coastal terminals prior to export. Newcastle export terminal, the subject of this case study, is on the east coast.

Grain export systems

Australia exports a wide variety of grains (cereals, pulses and oilseeds) including wheat, sorghum, barley, oats, lupins, field peas, canola, cottonseed, linseed, peanut, safflower, soybean and sunflower.

The export grains are stored in bulk, in concrete silo bins, metal silo bins, shed-type storages, and in some cases bunkers. The mix of storage facilities varies greatly from one export terminal to the next. There are about 19 grain terminals in Australia. Most are operated by public companies and co-operatives.

Use of methyl bromide

Australia used in the region of 200 t MB for export grains in 1998, which was a large export year. Only a small percentage of grain exports are treated with MB. It is used as a pre-shipment treatment to control cosmopolitan grain pests when required by the official authorities of importing countries. Official Australian export

Table 1 Volume and value of Australian grain production and exports in 1997/8

Grain type	Grain production ('000 t)	Export volume ('000 t)	Export value (US\$ million)
Wheat	19,417	15,235	2,394
Coarse grains ^a	9,463	3,379	520
Oilseeds ^b	2,056	908	236
Pulses	1,981	1,428	254
Total	32,917	20,950	3,404

^a Barley, oats, sorghum

^b Canola, cottonseed, linseed, peanut, safflower, soybean, sunflower

Source: ABARE 1999

regulations require grain to be free of insects at export. MB is sometimes used to disinfest grain as a pre-shipment treatment, where a rapid disinfestation is required for logistic reasons, for example to meet shipping schedules.

Only about half of the export grain terminals in Australia are equipped to use MB. It is applied in sealed vertical silo bins made of concrete or steel with recirculating facilities designed for this fumigant. The application rate for MB in export grains is 24 g/m³ for 24 hours under recirculation at a rate of about 1 airchange per hour. When Australian export grains are treated with MB it is applied only once, except in very unusual circumstances.

Commercial use of alternative – nitrogen and ICM

Nitrogen treatment has been used commercially in one export terminal in Australia since 1992. It has been successfully used or tested for a wide range of grains, including wheat, coarse grains, oilseeds and pulses.

Newcastle grain terminal uses integrated commodity management (ICM) and nitrogen routinely and has a capacity of 29,000 t installed for controlled atmosphere treatments. By mid-1999, Newcastle port had treated more than 262,678 t export grain with nitrogen. Another part of the terminal uses cylinder-supplied

Case Study 14

GRAINS EXPORTED FROM AUSTRALIA: IPM AND NITROGEN

phosphine in carbon dioxide (a system called Sirocirc[®]). Some of the bins at Newcastle were originally equipped with recirculation apparatus for MB. However, MB has never been used in this part of the terminal.

Technique

ICM for grain handling and storage prior to arrival at the export terminal ensures that pest levels entering the terminal are low. ICM practices include scrupulous hygiene in storage facilities and transport vehicles, treating structures with diatomaceous earth, grain cooling and phosphine fumigation.

Various methods of applying nitrogen have been demonstrated in full-scale commercial conditions, including Pressure Swing Absorption (PSA) and liquid nitrogen systems. Newcastle terminal applies liquid nitrogen to grain in gas-tight reinforced concrete bins. Liquid nitrogen is used as the source of gas because it is very convenient and requires low capital input.

Equipment for nitrogen treatments typically consists of:

- ▶ Gas-tight storage container for grain
- ▶ Gas supply, such as liquid nitrogen tanker or equipment that extracts nitrogen from air on-site
- ▶ Vapouriser to convert liquid nitrogen to gas
- ▶ Pipework leading from vapouriser to grain bins
- ▶ Small diffuser to introduce gas to bottom of bin
- ▶ Flow meters, a pressure sensor and oxygen sensor
- ▶ Vent at top of bin, allowing displaced air to vent

Initially, nitrogen is introduced at a fast rate into the bins, replacing almost all the air. When the atmosphere in the bin is less than 1% oxygen the nitrogen input is reduced to a small trickle feed to maintain the low-oxygen atmosphere. In a full bin containing about 2,000 t grain the treatment typically consumes about 1 m³ of nitrogen per tonne of grain. The typical exposure period is 14 days or more, depending on the temperature, and pest species.

Performance of alternative

The combination of ICM and nitrogen treatment is very effective. At the Newcastle terminal intensive sampling of treated grain prior to export has not detected any insects. Both PSA and membrane nitrogen systems have been successfully demonstrated as viable control treatments, but liquid nitrogen was chosen at Newcastle because of its convenience and lack of capital cost in this situation.

Nitrogen treatment is most effective when grain is warm (typically more than 20°C), but at lower temperatures a very long treatment time may be required. It requires a sealed system and works effectively in humid or dry climates. Nitrogen systems are effective when grain has less than 16% moisture content. (When grain has higher moisture levels hermetic storage is an effective alternative – see Case Study 15).

The operational advantages of nitrogen make it the preferred option at Newcastle terminal. The grain can be removed from bins without the need for an aeration period, whereas MB fumigation often requires an aeration period of up to 3 days before grain can be loaded onto ships. The safety requirements for using MB are complex, expensive and time-consuming compared to safety measures for nitrogen treatments.

Acceptability to regulators and markets

Nitrogen and ICM systems provide the opportunity to supply grain that is both pest-free and residue-free, increasingly demanded by markets. The grain treated with nitrogen at Newcastle terminal is very acceptable to purchasers.

Costs

During trials in Australia the cost of using liquid nitrogen for a 4 week exposure was found to be US\$ 0.45/t grain, including hire charges for the equipment. On the basis of a 4 week exposure (<1% oxygen) the PSA system cost US\$ 0.24/t grain, including hire costs. Setting up the bins for nitrogen treatment required only a small capital outlay.

Table 2 Performance and benefits of ICM + nitrogen treatment and MB

Nitrogen and ICM	MB system
Residue-free grain	Bromide ion residues, particularly if fumigations are repeated
Normal work can continue without restrictions on access because less stringent safety measures needed. Nitrogen is an inert gas	Expensive and time-consuming safety measures are needed, eg. licensed fumigators. MB is a toxic gas
No airing required before grain can be loaded on ship	Airing of up to 3 days is often required before grain can be loaded on ships
No sorption problems	Sorption problems mean that grain cannot be loaded immediately after treatment
Nitrogen can be extracted from air on-site or produced locally	MB is imported from Israel or USA
No effect on grain viability	Grains such as malting barley cannot be treated with MB because it affects grain viability

Case Study 14

GRAINS EXPORTED FROM AUSTRALIA: IPM AND NITROGEN

Commercial use of the liquid nitrogen system at Newcastle terminal for a typical 3 week treatment costs about US\$ 0.39/t grain for materials, equipment and labour. The cost of MB would be about US\$ 0.35/t. Nitrogen can be cheaper than MB, depending on the source of the gas. Nitrogen treatments avoid the costs of licensed fumigators and expensive safety measures.

Applicability to other regions

The alternative can be used in almost any geographical region, irrespective of the humidity or the climate. The main requirement is that grain storages need to be well sealed to avoid excessive gas usage, and that the grain is reasonably dry (< 16% moisture content). It requires warm grain (typically > 20°C) for full effectiveness, unless very long treatment times are used.

Nitrogen is used for high-value durable commodities (eg. organic grains) in Australia and Germany (GTZ 1998).



Silos equipped with nitrogen treatment facilities at a grain export terminal in Australia.

(CSIRO Stored Grain Research Laboratory)

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Stored grains in Cyprus: hermetic storage

REPORT CARD

Commodity: Stored barley, maize and wheat

Pests: Stored product pests

Alternative: Hermetic storage

Performance: Grain is free from insects (except for thin layer of top surface) after short storage period

Costs: Hermetic storage costs more than MB for one year's storage, but is cheaper over longer periods

Regulatory approval: None required

Comments: Hermetic storage capacity in Cyprus is 216,500 tonnes and is being increased. Suitable for many regions

Examples of commercial use: Various hermetic systems have been successfully trialled or used in Israel, China, Bangladesh, India, Ethiopia, Guatemala, Brazil and USA

Economic significance of commodity

Storage of locally produced and imported grain is important for food and feed security in Cyprus. Many farmers in Cyprus are involved in the production of feed barley and durum wheat. The average annual production for the period 1990–98 was 124,000 t. Cyprus also imported an annual average of 525,000 t of grain during the period 1990–98. In 1997–98 Cyprus imported 650,000 t of barley, maize and wheat. Cyprus does not export grain.

The value of stored grain in 1998 was US\$ 110 million. The Cyprus Grain Commission is a Government agency with sole responsibility for the import, collection, storage, handling and sale of grain in Cyprus.

Region

Grain is stored in all regions of Cyprus, mainly in Limassol, Larnaca, Nicosia and Pafos. The climate is Mediterranean, characterised by long, hot and dry summers (22–38°C) and mild winters. The annual average rainfall is 450 mm. The humidity in Nicosia (the centre of the island) varies from 50–80% in winter to 25–50% in summer; while in coastal regions such as Limassol, humidity is 60–75% in winter and 70–75% in summer. In summer, grain insects can multiply rapidly, and conditions remain favourable for insects for most of the year.

Commodity storage

In 1997–98 the Grain Commission stored 520,000 t of barley, 170 t of maize and 90,000 t of wheat. Grain is generally stored for 2–12 months.

The grain is predominantly stored in concrete silos (capacity 70,000 t). It is also stored in three hermetic concrete bins (capacity 70,000 t each), hermetic storage under PVC sheets (capacity 7,000 t), metal vertical bins (capacity 50,000 t), in horizontal stores (capacity 60,000 t) and semi-underground 'Cyprus Ctessifon' pits (capacity 10,000 t).

The main grain storage facilities in Cyprus are owned and operated by the Cyprus Grain Commission which employs 160 people. Some horizontal stores are owned and operated by local Co-operatives. The following insect pests are controlled in stored grain in Cyprus:

Tribolium spp., *Rhyzopertha dominica*, *Sitophilus* spp., *Oryzaephilus surinamensis*, *Cryptolestes ferrugineus*, *Trogoderma granarium*, *Liposcelis* (booklice), *Sitotroga cerealella*, *Plodia interpunctella*, *Ephestia kuehniella*, and mites

The Cyprus Grain Commission specifies that imported grain be "free from live insects" and that insecticide residues must not exceed levels permitted by European Union Regulations. The Commission uses a variety of techniques including hermetic storage, phosphine (eg. tablets, Siroflo[®]), insecticides and aeration.

Use of methyl bromide and phosphine

MB is not used for stored grain in Cyprus because satisfactory alternatives are in place.

Commercial use of alternative – hermetic storage

In 1988, two concrete platforms were constructed for hermetic storage in Nicosia, with capacities of 2,500 and 4,000 t grain. They have been used continuously for hermetic storage of local barley. The system was introduced in Cyprus as a cost-effective and rapid method for increasing national storage capacity and reducing the use of insecticides. In 1999, three additional concrete bins for hermetic storage were constructed in Limassol, each with a capacity of 70,000 t. Total capacity for hermetic storage in Cyprus is therefore currently 216,500 t. In 2001, a further six hermetic bunkers will be constructed.

Technique

Hermetic storage requires grain to be placed in a large container or structure that can be sealed. Insects present in the grain, and the respiration of the grain itself, use up the available oxygen and cause insects to die within 2–3 months, depending on circumstances.

There are various methods of construction. The two storage platforms in Cyprus consist of a reinforced concrete floor (20 cm thick) with a peripheral support wall (1 m high and 15 cm thick), and a surrounding concrete apron (80 cm wide) outside the wall. One platform is 50 m by 25 m, while the second is 75 m by 25 m. Each platform has two 5 m entrances on one side, to permit grain to be loaded and unloaded by truck.

The main equipment for this type of hermetic storage facility consists of:

- ▶ Concrete platform
- ▶ Polyethylene sheet (0.25 mm thick) and PVC sheets (0.8 mm thick, 10 m by 34 m)
- ▶ Hot-air welding tool for welding together PVC sheets
- ▶ Sandbags
- ▶ Conveyor for grain (eg. screw conveyor)
- ▶ Tubes for drawing air samples
- ▶ Meters to measure grain moisture, relative humidity, oxygen, carbon dioxide and grain vacuum; thermocouple cables and thermometer to measure temperature

The activities involved in using the hermetic storage in Cyprus are as follows:

- ▶ Before loading the grain, polyethylene sheets (underliner) are laid across the floor and walls and the sheets are joined with adhesive tape
- ▶ Trucks load grain onto the platform until the floor is covered, and the two entrances are sealed with wooden planks
- ▶ Loading is continued with screw conveyors that raise the grain along a central peak to a height of approximately 7 m
- ▶ The grain surface is smoothed and sealed using PVC sheets
- ▶ The sheets are placed over the wall, pulled over the top of the grain bulk and welded together to form a continuous liner
- ▶ A gastight seal is obtained by folding the overlayers and the underliners together at the base of the wall and securing with sand bags

- ▶ Polyester woven fabric strips (15 cm wide) are placed at 10 m intervals across the platform and anchored to the concrete apron to prevent the overliner moving in high wind
- ▶ After sealing, screw-cap inspection ports are welded along the peak (at 6 m intervals), allowing thermocouple cables and gas-sampling tubes to be inserted into the grain

The oxygen decreases and the carbon dioxide increases substantially within 1–3 months. The sealed sheets are inspected every month to ensure the seals are intact and that the sheets have not been damaged by rodents or other items. Routine inspections are carried out to check grain temperature, insect activity, oxygen, carbon dioxide and moisture migration.

Certain conditions (such as a large gap between initial grain temperature and ambient air temperature) can cause moisture to migrate to the grain surface, allowing mould to grow. If this occurs, it is important to remove the affected layer of grain prior to use. However, steps can be taken to prevent this problem. In some countries, waste corn cobs or grain husks are placed in a thick layer on top of stored grain prior to sealing to prevent any damage from mould.

Performance of alternative

For the past decade in Cyprus, hermetic storage has been used successfully for storing grain for periods of 3 months to several years. The system gives grain losses of only 0.009% and 0.2% after one and three years storage respectively. Any losses are mainly due to mould at the top surface of grain bulk; it is now technically feasible to avoid mould losses. Studies also found that, after 2–3 months hermetic storage, live insects were present only in the upper 0.5 m surface of the grain bulk. Even at the end of storage the deeper layers (0.5–7 m) of grain remain free from live insects.

Hermetic storage is as effective at controlling insects as MB and phosphine in grain stored for more than 5–6 months. It provides the advantage of on-going protection for stored grain, whereas systems relying on MB have to repeat fumigations every 3–4 months. After one year of hermetic storage, the germination of barley remains higher than 96%, while after three years of hermetic storage it remains higher than 88%. In contrast, MB reduces the quality of grain after 1–3 years storage. A comparison of hermetic storage performance with MB is provided in Table 1.

Case Study 15

STORED GRAINS IN CYPRUS: HERMETIC STORAGE

Table 1 Performance and benefits of hermetic storage and MB for grain protection

Hermetic Storage	MB system
Suitable for mid- to long-term grain storage	Not suitable for long-term storage because grain quality diminishes
No need for registration by pesticide authorities because no toxic chemicals are involved. No occupational safety hazards	Risks from handling toxic gas. Personnel require substantial training. Must be registered by pesticide authorities
Easy to use	More complicated to use, special equipment required
No insecticide residues in grain and grain products	Bromide residues in grain
Allows long-term storage (1–3 years) without the need to re-apply fumigants or treatments	Fumigant needs to be applied every 3–6 months. Number of MB applications must be limited, to stay within residue limits, necessitating other control techniques
High grain germination even after three years hermetic storage, indicating good quality grain	Grain quality is reduced after 1–3 years. Unsuitable for malting grade barley

Table 2 Costs of building and operating hermetic storage for 4,000 t barley in Cyprus

Cost	Total cost (US\$)	Depreciation (years)	Cost for 1 year storage (US\$)	Cost for 2 years storage (US\$)	Cost for 3 years storage (US\$)
Fixed costs					
Building concrete platform ^a	112,000	30	3,733	7,466	11,200
PVC sheet for covering grain	13,600	7	1,942	3,884	5,826
Polyethylene liner for covering floor	1,044	1	1,044	1,044	1,044
Total fixed costs			6,719	12,394	18,070
Current costs					
Electricity to inload grain	150		150	150	150
Labour to inload the grain and level the grain surface	500		500	500	500
Labour to cover the polyethylene liner	80		80	80	80
Labour to cover the grain and weld PVC sheet	1,000		1,000	1,000	1,000
Labour to remove the PVC sheet	310		310	310	310
Labour to inload the grain into trucks using a tractor	1,600		1,600	1,600	1,600
Total current costs			3,640	3,640	3,640
Total of fixed and current costs					
Total for 4000 t per year			10,359	16,034	21,710
Total for 1 t per year			2.59	4.00	5.43
Total operating costs^b					
Total for 4000 t per year			4,476	6,414	8,360
Total per t per year			1.12	1.60	2.09

^a Platform dimensions: 25 m wide, 75 m long, 7 m high

^b Cost of PVC, polyethylene and labour for covering and uncovering after storage

Source: Varnava 1999

The Cyprus Grain Commission plans to build additional hermetic storage facilities because the technique is proven very safe, it maintains grain quality and it increases storage capacity at low cost.

Acceptability to regulators and markets

Hermetic storage does not require regulatory approval by pesticide authorities because no toxic chemicals are used. The grain is free from pesticide residues and is very acceptable to purchasers.

Costs

In Cyprus, the total cost of using this type of hermetic storage for 4,000 t of grain is about US\$ 4,500 for one year, US\$ 6,500 for two years, or US\$ 8,400 for three years (Table 2). This gives a cost of US\$ 1.12/t for one year, US\$ 1.60 for two years or US\$ 2.09 for three years of hermetic storage.

In comparison, the cost for storing 4,000 t barley in vertical metal bins for one year (one treatment with organophosphorous insecticide, two treatments with phosphine tablets and one aeration) is about US\$ 4,800, about US\$ 10,000 for two years, or more than US\$ 15,000 for three years. This gives a cost of US\$ 1.20/t for one year, US\$ 2.50/t for two years or US\$ 3.75/t for three years. This chemical-based treatment is therefore 7–79% more expensive than hermetic storage over a 1–3 year period.

Applicability to other regions

Hermetic storage can be used in a variety of climates provided the grain is infested or has a moisture content of 13–18%. Various hermetic storage systems have been successfully trialled or used in Israel, China, Bangladesh, India, Ethiopia, Guatemala, Brazil and USA.

Technical information provided by:

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GrainPro Inc, 1334 G Street NW, Suite 605, Washington DC 20005, USA, Tel: +1 202 393 8714, Fax: +1 202 393 8719, Email: sales@grainpro.com, Website: www.grainpro.com – supplies a variety of hermetic storage structures

Hermetic storage in Cyprus – grain is piled onto a concrete platform and enclosed in sealed sheets

(Cyprus Grain Commission)



Grain storage facilities in Australia: diatomaceous earth

REPORT CARD

Commodity: Storage facilities for oilseeds, pulses and grains

Pests: Stored product pests

Alternative: Integrated pest management and diatomaceous earth slurry

Performance: Very effective in controlling pests in drier regions with low to medium humidity (below 70% relative humidity)

Costs: IPM + diatomaceous earth costs significantly less than MB

Regulatory approval: Certain diatomaceous earth formulations are registered as pest control products in Australia, Canada and USA

Comments: IPM + diatomaceous earth is widely used for grain storage facilities in Australia. The system can be used in many regions, provided the humidity is normally less than 70%

Examples of commercial use: Diatomaceous earth formulations are used for controlling pests in structures in Brazil, Canada, USA and Europe

Economic significance of commodities

Australia is a major grain producer and exporter, producing about 33 million t grain in 1997/8. Almost 21 million t (64%) were exported in 1997/8, and had an export value of US\$ 3,404 million. A breakdown of grain types is provided in Table 1 in Case Study 14.

Region

Grains are stored in all states of Australia, where the climate ranges from temperate to sub-tropical. In Queensland, one of the major grain producing states, the conditions at harvest are hot and humid. Temperatures range from 25 to 40°C at harvest, with a relative humidity of between 40 and 100%. When it enters the storage facility, summer-harvested grain typically has a temperature of 28–35°C and is close to 12.5% moisture content. The grain temperature remains at this level unless actively cooled. Grain is generally stored in conditions which favour pest reproduction, making pest control operations a vital part of long term storage.

Commodity storage

The amount of grain stored in Queensland varies from 1 to 3 million t. The amount stored in 1998 was 2.2 million t. Most of the stored grain (about 80%) is wheat, and the remainder comprises sorghum, barley, maize, sunflower, chickpea, cottonseed, meal and others.

There are hundreds of storage facilities in Queensland, operated by a number of private companies and co-operatives. Grainco Australia Limited (GAL), the subject of this case study, handles 90% of the grain storage in Queensland, as well as providing facilities nationally. GAL's major shareholders are growers.

Most of the grain is stored in bulk, primarily in concrete vertical silos, concrete bins, steel bins and also shed storages and pad storage. Grains for the domestic market are typically stored from

three months to two years, while grains for export are generally stored for up to one year.

There are many pests requiring control in grain storage facilities. The most common include:

- ▶ Red rust flour beetle, *Tribolium castaneum*
- ▶ Lesser grain borer, *Rhyzopertha dominica*
- ▶ Rice weevil, *Sitophilus oryzae*
- ▶ Saw tooth grain beetle, *Oryzaephilus surinamensis*
- ▶ Flat grain beetle, *Cryptolestes* sp.
- ▶ Psocids
- ▶ Several moth species

Use of methyl bromide

MB is generally no longer used for disinfesting grain storage structures in Australia. GAL stopped using MB for structures about 7–8 years ago because it was too expensive.

Commercial use of alternative – diatomaceous earth slurry and IPM

Use of diatomaceous earth (DE) for controlling insects in stored products and structures has increased significantly during the last decade. In Australia, the use of DE is widespread for disinfesting storage facilities for grain, pulses and oilseeds. DE is used extensively in the drier growing regions where it is highly effective. It is not used in port areas where the humidity is high.

DE is used as a structural disinfestation agent in many grain storage facilities in Queensland. This case study focuses on several facilities which store pulses and oilseeds and rely solely on DE + IPM for pest protection.

Techniques

DE is composed almost entirely of amorphous silicon dioxide, and is produced from fossilised diatoms (single-celled algae). DE controls insects by adhering to their bodies, damaging the protective waxy layer on the insect cuticle

(outer coat) by sorption and, to a lesser degree, by abrasion. Water is lost from the insect, resulting in death. DE also repels insects.

The various types of DE formulations have different characteristics and efficacy against pests. They are generally supplied as dusts, and a few can be used as slurries. The formulation commonly used for storage facilities in Australia is Dryacide®.

GAL introduced DE and IPM into grain storage facilities in the early 1990s in order to reduce reliance on chemical methods of pest control. The IPM programme for grain storage facilities places strong emphasis on insect monitoring, sanitation, and other practices which prevent insect numbers from building up. The main IPM practices for storage areas are:

- ▶ High level of hygiene and cleanliness eg. removing all dirt, debris and cobwebs, eliminating refuges for insects
- ▶ Cleaning and washing storage facilities immediately after they have been emptied
- ▶ Treating the floor, walls and ceiling of the structure with DE
- ▶ Monitoring insect control via trapping and visual assessment

GAL applies the DE as a slurry or dust. Slurry application is preferred because it reduces the dust hazard, although the application rate is much higher. Slurry application is widespread in Australia. The most common application equipment is a high-pressure slurry pump, which requires the following equipment and materials:

- ▶ High-pressure pump and hose – available off the shelf, minor modifications needed
- ▶ 3.5 horse-power petrol motor
- ▶ 180–220 litre tank
- ▶ DE and water
- ▶ Safety dust mask is required only during the brief mixing period, to protect eyes and lungs

The main steps in applying DE slurry are as follows:

- ▶ All grain debris is removed, the empty storage facility is thoroughly cleaned and washed
- ▶ In the tank, DE powder is mixed with water (0.1 kg DE per litre of water), creating a slurry
- ▶ The pump turns the slurry into a fine spray which is applied to the walls of the storage facility

It takes 20 minutes to carry out the treatment in a typical storage structure that can hold 5,000 tonnes of grain. The slurry dries on the walls

Table 1 Performance and benefits of DE + IPM and MB

DE + IPM system	MB system
Cleaning and treatment best carried out as soon as possible after storage facility has been emptied, to prevent pest build-up	Less need for cleanliness and hygienic practices
DE continues to exert its effect for a long time, providing on-going protection from insects	Provides no on-going protection from insects
DE treatment may be required every 12 months	Fumigations may be required every 3–6 months
Very low toxicity, generally regarded as harmless to humans. Occupational hazard from dust formulations can be minimised by using DE slurry	Highly toxic gas. Occupational safety hazard
Dust is easily removed from structures by washing	Washing is not required
Storage area is accessible during treatment	Storage area is inaccessible during treatment
Low cost of application and supply	High cost of application and supply

within 10–30 minutes, depending on the temperature and humidity. One litre of DE slurry covers approximately 13.3 m² of surface, giving about 6 g of active ingredient per m². After drying the DE becomes active in controlling insects. Once applied to the structure, pest control lasts for 1–5 years, depending on the type of structure, hygiene practices and level of activity. GAL normally cleans, washes and applies DE to the structures once a year.

Performance of alternative

The combination of activated DE + IPM in drier regions controls insects very effectively. DE is not suitable for areas with permanent, high humidity (more than 70% humidity) as DE-affected insects under these conditions will not ‘dry out’ and die. DE formulations vary considerably in efficacy. Certain forms have naturally high levels of insecticidal activity. Some formulations are mixed with silica aerogel, and some are ‘enhanced’ by being subjected to a heat treatment and are generally more effective than untreated DE.

MB fumigation kills insects quickly in a structure but provides no on-going protection, so that pest populations can build up again and repeated fumigations are necessary (perhaps every 3–6 months). In contrast, the dried DE slurry kills initial insect populations more slowly (in a matter of weeks rather than hours) but provides on-going protection, continuing to control insects for very long periods of time (1–5 years). A comparison of DE + IPM performance with MB is summarised in Table 1.

Acceptability to regulators and markets

IPM does not require regulatory approval. DE normally requires regulatory approval as an insecticide. The Australian pesticide registration

Case Study 16

GRAIN STORAGE FACILITIES IN AUSTRALIA: DIATOMACEOUS EARTH

Table 2 Costs of DE slurry + IPM and MB for a storage facility^a

Item	Costs of DE + IPM system (US\$ per year)	Costs of MB ^b (US\$ per year)
Capital costs		
High pressure pump and tank	4,000	0
Safety equipment	200	2,000
MB dispensing gear	0	300
Sub-total	4,200	2,300
Operating costs		
Methyl bromide	0	2,500
DE powder	100	0
Labour (including hygiene)	1,000	1,500
Sub-total	1,100	4,000
Total in year 1	5,300	6,300
Total in year 2	1,100	4,000

^a Storage capacity of 5,000 tonnes grain
Source: Bridgeman 1999

^b Assumes only one MB fumigation per year

authorities have approved certain DE formulations for insect control in storage structures, grain, pulses and oilseeds. The authorities restrict the amount of a potentially harmful component, crystobolite, in approved formulations.

Use of DE slurry + IPM for structures is acceptable to grain purchasers and consumers because it does not contaminate the bulk of the grain with chemical residues.

Costs

For structures, the DE + IPM system has lower capital and operating costs than MB fumigation. After the initial investment, the cost of cleaning and using DE slurry for a typical size storage structure (5,000 tonnes capacity) for one year is US\$ 1,100. The cost of using MB would be US\$ 4,000 if applied once a year (Table 2). The MB treatment is almost twice the cost of the DE + IPM system, after 2 years of operations.

Applicability to other regions and uses

DE can be used effectively in many geographical regions, provided the humidity is less than 70%. DE is used commercially for controlling pests in structures in Brazil, Canada, Europe, USA and Australia. DE can be combined with other treatments. In Canada, for example, a particular DE formulation combined with heat (41°C) was demonstrated to be effective in controlling pests in structures, and the technique is now used commercially in a flour mill with good results.

Certain DE formulations are registered as insecticides in the USA, Canada, Australia, Germany, Croatia and Brazil. Trials are being undertaken in Mexico, Pakistan, China, Jordan,

Saudi Arabia, Turkey, Kazakhstan, Egypt, several countries in Africa, Cyprus, the UK, Austria and Denmark.

Technical information provided by:

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Dr Zlatko Korunic, Director of Research, Hedley Technologies Inc, 2600 Skymark Ave, Suite 101, Bldg 4, Mississauga, Ontario L4W 5B2, Canada, Tel/Fax +1 519 821 3764, Email: hedzk@ibm.net – Company produces Protect-It™ diatomaceous earth products.

Food warehouses in Hawaii: integrated pest management

REPORT CARD

Commodity: Food warehouses containing a variety of stored products

Pests: Stored product pests

Alternative: Integrated pest management based on hygiene, insect trapping and monitoring

Performance: Excellent control of insects

Costs: IPM system costs substantially less than MB

Regulatory approval: None required for insect monitoring and trapping. Pyrethrins are registered by pesticide authorities in many countries

Comments: This IPM system has been used for 10 years with excellent results in several food facilities in Hawaii, a humid tropical environment. It can be adapted for many other regions

Examples of commercial use: IPM systems are used in food processing facilities in Canada, Australia, Denmark

Economic significance of commodities

Food warehouses in Hawaii often hold large consignments of high-value food products such as rice, nuts, dried fruit, spices, candy, pasta, pet foods and a variety of flour-based products.

Potential infestation of these foods during storage is a major concern to companies involved in food manufacturing, warehousing and distribution. Any infestation complaint creates adverse publicity and a financial loss, but the most significant liability is from possible litigation or regulatory sanctions.

The food warehouse featured in this case study is owned by HFM FoodService, one of the largest food service distribution companies in Hawaii, with annual sales of more than US\$ 74 million.

Region

Hawaii has a tropical climate. Temperatures vary from 23 to 27°C and the relative humidity ranges from 50 to 80%. Stored-product pest insects can breed rapidly in and around food facilities all year round.

Commodity storage

Most food facilities in Hawaii, including the HFM FoodService warehouse, are left partially open for ventilation making them particularly susceptible to infestations from outside.

The principal insect pests that require control in food warehouses are:

- ▶ Cigarette beetle, *Lasioderma serricorne*
- ▶ Red flour beetle, *Tribolium castaneum*
- ▶ Indian meal moth, *Plodia interpunctella*
- ▶ Almond moth, *Ephesia cautella*
- ▶ Lesser grain borer, *Rhyzopertha dominica*
- ▶ Rice weevil, *Sitophilus oryzae*
- ▶ Book lice, Psocid species

Use of methyl bromide and insecticides

In a number of countries, MB is used to control these stored product pests. However, MB has

not been used in the HFM FoodService warehouse in Hawaii. Prior to 1989 HFM used insecticide fogging (in ultra-low doses) as a control method. But due to poor results, high cost, worker safety concerns and increasing public and regulatory aversion to pesticide use around foods, fogging was phased out from 1987 to 1989 and replaced by an extensive hygiene and pheromone trapping programme described below.

Commercial use of alternative – insect trapping and monitoring system

During the past 10 years, Food Protection Services (FPS), a pest management company, has worked with HFM FoodService to implement a cost effective IPM programme for protecting food in a large warehouse in Hawaii. Variations of this pest control system are used in a number of other premises in Hawaii.

Techniques

The FPS system used in the HFM warehouse is based on the principle of stock control, a high standard of hygiene, early detection and removal of pests. Pest numbers are not allowed to build up to problem levels, so fumigation is not required. The IPM system includes five components described below:

- ▶ Trapping and monitoring insects
- ▶ Locating and removing infested products
- ▶ Suppressing insects
- ▶ Repelling insects that try to enter the warehouse
- ▶ Attracting and killing insects outside the warehouse

Trapping and monitoring

Seven stored-product insects are monitored using traps with pheromone (insect hormone) lures for Phycitid moths, cigarette beetles and red flour beetles. Traps are placed in a symmetrical grid pattern throughout the large warehouse, at intervals of 4–15 m (86 sites in

Case Study 17

FOOD WAREHOUSES IN HAWAII: INTEGRATED PEST MANAGEMENT

this building). ‘No Survivor’ traps are suspended at eye level on the storage rack legs and ‘Flite Trak M²’ pit-fall traps are placed on the floor at the base of rack legs. Although the pheromone lures are highly specific, moth lures will attract several Phycitid species including Indian meal moths, almond moths and Mediterranean flour moths. The Flite Trak traps contain an aggregation pheromone that attracts both sexes of red and confused flour beetles, plus food oil which is attractive to rice weevils and merchant grain beetles.

Six industrial ‘insectocutors’ are used primarily to detect the presence of species that are not monitored by pheromone traps, such as lesser grain borer, drugstore beetle, flat grain beetle, foreign grain beetle, wardrobe beetle, hairy fungus beetle, *Trogoderma* and others. Each insectocutor contains two UV bulbs (122 cm long) that attract and kill flying insects. They are suspended 7.5 m high in the aisles between the warehouse racks. About 54 different species of stored-product beetles and 11 species of moths have been captured in the insectocutors. All traps are inspected weekly, and the insects are identified, counted and removed.

Location of infestations

If monitoring indicates an infestation, data from traps in the ‘hot spot’ area are used to create triangulation diagrams that pinpoint the approximate location(s) of the infested material in the warehouse. This is feasible because the layout of the trapping grid is kept constant, and all the lures in the traps are the same age so that certain traps are not more attractive than others. Products in the identified area are inspected visually and the infested products are quickly removed from the warehouse and discarded.

Suppression of insects

Fugitive insect populations in the warehouse are suppressed by a combination of mass trapping using pheromones, and chemosensory confusion. Arrays of traps baited with lures of various ages (1 to 4 months old) are sometimes employed at high densities to allow accurate monitoring for triangulation while at the same time creating chemosensory confusion, disrupting the normal communication and mating behavior of insects. The insectocutors also help to suppress fugitive insects within the warehouse.

Repellent barrier to prevent entry of insects

The need for ventilation in topical warehouses means that most warehouses in Hawaii are not insect proof. They are designed so that convection currents created by a hot roof draw air in through the open doors and windows, and out through ceiling vents. This chimney effect draws insects into the warehouse. Pest-excluding tactics like strip curtains and air doors cannot be used. To counter this problem at the HFM warehouse, a series of pyrethrin foggers are deployed around the inside perimeter and doors to continuously repel insects that try to enter the building. These small, battery-operated devices discharge 52 mg of 1.75% pyrethrin aerosol every 15 minutes creating a highly repellent barrier around all openings to the warehouse. The HFM FoodService warehouse uses one fogger device for each 708 m³.

Pheromone Enhanced Mortality to prevent entry

The HFM FoodService warehouse is located next to a feed warehouse and grain elevator which can be a source of insects. To prevent these insects reaching the warehouse, Pheromone Enhanced Mortality (PEM) techniques were developed using pheromone lures to attract

Table 1 Comparison between FPS system, ULD insecticide fogging and MB Fumigation

FPS system ^a	ULD insecticide fogging ^b	MB fumigation
Monitoring allows early detection and removal of infested products	No early detection of insects	No early detection of insects
Continuous suppression and removal of insect populations	Only kills insects exposed during fogging	Kills all insects in products during fumigation – but no on-going control of insects
Little risk of customer complaints about infested products because infested products are detected and removed	Significant risk of customer complaints because internal infestations are disguised, not eliminated or removed	Significant risk of customer complaints because insects are killed, but packages containing dead insects may be shipped to customers
Minimal pesticide residues on packages and equipment	Pesticide residues in packages and equipment	Pesticide residues in products
Facility can operate continuously	Facility has to shut down for half a day during treatment	Facility has to shut down for 2 days during treatment
Does not use substances that are toxic to humans; minimal worker safety concerns	Uses insecticide that may pose safety risks; some worker safety concerns	Uses a toxic fumigant; worker safety concerns

^a Food Protection Service IPM system

^b ultra-low dose insecticide system

insects on to surfaces such as hatch covers, silo cones and outside walls which had been spot treated with cyfluthrin (an insecticide) or into lethal proximity with pyrethrin foggers. PEM uses pheromone lures to overcome the repellent effects of the pesticides, creating a fatal attraction before the insects can enter the warehouse.

Performance of alternative

The FPS system has dramatically reduced infestations in the warehouse, providing continuous and effective control of insects. The system prevents insect numbers building-up and keeps food commodities cleaner. HFM FoodService is very satisfied with this system because it has eliminated the operational disruptions associated with fumigations and other methods. Table 1 compares major features of the FPS system with the previous treatment of ultra-low dose (ULD) insecticide fogging, and MB fumigation.

Acceptability to regulators and markets

The use of insect pheromones for food protection does not require regulatory approval. Pyrethrin is approved as an insecticide in the USA and many other countries.

Use of the FPS system has dramatically reduced customer complaints about infestations in products. Retailers and customers find the products stored under this system very acceptable because they do not have to worry about insects or pesticide residues.

Costs

MB fumigation costs four times higher than the FPS system on an annual basis. Table 2 compares the capital and operating costs of the continuous FPS system, weekly ULD fogging and twice-yearly MB fumigation.

Applicability to other regions and uses

Governments and industries in many countries are now moving towards environmentally friendly, proactive, IPM programmes for preventing infestation by storage pests, rather than carrying out fumigations after infestations have reached substantial levels. The FPS system described in this case study has been in use at HFM and a number of other food warehouses in Hawaii for the past ten years. The FPS system can be adapted to suit other climates and regions.

Pest management specialists in Canada have developed guidelines for implementing IPM systems in flour mills and other food processing facilities (Health Canada 1998).

Table 2 Actual costs of FPS system compared to ULD insecticide fogging and MB fumigation

Item	FPS system (US\$ per year)	ULD fogging ^a (US\$ per year)	MB fumigation ^b (US\$ per year)
Pesticides and fumigants	4,380 ^c	20,800	13,720
Insect monitoring equipment	6,492	0	0
Gas monitoring equipment	0	0	2,000 ^d
Application equipment	1,505 ^d	3,000 ^d	2,000 ^d
Safety Equipment	0	200 ^d	5,000 ^d
Operational shut down	0	negligible	40,000
Labour	1,560 ^e	3,120	1,000
Total in year 1	13,937	27,120	63,720
Total in year 2	12,432	23,920	54,720

^a Fogging carried out each week ^b MB fumigation carried out twice a year ^c Pyrethrin replaced each month
^d Mostly capital expenditure in year 1 ^e 2–3 man hours per week
Source: Pierce 1999

Technical information provided by:

Mr Lawrence H. Pierce, Food Protection Services, Mililani, Hawaii.

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Pheromone trap – one of three types used in a large warehouse in Hawaii to monitor insect numbers and species.

(Melanie Miller)

Papaya exports from the Cook Islands: heat treatment

REPORT CARD

Commodity: Papaya exports from the Cook Islands to New Zealand

Pests: Quarantine pests: fruit flies

Alternative: Heat treatment

Performance: Gives quarantine security equal to MB

Costs: Treatment costs more than MB

Regulatory approval: Heat treatment is approved as a quarantine treatment by New Zealand and a number of other countries

Comments: Capacity for treating more than 1,600 tonnes papaya per year in the Cook Islands at present. There are plans to extend the treatment to other commodities

Examples of commercial use: Heat treatments are used as quarantine treatments for fresh produce such as papaya, mango and eggplant in the USA, Australia, Fiji, Tonga, New Caledonia, Hawaii and Mexico

Economic significance of commodity

The Cook Islands in the Pacific produced 258 t papaya for export in 1997, and additional quantities for domestic consumption. Production levels vary from year to year depending on weather patterns, especially hurricanes. 1998 exports were only about 100 t in a season affected by hurricanes.

In 1997, papaya exports from the Cook Islands were worth US\$ 322,000 on arrival at the wharfside in the importing country (wholesale value). New Zealand is the primary export market.

The papaya sector provides employment for several thousand people in the Cook Islands.

Region

The Cook Islands is a South Pacific nation about 3 hours flying time north of New Zealand. The papaya production area in the Cook Islands is sub-tropical, with high humidity and temperatures ranging from 25–32°C summer and 15–22°C in winter.

Commodity export system

There are probably about 60 registered papaya growers. Less than 10 growers export significant quantities of papaya from the Cook Islands.

The quarantine treatment is carried out in a treatment plant located at the airport, before the fruit are exported by air.

Use of methyl bromide and fumigants

The Cook Islands has not used MB for papaya exports but instead used another fumigant called ethylene dibromide (EDB). In 1994, New Zealand stopped accepting EDB-treated products due to concerns about human health. The Cook Islands could have adopted MB at that stage, but instead developed a heat treatment because MB is typically not very effective against fruit fly. There was also concern that MB or similar fumigants would be withdrawn in the

future due to their toxicity.

The quarantine pests requiring control in Cook Islands papaya are:

- ▶ Fruit flies: *Bactrocera melanotus* and *B. xanthodes*.

Commercial use of alternative – heat treatment

Heat treatments have been used commercially in the Cook Islands for papaya exports since 1994. The amount of papaya treated varies greatly each year (Table 1) because production is adversely affected by climate (drought, hurricanes) and export is constrained by air freight space.

There is one heat treatment facility in the Cook Islands, which has capacity to treat 1,664 t papaya per year. Heat treated mangoes from the Cook Islands have also been exported to New Zealand in small quantities. There are plans to expand exports to cover other commodities such as eggplant (aubergine).

Table 1 Quantity of papaya given heat treatment in Cook Islands

Year	Papaya treated (t)	Product value ^a (US\$)
1995	458	508,821
1996	569	650,896
1997	258	289,331

^a Cost, insurance and freight charges ie. cost to importer of buying goods and shipping to wharf in importing country

Source: HortResearch 1999

Technique

There are various methods for applying heat treatments to kill quarantine pests. In the Cook Islands, a high-temperature forced-air (HTFA) treatment is used, comprising a treatment of 47.2°C for 20 minutes in sealed chambers.

The harvested fruit is washed, inspected and placed in treatment bins (400 kg fruit per bin).

Two heat treatment chambers are loaded with 4 bins each. Calibrated temperature probes are placed in the centre of four large fruit (top 5% by weight of total weight range in chamber load) and placed in the coolest part of the chamber i.e. at the top of treatment bins. The fruit mass is heated using recirculated air until the fruit centre temperature (FCT) of all probed fruit in the load attains 47.2°C. This temperature is maintained for 20 minutes. The fruit load is then rapidly cooled by showering with recirculated water until the FCT reaches approximately 30°C. The load is left overnight to dry at cooler temperatures, and is packed for export the following day or consolidated over a longer period, depending on available flights.

The equipment for heat treatment in the Cook Islands consists of :

- ▶ A water dump tank and mechanised fruit conveyer system to sort and inspect fruit
- ▶ Heat treatment unit (consisting of duplicate, independent chambers; warm air generated by a diesel engine)
- ▶ Ancillary equipment e.g. fork lift to load and unload fruit bins
- ▶ A secure fly-free area into which treated fruit are stored overnight following treatment

The steps involved in using the equipment are as follows:

- ▶ Papaya are delivered by growers to treatment plant (fruit in numbered 'field bins')
- ▶ Bins are unloaded from truck using forklift
- ▶ Fruit is weighed using platform scales
- ▶ Fruit is placed in water dump by forklift, separated, sorted and graded
- ▶ Fruit is hand placed into treatment bins
- ▶ Forklift places each bin by chamber door
- ▶ Quarantine officer inserts temperature probe into pre-selected largest fruit in top centre of bin
- ▶ Forklift loads bins one at a time into the HTFA chamber
- ▶ Computer-controlled heat treatment is initiated
- ▶ After treatment, forklift unloads bins into 'fly-free' area

Performance of alternative

In order to gain approval as a quarantine treatment, the heat treatment was trialled in the Cook Islands. The heat treatment was shown to be effective in killing the quarantine insects *Bactrocera melanotus* and *B. xanthodes*. This provided a similar level of quarantine security as MB fumigation.

Heat treatments	MB system
Workers do not have to handle a toxic fumigant	Highly toxic gas that needs to be handled with extreme care
Treatment time of 20 minutes at correct temperature; cooling period of 1.5 hours; 12 hour 'rest' (recovery) period for the fruit	Treatment time of 2 hours followed by airing of 3 hours before fruit can be loaded
Fruit pass through central facility which improves opportunity for security against quarantine pests. Improved quality control	Fruit packed individually by growers and fumigated in boxes. Less stringent inspections and quality control
Facility equipped with cool storage facilities which adds to capital cost but also improves fruit shelf-life	Cool store facilities not required (although it is commercially beneficial to have them)
Fruit quality can be improved: colour develops evenly and shelf-life is extended slightly	Fruit may develop rot on skins after MB treatment
Treatment does not utilise toxic fumigant which may be banned in the future	Treatment is currently exempt from controls under the Montreal Protocol. However, some governments and companies have banned or restricted use of MB due to its toxicity. The cost of MB may increase as a result of government policies

Now that the heat treatment has been optimised in the Cook Islands, it is proving very effective in commercial practice. No consignments of papaya have been rejected on entry to New Zealand due to fruit fly infestation.

The heat treatment has negligible effect on fruit quality when it is carried out properly. In fact, heat treatment of papaya can enhance the market quality of fruit. The treatment produces an even development of colour on the fruit, and slows down the rate of internal ripening, helping to extend fruit shelf-life slightly. The fruit flesh does not develop the bitterness characteristic of fruit treated with EDB. Heat treatments do not produce the rapid development of rots on the skin that occurs with MB fumigation (Table 2).

Acceptability to regulators and markets

The heat treatment has been approved by the quarantine authorities of New Zealand. It does not require regulatory approval by pesticide and food residue authorities.

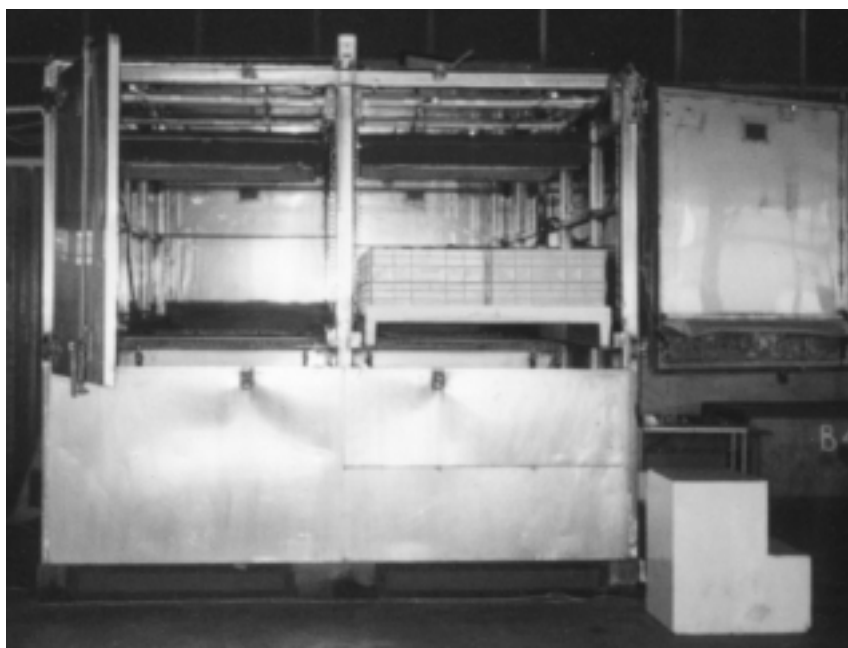
The treatment is commercially successful. Fruit treated with this heat treatment achieve the same prices in the market as fruit treated with fumigants. The Cook Island exporters have the opportunity to promote the fact that the fruit has not been chemically treated after harvest.

Costs

Commercial use of the heat treatment in the Cook Islands costs about US\$ 1.50 per export carton of papaya. Using MB would cost less. The export costs could be reduced by making

Case Study 18

PAPAYA EXPORTS FROM THE COOK ISLANDS: HEAT TREATMENT



Heat chamber used for fruit quarantine treatments in the Cook Islands

(Robert Petry)

changes such as using sea freight (estimated at US\$ 1.20 to 1.80) instead of air freight (US\$ 5.90 per carton), providing shelf-life at the retail level is not shortened unacceptably.

The installation cost of a MB fumigation chamber would be about US\$ 50,000, whereas the total installation cost of the heat treatment plant (including coolstores) in the Cook Islands was approximately US\$ 600,000. However, this was a relatively high price. Commercial heat treatment chambers can now be installed for about US\$ 155,000 (capacity 2,500 kg per run) to about US\$ 250,000 (capacity 3,000 kg per run), including equipment, full staff training and certification.

Application to other regions and uses

Heat treatments are used commercially as quarantine treatments in a variety of countries such as the USA, Australia, Cook Islands, Fiji, Tonga and Mexico to disinfest commodities such as papaya, mango and eggplant. Heat treatments could be used effectively for tropical fruit flies found in many other countries.

Heat treatments are also suitable for controlling temperate lepidopteran pests and thrips. The treatments applied to papaya and mango could be adapted for controlling temperate pests in avocado, litchi, bell pepper, nectarine and apricot. It could therefore be applied in future in countries such as Western Samoa, Vanuatu, Vietnam, India and New Zealand.

Technical information supplied by:

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Annex 1

About the UNEP DTIE OzonAction Programme

Nations around the world are concerned about the emissions of man-made CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide and other ozone-depleting substances (ODS) that have damaged the stratospheric ozone layer – a shield around the Earth which protects life from dangerous ultraviolet radiation from the Sun. Over 167 countries have committed themselves under the Montreal Protocol to phase out the use and production of these substances. Recognising the special needs of developing countries, the Parties to the Protocol also established a Multilateral Fund and appointed implementing agencies to provide technical and financial assistance to enable the developing countries to meet their commitments under the treaty. UNEP is one of the Fund's implementing agencies; the others are UNDP, UNIDO and the World Bank.

Since 1991, the UNEP DTIE OzonAction Programme in Paris has been strengthening the capacity of governments (especially National Ozone Units) and industry in developing countries to make informed decisions on technology and policy options that will result in cost-effective ODS phase-out activities with minimal external intervention. The Programme accomplishes this by delivering a range of need-based services, including:

Information Exchange

to enable decision makers to take informed decisions on policies and investments. Information and management tools already provided for developing countries include the OzonAction Information Clearinghouse (OAIC) diskette and World Wide Web site, a quarterly newsletter, sector-specific technical publications for identifying and selecting alternative technologies, and policy guidelines.

Training and Networking

to provide platforms for exchanging experiences, developing skills, and tapping the expertise of peers and other experts in the global ozone protection community. Training and network workshops build skills for implementing and managing phase-out activities, and are conducted at the regional level (support is also extended to national activities). The Programme currently operates eight regional and sub-regional Networks of ODS Officers comprising 95 countries, which have resulted in member countries taking early steps to implement the Montreal Protocol.

Country Programmes, Institutional Strengthening and Refrigerant Management Plans

to support the development of national ODS phase-out strategies and programmes, especially for low-volume ODS-consuming (LVC) countries. The Programme currently assists 79 countries in the development of their Country Programmes and implements Institutional-Strengthening projects for 67 countries. UNEP also assists LVC countries in the development of Refrigerant Management Plans, integrated national strategies to phase out ODS in the refrigeration sector.

For more information about these services please contact:

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Annex 1

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The mission of the UNEP Division of Technology, Industry and Economics (UNEP DTIE) 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

UNEP DTIE is located in Paris and is composed of one centre and four units:

- **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 whose economics are 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 OzoneAction (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 Unit.
- **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.

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

Annex 2

Contacts for Implementing Agencies

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

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Annex 3

Glossary of acronyms and terms used in these case studies

Acronym/Term	Meaning
Allelopathy	Use of plant-produced materials (eg. exudates, residues) that protect plants against attack
Biological controls	Living organisms used to control pests and diseases
Compost	Decomposed waste plant or animal materials
DE	Diatomaceous earth: Abrasive, fossilised remains of diatoms consisting mainly of silica with small amounts of other minerals that cause damage mainly to arthropod pests
Durables	Commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods
FPS system	Food Protection Service pest control system, a type of IPM programme
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
Hydroponic	Soil substitute system where water circulates with nutrients and needs careful management
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
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
Perishables	Fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs that generally have limited storage life
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
QPS	Quarantine and pre-shipment
Resistant varieties	Plant varieties that are able to resist attack by specific pests
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
Thermocouple	Device that measures temperature in a very localised area
<i>Trichoderma</i>	A beneficial soil fungus used as a biological control agent
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation

Units used in this report

Unit	Meaning
Hectare, ha	area of 10,000 square metres or 2.47 acres
Micron	thickness (length) of 0.001 millimetre or 0.000089 inches
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

Annex 4

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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 reflect the latest environmental information and technological and scientific developments. Through this dynamic process, significant progress has been achieved globally in protecting the ozone layer.

As a key agency 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.

Case Studies on Alternatives to Methyl Bromide, which presents a range of alternatives technologies, is neither comprehensive nor exhaustive. More information on these technologies will become available as they are further developed and countries gather more experience as they move ahead with methyl bromide phase out.

I encourage you to share your experiences with the OzonAction Programme so that we can inform others involved in this issue about the lessons you learned. Send us an e-mail, fax or letter about your experiences and successes in phasing out methyl bromide. We will consider it as an important part of collective learning.

Based on the feedback and information received, UNEP will update these case studies on a periodic basis to reflect the latest developments. We will also disseminate your experiences and stories through a variety of channels, including the *OzonAction Newsletter* and the OzonAction Programme's website (www.uneptie.org/ozonaction.html). 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 a pen and write to us. Let us learn collectively to protect the ozone layer.

**– Rajendra M Shende, Chief,
UNEP DTIE Energy and OzonAction Unit**