REPORT

WORKSHOP ON NON-CHEMICAL ALTERNATIVES TO REPLACE METHYL BROMIDE AS A SOIL FUMIGANT

26-28 June 2007
Budapest
Hungary

Edited by
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UNEP Global Environment Facility FIAT PANIS

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Abbreviations

AITC	Allyl Isothiocyanates
CFU	Colony-Forming Units
EPA	United States Environmental Protection Agency
EU	European Union
FFS	Farmers Field School
FOL	Fusarium oxysporum f.sp lycopersici
FOM	Fusarium oxysporum f.sp melonis
ICM	Integrated Crop Management
INIA	Instituto Nacional de Investigaciones Agrarias
IPM	Integrated Pest Management
MAPA	Agriculture, Fisheries and Food
MB	Methyl Bromide
MBTOC	Methyl Bromide Technical Option Committee
MITC	Methyl Isothiocyanates
MMA	Ministries of the Environment
MNSV	Melon Necrotic Spot Virus
MYCPP	Multy Year Crop Protection Plan
NCS	Nematode Control Strategy
NFT	Nutrient Flow Technique
PCN	Potato cyst nematode
PE	Polyethylene (PE)
PPO –AGV	Applied Plant Research
TOT	Training of Trainers
UNEP	United Nations Environment Programme
USA	United States of America
VFA	Volatile fatty acids

Preface

Soil-borne pests are a major constraint to the production of various economically important crops, especially vegetables and ornamentals. Soil disinfection is a normal practice to combat several soil-borne plant pathogens, weeds and arthropods pests, and is currently implemented before planting to avoid any damage to the crops once they are planted.

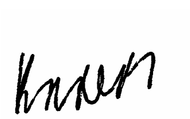
Methyl bromide (MB) has been the main agent used for the control of soil-borne pests worldwide. However, the discovery of its ozone-depleting effect has prompted the parties of the Montreal Protocol to agree on a phase-out of its use and production. All country signatories to the Protocol have been identifying and validating new alternatives to replace MB. Significant progress has been made in this area: indeed, the Methyl Bromide Technical Option Committee (MBTOC) has asserted that every single crop can be produced successfully without its use.

The phasing out of MB provides an opportunity for farmers to be more innovative in their approach to pest management. Understanding the biology and host range of the economically important pests that pose risks to a given crop is an important element in the development of a new approach for soil pest control.

At present, there are several chemical fumigants already in use, but some new non-chemical alternatives have also been identified, most of them providing good soil-borne pest control if properly combined and integrated. These alternatives are more environmentally friendly than the routine use of other chemical fumigants, and their success will largely depend on regular pest monitoring and the use of all possible resources to reduce and prevent the incidence and effects of a given disease or pest.

In understanding the need for the development of environmentally viable approaches to soil pest management, FAO and the United Nations Environment Programme (UNEP) decided, jointly with the authorities of the Ministry of Environment in Hungary, to organize a Subregional Technical Workshop with the participation of several specialists from Bulgaria, Hungary and Poland, as well as from other parts of Europe. The Workshop, held in Budapest, 26–28 June 2007, aimed to exchange information and experiences on the non-chemical alternatives already validated in each of the above-mentioned countries and discuss possible ways of their future use in the countries.

The present document compiles most of the information presented and discussed at the Workshop, which may also be useful to scientists, extension workers and farmers in other regions of the world.



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INTRODUCTORY PAPERS

The phasing out of methyl bromide

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Summary

The historical consumption of MB is described as well as the efforts to identify and validate new alternatives for soil-borne pest control, such as the use of floating beds and substrates such as rockwool; the use of the fumigants such as dazomet, metam sodium, Nemathorin 10 G and Vydate 10 G (Oxamil); growing of resistant cultivars or grafting on resistant rootstocks, and the use of preparations based on microorganisms for biological control of soil-borne pest.

Introduction

MB has been used in Hungary since 1982 for soil fumigation only, in different vegetables under greenhouse and in the open field. Figure 1 clearly shows the use of the fumigant from 1998 to 2003. Figure 2 indicates that the main uses of MB have always been as a soil fumigant in vegetables, tobacco and other minor crops. Table 1 shows the main target pests for MB application, which were mainly soil diseases, including damping-off, nematodes and *Gryllotalpa gryllotalpa*, among others.

It is clear that once Hungary started to comply with the initial convention and the Montreal Protocol, the use of the fumigant was reduced year after year. Hungary signed the Vienna Convention in 1988, became a signatory of the Montreal Protocol in 1989, and later signed the amendments of London (1993), Copenhagen (1994), Montreal (1999) and Beijing (2002).

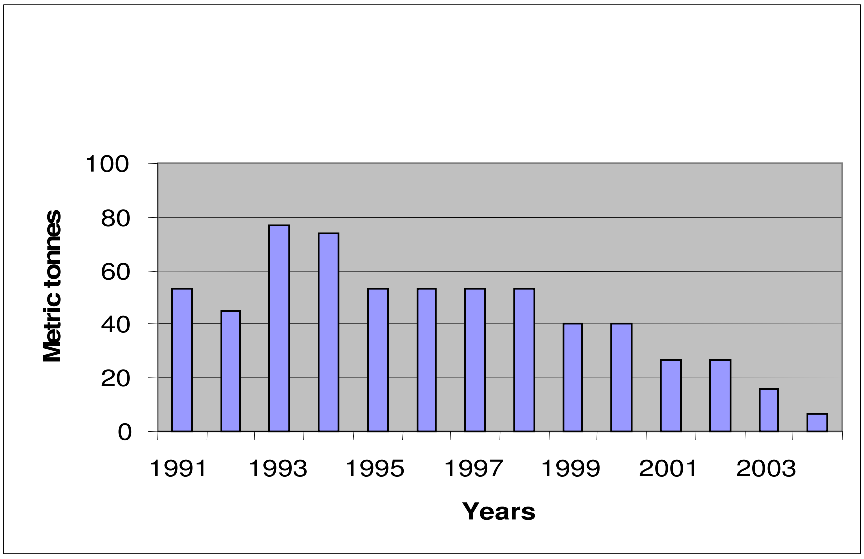

Figure 1: Consumption of MB in Hungary, 1991–2003

Hungary initiated a programme for identifying and validating new alternatives to replace the use of MB in different crops. As a result of this work, there are currently several alternatives already implemented and largely used by farmers: hydroponics, the use of floating beds and various substrates other than soil, e.g. rockwool; the use of other fumigants that are non-aggressive with the ozone layer, such as dazomet, metam sodium, Nemathorin 10 G and Vydate 10 G (Oxamil); growing of resistant cultivars or grafting on resistant rootstocks; and the use of preparations based on microorganisms for biological control of soil-borne pests.

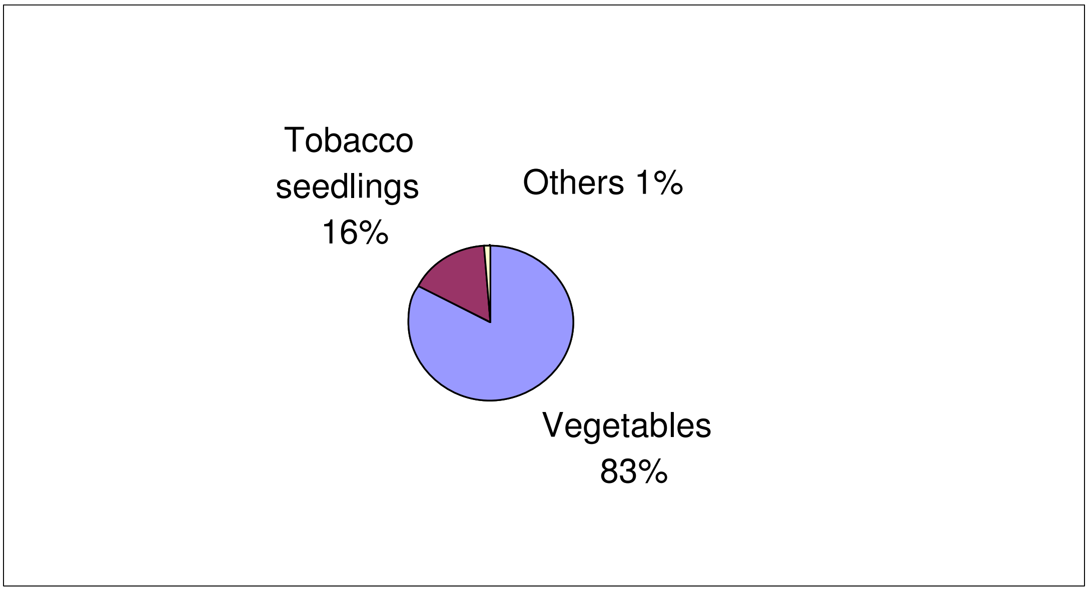

Figure 2: Pre-planting MB use in crops, 1995–98

Table 1: Main target pests for the control by methyl bromid

Crops	Pests
Vegetables: sweet pepper (paprika) tomatoes cucumber	Meloidogyne spp. (6 sp.) Fusarium oxisporum Sclerotinia spp. Bothrytis spp.
Tobacco seedling	*Pythium debarianum* *Fusarium sp.* *Gryllotalpa gryllotalpa* *Thrips tabaci*

Non-chemical alternatives to methyl bromide for soil-borne pest control

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Summary

A brief description of non-chemical alternatives to MB as a soil fumigant is given. There are various useful alternatives: soilless substrates, hot water steam, biological control agents, which include various pathogen antagonists, resistant cultivars and grafting, organic amendments and biofumigation, soil solarization and use of plant covers. Most of these alternatives are able to suppress the growth and development of several pests in soil. The application of these control strategies may be technically effective and economically feasible; however, they cannot exert action over the whole set of pathogens, nematodes and weed seeds in soil. Their successful application requires an integrated approach involving the application of combined control strategies according to the pest presence/abundance in soil. This integration is achievable by implementing Integrated Pest Management (IPM), which should take into consideration the presence of main pests in soil and guide the application of available alternatives when required. IPM for soil-borne pest control is likely to be improved with more data and knowledge of ecological behaviour of soil-borne pests. Hence, more basic research is required in this area for better understanding of the behaviour of soil pests and possible natural mechanisms for their suppression.

Introduction

Soil-borne pests are a major constraint to the production of several economically important crops, especially in horticulture. Disinfection of soil is therefore an essential activity to control soil-borne plant pathogens, weeds and arthropod pests for preventing their damage and keeping the production at the required level.

Soil disinfection is currently implemented before planting, using some extremely toxic chemicals or by physical means. The most popular fumigant has been MB, which has a broad spectrum action over several pest organisms in soil and has been used for many years.

The damaging effect of MB on the earth's protective ozone layer became known in the early 1990s, prompting the parties to the Montreal Protocol to agree on a phase-out schedule and a production and import ban to come into effect in 2005 in industrialized countries (Wallstrom, 2004).

Most of the country signatories of the Protocol are identifying and validating new alternatives to replace MB as a soil fumigant. Initially, the trend was to use some well-known methyl isothiocyanates (MITC) fumigants (metham sodium or dazomet), generally more expensive and without the same effectiveness as MB, as well as other methods, usually a combination of two or more control strategies, which provide new options for soil-borne pest control.

The status of soil-borne pest control and Integrated Pest Management (IPM)

The soil is correctly viewed as a dynamic body consisting of mineral and organic materials, gases and various living organisms (Leeper and Uren, 1993; Van Veen, 1997), some of which are beneficial for soil fertility and plant nutrition, while others – including various pathogens, nematodes, insect larvae and weed seeds – can cause serious injury to plant growth and productivity.

The behaviour and constituency of pathogens in soil is complex, and its understanding may help to implement better mechanisms of pest suppression, such as microbial competition with soil-borne pathogens, stimulation of soil biota using organic amendments or induction of plant resistance. In this context, Park (1963) stated that the apparent complexity of the biology of plant pathogens in soil is partly the result of the soil's opacity, which makes observations difficult and requires the use of indirect methods, whose interpretation is sometimes ambiguous.

Certainly, with the use of MB as a soil fumigant, no ecological information was necessary. The effectiveness of the fumigant was a guarantee of highly effective control of most pathogens and other pests in soil. It is also well acknowledged by all stakeholders that no single chemical alternative currently used exactly matches the broad-spectrum efficacy of MB. In several cases, the use of MITC fumigants or chemical cocktails of different fumigants, i.e. *1,3-dichloropene* with chloropicrin, appears to be satisfactory to some extent, but not in controlling the whole set of pests in soil.

There are several non-chemical alternatives able to suppress the growth and development of various pests in soil, which may be technically effective and economically feasible. However, most of them may have a very selective activity, i.e. controlling a group of pathogens or other pests, but not affecting others. In this context, success for the application of non-chemical alternatives requires an integrated approach involving combinations of multiple control strategies according to the pest presence/abundance in soil.

Rational integration of different control strategies for soil-borne pest control, or IPM, is the real option (FAO, 2001). Relevant control alternatives should be applied according to the problems in the soil. IPM may contribute to improving the health of crops, with fewer losses caused by pests, affecting humans and environment to a lesser extent.

According to the United States Environmental Protection Agency (EPA) (2007), IPM implementation reduces the need for fumigation and decreases production costs, relies on a preventative proactive response, and reduces disease outbreaks, thus increasing biological diversity.

Although IPM excludes the use of chemicals, it is difficult to talk about IPM implementation when heavy toxic fumigants or substances are currently used to control soil-borne pests.

IPM for soil-borne pest control needs further improvement. Knowledge of the ecological behaviour of soil-borne pests is the key for such an improvement (FAO, 2001). More basic research on understanding which pathogens cause yield reductions in non-fumigated soils and on rhizosphere microbial ecology are still be needed.

Available non-chemical alternatives for soil-borne pest control

Significant progress has been made in the past four years in identifying alternatives to MB for soil fumigation. In spite of the widespread use of this soil fumigant, the MBTOC did not identify a single crop that could not be produced successfully without the use of this fumigant (Batchelor, 2000).

Alternatives for soil-borne pest control vary from the application of chemical fumigants, most of which are less effective than MB, or a combination of physical, chemical and/or cultural control strategies.

IPM programmes for soil-borne pest control incorporate various biologically based strategies, which include: cultural practices such as crop rotation, planting time, resistant plant varieties and grafting; application of organic amendments and biofumigation, cover crops and/or plastic mulching; biological control to promote rhizobacteria; and the use of substrates other than soil (Greer and Diver, 1999). Physical methods such as soil solarization, hot water and steam are also part of this approach, but their implementation will greatly depend on affordability by farmers. Rational chemical control is also part of IPM, which does not exclude chemicals, but tries to reduce its use to a possible minimum.

Non-chemical alternatives offer various advantages, the main one being their environmental viability. Each of these alternatives has its own limitations, either technically or economically. It is only by implementing IPM that one may get the required effect on pest control.

Soilless substrates

Any substrate should accomplish the same functions played by soil, i.e., to serve as reservoir for nutrients and water, and to provide physical support for the root system of the plant.

Substrates other than soil may also provide an environment free of several commonly found soil-borne pests. These substrates avoid rather than control soil-borne pests.

Among the substrates, there are: solid substrates, such as gravel and sand, peat, vermiculite, perlite, bark chips, coconut fibre, rice hulls, sawdust; the porous fibre, known as rockwool, which is largely applied in several European countries; and expanded clay pebbles, among others (FAO, 1990).

There are versions of these substrates; for example, coconut fibres used in soil and hydroponics due to their biodegradability and resistance to rot, appear as compressed in form of bricks or cubes, or shredded fibres (Star Fibre Co., n.d.). Coconut bricks or cubes are largely used for plant propagation, while the shredded form is suitable to flow and drip systems. The latter are able to retain its original form and can be reused in hydroponics.

Rockwool is glass wool made from volcanic rocks and comes in various forms (Caltieri, 1987). Coconut fibre is sometimes used to top off rockwool growing media.

Combinations of some substrates are also common. For example, vermiculite retains moisture well, while perlite provides the necessary circulation of oxygen; both of these combined in a 50/50 percent proportion provide a good balance of moisture and oxygen (Gibson, 2001).

As already indicated, some of these growing media are reusable. Expanded hydroton clay are light-weight pellets, which can be cleaned, sterilized and re-used (Anon., 2006).

The most popular liquid substrate used at present is the "floating tray system", consisting of the use of polystyrene trays where healthy plants seedlings float in water. This method has been implemented extensively and with success in the production of tobacco seedlings in Brazil (Salles, 2001).

The major drawbacks of these systems is that they require good control of nutrient and salinity, and are not affordable by all farmers, since there are several costs related to the disinfections, recycling and disposal of solution and substrates (FAO, 2001).

Heating and steam

Hot water is a mean for soil disinfection. Water at temperatures above 95°C should be injected into the first 20–25°cm. This method is applied pre-planting in several small areas for the production of vegetables and other minor crops. It requires boilers for heating water. In Japan, it is asserted that soil disinfection may last up to three years with this method (Tateya, 2001).

The major drawback of the method is that it is not easy to obtain uniform temperature at the required soil depth. Further, there is a need for adequate water and fuel.

Steam was the primary method of soil sterilization in the greenhouse industry prior to the emergence of soil fumigants. Steam heat is highly effective and environmentally safe. Equipment and fuel costs are expensive, however, and treatment between crops is labour-and time-consuming (Greer and Diver, 1999).

There are various methods of steaming, such as (i) sheeting the soil and piping in steam for 6-8 hours for heating and sterilizing the first 30°cm of soil; and (ii) pumping steam into subsurface drainage pipes for sterilizing the first 40–45°cm of soil, among others.

The first indicated method is applied in Italy and in other countries for the production of valuable greenhouse crops (Gullino, 2001). In experiments in Italy, steam has been combined with potassium hydroxide in order to cause an exothermic reaction with water in an open field area. This combined treatment reduced the incidence of *Fusarium* wilt to a larger extent (77–96 percent) than steam only (70–89 percent) (Luvisi, Materazzi and Triolo, 2006)

Steam requires a boiler, fuel and replacement of tarps. The method is of low selectivity and may bring about a biological vacuum and consequent pathogen recolonization (Gullino, 2001).

Biological control agents

At present, there are several biological agents (Table 2) that reduce or suppress several pathogens in soil in different ways, including nematodes. The mechanism of action of these agents can be of a different nature (Elmer, 2006):

- *antibiosis*, inhibition, decomposition or destruction of the pathogen by the metabolic product (enzymes, volatile compounds, toxic substances and antibiotics) of the antagonist;
- *competition*, which occurs when the antagonist directly competes for the pathogens resources such as nutrients, oxygen and space, etc. An example of this mechanism is *Pseudomonas fluorescens,* known to produce siderophores,[1] which strongly bind to iron, blocking this element to other soil microorganisms, which cannot grow without it;
- *parasitism, hyperparasitism or mycoparasitism*, which takes place when the antagonist invades the pathogen by excreting extra cellular enzymes, phenols, chitinases, cellulases and other lytic enzymes.

Table 2: Main microorganisms used for biological control in soil

Bacteria	**Fungi**
Pseudomonas spp.	*Trichoderma harzianum*
Pseudomonas fluorescens	*Trichoderma viridae*
Pseudomonas putida	*Coniothyrium minitans*
Agrobacterium radiobacter	*Sporidesmium sclerotivorum*
Bacillus spp.	*Arthrobotrys*
Streptomyces spp.	*Dactylaria*
Pasteuria penetrans	*Dactycella*
	Monacrosporium
	Paecilomyces lilacinus (251)

Bacterial strains used for biological control currently prevent infectious diseases of plant roots producing antifungal antibiotics, eliciting induced systemic resistance in the host plant or interfering specifically with fungal pathogenicity factors during root colonization (Haas and Défago, 2005).

[1] Siderophore is a low molecular weight substance that binds very tightly to iron. It is synthesized by a variety of soil microorganisms to ensure that the organism is able to obtain sufficient amounts of iron from the environment.

Streptomyces griseoviridis (strain K61), commercially well known as Mycostop (100 millions of colony-forming units [CFU] per gram), a naturally occurring soil bacterium (Anon., 2003), and the fungi based on *Trichoderma* are among the most commonly used pathogens for biocontrol in soil. Both agents are used for the control of root diseases caused by *Pythium, Phytophtora, Rhizoctonia* and *Fusarium*.

In the United States of America (USA), the strain T22 of *Trichoderma harzianum* is effectively used for seed treatment at temperatures above 22–23°C. This kind of treatment puts all inoculum where it needs to be germinated on the emerging root (Bjorkman, 1999) and is effective in the summer. There are formulations of *Trichoderma harzianum* plus *T. koningii*, commercially known as Promot plus, and recommended for seed treatment. This product is claimed to work well against *Rhizoctonia solani*, species of *Pythium,* and *Sclerotia rolfsii*.

Paecilomyces lilacinus strain 251 is a fungus unable to grow or survive at human body temperature (EPA, 2005). It is effective in controlling plant root nematodes by infecting eggs, juveniles and adult females (ibid., 2005). It acts well against root-knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Heterodera* spp. and *Globodera* spp.).

Most of these bioagents should be used in preventative treatments since they will not be able to cut the development of the disease once established. It is for this reason that they are usually applied in combination with other control measures and their use is recommended as part of an IPM system (Minuto *et al*., n.d.).

Resistant cultivars and grafting

Breeders are regularly looking for crop varieties that are resistant to several important diseases, but the task is not easy. What is usually revealed as resistant in one site becomes susceptible in other one due to differences in pathogens races.

There are often high-yielding varieties, but with no resistance to important soil pathogens. It is for this reason that grafting, a method of asexual propagation consisting of fusing tissues of one plant into another, is becoming very popular. If the plant serving as rootstock is resistant to various soil pathogens, then the productive variety can be inserted, which will avoid possible diseases.

Grafting is a suitable measure to be integrated in the control system to be adopted. It allows to prevent damage from specific pests, but not the whole complex. Successful grafting has been achieved in tomatoes, pepper and cucurbit crops, among others. In most cases, grafting has prevented damage in plant roots from several diseases and nematodes (Bruton, 2005; Rivard and Louws, 2006). In some cases, the crop grafted may be tolerant to a set of pathogens and nematodes, while susceptible to others. In Italy, for example, this was reported for pepper grafted onto rootstocks “Graffito” or “Gc 1002” (Morra and Bilotto, 2006): it appeared to be tolerant to *Phytophtora capsici*, but susceptible to *Verticillium dahliae*, *Fusarium oxysporum*, *F. solani* and the root-knot nematode *Meloidogyne incognita.* Hence, careful assessment of resistance/susceptibility of the rootstocks is required *a priori.*

Organic amendments and biofumigation

Soil organic amendments have been used for a long time to improve physical properties of the soil. Their application normally improves soil organic matter, water retention, permeability, water infiltration, drainage, aeration and structure. In addition, organic soil amendments may also stimulate the activities of microorganisms that are antagonistic to various soil-borne pests, including nematodes (Stephen and Kostewicz, 2003).

The most common organic amendments are peat and manure, which when applied, are mixed thoroughly into soil. Another common organic amendment is compost, which can be prepared from residues of decaying plants and animal wastes. During the composting process, organic wastes are decomposed, plant nutrients mineralized into plant-available forms, and pathogens destroyed (Parr and Hornick, 1992). This practice has been used for a long time by farmers to convert organic wastes into useful soil amendments.

There are several good examples of improved disease and nematode control with the use of organic amendments. Cooperband (2002) reported that an application of an average of 10 tonnes/ha of raw and composted organic amendments reduces the incidence and severity of root rot diseases such as Pythium.

Singh Param, Nagra and Mehrotra (1981) found that *Rhizoctonia* root rot of gram was significantly controlled by the amendment of soil with wheat straw, maize straw and sorghum straws, i.e. those with a relatively high C/N ratio. However, in general, amendments with C/N ratios > 25, i.e. with a lower content of N, immobilize nitrogen; with respect to plant nutrition, organic amendments with higher N content are the preferred ones (Smith, n.d.).

In their process of decomposition in soil, organic amendments released various substances that are lethal to soil nematodes. In addition, they also stimulate the activities of microorganisms that are antagonistic to plant parasitic nematodes (Akhtar and Mali, 2000).

Biofumigation refers to the use of plants containing biologically active compounds to suppress soil-borne pests and diseases in agricultural production systems (Stapleton, 1998). Various crops, animal manure and industrial wastes are used effectively for biofumigation. Normally, incorporated organic mass once in decomposition releases several volatile compounds that are effective in controlling fungi, insect, nematodes and weeds.

Many plants in the *Brassicaceae* family produce glucosinolates naturally, which degrade into compounds such as MITC and allyl isothiocyanates (AITC) (Angus *et al.*, 1994). The plants used most often for incorporation are different types of black and white mustard, winter rape and broccoli, which are able to produce a huge aerial biomass in short periods of time and release the above-mentioned biocides.

Soil solarization

Soil solarization is a pre-plant and hydrothermal soil treatment to control soil-borne pathogens and pests (DeVay, 1991), in which a transparent plastic, allowing the sun rays to pass, is laid on the soil surface to trap solar radiation and heat the soil. Such a treatment disinfects soils without leaving toxic residues, increases the levels of available mineral nutrients in soils by breaking down soluble organic matter and making it more bioavailable, and changes the soil microflora to favour beneficial organisms.

This method was firstly developed when Katan and his colleagues in Israel covered the moist soil with transparent polyethylene (PE) film for 14 days and later noticed that this method reduced by 94-100 percent the incidence of *Fusarium oxysporum* f. sp. *vasinfectum* and *Verticillium dahliae* at 5°cm (DeVay, 1991).

The efficacy of solarization is due to the fact that most plant pathogens and pests are mesophylic, and do not tolerate temperatures above 31–32°C. All soil-borne organisms are normally directly or indirectly inactivated by heat; they become weakened and vulnerable to changes in the gas environment in solarizing soil or to changes in the populations of other organisms that may exert a form of biological control (Stapleton and DeVay, 1982; Katan, 1987). The success of this method greatly depends on moisture for maximum heat transfer to soil-borne organisms, while the thermal decline of soil-borne organisms during solarization depends on both the soil temperature and exposure time (DeVay, 1991). Unfortunately, this method will fail in several temperate countries, and in hot climate areas, may not be effective under certain conditions if the required period of solarization is not followed. It is for this reason that, in some countries, farmers cannot afford to wait 6-8 weeks of solarization for planting the crops.

Control of root-knot nematodes has proven difficult with the use of soil solarization, while biofumigation has also been somewhat erratic for the control of soil-borne diseases. It is for this reason that soil solarization is combined with bio-fumigation for root-knot nematode control. Obtained results indicate that biofumigation increases the efficacy of solarization. Thus, higher levels of control are achieved at lower temperatures or over shorter periods (Ploeg and Stapleton, 2001). This combination shortens the period of solarization and also improves the control of soil-borne pests. It is already largely implemented in some countries such as Jordan and Spain.

Use of plant covers

Historically, farmers have known that crop rotations are important for maintaining agricultural productivity. During the last decades, however, the trends toward specialization, mechanization and the use of agrochemicals have significantly reduced this practice.

Although crop yields have increased with simple rotations or monocropping, these practices have also brought about some negative consequences, including pest outbreaks and soil degradation. In light of this, in several areas of the world, farmers have renewed their interest in rotations, and cover crops seem to be useful for short periods of rotation. The incorporation of legumes into the soil provides nitrogen, improves soil structure and water infiltration, traps nitrates preventing their leaching, reduces the incidence of diseases and nematodes, and controls weeds. The use of plant covers has even replaced the traditional use of black polyethylene mulch.

Among the most recommended covers are, *inter alia*, annual ryegrass (*Lolium multiflorum*) (Satell *et al*., 1998a), sweet clover (Verhallen, 2001), *Vicia villosa* Roth (Hairy vetch) and (Satell *et al*., 1998b).

An ill-chosen cover crop should have some disadvantages in a wrong crop rotation. One example is that vetch may serve as host of sclerotinia and increases the incidence of the disease in a subsequent lettuce crop (Thomas *et al*., n.d.). Some cover crop species can become serious weeds if improperly selected or managed, such as vetches or cereal rye producing enormous amounts of biomass, which can hinder various agricultural operations in the field (Ingels *et al*., 1996).

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COUNTRY REPORTS

Non–chemical alternatives used in Bulgaria

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Summary

The main non-chemical alternatives for the control of soil-borne pests used in Bulgaria include: cultural practices such as crop rotation and soilless substrate; physical methods such as steaming, soil solarization; and biological control through the use of Trichoderma, BioAct WG (Paecilomyces lilacinus, strain 251). Some of these methods have recently started to be used with good acceptance by farmers.

History of greenhouses in Bulgaria

In Bulgaria, in 1931, the first greenhouse was constructed in the town of Kyustendil. It was heated with mineral water at a temperature of 75°C. Greenhouse areas in the country increased to 17 ha in 1964, and to 850 ha in 1985. However, from 2001 to 2004, a decrease of greenhouses took place (Figure 3).

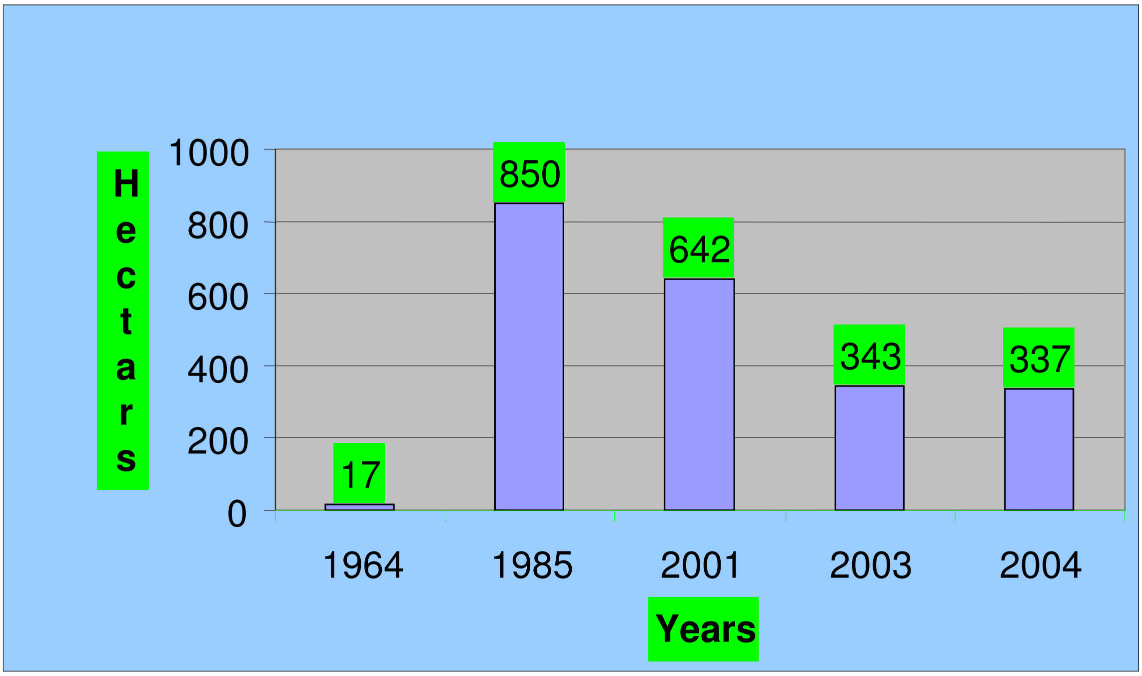

Figure 3: Glass greenhouse area in Bulgaria 1964–2004

At the same time, the area under plastic greenhouses was 1 500 ha in 1985, and also decreased, to only 443 ha in 2004 (Figure 4).

Non-chemical alternatives used in Bulgaria to replace MB as a soil fumigant.

Cultural practices

The following cultural practices have been used as non-chemical alternatives to MB:

- Crop rotation is a useful alternative, but it is very difficult to implement in greenhouses. It is also ineffective against several soil-borne fungi such as: *Rhizoctonia solani, Verticillium dahliae* and *Fusarium* sp.

- Resistant varieties are considered the best method for the control of various plant diseases. Resistant varieties provide an ecological solution, exclude fungicide application, rendering the production highly economically feasible and providing a high return on investments.

- Soilless substrate (hydroponics) is a technology of interest for growing vegetables. The area of soilless substrates has recently increased. At present, soilless cultivation covers about 30 ha in the country. This method has proved to be a good alternative to MB since fumigation of soil is not necessary. A limiting factor for its wide application is the high initial investment.

- Other cultural methods practised are irrigation and draining, soil cultivation, application of fertilizers, grafting, and the use of clean seeds and planting materials.

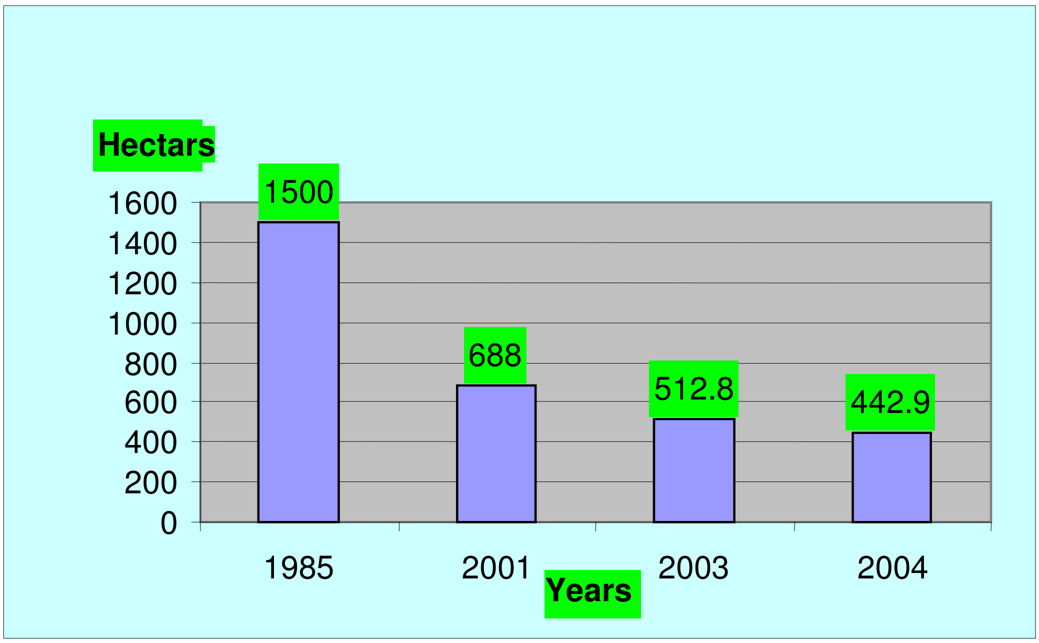

Figure 4: Plastic Greenhouses in Bulgaria

Physical methods

Physical methods have also been used for soil-borne pest control, including steaming and solarization:

- Steaming, which provides a wide spectrum of pest control, does not leave any harmful residues in the soil, and no waiting period is required for planting. However, this method is of low selectivity, creating a “biological vacuum”; it requires high initial investment for its implementation, consumes a high quantity of energy. Furthermore, its cost per ha is about € 20 000.

- Solarization is a recent development for soil disinfection, which has been used in Bulgaria for the last five-six years. Research on this method started in 1998 in the country. It consists of the use of plastic transparent sheets covering clean and moist soil to enable sunrays to pass through and to be absorbed, thus creating a heating system in soil that will later control several weeds and other pathogens present in soil. This method is effective when the soil is deeply prepared and is initially irrigated at field capacity. Heat leakage should be avoided by making sure that the plastic sheet edges are buried well. Air gaps between the plastic and soil should be minimized as they inhibit heat transfer into the soil.

Meteorological data in Bulgaria show that July and August are the most suitable months for solarization since they are the sunniest and hottest.

The number of sunshine hours per month is 317.8 on average in July and 293.8 in August. The solar radiation in summer is 20 percent higher in Bulgaria than in the Netherlands.

Biological control

Biological control consists of the use of biological control agents, which may compete for substrates, release antibiotics and other compounds that are biologically active, cause direct parasitism, induce plant host resistance and/or improve its physiological status.

As a result of the conducted research, a biological product called “Trichodermin NPA” was registered in Bulgaria with the following number: Order RD 12-42/10.09.2004 of MAF. The product is based on the fungus Trichoderma sp., strain 6, which is effective against soil-borne fungi, such as *Verticillium dahliae, Fusarium* sp., *Rhizoctonia solani* and *Pythium* sp.

Trichodermin is applied at a rate of 100–300 kg/ha after soil treatment, e.g. solarization, steaming or fumigation. For treating other substrates, it is applied at a rate of 2-3 kg/m^3 before planting. Seedlings for transplanting can be watered with a solution of 2 g of the product/plant. Similarly, trichodermin can be applied 20 days after transplanting by watering the plants with a solution 2 g/plant dissolved in 200–250 ml water. This treatment can be repeated if necessary.

There is another product called “BioAct WG”, which is highly effective against the nematode *Meloidogyne arenaria* Neal. This granular formulation belongs to Prophyta and is based on the fungus *Paecilomyces lilacinus*, strain 251. It is also effective for the control of nematodes such as *Meloidogyne* spp., *Pratilenchus* spp., *Heterodera* spp. and *Globodera rostochiensis*.

This formulation can be applied effectively even in combination with other bioagents and is suitable for use in integrated systems. It is normally applied 14 days before transplanting at a rate of 40 kg/ha in a final solution of 100–500 litres of water, and soil-incorporated at 10-15°cm depth. This treatment requires the soil to be well prepared for its uniform distribution in the soil. Seedlings for transplanting can be treated at a proportion of 10 g of the product per 100 plants. After transplanting, it is applied by watering the plants with BioAct solution 0.2 g/plant in 200–250 ml water. The treatment can be repeated if necessary.

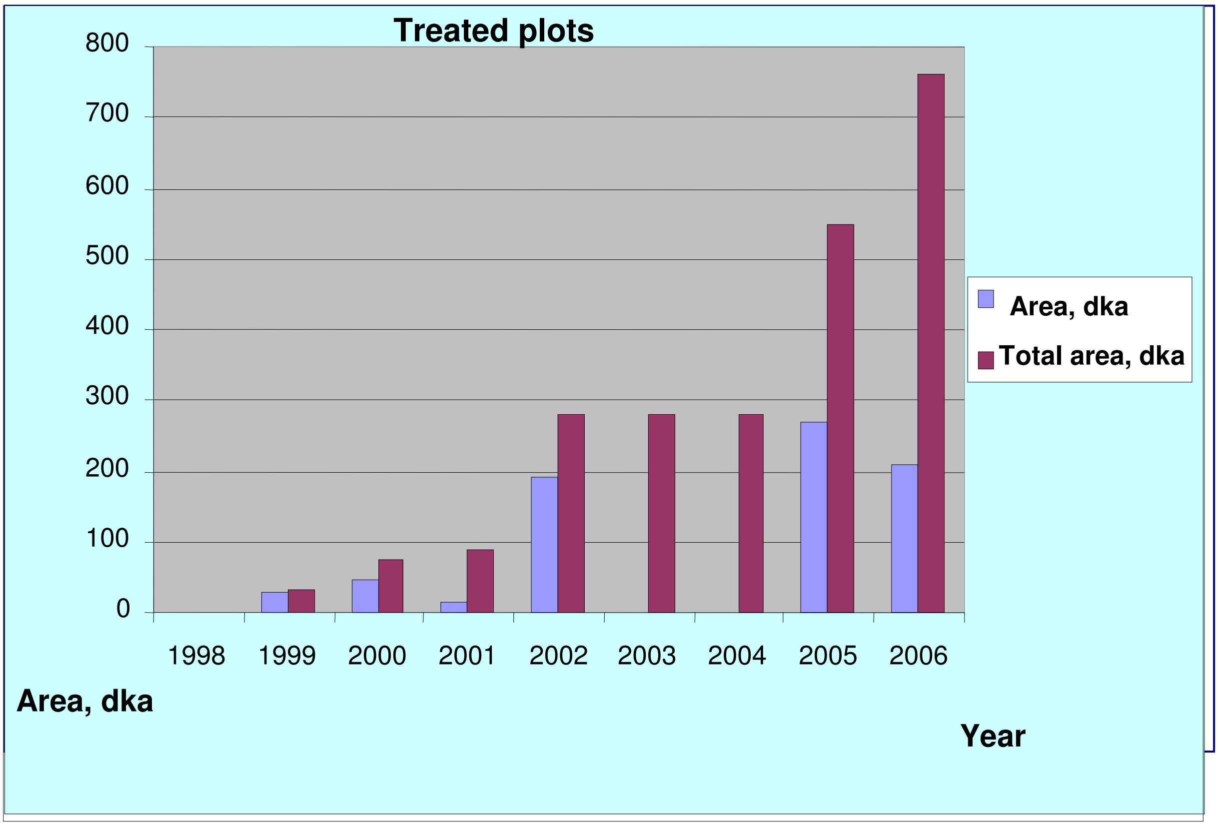

Figure 5: Diagram of the treated plots in dka applying both methods starting from 1999 to the present

The Maritsa Vegetable Crops Research Institute in Plovdiv conducted a test of this bionematocide against *Meloidogyne arenaria* Neal in cucumbers during the 2003 cropping season. The treatments studied were non-treated control, Vydate (oxamyl) 10G at 100 kg/ha, BioAct WG – one treatment three weeks after transplanting, and BioAct WG – two treatments three and five weeks after transplanting.

At the end of crop cycle, the level of attacked plants in the treatments was lower than that in the non-treated control (Figure 6). Interesting data was gathered regarding the rate of infestation, the index of gall-formation and effectiveness of the product. Low infestation rates prevailed in all treatments, while in the control there were a high number of plants with grade 4 infestation (40.74 percent). The gall formation index had the highest values in the control (75 percent) and the lowest one in the treatment with Vydate 10G (25 percent). Both treatments with BioAct WG showed a gall formation index of 48.75 percent and 44.75 percent, respectively. The highest effectiveness in general was obtained with the use of oxamyl followed by treatments with BioAct WG, with 51.25 percent and 55.26 percent, respectively. Taking into consideration that BioAct is a biological product and its benefit for the environment is clear, it is evident that its application for nematode control should be prioritized. It can be effectively used with other bioagents, such as *Trichoderma harzianum*, *Gliocladium virens*, *Pseudomonas fluorescens* and *Bacillus polymyxa*. The results obtained clearly show the convenience of using BioAct WG (*Paecilomyces lilacinus*) as another component of the integrated system of pest management in vegetables grown under greenhouse conditions.

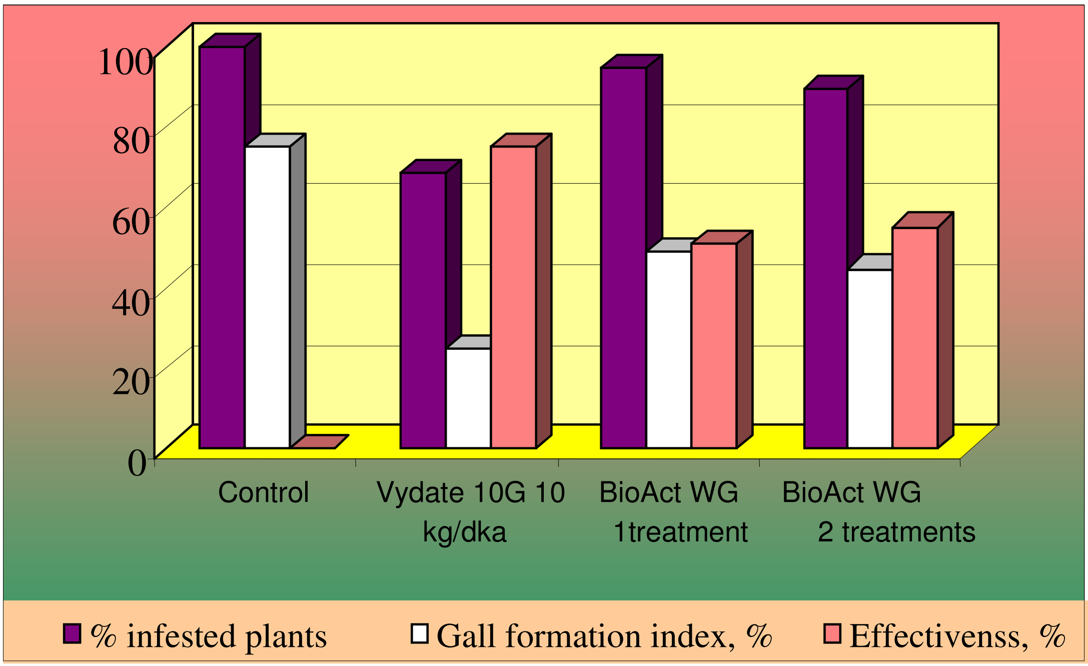

Figure 6: Action of bioproduct BioAct WG compared with Vydate 10G

The post-activity of BioAct WG in the second transplanted cucumber in the same previously treated areas was studied. Data obtained categorically confirmed the efficacy of BioAct WG against *Meloidogyne arenaria* (Figure 6*)*. The record index of gall formation was 76.09 percent in the control, 70.31 percent in Vydate 10g, and 51.47 percent and 56.94 percent in both treatments with BioAct WG, respectively (Table 3).

Table 3: Post-activity of BioAct WG against *Meloidogyne arenaria* Neal in cucumbers

Variant	Percentage of infested plants	% plants by grade of infestation					Index of gall formation, %
		0	1	2	3	4	
Control (non-treated)	100.00	0.00	17.40	8.70	26.09	47.83	76.09
Vydate 10G 10 kg/dka (standard)	100.00	0.00	12.50	31.25	18.75	37.50	70.31
BioAct WG 1 treatment	82.35	17.65	17.65	29.41	11.76	23.53	51.47
BioAct WG 2 treatments	88.89	11.11	11.11	38.89	16.67	22.22	56.94

As a result of the research conducted in Bulgaria, it is clear that the best alternatives for the replacement of MB are soil solarization and the application of biological products, such as Trichodermin and BioAct, which can be used effectively as part of the IPM procedures.

Hydroculture in Hungary

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Summary

In 1994–98 in Hungary several farms started to grow tomato, sweet pepper, cucumber, and ornamentals (carnation and gerbera) on various soilless substrates, such as rockwool, coconut fibres, peat and perlite. The introduction of this new technology was possible owing to the assistance from the Netherlands and Denmark.

Vegetables production

In the past, tomato, sweet pepper and cucumber were mainly grown on soil treated with MB, formulation Metabrom 980) at a rate of 60-80 g/m^2. This application was carried out every three years in growing tomato varieties resistant to nematodes; otherwise, the areas of the crops were treated pre-planting with MB.

In this way, tomato gave yields of 18-22 kg/m^2/year; sweet pepper, 10-15 kg/m^2/year; and cucumber, 25-30 kg/m^2/year.

The application of the fumigant was stopped due to the following economical considerations:

- tomato production was not able to reach 20-22 kg/m^2/year.
- the costs of the production increased continuously and MB was too expensive.
- the Hungarian Government supported the shift towards a new technology. New research was started in this area, with 40 percent of financial support given by the government.

In 1994–98, several farms started to use soilless cultivation. This shift was possible with the assistance from the Netherlands, including new machinery, a dripping system and growing materials, as well as recipes imported from the Netherlands and Denmark. Initial attempts of soilless cultivation were successful; crop root systems were possible to keep for longer periods in new substrates other than soil.

Tomato, sweet pepper and cucumber started to be grown on rockwool, coconut fibres, peat and perlite. The plants could grow up to 49 weeks on these substrates, with high yields and quality.

By this method, cucumber gave yields of 50-60 kg/m^2/year; tomato, 45-50 kg/m^2/year; and sweet pepper, 20-25 kg/m^2/year.

During the 1998–2002 period, most of the small farms shifted to soilless cultivation.

Ornamentals

Before adopting soilless methods, gerbera, rose and carnation were grown on soil ridges, with pre-planting treatment of MB at 100 g/m^2. The treatment never assured complete control of soil-borne pests. In several cases, the areas had a recontamination of diseases. It was possible to grow gerbera and carnation for a two-year period, and rose for a five-year period. In most cases, crop yield losses of 30-40 percent were recorded.

It is for this reason that there was also a shift towards soilless cultivation of these crops.

At present, gerbera is grown in buckets with rockwool, growcubes or coconut fibres. The cycle of the plant reaches three years, with little yield losses, less than 10 percent, and yields of up to 200–250 stems/m^2/year.

Roses are grown in buckets, as above. The growing period is seven years with no losses incurred, and the yields are 250-300 stems/m^2/year, with a very high quality.

Carnations are also grown in buckets as above, with a growing period of 2-3 years, with no losses, and the yields are also 250-300 stems/m^2/year, with a very high quality.

Due to this development, there is currently an increased number of greenhouses for growing several crops on soilless substrates, which enables farmers to grow more than one crop during the year, and also to minimize the problems of soil-borne pests.

Grafting as an alternative for vegetable production in Hungary

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Summary

Areas growing grafted crops have recently increased in Hungary. This increase is due to the need to increase crop productivity by extending their growing periods and using high-yielding varieties. Grafting is a technology that enables farmers to better protect the crops with less inputs for pest control. At present, grafted paprika is grown in heated plastic tunnels, in a total area of 22 ha, while tomato plants are grafted mainly on Maxifort rootstock, grown in large greenhouses. These plants are either grafted in Hungary or imported. Integration of grafting with other control strategies improves pest management of these crops.

Vegetable production in Hungary

The trend of vegetable production in the open field in Hungary during the last four years is shown in Figure 7. The main crops grown outdoors are sweet corn, pea, watermelon, tomato, pepper and onion. The production in glass and greenhouses is shown in Figure 8 The main crops grown indoors are pepper, tomato, cucumber and brassicas.

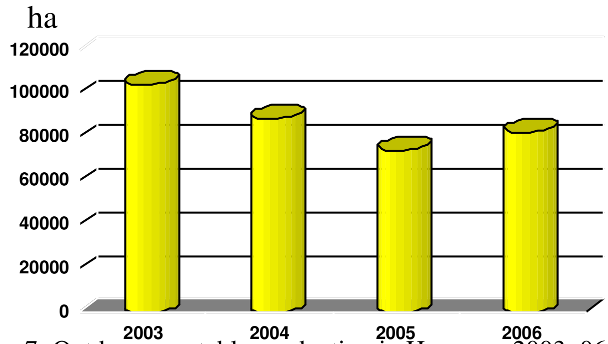

Figure 7: Outdoor vegetable production in Hungary, 2003–06

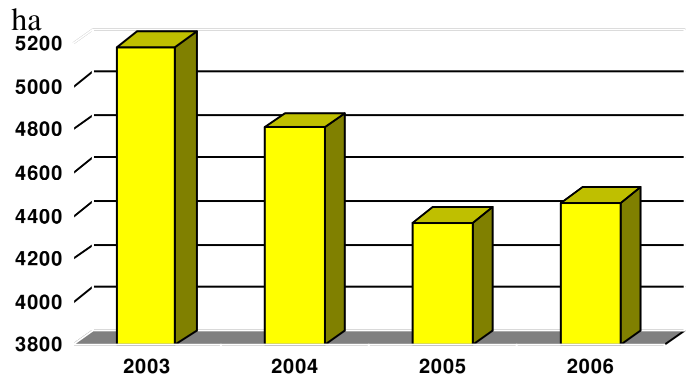

Figure 8: Greenhouse (glass + plastic) vegetable production in Hungary, 2003–06

It is clear from both figures that there is a reduction of the areas of crops grown in the open field as well as indoors. Obviously, a decrease of production of these crops has also been recorded (Figure 9 and Figure 10).

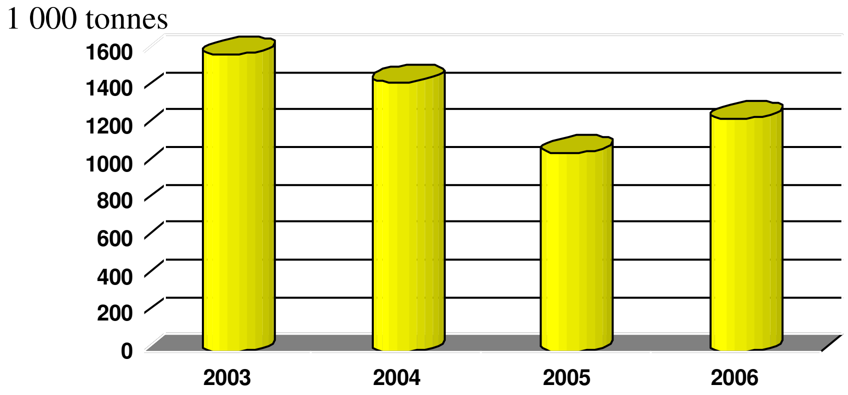

Figure 9: Vegetables production in Hungary in the open field, 2003–06

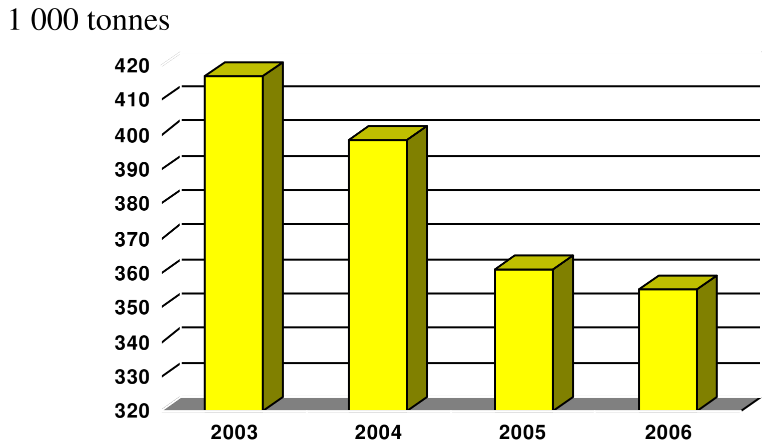

Figure 10: Vegetables production in Hungary in glass and plastic greenhouses

At present, there is a trend towards introducing and expanding the areas with grafted crops. The reason for such an expansion is to extend the growing period using selected productive and better adapted varieties, with less use of pesticides and fumigants and improved control of soil-borne pathogens. Grafting also enables farmers to use fertilizers efficiently, obtain higher yields and improve the quality of the produce.

In the late 1990s, the first trials with grafted young plants were conducted by Arpad with S&G and CAVI. The main crops were grafted pepper and young tomato plants imported from Italy, pepper and melon from Grow Group, watermelon from KITE, tomato from Palántakert, pepper, tomato and melon from SL Palánta, and watermelon and cucumber from other private growers.

Grafting

Grafted young paprika plants are currently grown in heated plastic tunnels, in a total area of 22 ha, mainly sweet yellow variety and a few hot green peppers. An average of 500 000–600 000 pieces are grafted in Hungary annually, while others are imported. Such a method provides a density of 3 plants/m^2. The main rootstock is Snooker.

Grafted pepper plants have the advantages of having larger and stronger root mass and growing more vigorously; both productivity and quality are increased. Some differences are shown in Table 4.

Table 4: Pepper plants grafted vs. own-rooted

	Grafted	**Own-rooted**
Plants/m^2	3-4	5-6
Stem(s)	2	1
Young plant cost ft/m^2	630	300
Yield (kg/m^2)	20-22	13–15
Income (ft/m^2)	4 000-4 400	2 600–3 000

Tomato plants are grafted mainly on Maxifort rootstock, grown in large greenhouses. These plants are either grafted in Hungary or imported. In total, 500 000–600 000 grafted tomato plants are planted in Hungary annually, covering an area of 27-30 ha. The plants are grown on rockwool as the substrate or in containers (**Table 5**).

Table 5: Tomato plants grafted vs. own-rooted

	Grafted	**Own-rooted**
Plants/ m2	1.7–1.8	2.5–3
Stem(s)	2	1
Yield (kg/m2)	40-45	30–35

Grafted watermelon is grafted on Cucurbita or Langenaria rootstocks. The plants are grown mainly in the open field. A total of 3.2–3.3 million grafted melon are planted annually, covering an area of 1 000 ha, all with plastic mulch and precise fertigation (Table 6).

Table 6 Watermelon grafted vs. own-rooted

	Grafted (Langenaria root)	**Grafted (Cucurbita root)**	**Own-rooted**
Yield (t/ha)	70–75	75–82	55-60
Price of young plants (ft/db)	140-150	150–160	50
Plant density (pl./ha)	3 000–3 200	3 000–3 200	6 000

There is a need now and in the future to integrate grafting with other pest management strategies. This is the only way to attain environmentally friendly horticulture and healthy produce for consumers.

Growing in containers in Hungary

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Summary

The use of substrates other than soil as well as pots or containers for vegetables and ornamentals production in Hungary will be described in this paper. Bog-peat, low moor peat, coconut fibres, perlite, fired clay granules, sand and other organic substrates (straw and waste wood) are among the main alternative substrates, while the most common containers are buckets, including polystyrene ones, boxes and polyethylene sacs. This paper explains that the best substrate should serve as a stake and make nutrients easily accessible to the plant. It should also have hydraulic conductivity and be free from soil-borne pests.

Introduction

A time-honoured method of soilless production is cultivation in artificial media (hydroponics), which shows considerable development in wealthy farms (e.g. in the Netherlands, Spain). The less capital-intensive solution is cultivation in containers or buckets, which can be applied successfully, even in smaller farms. Considering the capital and size of the Hungarian gardens, this procedure for growing has been selected for adaptation to country conditions.

The most important function of the growing substrate is to replace the soil, serving as a stake and thus conducting the nutrients to the roots. An essential principle here is that structure should not change during the cultivation; it should be stable, free from decomposition, and have no effect on the composition of the nutrient solution. Also, it should ensure the optimal amount of oxygen for the roots. In addition, it should have a certain level of hydraulic conductivity and hydrous capability, be free of pathogens, pests, and chemicals that are harmful to humans or plants.

Several natural substrates with appropriate structure, and physical and chemical characteristics are available for the production in buckets (containers). In addition, industry produces more and better substrates suitable for fixing roots. To develop a successful procedure, the advantages and disadvantages should be known as well as the possibilities of their use.

Available substrates in vegetable production in Hungary

Bog-peat

This is taken mainly from peat-moss mud in North Europe (Lithuania, Finland). It has a fibrous structure, maintains its flexibility even after pressing, has a large amount of plant residue and acid reaction (pH 3-4), and a low nutrient content.

Low moor peat

Generally, only these types of peat are available in Hungary. They are usually neutral, darker, and contain a significant amount of humic compounds. After drying, it is difficult or impossible to wet again; it hardens after pressing, becoming airless. It may contain a harmful quantity of sodium. The growers often apply it as an additive because of its low price.

Coconut fibres

These fibres are used for hydroponics in many countries. The pH value of coconut fibres is stable and its potassium and calcium content may be different depending on its preparation. It can be used for a year because it decomposes considerably, which alters its original characteristics. It is transported dried and pressed.

Perlite

Perlite is produced at high temperatures by heating volcanic rock. It has aggregates, is chemically inactive, and puts up a good resistance to the effects of acid and base. Its field capacity is very good. Further, it is free from pests and pathogens, and relatively cheap.

Fired clay granules

The feedstock of fired clay granules is lime-free clay mineral. Clay granules are of a sterile, porous, tubular structure with excellent capillary characteristics. Their mechanical resistance is high; they can be used for many years because of its durable structure. Its mass is much less than gravel, which enables easy transport.

Sand

Sand was previously used as an additive to make substrates looser and also for producing special soil mixtures for different growing purposes. Because of its low price, growers currently use it entirely as a substrate for vegetable growing as well. Its reaction is neutral (pH 7). Its ion-changing capacity and water-holding capacity are low.

Other organic substrates (*straw, waste wood, etc.*)

Most of the growers used these substrates because of their low cost. Most of them extract nitrogen from the nutrient solution during their decomposition. Due to their physical and chemical characteristics, they can be added up to 20 percent of the mixture. The use of these substrates in vegetable growing is not recommended.

In Hungary, several substrates and substrate mixtures are available. There are a large number of combinations, depending on the grower and growing conditions (Table 7).

Pots applied in Hungary

Buckets

Buckets are the most widely containers in hydroponics. The quality of the buckets can be very different and always depends on the producer and the feedstock applied.

Hungarian growers prefer them because of their wide availability and reasonable price.

Plastic containers

Made from polyethylene, plastic containers come in various sizes and colours, the most popular being black and pale-coloured. While they have the advantage of being cheap and light, they are also vulnerable to UV radiation and tear easily. They can be used for two–three years at the most.

Other plastic pots and boxes

A few years ago, in addition to the traditional buckets, some farmers started to use window boxes (flower boxes) for soilless vegetable production. At present, these boxes are one of the most popular growing pots in Hungary, especially among growers using coconut peat as a substrate. Some manufacturers are specialized in producing sized and "pre-punched" boxes, especially for the soilless vegetable growing method. Although expensive, they can be used for many years.

Table 7: Mixed substrate used in Hungary

1.	100% perlite
2.	100% coconut fibres
3.	50% bog-peat 50% perlite
4.	70% bog-peat 30% perlite
5.	50% bog-peat 30% perlite 20% sand
6.	60% bog-peat 20% perlite 20% sand
7.	60% low moor peat 20% bog-peat 20% perlite 3 kg/m^3 fetrilizer
8.	60% low moor peat 25% bog peat 15% perlite 3 kg/ m^3 fertilizer
9.	75% peat mixture 25% perlite
10.	75% bog-peat 25% perlite 3 kg/ m^3 fertilizer
11.	40% low moor peat 30% bog-peat 30% perlite 3 kg/ m^3 fertilizer
12.	100% sand

Polystyrene buckets and boxes

These pots are produced expressly for soilless vegetable production. The capacity of the containers varies between 10-45 litres. They are not used in Hungary, but are widely used in Spain and in the Mediterranean region. With their thick walls and good quality, they can be used for many years in vegetable forcing.

Polyethylene sacs

These can be filled with almost any substrate. Growers frequently apply coconut fibres. In practice, they can be used for one-two years. Their advantage is that they are cheap and light; however, the filling requires a great deal of labour. They are usually pale in colour.

Biological pest control at Arpad-Agrar

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Summary

The importance of the use of biological agents for pest control is described, particularly for soil-borne pathogens and nematodes. In Arpad Co., biological control has become an important activity for reducing the use of pesticides and minimizing pest damage. The current biocontrol alternatives are *Orius leavigatus*, a predatory bug used for the control of thrips; *Aphidius colemani*, a parasitic wasp against aphids; *Phytoseuiulus persimilis*, a predatory mite against spider mite; *Encarsia formosa*, a parasitic wasp for the control of whitefly; and *Macrolophus caliginosus,* a predatory bug against whitefly and spider mite. For the control of leaf miners, parasitic wasps *Dacnusa* and *Diglyphus* are used early in the season. *Bacillus thuringiensis,* prepared as the formulation Scutello 2X, is applied against caterpillars. Wilt diseases caused by Fusarium, Verticillium, Rhizoctonia and Phytium are controlled by two microbiological preparations, Mycostop based on *Streptomyces griseoviridis* K61, and Koni, based on *Coniothyrium minitans* K1. Another preparation, Trifender, is used against wilt diseases caused by Sclerotinia, which is based on the microorganism *Trichoderma asperellum.*

Introduction

The agricultural company Arpad was founded in 1960 as a cooperative and is located near the city of Szentes, in southeast Hungary. It is one of the largest of its kind in the country. The name originated from Árpád (the founder of Hungary), the leader of the tribe of Magyars, who lived more then 1 100 years ago.

Arpad's activities are concentrated on open-field agriculture, animal husbandry, food processing, wineries and bakeries. In addition to these activities, Arpad owns 30 ha of glasshouses, divided in three greenhouse operations.

The cooperative has 20 thermal wells that supply heating energy to more than 60 ha of greenhouses. It also has the largest thermal-heated greenhouse area in Europe. In fact, Hungary is the second country in the world, after the USA, to use thermal water (more than 200 ha) for horticultural purposes.

The main protected crop is pepper, specifically the white type of sweet pepper (11 ha) and the long green hot pepper (3 ha), followed by tomato (9 ha) and cucumber (1 ha). There are also 3 ha of nurseries of young plants.

Problems of chemical crop protection

Arpad's production also faces various problems during the crop cycle, such as plant burning; flower abortion and the hazard of the control means for the environment, workers and customers. It also faces problems of pest resistance and tolerance, control of pesticide use, and measures to avoid their residues.

To this end, the cooperative has been seeking resistant cultivars, applying good sanitation techniques in greenhouses, cleaning weeds, conducting a system for pest monitoring, the use of traps with glue or pheromones, and climate control for providing the right temperature and humidity of the indoor environment.

Biological control has become an important activity for reducing the use of chemicals and minimizing pest damage. Here, the most important challenge is finding the right biological technology for the control of specific pests.

For different target organisms, Arpad has been able to implement specific biological control measures, as detailed below.

Thrips are controlled releasing the predatory mite *Amblyseius cucumeris*. Thrips can cause serious damage in several crops under greenhouses. With the widespread application of other substrates, the thrips problem has increased. Soil treatments that made thrips hibernation impossible are not applied in soilless cultivation. *Amblyseius cucumeris* is a beige predatory mite of less than 1 mm. As an arachnid it has eight legs. In spite of its modest appearance, it is still conspicuous because of its mobility on the surface of a leaf or in the flower. The agent has been applied in 14 ha of sweet and hot peppers. There are other species of the same genus, *Amblyseius degenerans*, also a predatory mite for thrips control and *Amblyseius swirskii*, a predatory mite against spider mite, thrips and whitefly in cucumber.

Orius leavigatus, a predatory bug, is used for the control of thrips. This is a pirate bug and the most voracious beneficial insect against thrips. It only attacks adult thrips. One can often see an *Orius* with a thrips stuck on its rostrum walking on a leaf.

Application of *Aphidius colemani*, a parasitic wasp against aphids, which reproduces very fast, can be released for a preventative or early curative control.

Phytoseuiulus persimilis, a predatory mite against *spider mite*, is a pest that spares few greenhouse crops and reproduces quickly in dry and warm weather. This agent has been used for a long time for the control of red spider mite. The predatory mite *Phytoseiulus persimilis* probably originates from Chile, but has been spread by man, involuntarily or intentionally, throughout large areas of the world. A *Phytoseiulus* mite deposits its eggs in or close to a spider mite colony. They are distinguished from spider mite eggs by their oval shape and light orange colour and by being twice as large.

Encarsia formosa is a parasitic wasp for the control of *whitefly*, a very common pest in greenhouses. The female of wasp *Encarsia formosa* does not need fertilization. The female lays its eggs preferably in the third or early fourth instar greenhouse whitefly larva. Ten days after parasitization, about 11 days later, an adult *Encarsia* leaves the pupa through a round exit hole. The larva pupates and turns black. This is a very effective agent for the control of whitefly.

It is also possible to release *Eretmocerus eremicus*, a parasitic wasp against whitefly, which is effectively used in protected crops and against whitefly in tobacco (*Bemisia tabaci*). The large temperature fluctuations that affect the crops of southern Spain have stimulated the search for new alternative solutions. Biobest observed that in the Mediterranean region another parasitic wasp of whitefly, *Eretmocerus mundus*, was present and well adapted to the climatic conditions. *Eretmocerus mundus* parasitizes several species of *Bemisia*.

Macrolophus caliginosus is a predatory bug against whitefly and spider mite. It originates in the Mediterranean region and predates several pest insects, with a particular preference for whitefly.

Parasitic wasps *Dacnusa* and *Diglyphus* are used early in the season against leaf miners. Timely control of leaf miners is important to achieve expected results. Leaf miners puncture holes in the leaves to feed on plant juice and/or to deposit eggs inside the leaves. The larvae chew mines through the leaf. The damage can accumulate considerably. The parasitic wasp *Diglyphus isaea* is an efficient biological control agent against this pest.

Bacillus thuringiensis, prepared as the formulation Scutello 2X, is applied against caterpillars. These pests, if not controlled in time, may cause enormous damage.

Two microbiological preparations are used against wilt diseases caused by Fusarium, Verticillium, Rhizoctonia and Phytium: Mycostop, based on *Streptomyces griseoviridis* K61, and Koni, based on *Coniothyrium minitans* K1. Another preparation, Trifender, is used against wilt diseases caused by Sclerotinia, which is based on the microorganism *Trichoderma asperellum.*

Farmers training on alternatives for soil-borne pest control in Hungary

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Summary

This paper explains with detail the success of farmers' training in Hungary on alternatives to MB during the 2006-07 period, describing the number of farmers participating in each site, their age, gender and occupation. Shortcomings of the conducted courses are emphasized and measures proposed for future training. The conclusions of the training indicate that more practical work must be included in several sites, and more sessions on theory in others.

Characteristics of training

Training exercises consisted of a season-training of trainers (TOT), which was conducted from April to July 2006, and Farmers Field School (FFS) sessions from November 2006 to June 2007.

The organization and theoretic part of the TOT were adequate, but it was observed that more practical sessions are needed, including diagnoses and updated cost evaluations of different alternatives. Other minor shortcomings of the course should be corrected for the future.

As concerns the FFS, Figure 11, clearly shows the number of participants in different areas of the country as well as gender. It is clear that in some areas, women's participation was significant, as in Gyula and Arpad-Agrar, but there were sites with no women participants.

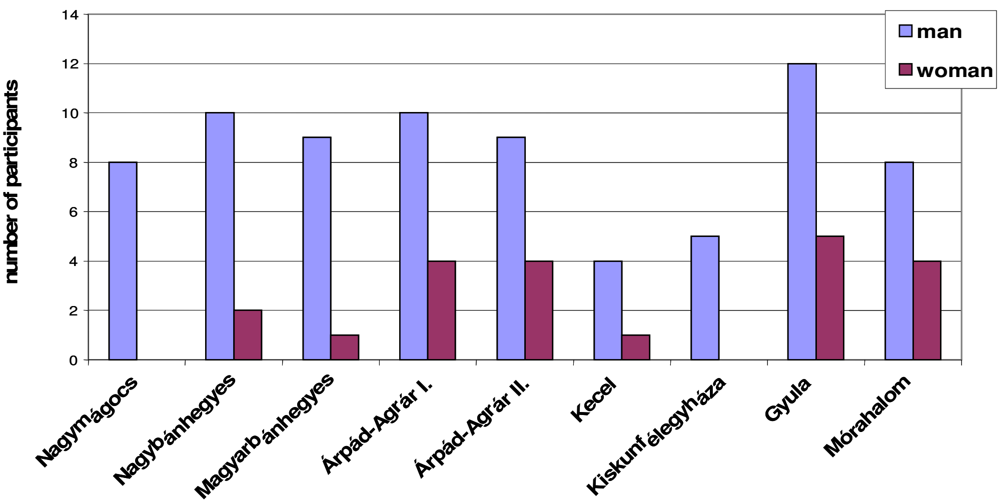

Figure 11: No. and gender of participants in the FFS

Figure 12 shows the participants classifiedby their age. The age groups of 26-35 years old and 46-55 years old were the most important in various areas.

Figure 13 gives the information of the participants according to their areas of work. It is clear that farmers working in horticulture were the main participants in this training.

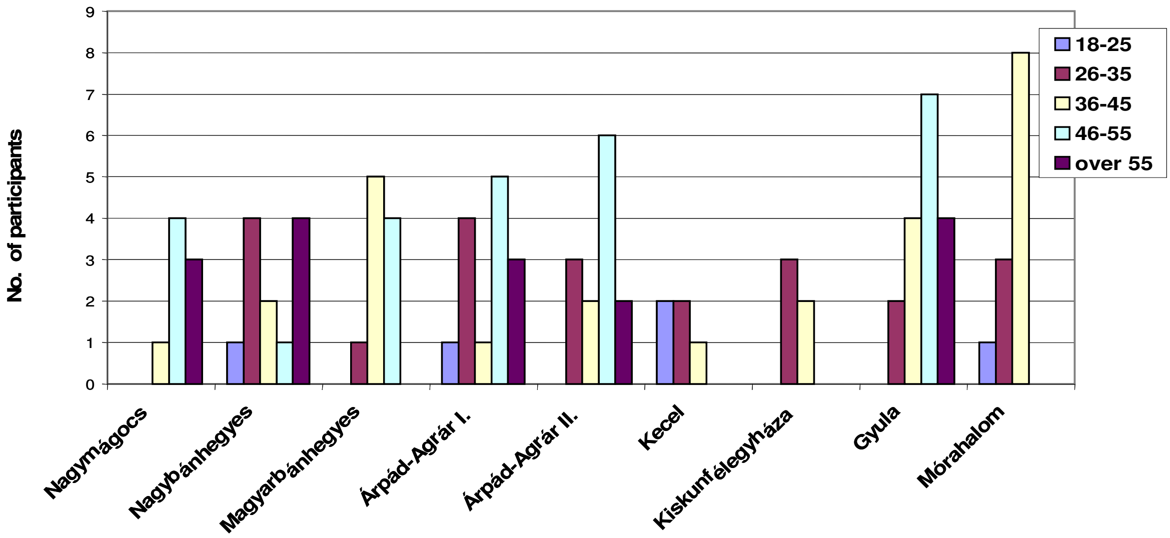

Figure 12: The age of FFS Participants

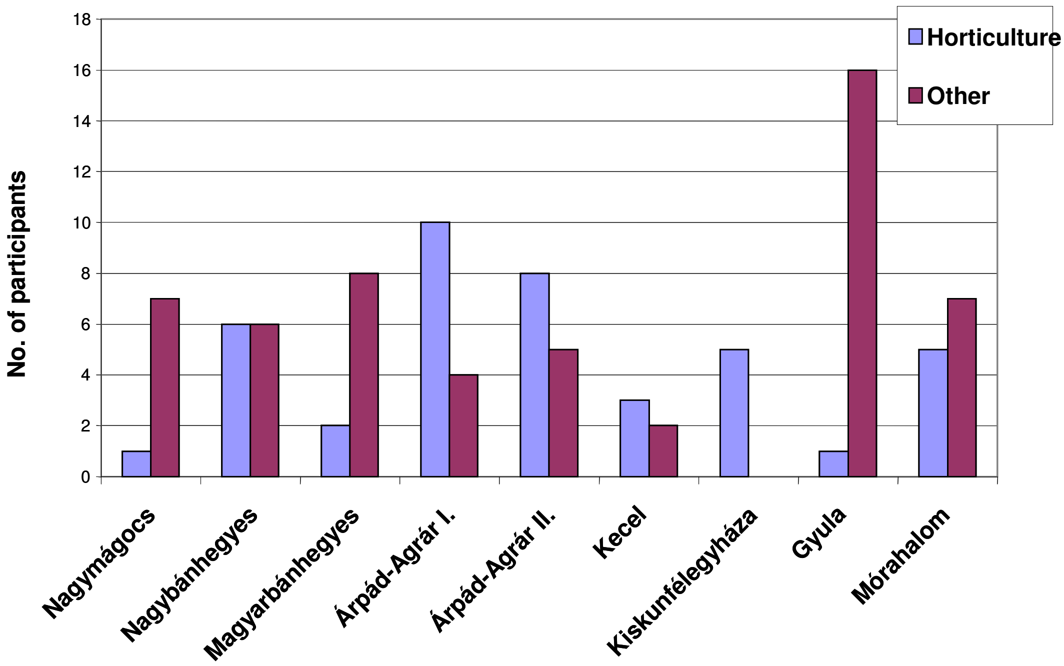

Figure 13: Participants in the FFS according to their areas of specialization

Conclusions

The conclusions regarding the FFS indicate that more practical work must be included in several sites, and more sessions on theory in others.

Table 8: FFS conclusions

Place	What did they like?	What would they change?
Nagymágocs	Updated information	More practice
Nagybánhegyes	Realistic approach Brief summary of problems Sharing new information	More practice and theory
Magyarbánhegyes	Increased knowledge New information Experience-sharing with peers	More practice More theory
Arpad-Agrar I.	More research on the problem Knowledge of MB alternatives	More practice More theory
Kecel	Practical presentations Information on new methods	More practice
Kiskunfélegyháza	New information Hydroponic technology New methods, e.g. grafting	More theory
Gyula	Linking of practice and theory Excellent facilitators Knowledge sharing Good atmosphere Practical approach	More practice More theory More market information
Mórahalom	Practical atmosphere Increased knowledge	More practice More theory More information on biological control

Non-chemical alternatives for soil uses on horticultural production in Poland

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Summary

The paper presents the history of the use of MB in Poland and the ways new alternatives were identified for soil-borne pest control. Since MB was introduced only in 1990 as a soil fumigant, Polish farmers traditionally used other methods for managing soil-born pathogens and nematodes. Once the fumigant was to be phased out, new alternatives were identified, including cultural methods using ring, trough and straw-bale, hydro-peat and multi-container cultures, rockwool, grafted plants and resistant cultivars. The main biological control agents used are those based on *Pythium oligandrum, Agrobacterium radibacter* K84, *Conithyrium minitants* and *Trichoderma viride* B35. In addition, various organic amendments are also used as biohumus 20%, chitosan 2%, garlic pulp, grapefruit extract 33%, grapefruit extract 20%, extract of plant tissues 0.56% (cytokinins) and grapefruit extract plus garlic extract.

Introduction

In the last decade, significant progress has been made worldwide in developing alternatives to MB. Moreover, a constant increase in the number of published articles on chemical and non-chemical alternatives is evident. Many of these publications have been presented at international workshops and conferences held in different, mostly developed, countries. Although there is a great deal of published information on materials and technologies that can replace MB, only the regularly published *MBTOC assessments of alternatives to MB* provides useful information on MB alternatives.

MB was used for soil fumigation in Bulgaria, Hungary and Poland, in crops such as tomatoes, peppers, cucumbers and strawberries, and in some ornamentals and tobacco seedlings production. In Poland, in the early and mid-1990s, MB was predominantly applied in tomatoes and cucumbers grown in greenhouses as well as carnations. Since 2000, when the strawberry runner production starts to move from southern Europe to Poland, the farms involved became the biggest MB consumers. Since 2005, MB was licensed for critical use in this crop.

In spite of a great number of identified alternatives worldwide, it was obvious that immediate adoption of an alternative in a new area on a commercial scale without earlier testing would rarely be successful. Factors affecting acceptance of alternatives include, among others, local availability, registration status, costs, labour inputs, compatibility with cropping timing and efficacy against target pests. Between 2000 and 2002, the UNEP Regional Demonstration Project identified and evaluated environmentally sustainable alternatives to replace MB in horticultural crops in Poland. Within the framework of his project, both chemical and non-chemical alternatives were tested in field-grown vegetables (cabbage, celeriac and tomato), strawberries, greenhouse peppers and tomatoes.

Past and current alternative methods in protected cultivation in Poland

In contrast to most European countries, in Poland MB as a soil fumigant was registered as late as 1989 and was introduced in 1990. As a consequence, Polish growers were forced for many years to use methods of controlling soil-borne pathogens other than MB fumigation. It resulted in the introduction and commercial use of several soilless methods in protected cultivation, the most common of which are briefly described below.

Cultural methods

Several growing techniques under greenhouse conditions enable to eliminate or reduce the need for soil disinfestation. The best-known techniques include ring, trough, bag, straw-bale and hydroponics culture. These types of culture are characterized by utilizing growing media other than soil and confining the root system to a relatively small volume of substrate.

Ring culture. This method was promoted mostly for tomatoes and gerbera. The tomato plant is set into a bottomless round ring (about 22°cm diameter, 20°cm tall) or sleeve of plastic film. The rings are spread out in a bed containing a layer of about 10°cm of substrate (sphagnum peat or mixtures of peat and pine bark, or peat and vermiculite). The same materials are used to fill the rings. Sometimes, the ring containers are placed directly on the soil surface. Ring culture was very popular in tomato growing until the early 1990s, when the rockwool substrate started to be introduced. Nevertheless, this method is still successfully used in some small farms. One of the major benefits of ring culture is the chance to minimize hazards arising from soil infestation with different root-invading pathogens, especially in the case of *Pyrenochaeta lycopersici* and *Didymella lycopersici,* but there is no protection effect against *Phytophthora parasitica, P. cryptogea, Rhizoctonia solani* and *Fusarium oxysporum* f. sp. *radicis-lycopersici*.

Trough culture. In this system, tomato plants are grown in long, narrow beds containing growing medium such as peat, sand, perlite, composted bark, sawdust, or many combinations of these ingredients. Troughs should be 12–15°cm deep and at least 60°cm wide to accommodate two rows of tomatoes. The troughs must be lined with PE or PVC film to be impermeable to roots. This system of cultivation can be considered a true soilless culture due to a complete separation of the roots from the original soil. In comparison with the ring culture, this method requires higher investment costs. Long-term use of the substrate is possible provided that it is disinfested (preferably by steaming) before each new planting. In the recent past, this method was discarded and replaced by the rockwool system for growing vegetables.

Straw-bale culture. Here, greenhouse tomatoes or cucumbers are grown on top of decomposing bales of wheat, barley or rye straw. The bales are sometimes placed on a sheet of plastic film to isolate the straw from the soil. Sphagnum peat is usually used as a capping soil. This method is still very popular in Poland, especially in cucumber growing in plastic tunnels. On some farms facing severe soil infestation, soil fumigation with MB was used before setting the straw bales in greenhouses. The performance of plants grown on straw bales is, as a rule, very good due to increased temperature in the root zone and carbon dioxide released during decomposition of the straw. This growing system constitutes both a biological heating medium and thermal insulation from original soil and gives a limited protection against infestation of the roots by soil-borne pathogens. However, some pathogens, such as *Phomopsis sclerotioides* and *Fusarium solani* f.sp. *cucurbitae* may severely affect cucumber plants grown on straw bales. The damage could be higher than those observed in cucumber grown in soils. The cultivation of cucumber and tomato on straw bales is very often integrated with grafting onto resistant rootstocks. This system creates favourable conditions for the application of biological control agents, particularly those based on *Trichoderma* spp.

Hydro-peat and multi-container cultures. These two hydroponics growing methods developed in Poland in the mid-1970s can be regarded as precursors of the rockwool hydroponics system in the country. In the hydro-peat method, the 40°cm-high rings filled with sphagnum peat were placed in troughs in a 5°cm-deep layer of stagnant nutrient solution. The nutrient solution was replenished periodically. In the multi-container system, trays shaped like inverted cones with perforated bottoms, holding 10 litres of substrate (sphagnum peat – bark mixture, 2:1), were placed in the second container with a nutrient solution and were dipped in the nutrient solution within the limits of 4–6°cm. Both systems provided dubious protection from soil-borne diseases. In the hydro-peat method, severe outbreaks of *Fusarium* crown and root rot of tomato and *Phytophthora* root and crown rot were observed under commercial conditions. Recently, these methods have ceased to be used.

The rockwool growing system. Growing on rockwool has replaced other soilless organic substrates. Rockwool culture system has been successfully used for growing greenhouse tomatoes, cucumbers, eggplants, peppers, roses and other crops. Other artificial substrates (glass wool, polyurethane foam) are also used on a limited scale. Introduction of this method on a commercial scale began in Poland in the early 1990s, and the total area of greenhouses growing on rockwool increased to more than 800 ha. In general, tomatoes and cucumbers are grown on this substrate. At present, in Poland, an open rockwool system has been used, which allows the excess nutrient solution to discharge into the environment as run-off. However, one should be aware that future implementation of recirculation systems may also be obligatory in Poland to avoid problems of soil and water pollution. Since there are serious problems with the disposal of reused rockwool slabs, some decomposable materials serving as an anchoring medium (e.g. slabs made of coconut fibre) are being introduced on a commercial scale. The rockwool hydroponics system was first introduced in large greenhouse farms, where MB was previously used for soil and substrate fumigation. The average consumption of MB in the early 90s amounted to 50–53 tonnes annually.

There is no doubt that the health status of plants grown on rockwool is much better than that of plants traditionally grown in the soil. This technology had practically eliminated the occurrence of diseases such as corky root rot of tomato and *Rhizoctonia* disease. On the other hand, zoosporic plant pathogens (*Pythium* spp., *Phytophthora* spp., *Olpidium* spp.) may constitute a very serious phytosanitary problem, and appropriate preventive measures are necessary to avoid heavy yield losses. The hydroponics system creates almost ideal conditions for the introduction of different biological control agents. The suitability of using biocontrol agents in such a system was confirmed in our experiments (Table 9).

Figure 14: Disease progress of verticillium wilt of pepper grown in soil treated with MB and different alternatives in unheated plastic greenhouses on the farm at Grabowa

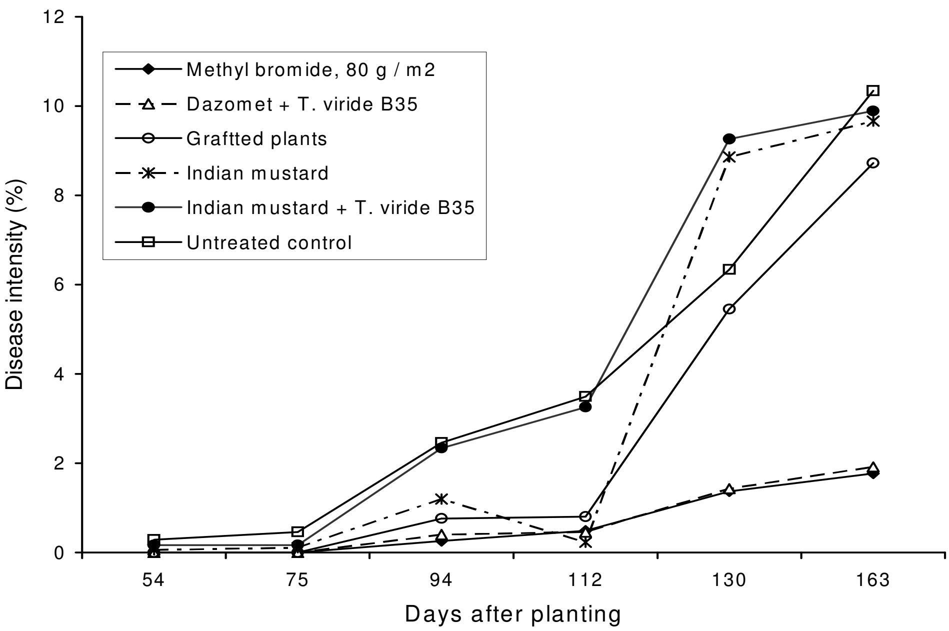

Table 9: The efficacy of preventive application of chemical and biological treatments in greenhouse cucumber grown as a fourth crop on re-used rockwool slabs (autumn cultivation)

Treatment	**Mean root rot severity index (scale 0-5)**	**Marketable yield**	
		kg m^{-2}	**% of control**
Previcur 607 SL 0,03% (propamocarb)	1.5 b *	10.5 a	112.9
Mycostop (*Streptomyces griseoviridis* K61)	1.4 b	10.6 a	113.9
Vital Plus (*Trichderma viride* B35)	2.3 ab	10.7 a	115.0
Control (without any treatment)	3.1 a	9.3 b	100.0

* values in columns followed by the same letter are not significantly different according to Duncan's multiple range test (P=0.05)

Use of grafted plants and resistant cultivars

Great progress has been made in resistance breeding of tomato. Many modern tomato hybrids, which are often grown in greenhouses, combine effective resistance genes against 5–7 pathogens. Recently, the following soil-borne pathogens have been able to be controlled genetically: *Verticillium dahliae, Fusarium oxysporum* f.sp. *lycopersici* (races 1 and 2), *F. o.* f.sp. *radicis-lycopersici, Pyrenochaeta lycopersici* and *Meloidogyne* spp. On the other hand, cucumber and pepper cultivars resistant to the most important soil-borne pathogens are not yet available commercially.

Resistant rootstocks provide excellent control of several diseases caused by some soil-borne fungi and root-knot nematodes in vegetables. Nevertheless, it should be pointed out that there are currently no tomato and cucumber cultivars or rootstocks resistant to *Pythium* spp., *Phytophthora* spp. and *Olpidium* spp., which are of special importance in hydroponics. This situation makes it obligatory to use different measures for controlling diseases caused by these pathogens. Cucumber grafted on *Cucurbita ficifolia* is resistant to *Fusarium oxysporum* f.sp. *cucumerinum* and has been used for several years in Poland. It seems that this technique will be used more widely in the nearest future. Growing grafted pepper is a relatively new technology, which is practised on a commercial scale in Hungary. Demonstration trials with bell pepper grafted on Snooker rootstock, conducted under commercial conditions in Poland, revealed unsatisfactory results (Figure 14). Lack of the success seems to be attributable to the fact that this rootstock has no resistance to verticilium wilt, which in the country conditions is the main factor limiting the productivity of this crop. In the past, when multiple–resistant tomato cultivars were scarce, grafting of tomato on specific rootstocks was popular and aimed mainly at protection against *Pyrenochaeta lycopersici*. Recently, in hydroponically grown tomatoes, there is an increased use of grafted tomato, even of the resistant cultivars on rootstocks, such as Maxiford, Beaufort, and He-Man.

Tomato plants are grafted using the so-called Japanese method, which results in much stronger root system and higher yields (by 10-15 percent), even in the absence of root pathogens. In Poland, there are several modern nursery greenhouse farms producing transplants of different crops, including grafted cucumbers and tomatoes. Moreover, the growers can order grafted eggplants and pepper.

Biological control

In Poland, the number of available biocontrol agents is limited (Table 10). Biocontrol agents, when used alone, are effective in certain cases only. In general, biological control agents can provide satisfactory protection of roots against pathogens only in the case of integration with other disease control measures (fumigation, steaming, solarization, organic amendments, etc.). It seems that for most combined applications, biocontrol agents based on *Trichoderma* spp. are the most universal and relatively stable in performance (Figure 14).

In contrast, the performance of biocontrol agents applied alone in traditional soil cultivation was erratic, depending on crop and location. Crops grown in greenhouses, particularly those grown in small volumes of substrates, offer almost an ideal opportunity for the use of biocontrol agents. In the case of field crops, the antagonistic organisms should be introduced at the earliest stages of plant growth. This can be achieved using biocontrol agents for seed dressing or at the time of transplanting. A satisfactory plant growth improvement was observed under field conditions in the cultivation of cabbage, celeriac, leek and tomato.

Table 10: Commercially available biocontrol agents in Poland

Trade name	Microorganism	Activity against
Polyversum	*Pythium oligandrum*	Fungi
Polagrocyna PC	*Agrobacterium radibacter* K84	A. tumefaciens
Contans WG	*Conithyrium minitants*	Sclerotinia spp.
Vital Plus	*Trichoderma viride* B35	Fungi

Up to now, Polyversum has been the most often used biocontrol agent in Poland, especially in hydroponics for vegetables grown under greenhouse. In 2007, the first year of Vital Plus (*Trichoderma viride* B35) use, this biocontrol agent was applied in a total area of 93 ha of Brussels sprouts, cabbage, celeriac, leek, tomato and peppers. In addition, the agent was used in cucumbers and tomatoes grown in rockwool under greenhouse conditions in a total area of 15 ha.

Organic amendments and natural products

Soil is improved with composts, animal manure, green manure, composted bark, residues of some brassicas and various by-products from the agriculture and food industry is done in many countries to suppress certain soil-borne pathogens. This phytosanitary measure is especially important for field crops. The use of cover plants (e.g. *Vicia villosa, Trifolium incarnatum, Secale cereale*) can also be useful for building up environmentally friendly sustainable systems for vegetable production in regions of temperate climates.

Table 11: Commercially available natural plant protection products in Poland

Trade name	Active ingredient	Activity against
Antifung 20 SL	Biohumus 20%	Fungi
Biochikol 020 PC	Chitosan 2%	Fungi, bacteria, viruses
Bioczos BR	Garlic pulp	Fungi, bacteria, insects
Biosept 33 SL	Grapefruit extract 33%	Fungi, bacteria
Grevit 200 SL	Grapefruit extract 20%	Fungi, bacteria
Sincocin AL	Extract of plant tissues 0.56% (cytokinins)	Fungi, nematodes
Zaprawa ziołowa PNOS-1LS (seed dressing)	Grapefruit extract + garlic extract	Fungi

Sinapsis juncea and other brassicas, mainly canola, have been used commercially in the field as preceding crops. The green biomass of these plants is incorporated into the soil. *Sinapsis juncea* cv. Malopolska is the most effective cultivar due to its rich release of glucosinolates in soil. The IPM strawberry fruit production system in Poland includes mustard as the preceding crop. However, in trials with field vegetables and greenhouse-grown peppers, soil-incorporated Indian mustard did not provide satisfactory results (Figure 14). In Poland, there are also commercially available natural products with antifungal activity (Table 11). These products have mainly been used in organic and ecological farming. Some of them are recommended for controlling soil-borne fungi. Biochikol 020 PC containing chitosan, a natural polysaccharide derived from the shells of sea crustacean, provides protection of different crops against *Pythium ultimum, P. splendens, Pythium* spp., *Fusarium oxysporum, F. avenaceum, F. culmorum, Fusarium* spp. and *Phytophthora* spp. An extract of vermicompost, Antifung 20 SL, has been recommended for soil treatment against *Pythium* spp., *Phytophthora* spp. and *Rhizoctonia solani* in the production of ornamental plants and vegetables. Similarly to biocontrol agents, the efficacy of the above-mentioned products applied in soil and other substrates was variable and, in most cases, only partial protection could be achieved.

Table 12: Effectiveness of chitosan in the control of F. oxysporum f.sp. dianthi ten weeks after planning

Treatment	**Concentration (a.i./ml)**	**Percentage of diseased plants**	**Discoloration of vessel (cm)**
Control infested	-	84	3.34.a
Tiophanat-methyl	0.07%	30	2.45 a
Chitosan	0.025%	40	3.30 a
Chitosan	0.05%	40	1.50 a
Chitosan	0.10%	30	2.50 a

(Source: Skrzypczak and Orlikowski (1998)

Heat treatment

Soil steaming is a credible alternative to MB for soil-borne pest control in protected production systems. More than 25 years ago, steaming was commonly used in Poland, and up to 300 ha were steamed annually. Although the effectiveness of soil steaming is unquestionable, this method is very seldom used in Poland due to high costs. However, steam seems to be acceptable for greenhouse production of ornamental plants, grown directly in soil or substrates. Recently, only a small number of greenhouse farms have been equipped with stationary steam boilers, where soil steaming has been conducted on a regular basis, usually using the old Hoddesdon pipe method. For steaming of different organic substrates and potting composts, bunker steaming is being used. In some regions, where numerous small farms grow ornamental plants, there are few contractors providing soil steaming services to the growers in the vicinity. It is important to recall that this method creates an empty microbial niche, which allows a rapid colonization of the soil or substrate by different biological control agents.

Combined application of non-chemical alternatives with chemical alternatives

From our experience regarding the effectiveness of non-chemical alternative methods of crop protection against soil-borne pathogens, it can be concluded that for a particular crop, it is possible to identify a non-chemical approach that would reduce the incidence and severity of soil-borne diseases to a level acceptable for growers. Integration of soil disinfestation with ring culture of tomatoes reduced the severity of root infestation with root-knot nematodes and *Pyrenochaeta lycopersici*. The combined use of grafted tomato or eggplant with soil disinfestation revealed to be more efficient than each treatment applied separately.

A combined application of the biocontrol agent based on *Trichoderma* spp. with a 25 percent reduced rate of soil fumigants, such as dazomet and 1,3-D CP, was always found to be more effective than each treatment applied alone. The introduction of *Trichoderma* spp. to fumigated soil better controlled the root rot complex of tomato and pepper than fumigation alone. The same was true for increased efficacy of controlling *Verticillum*-wilt of pepper. Also, an integrated application of dazomet and *Trichoderma* in terms of yields was very good, regardless of the degree of soil infestation. The efficacy of *Trichoderma viride* B35 applied alone was very variable depending on the year and location. None of the alternative treatments tested in the production of strawberry runner plants was as effective as MB.

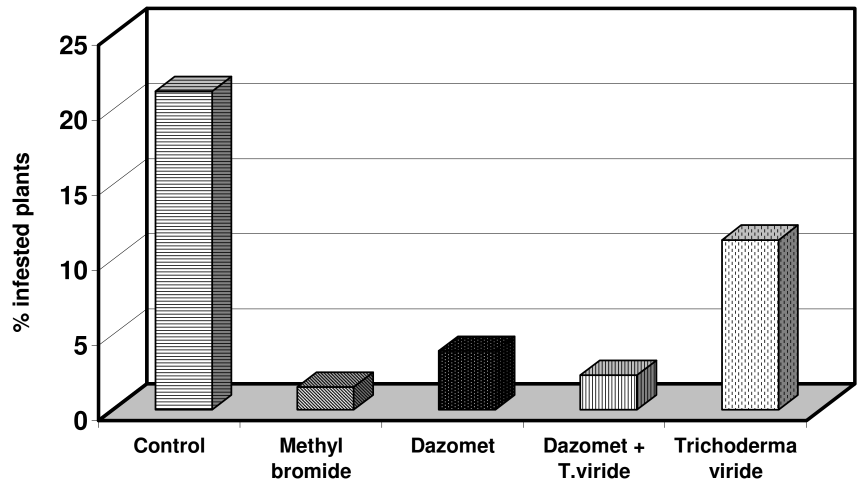

Figure 15: The influence of chemical, biological and integrated control of *Verticillum Dahliae* on final diesease incidente in bell pepper plants (mean of six trails)

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NON-CHEMICAL ALTERNATIVES AND IMPLEMENTATION METHODS

Nematode control strategy (NCS) and physical soil disinfestation methods used in the Netherlands

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Summary

During the last 15 years, much effort has been expended in the Netherlands to diminish the volume of nematicides used. Alternatives for soil fumigants are difficult to find. The solution for one nematode problem can cause a problem with another species. Based on basic principles of Dutch nematologists Oostenbrink and Seinhorst, a systematic approach on the farm level is implemented to reduce the dependence on nematicides. Starting with the original schemes of Hijink and Oostenbrink (1968), the Applied Plant Research (PPO) –AGV Research Unit revitalized the idea of a Nematode Control Strategy (NCS) based on an economically sound crop rotation, appropriate to the nematode situation on the farm or on the field (Molendijk and Mulder, 1996). In this IPM strategy, nematicides are only applied when necessary and serve as a complementary emergency tool. To develop a sound nematode control strategy, a thorough knowledge of host ranges and intolerance of crops to the most important nematode species is indispensable. For the most important arable and green manure crops, this information was collected on the predominant plant parasitic nematode species and used for a new scheme. The PPO nematode scheme has been made accessible on the Internet and is used to design nematode control strategies on the farm level. Additional measures such as several soil disinfestation methods and the use of catch crops are presented for arable crops and field vegetables as well as for bulb crops and horticulture.

Introduction

Dutch agriculture can be characterized as a high input/high output production system. High costs for soil and labour make it necessary to reach high production levels in both yield and quality of profitable crops. This leads to an intensive production of potatoes, sugar beet, industrial vegetables and flower bulbs, among others, and a low production of cereals.

In these intensive cropping systems, no damage by nematodes is tolerated. Table 13 lists the group of nematodes causing the most problems in arable farming.

At the end of the 1960s, the use of fumigant nematicides became economically feasible for arable farming. Legislation, focusing on the control of potato cyst nematode (PCN), prescribed the use of fumigants in crop rotations in which potatoes were grown more frequently than once in every four years. As a result, soil fumigation became common practice. In the 1984–88 period, about 10 million kg a.i. of fumigants were used yearly, or approximately 9.5 kg a.i./ha. The total pesticide use per ha was 20 kg/a.i./ha.The wish to cut back on the use of pesticides resulted into the Multi Year Crop Protection Plan (MYCPP) (Anon., 1991) and focused on diminishing the use of and dependence on pesticides. The aim to reduce fumigant nematicides by 70 percent after 2000 with respect to the 1984-88 reference period was already achieved in 1993.

Table 13: The most important nematode groups in Dutch arable farming and field production of vegetables

All soil types including clay	**Sandy soils**
Potato cyst nematode	Root-knot nematode
Beet cyst nematode	Root lesion nematode
Pin nematode	Trichodorids
Stem nematode	Xiphinema
	Longidorus

PCN problems in starch potatoes are solved with new resistant varieties. There are not enough *Globodera pallida*-resistant varieties available with good production characteristics to solve PCN problems in ware and seed potatoes. Given this situation, PCN can be controlled by diminishing the cropping frequency of potatoes, but this is economically not acceptable. A wide cropping frequency is not a solution for other genera of nematodes that are polyfagous and have broad host ranges. Important representatives are root-knot nematodes from the genera *Meloidogyne* and the root lesion nematode *Pratylenchus penetrans*. To prevent or control these nematodes, a pro-active approach is needed. When farmers neglect to prevent problems in a timely manner, any corrective measure would be too late and they would be forced to use nematicides. The alternative is a thorough analysis of the nematode situation on the farm and even on the plot level to develop a NCS fitted to the specific situation. In arable crops and field vegetables, this strategy has proven to be economically feasible (Molendijk and Korthals, 2005).

In horticultural and bulb crops with mainly monocultures, other methods are used to control soil-borne pathogens. Steam sterilization of soil and soilless cultures are common practice in horticulture. Bulb fields are sometimes flooded to control plant parasitic nematodes and fungi, the “inundation method”. A new development is soil treatment with extremely hot air. All of these methods are discussed below.

Nematode control strategy

The crux of a NCS is the well-known concept of crop rotation. What is essential in controlling polyfagous nematodes is not the cropping frequency, but the selection of crops and their sequence within the rotation. The basic idea is to grow a non-host or poor host as the preceding crop of an intolerant, important cash crop. To design such rotations, a thorough knowledge is needed about host ranges and sensitivity to damage.

Valuable information was gathered in the 1950s and 1960s (Hijink and Oostenbrink, 1968), which had to be revised and adjusted to more nematode species, crops and cropping methods. In 1991, PPO started research projects on *Paratrichodorus teres*; in 1992, on *Meloidogyne fallax*; in 1995, on *M. chitwoodi*; in 1998, on *Pratylenchus penetrans*; and recently, on *Trichodorus primitivus* and *Paratrichodorus pachydermus.* PPO provides the information on host status and tolerance to damage within the PPO nematode scheme in an original format designed by Hijink and Oostenbrink (1968). In this scheme, multiplication of crops of a specific nematode is represented in dots, and tolerance to damage, in colours. (Table 14 shows a black and white example.)

Table 14: PPO-AGV nematode scheme for green manure crops.

Crop	*Heterodera schachtii*	*Heterodera betae*	*Meloidogyne hapla*	*Meloidogyne naasi*	*Meloidogyne chitwoodi*	*Meloidogyne fallax*	*Pratylenchus penetrans*	*Trichodorus & Paratrichodorus spp.*	*Tobacco rattle virus*	Crop
Oil radish	- - R	- - R	●●	-	●R	●R	●●●	●	-	Oil radish
White mustard	- - R	- - R	●	-	●●	●●	●●●	●	●●●	White mustard
Perennial ryegrass	-	-	-	●●●	●	●●●	●●	●●●	●●	Perennial ryegrass
Italian ryegrass	-	-	-	●●●	●●	●●●	●●●	●●●	●●	Italian ryegrass
Rye	-	-	-	●●	●●●	●●	●●●	●●●	●●	Rye
Clover	-	●	●●● R	-	●●● R	●●● R	●●●	●●●	●●	Clover
Lupin	?	?	●●●	?	?	?	●●	?	?	Lupin
Phacelia	-	-	●●	-	?	●	●●●	●●	●●●	Phacelia
African Marigold	-	-	-	-	-	-	- -	●●●	●●●	African Marigold

Legend damage	
white	Unknown
green	no
yellow	little
orange	moderate
purple	serious

Legend Increase	
?	unknown
- -	active decline
-	non host
●	poor host
●●	moderate host
●●●	good host
R	depending on variety

(Source: Format based on Hijink and Oostenbrink, 1968)

Note: Dots represent the ability of nematode multiplication; colours represent sensitivity to damage

Although crop rotation is the basis of a NCS, it is just one of the elements of a NCS (Figure 16). An NCS should be based on:

- prevention, by using certified planting material and strict farm hygiene practices;
- an inventory of potential problems considering soil type, cropping history and planned crops within the rotation;

- an inventory of actual problems through soil sampling and crop inspection to determine nematode species and population densities for each field;
- the design of a sound crop rotation scheme (including green manure crops) based on potential and actual problems and economic feasibility;
- the use of resistant varieties;
- the prevalence of other soil-borne diseases e.g. *Rhizoctonia solani* and *Verticillium dahliae*;
- additional measures such as black fallow, the use of catch crops, soil disinfestation, etc. and nematicide application when no other solutions are available.

Tools for designing a sound crop rotation scheme can be found on the Internet in Dutch (www.digital.nl), which provides growers with background information about nematode biology, symptoms, etc. Growers can also insert names of crops that they are interested in and the program will generate a table with the relevant crop nematode combinations (Beers and Molendijk, 2004).

Additional measures

Black fallow

Elimination of *Meloidogyne hapla* under non-hosts or black fallow is high, reaching up to 95 percent in one season under Dutch climatic conditions. Because of this high mortality at increasing temperatures, any postponement in planting reduces the initial population. The efficacy of black fallow also applies to other *Meloidogyne* species such as *M. chitwoodi* and *M. fallax* (Molendijk and Korthals, 2005).
In a *Pratylenchus penetrans*-infested field in the Netherlands, the effect of a three-month summer period of black fallow resulted in a nematode population decrease of approximately 90 percent (Runia, 2004).

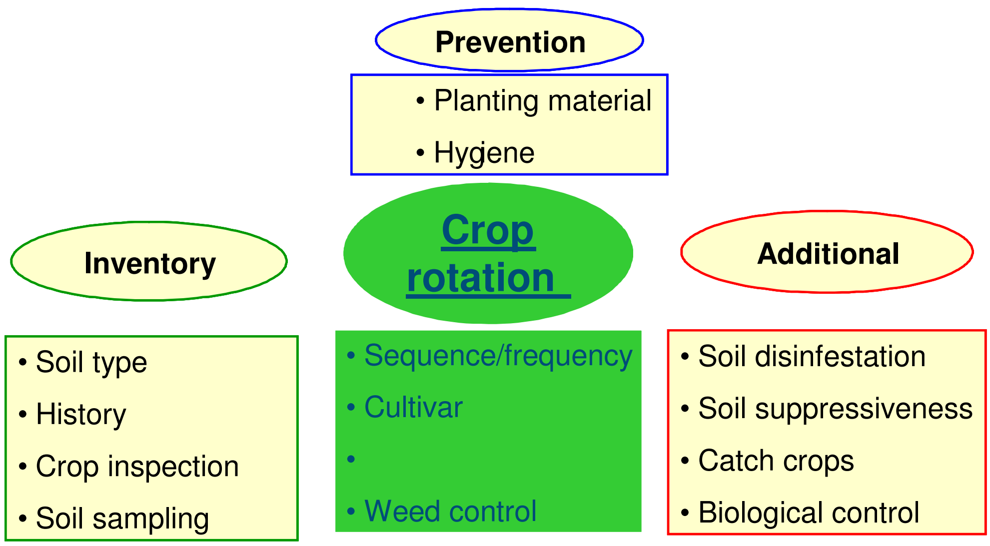

Figure 16: Nematode Control Strategy

Catch crops

An effective catch crop for root lesion nematodes (*Pratylenchus penetrans*) is the green manure crop *Tagetes patula* (Evenhuis, Korthals and Molendijk, 2004). This crop completely eradicates *P. penetrans* provided that the whole furrow is penetrated by *Tagetes patula* roots.

In addition, *Pratylenchus* nematode levels remain low for several years under the host plant strawberry. An important side-effect in addition to eliminating *P. penetrans* is the reduction in incidence of the fungal pathogens *Verticillium* and *Rhizoctonia*. Further, since *Tagetes patula* is not a host for *Meloidogyne hapla*, this nematode is reduced. In the Netherlands, this method is widely applied in strawberry; it is estimated that at least 70 percent of Dutch strawberry growers grow *Tagetes patula*. This method can be regarded as a non-chemical alternative to MB in many aspects.

Soil disinfestation

Anaerobic composting

This method of soil disinfestation is based on eliminating pathogens and pests in the soil by creating soil conditions without oxygen in which toxic compounds are produced. This situation is created by amending 40 tonnes of fresh organic material in furrows of 0–30°cm depth. Fresh non-woody organic material should be incorporated in the soil and divided equally, for instance, with a rotating spading device. After amendment of the organic material on dry soils, 30-40 mm of water should be applied to enhance decomposition processes (Lamers, Wanten and Blok, 2004). This method is highly effective against most relevant pathogens and pests in the country. The method of anaerobic composting is used in the Netherlands on a very limited scale, because although effective, it is relatively costly in comparison with, for instance, metam sodium or a *Tagetes patula* catch crop. Anaerobic composting is occasionally used by growers of high-value *Asparagus* mainly to control *Fusarium oxysporum* f.sp. *asparagi*.

Inundation

Inundation is the flooding of fields that thus creates anaerobic conditions in the soil underneath. The method is applied in the Netherlands mainly in bulb fields and can be used only on sandy soils with an impermeable subsoil layer or in regions with high water tables (Van Zaayen, 1985). In terms of efficacy, the method is selective in against fungal pathogens and plant parasitic nematodes and weeds.

Steam sterilization

Lethal temperatures for several nematode species were established by Wageningen University. Root-knot nematodes, cyst nematodes, and leaf and stem nematodes were completely eliminated at 51 ^{o}C. A small proportion of 0.1 percent of pin nematodes (*Paratylenchus* spp.) survived at 55 ^{o}C. The practical recommendation for growers in the Netherlands is an exposure time of half an hour at 70 ^{o}C, which will completely kill all plant parasitic nematodes (Bollen, 1981).

In the Netherlands, steam sterilization is applied mainly in greenhouses for high-value flower crops or organic vegetable crops.

Sheet steaming and *negative pressure steaming* are the methods used in steam sterilization: fuel consumption with these methods is 7 m^3 and 4 m^3 gas per m^2 soil, respectively. More information on steaming methods is published by Runia (2000).

In addition, a mobile steam sterilization unit disinfests nematode infested bulb fields. The soil is rotavated up to a 25°cm-depth, which is also the steaming depth. Fuel consumption is 1 litre of fuel oil per m^2; the capacity is 100 m^2 per hour (see www.geerlings.nl). All nematodes, insects, fungi and parasitic bacteria are thus eliminated to a depth of 25°cm, providing that the recommended exposure time of half an hour at 70°C is followed (Bollen, 1981). This method is rarely applied in high-value bulb fields, and not applied in the Netherlands in strawberry fields due to high costs and limited capacity.

Hot air treatment (Cultivit®)

A new development in physical soil disinfestation is the application of hot air. The method has been developed over the past seven years and applied commercially for four years in Israel. The method is based on blowing extremely hot air into rotavating soil. After building and testing various prototypes, the inventors reached an optimal speed of blowing air and rotavating. The advantage of hot air treatment is an adequate capacity for field applications and a reduced energy consumption of 90 percent in comparison with a mobile steam device. In *Meloidogyne*-infested fields in the Mediterranean (Cyprus and Israel), squash yield increased after hot air treatment, from 90 to 150 percent with respect to untreated control, although nematode numbers were not reduced (Runia, 2005). Thus, the general concept of soil disinfestation is not applicable to hot air treatment. Any positive effect in yield cannot be explained by the reduction or elimination of pathogen or pest counts (Runia, 2005).

Production of hot air devices for commercial application started in 2006 in the Netherlands. Trials in the country are presently performed in horticultural crops such as tomato, sweet pepper and radish (Runia, personal communication) under temperate climatical conditions.

Chemical soil disinfestation

In the Netherlands, chemical soil disinfestation with the fumigant metam sodium applied by rotary spading injection is an effective and economically feasible method for soil disinfestation and is used in open field crops on sandy and loamy soils (Runia, Molendijk and Evenhuis, 2007). The application of metam sodium is currently restricted to once in five years.

Non-fumigants such as granulates are sometimes applied, but are expensive and only economically feasible in high-value crops with high nematode infestation levels. Special dosing equipment is required to guarantee optimal efficacy (Runia, Molendijk and Evenhuis, 2007).

Concluding remarks

The NCS can be regarded today as a useful package of measures for growers in the Netherlands. New methods and advancing technology improves the NCS permanently. It is a challenge to develop such a strategy worldwide in order to facilitate growers with a tailor-made approach to cope without MB.

In 1992 in the Netherlands, MB was completely banned as a soil fumigant (Ministry of Housing, Physical Planning and Environment, 1992). Other chemical compounds have also been prohibited since then, such as (cis)-dichloropropene, or limited in use, such as metam sodium. Soil-borne pests and pathogens are currently controlled by the following methods or means (Runia and Greenberger, 2004):

- in protected cultivation with horticultural crops, all vegetables and some flower crops are grown as soilless cultures;
- steam sterilization of soil is used in flower crops, which are still grown in soil;
- steam sterilization is incidentally applied in open-field bulb cultures;
- inundation (flooding) is applied in open-field bulb cultures;
- anaerobic composting is incidentally applied in high cash crops such as *Asparagus*;
- catch crop *Tagetes patula* is widely used in strawberry to control *Pratylenchus* penetrans;
- in all open-field crops, the NCS is widely used;
- in open-field arable, vegetable and bulb crops, metam sodium can be applied once in five years. Dosages differ from 300 to 750 litres/ha depending on crop type;
- possibilities and limitations for hot air soil treatment are still under investigation.

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Use of soilless substrates

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Summary

Contrary to cultivation of plants in soil, any soilless cropping system requires a continuous supply of water and nutrient solution. The technical set-up of open systems is simpler and the spread of root infesting pathogens is limited. The disadvantage is the run-off of excessive nutrient solution, causing environmental hazards. Recirculating nutrient solution methods have ecological benefits but need exact crop management. Under certain conditions, pathogens can more easily spread in such a system endangering the entire crop.

There are a number of different technologies available, including the low-cost, low-input ECOPONICS system, discussed in more detail below. There are many different substrates for soilless cultivation. The right choice should depend on local availability – but at the start, they must be free of pathogens. When reused, they must be disinfected.

Continuous cropping in greenhouses can result in increased soil salinity, but the most destructive organisms are phytopathogenic fungi, such as *Pythium, Phytophthora* and *Olpidium*, as well as various bacteria and nematodes. To avoid problems from the start, the grower must take care that only healthy seedlings are transplanted, but also that the water for irrigation is clean. Soilless cultivation technologies have the huge advantage of optimizing growing factors such as substrate temperature, water, pH and nutrient solution to best meet the plants' need for continuous growth without stress.

In recent years, the Chair of Vegetable Science (Technische Universität München, Chair of Vegetable Science: Crop Physiology and Quality Research, Germany) developed a low-cost hydroponics system for soilless culture. It was further modified and introduced into the Mediterranean region under the ECOPONICS project financed by the European Union during 2002 and 2006. This innovative technology can be installed at a considerably reduced cost and with less technical know-how, having a yield potential that is not much lower than high-tech systems. This was proven in practice for sweet pepper and tomato cultivations.

Introduction

Soilless cultivation is a combination of biological and ecological technologies to optimize plant growth for better crop response. A number of different systems are available to the growers for designing hydroponics installations to meet the need of plants, while also suiting the grower's budget (Figure 17).

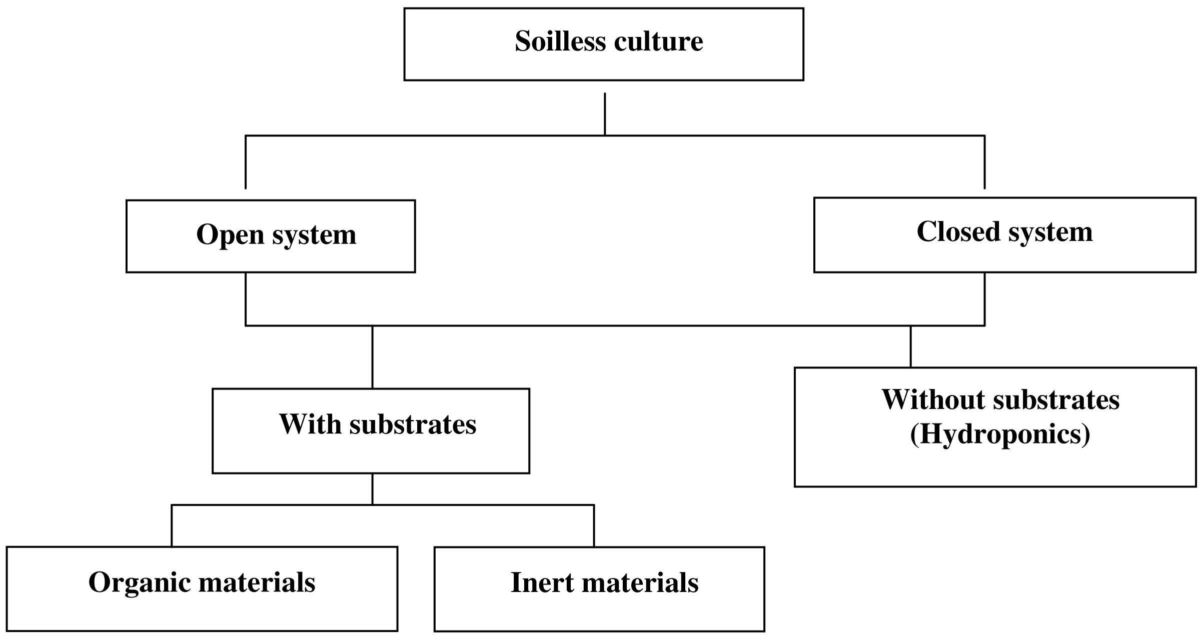

Figure 17: Systems available for soilless cultivation

With soilless cultivation the producer has the major advantage of supplying water and nutrients to the plants according to the requirements of a certain growth stage. But with limited technology, the quality and quantity of water as well as unbalanced nutrient solutions can quickly become problem areas (McPherson *et al.*, 1995; Runia *et al.*, 1988). The result is crop stress with plants more susceptible to pests and diseases.

Clean water is essential and the quality depends mainly on the available sources; it can be municipal tap water, well or surface water, or collected rainwater in ponds. Water quality is also associated with the concentration of dissolved minerals and the presence of biotic components such as algae, fungi, bacteria and other particulate residues. Surface or collected rainwater may have the potential of contamination by phytopathogens, although it is not very probable. More problems will be associated with too large a concentration of ions, as well as unfavourably high pH and alkalinity levels (Table 15).

Soilless cultivation is distinguished by the way the nutrient solution is supplied, either in excess, allowed to drain into the soil and even into the groundwater, or recirculated in a closed system. For environmental reasons, only closed systems should be installed in which the nutrient solution is collected and re-used, providing water and fertilizer savings with the major benefit of good environmental stewardship (Ehret *et al.*, 2001).

In 1966, when Alan Cooper first developed the hydroponically operated nutrient flow technique (NFT) with a circulating nutrient solution, the obvious advantage was less energy consumption than the costly steam sterilization of soil and soil-based substrates, and the protection of crops from soil-borne diseases. These aims, however, cannot always been attained. In general, tomato, cucumber, lettuce, pepper, and a number of ornamentals will grow successfully in various hydroponics systems with lesser problems than normally associated with soil-grown cultivation. But crop damage, occasionally even devastating destruction, can still be caused by root parasites. With all its known disadvantages, soil still has the capacity to dampen the extreme effects of soil-borne pathogens, mostly due to containing beneficial microflora. A soilless medium has much less buffering capacity. When a pathogen reaches plant roots, the disease outbreak may be severe (Jarvis, 1991).

The spread of phytopathogens in an open irrigation system is not as likely as in a recirculated nutrient solution with inoculums infecting the roots (Jenkins and Averre, 1983). The risk of infection and reinfection becomes higher.

Table 15: Values for optimal water quality for open and closed hydroponics systems

Parameter	Units	Open system	Closed system
EC	dS m^{-1}	< 1.0	< 0.4
pH		5-6	5-6
Total salt content	mg l^{-1}	< 500	< 250
HCO^{3-}	mmol l^{-1}	< 10	< 5
Na	mmol l^{-1}	< 3	< 1.3
Cl	mmol l^{-1}	< 2.8	< 1
SO_4-S	mmol l^{-1}	< 4.65	< 1.55
Zn	µmol l^{-1}	< 10	< 5
Fe	µmol l^{-1}	< 17.9	< 8
Mn	µmol l^{-1}	< 20	< 6

(Source: Schröder and Lieth, 2002)

The substrate in use dictates the root environment in a matrix of solids, liquids and gases (Gruda and Schnitzler, 2000). Growth media should be well suited for water and nutrient holding capacity, as well as exchange of oxygen, carbon dioxide and ethylene (Figure 18). Adequate substrate aeration is of vital importance for plant growth and managing the microflora in the rhizosphere (Waechter-Kristensen *et al.,* 1997).

Suitable substrates for crop production in hydroponics not only have to meet physical requirements, but also biological ones. Principally, they must not be contaminated by any pathogens harmful to plants. This is highly important for substrates used for seedlings as well as for crop production. Inert materials have lesser problems than organic ones due to their manufacturing processes. Contamination may occur during processing, in handling during trade, or in storage before use by growers. A special case is the reuse of substrates. Where pests and diseases were a problem in the previous crop, particularly with root-infecting pathogens, such substrates should never be reused again.

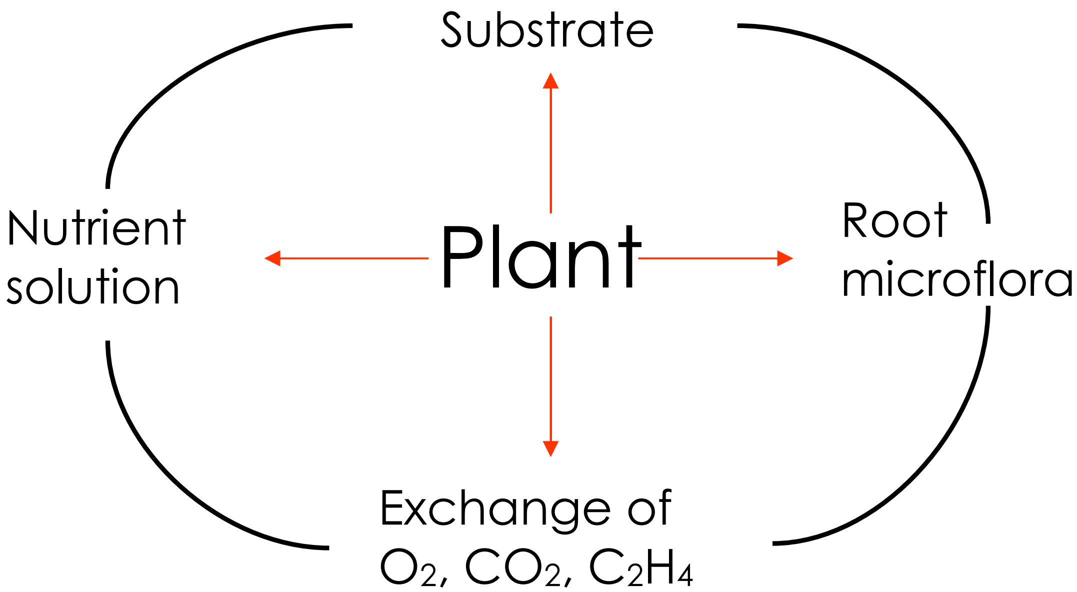

Figure 18: The matrix for good plant development in hydroponics

Plants grown in soilless culture may be attacked by the same pests and diseases as traditionally cultivated in soil. Frequency and degree of severity, however, may be different. This is not only true for the soil-borne and root-infesting pathogens, but also for the airborne diseases, because the microclimate environment changes in soilless cultivation have generally led to an observed reduction in diversity and frequency of soil-borne diseases.

Nevertheless, the biggest problems in substrate cultures can arise from phytopathogenic fungi, well adapted to the aquatic surrounding and able to produce zoospores. *Pythium*, *Phytophthora* (Armitage, 1993) and *Olpidium* belong to these species with relative abundance. *Pythium aphanidermatum* (Postma *et al*., 2000) on cucumber, lettuce and various ornamentals seem to find favourable conditions to infest plants in soilless cultures. *Phytophthora cryptogea* often attacks gerbera, but also tomato, lettuce and other crops. *Olpidium brassicae* and *O. radicale* are not very serious alone, but act as vectors for virus infestations such as LBVV on lettuce (Tomlinson and Faithfull, 1980) and TNV on pepper, lettuce, cucumber and tomato (Paludan, 1985). *Plasmophora lactucae-radicis,* normally a leaf disease, can become a problem on subterranean plant organs of lettuce. *Fusarium oxysporum* f.sp. *lycopersici* is a fungus without zoospores, but will cause wilting on carnation (Rattink, 1983) and *Gnomonia radicicola* on roses (Amsing, 1995). The latter seems to prosper favourably on roses in soilless culture, but is virtually unknown in soil cultivation.

Bacterial diseases are not very common in soilless culture, except in tomatoes and other solanaceae where bacterial wilt can occasionally appear through *Clavibacter michiganensis* spp. *michiganensis* (Griesbach and Lattauschke, 1991), *Pseudomonas corrugata* and *Ralstonia solanacearum*.

Finally, nematodes such as Meloidogyne incognita on tomatoes and several ornamentals (Vetten, 1996), *Pratylenchus vulnus* on roses and *Radopholus* similes on *anthuriums* can make problems (Amsing and Runia, 1995).

Soilless culture is no guarantee for pest-and disease-free plant cultivation. But this technology provides easier ways to handle negative exogenous factors in order to minimize or to even prevent infestations, contrary to production in soil. The control of growth factors such as root zone temperature, water and fertilization are quickly adjustable to increase the hardiness of the plants. Substrate temperatures can be optimized with little effort. Here are some examples of controlling factors that benefit plant growth. It is known that *Phytophthora cryptogea* will attack tomato plants easier at low temperatures in the root environment. On the other hand, only substrate temperatures above 20 C favour the spread of *Pythium aphanidermatum* (Jarvis, 1991) and only above 17°C will *Fusarium* wilt in carnations become infectious. It is easy and beneficial to regulate the nutrient solution in soilless cultivation. An additional 10 – 30 mmol/l $Ca(NO_3)_2$ will slow down the zoosporulation of *Phytophthora parasitica* to reduce the infection of *vinca* roots. A high K/N ratio of 4:1 prevents *Erwinia carotovora* spp. *carotovora* on tomato. The addition of 1.7–3.4 mmol/l silicium significantly reduces *Pythium ultimum* on cucumbers. A higher concentration of Cu-ions in the nutrient solution lowers the risk of *Phytophthora cryptogea* on gerberas. There is less infection by *Fusarium oxysporum* f.sp. *dianthi* at pH 7.5 than at pH 5.5. Cucumbers are infested more quickly by *Pythium* sp. at pH 5 than at pH value of 6 (Göhler and Molitor, 2002).

Soil-grown plants in greenhouses have higher evapotranspiration than in soilless cultivation, which reduces relative air humidity to expose the leaves to *Botrytis* and powdery mildew infections, particularly during winter months. On the other hand, too low air humidity in the greenhouse environment is contraindicative to beneficial insects and can increase the population of several insect pests.

Soil and hydroponics systems must never be combined in the same greenhouse. The chance of disease infection increases in soilless culture when seedlings and transplants are first produced in soil blocks or peat pots and then transplanted in sterile substrate. It is better to grow seedlings from the start in rock wool blocks, vermiculite or some other inert substrate. Danger comes when already infected plants are introduced into the soilless system. *Fusarium* crown and root rot of tomato can already be established in the plant at the seedling stage without disease symptom, only to appear when the plants become stressed, e.g. during first fruit load (Jarvis, 1991).

Hydroponics offers an excellent environment for the beneficial effect of grafting disease-susceptible cultivars on resistant rootstocks. Seed companies offer ready-made materials mainly for disease-susceptible cucumber, tomato and melon cultivars.

Over the past years, various techniques were developed for the treatment of recirculating nutrient solution (Runia, 1995). Some systems are connected with a high cost of installation and upkeep. Some treatments affect the nutrients dissolved in the solution. Ideally, pathogens should be removed without complete sterilization of the solution (Van Os, 1998). There are several techniques that apply either heat, chemicals, radiation or filtration (Ehret *et al.*, 2001).

A method smartly adapted for closed soilless cultivation systems in the horticultural industry is the inexpensive, slow sand filtration method (Figure 19) for the elimination of *phytopathogens* from reused irrigation water or nutrient solution (Wohanka *et al.*, 1999). Its effectiveness goes beyond the mechanical straining effect. The biological activity is considered the most important purification mechanism (Brand, 2000). Slow filtration is highly effective against the most relevant *phytopathogens* with limitations on viruses and nematodes only. This method requires low energy input with low cost and ease of self-construction, maintenance and operation.

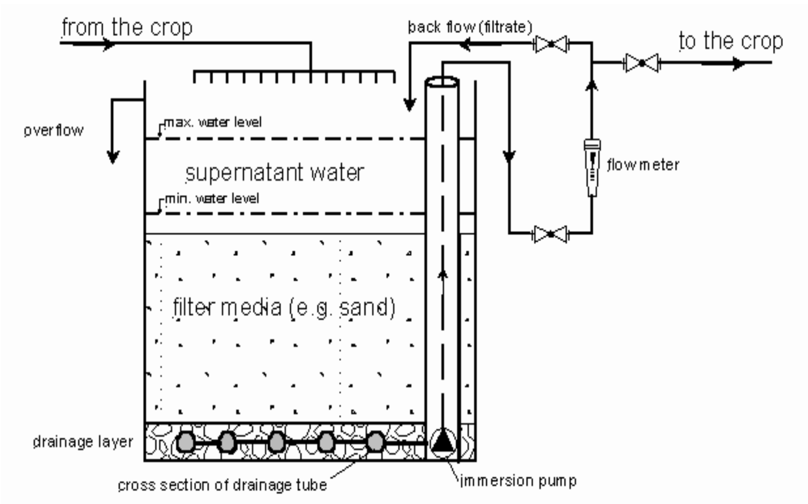

Figure 19: Set-up of slow filtration according to Wohanka

Where technical know-how or budget constraints is a problem, the ECOPONICS technology can be a practical approach to soilless cultivation. Figure 20 presents the scheme of this system (Heuberger *et al.*, 2004).

Fertilizer solution with dissolved mineral nutrients is pumped from a tank into the irrigation laterals to the plants in containers. The pots are placed in gutters with a 1 percent slope to collect the drained and excessive nutrient solution at the end of a row to be circled back to the tank. Flotation valves, a timer and water gauges control the system. Recycled nutrient solution in the tank is checked daily for EC and pH values by hand-held instruments. Needed adjustments are done with nutrients from stock solutions separately containing either fertilizer formulations with Ca or sulphate. There are some important issues that should be followed:

1. use completely water-soluble fertilizer with low N-and high micro-nutrient content;

2. take additional N as NO_3^- or $NH4^+$ to control the pH value at around 5.5; use $Ca(NO_3)^2$, NH_4NO_3, or $(NH_4)_2SO_4$;

3. supply required Ca with $Ca(NO3)_2$ or $CaCl_2$;

4. be sure to mix, in separate tanks, fertilizers containing Ca^{2+} and SO_4^{2};

5. control pH around 5.5 in the nutrient solution and add nitric acid when needed – adjust the amount of irrigation to reach approximately 40 percent drainage.

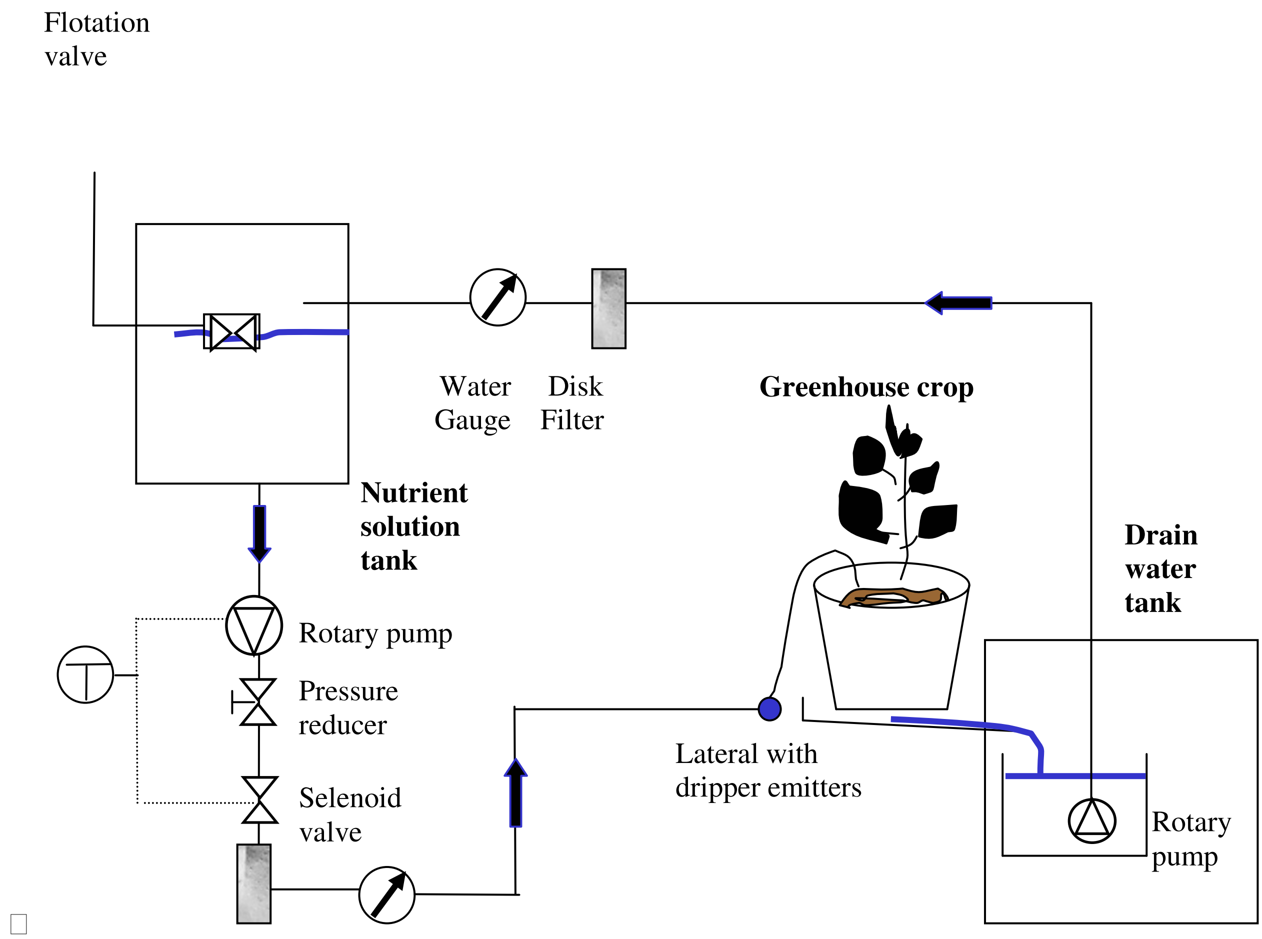

Figure 20: The technical installation for the recirculation of nutrient solutions with manual adjustment nutrients according to measured pH and EC values

EC Values remaining high over several days is an indication for too much salt accumulation in the substrate or drain water. This is the time to replenish the entire nutrient solution with a new mixture. Also, washing the substrate in the pots with clean water may be necessary.

The cost of a low-tech hydroponics system compares favourably with high-tech installation, at 30 percent of the cost, although with approximately 40 percent less yield. The low-tech system requires more personal involvement than a computer-controlled operation. Therefore, local labour cost, personal technical know-how, extension services and available cash, together with the size of the farm and the required crops for the market should lead to the right choice to invest in profitable hydroponics.

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Soil solarization: an environmentally-friendly alternative

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Summary

Soil solarization or “solar heating” is a non-chemical disinfestation practice that may serve as a component of a sustainable IPM programme. Solarization effectively controls a wide range of soil-borne pathogens, insects and weeds. Soil solarization is based on the exploitation the solar energy for heating wet soil mulched with transparent PE sheets to 40–55ºC in the upper soil layer. Thermal killing is the major factor involved in the pest control process, but chemical and biological mechanisms are also involved. The efficacy of the thermal killing is determined by the values of the maximum soil temperature and amount of heat accumulated (duration x temperature). The use of organic amendments (manure, crop residues) together with soil solarization (biofumigation) elevates the soil temperature by 1–3ºC, and improves pest control due to a generation and accumulation of toxic volatiles. Although cheaper than most chemicals used as soil fumigants, not all crops can afford the PE prices, particularly in developing countries. Not all soil-borne pests and weeds are sufficiently controlled. Cheaper and more environmentally accepted mulching technologies are needed before expanding the range of the controlled pests by solarization.

Introduction

Concern over environmental hazards and increased public awareness on human health issues caused by pesticides such as MB to the stratospheric ozone have directed much attention to alternative practices for chemical pest control (Katan, 1999; 2000). Soil solarization or “solar heating” is a non-chemical disinfestation practice that has potential application as a component of a sustainable IPM approach. In addition, it also increases the availability of soil mineral nutrients, reduces crop fertilization requirements and results in improved plant growth and yield (Stapleton and DeVay, 1986). Solarization was originally developed to control soil-borne pathogens as first reported by Katan *et al*. (1976), but it was soon found as an effective treatment against a wide range of other soil-borne pests and weeds including more than 40 fungal plant pathogens, a few bacterial pathogens, 25 species of nematodes and many weeds (Stapleton, 1997). The virtues of solar energy are not new; however, the innovation in developing soil solarization is the use of a modern tool to this end, namely, plastic sheets. Thus, implementation of this technology is easy to accomplish under a wide range of crop production systems. Soil solarization is based on utilizing the solar energy for heating soil mulched with a transparent PE sheet, reaching a level of 40-55ºC in the upper soil layer. There is a gradient of temperatures from the upper to lower soil layer during the appropriate season. The temperature elevation is facilitated by wetting the soil before and/or during mulching with the PE sheet. The main factor involved in the pest control process is the physical mechanism of thermal killing. In addition, chemical and biological mechanisms are involved in the pest control process.

Principles of soil solarization

The basic principle of soil solarization is to elevate the temperature in a moist soil to a lethal level that directly affects the viability of certain organisms. The heating process also induces other environmental and biological changes in the soil that indirectly affect soil-borne pests as well as survival of beneficial organisms (Katan, 1981). The values of the maximum soil temperature and amount of heat accumulated (duration * temperature) determine the potential of the thermal killing effect on soil-borne pests (Katan, 1987) and weed seeds (Stapleton *et al*., 2000a; 2000b). Currently, the most common practice of soil solarization is based on mulching moistened soil with transparent PE. The duration of soil mulching that is required for successful effect is usually four to six weeks, depending on the pest, soil characteristics, climatic conditions and the PE properties (Katan, 1981 and 1987; Rubin and Benjamin, 1984). Pest population and environmental conditions are unmanageable variables, while soil moisture and PE properties could be modified as needed. Soil pre-treatment and appropriate PE technology may overcome unfavourable environmental conditions prevailing in some regions or in certain seasons, increasing weed (or pest) sensitivity and soil, shortening soil mulched duration (Stevens *et al*., 1991).

Soil moisture improves temperature conductivity in soil and the sensitivity of microorganisms to toxic agents. Hence, pest control is better under "wet heating" than "dry heating". This applies also to weed control, presumably because moist seeds are in a more advanced metabolic activity (Shlevin *et al*., 2004). Therefore, all soil pre-treatments that improve water capacity, such as soil cultivation or drip irrigation during mulching, may improve soil solarization efficacy. Drip irrigation during the solarization process is essential for maintaining a wet soil surface, enabling the heat transfer to deeper layers. Moreover, good soil preparation that leads to a smooth soil surface facilitates plastic mulching and prevents tearing.

Biofumigation

The use of organic amendments (biofumigation) such as animal manure or incorporated cover crop residues combined with soil solarization may further elevate the soil temperature by an additional 1–3ºC (Gamliel and Stapleton, 1993a, 1993b; Gamliel, Austeraweil and Kritzman, 2000; Lira-Saldivar *et al*., 2004). Gamliel, Austeraweil and Kritzman (2000) proposed that this elevation is a result of the improved thermal conductivity in moist soil, exothermic microbial activity or a combination of both. Combining soil solarization with organic amendments leads to the generation of toxic volatile compounds that accumulate under the plastic mulch and consequently enhance the vulnerability of soil organisms to soil solarization Gamliel, Austeraweil and Kritzman, 2000). The nature of these volatiles may vary according to the origin of the organic matter (Chou and Patrick, 1976; Wainwright, Nevell and Grayston, 1986; Wheatley, Millar and Griffiths, 1996), especially when a high soil temperature is employed (Gamliel and Stapleton, 1993a, 1993b; Gamliel, Austeraweil and Kritzman, 2000). Gamliel, Austeraweil and Kritzman (2000) have shown that the type of plant residues or manure incorporated into solarized soil may generate measurable amounts of volatiles such as ammonia, methanethiol, dimethyl sulfide, allylisothiocyanates, phenylisothiocyanates and aldehydes. These compounds accumulate under the PE to above a threshold level that is toxic to soil flora and fauna. The elevated soil temperature also increases the sensitivity of soil pests to the toxic effect of the captured volatiles (Gamliel, Austeraweil and Kritzman, 2000), further deteriorating the seedbank persistency (Lynch, 1980; Petersen *et al.*, 2001). For example, Peterson *et al.* (2001) indicated that isothiocyanates released by turnip-rape (*Brassica rapa*) in mulched soil suppress weed infestation in the field. High concentrations of isothiocyanates in soil strongly suppressed the germination of several weeds and crops, such as scentless mayweed (*Matricaria inodora*), smooth pigweed, barnyardgrass (*Echinochloa crusgalli*), blackgrass (*Alopecurus myosuroides*) and wheat (*Triticum aestivum*).

The use of plastic mulch for soil solarization

In general, all types of transparent PE sheets commonly used in agriculture are appropriate for solarization purposes. Part of the solar radiation is transmitted through the transparent PE, absorbed by the soil surface and transformed to conserved heat. Some PE sheets differ in their chemical and physical properties such as thickness, colour and wavelength transmission, UV protection and durability. The PE largely prevents the escape of long-waves radiation and water evaporation from the soil to the atmosphere, consequently exerting a greenhouse effect. In addition, the water vapours accumulated on the inner surface of the PE sheet further enhance the greenhouse effect, resulting in higher soil temperatures (Stevens *et al.*, 1991). Black PE however, absorbs most of the solar radiation and heats up but does not transmit the radiation, due to the insulating air layer between the plastic mulch and soil surface. Thus, black plastic mulch usually provides a lower soil temperature and poorer pest control (Horowitz, Regev and Herzlinger, 1983; Rubin and Benjamin, 1983; Mudalagiriyappa, Nangappa and Ramachandrappa, 1996; Abu-Irmaileh and Thabani, 1997; Singh, 2006). Thin PE is economically cheaper and reflects less radiation than the thicker sheet, resulting in a slight increase in ST. Unfortunately, thin PE tends to deteriorate faster than the thicker layer under field conditions. Avissar *et al.* (1986a; 1986b) reported that aged (previously used) PE for soil solarization is more efficient in temperature elevation than new PE due increased radiation influx at the soil surface.

The *double-tent technique*, in which the soil is mulched with two layers of PE (with a space of 3 to 7°cm between the sheets), increases soil temperature by an additional 10ºC with respect to a single-layer solarization (Ben-Yaphet *et al.*, 1987). The double-tent technique was found to be more effective than one single PE (McGovern, McSorley and Wang, 2004), especially against weeds in nursery containers (Stapleton *et al.*, 2000a; Stapleton *et al.*, 2002). It is obvious that the double-tent technique raises both the economical cost and the environmental hazard due to PE pollution, and should be used only in special cases.

In the last decade, alternative technologies to PE were suggested, e.g. soil mulching with sprayable polymers (Gamliel and Becker, 1996), or the use of paraffin-wax emulsion as a mulching material (Al-Kayssi and Karaghouli, 2002). However, their cost-effectiveness and efficacy were not fully studied, particularly when combined with the common PE mulching.

Limitations of soil solarization

The major constraints that limit the adoption of soil solarization in practice are the relatively long duration of the process and the climatic dependency. The cost of solarization is relatively low compared with other available alternative; however, it can be a limiting factor depending on the country, the crop type, the production system (e.g. organic versus conventional farming) and the cost and availability of alternatives. Soil solarization as a non-chemical tool for weed management was proven to be more cost-effective and profitable than MB (Stapleton et al., 2005) or some other treatments (Boz, 2004), especially in high-income crops (Abdul-Razik et al., 1988; Vizantinpoulos and Katranis, 1993).

Technological innovations, such as mulching the soil with sprayable polymers or using a variety of PE sheets or other mulch techniques (Gamliel and Becker, 1996; Al-Kayssi and Karaghouli, 2002), will facilitate the application and use of soil solarization in agriculture. These facilitations should result in reduced mulch duration, an increase in the geographical range of usage, a broader range of controlled weeds, improved persistency of the PE sheets, decreased PE pollution and a significant decrease in the total economical cost of mulching. However, in addition to the favourable effects of soil solarization, there are also unfavourable ones: (i) there are geographical limitations on where the method can be used in terms of solar radiation availability; (ii) the soil is occupied for at least one month with the mulch; (iii) although cheaper than most chemicals used for soil fumigation, not all crops can afford the PE prices; (iv) it is difficult to protect the PE sheets from damage caused by wind and animals; (v) there is no full environmentally-accepted solution for the used PE; and (vi) not all soil-borne pests and weeds are sufficiently controlled.

Conclusions

The global changes and the constant increase in the erosion of the natural ecosystem emphasize the importance of soil solarization as a viable environmental IPM tool in agricultural production systems. The effectiveness of soil solarization as an established soil-borne pests control method is well demonstrated under various agro-ecosystems, especially in regions with high levels of solar radiation, but also in cloudy weather (Peachey et al., 2001).

Future research should aim at the development of: improved technology, e.g. cheaper and more environmentally accepted mulching technology; large-scale application technologies; and new plastic formulations for improved soil temperature transmission in the vertical soil profile. These improvements should extend the use of this technology beyond the season limitations and make soil solarization suitable for marginal climatic regions and for less profitable crops. Also, these improvements will expand the range of the controlled pests and reduce the duration of the process.

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The use of biofumigation in Spain

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Summary

Spain was the fourth country in MB consumption in the world, with a total of 4 191 tonnes of MB applied as a soil fumigant in 8 988 ha of various crops, mainly strawberry (33 percent), pepper (29 percent), cucurbits (9 percent) and cut flowers (9 percent). Biofumigation and biosolarization are the main non-chemical alternatives, followed by soilless cultivation, crop rotation, the use of resistant varieties and grafting, which are effective when integrated in the Integrated Crop Management (ICM) systems. The alternatives cost less, are equally effective as MB, and do not pose problems in their application. In 2008 in Spain, the critical use of MB is 232 tonnes: 215 tonnes for strawberry nurseries and 17 tonnes for cut flowers. The other areas not treated with MB will benefit from biofumigation and biosolarization for soil biodisinfection against both nematodes and fungi as well as virus and bacteria remaining in crop residues. Soil biodisinfection is also effective for weed control. The use of manures and crop residues, applying ecological criteria in crop production based on local resources, also enhances soil fertility and improves soil structure.

Introduction

In Spain, a European Union (EU) member, MB was phased out in 2005. The fumigant was exempted for some critical uses, where conclusive technical, economic and social reasons were indicated. There was a gradual withdrawal of up to 60 percent in 2001 and 75 percent in 2003, while in 2005, Spain requested the exemption of 1 059 tonnes (25.3 percent) for critical use, including 556 tonnes for strawberry production, 230 tonnes for strawberry nurseries and 73 tonnes for use in cut flowers. It is important to point out that MB was used in Spain for the control of a limited number of fungi (*Fusarium, Phytophthora* and *Verticillium*) and root-knot nematodes (*Meloidogyne).* The effectiveness of MB depends on soil conditions such as pH, moisture, depth, content of organic matter, biological activity and temperature (Bello and Tello, 1998, Bello *et al*. 2001). The EU has solicited 244 tonnes for 2008, of which 232 tonnes are for strawberry nurseries (215 tonnes in Spain) and cut flowers (17 tonnes in Spain). The rest of MB in EU is used for strawberry nurseries (12 tonnes) in Poland (MBTOC, 2007).

The major non-chemical alternatives in Spain are:

- resistant cultivars: peppers, tomatoes, sweet potatoes;

- grafting in vegetables (curcubits, eggplants, tomatoes, peppers) as well as in perennial plants;
- cultivation in substrates including natural and synthetic materials, especially for cut flowers, nursery plants, vegetables;
- steaming: mainly in cut flowers and vegetables;
- solarization, especially in curcubits;
- biodisinfection – biofumigation and biosolarization, which is based on the use of gases from the decomposition of organic matter;
- biocontrol agents, i.e. improving antagonists by natural methods.

These non-chemical alternatives are part of the ICM systems, which include combined application of biological alternatives, cultural practices and reduced doses of low-risk chemicals. It is important to clarify that chemicals are solely used to comply with the gradual reduction imposed on the Parties to the Montreal Protocol, but they are not the solution for the future (Porter *et al.*, 2006).

Various projects have been funded, under the coordination of the Instituto Nacional de Investigaciones Agrarias (INIA), by the Ministries of the Environment (MMA) and Agriculture, Fisheries and Food (MAPA), in collaboration with the Autonomous regions of Andalucía, Castilla y León, Murcia and Valencia, as well as with researchers from the Consejo Superior de Investigaciones Cientificas and a number of universities. These projected aimed at searching for alternatives to MB. Since 1992, intensive work has been carried out on the development of new alternatives to replace MB in Spain. Bolívar (1999) and Barrés *et al*. (2007) summarized the major finding – that biofumigation plus solarization provides good results when applied under appropriate conditions. However, there are still no suitable alternatives in Spain for strawberry nurseries (López Aranda *et al.,* 2005).

The cultivation of tomato is a good example of MB reduction in Spain, since only 875 ha were treated with this fumigant (Varés, 1998), which represents 10 percent of the cultivated area in controlled environments and only 1.5 percent of the total area for this crop. The low consumption of MB in tomatoes is noteworthy, because this crop consumes 5 271 tonnes (37 percent), being the highest MB-consuming crop in the EU. As alternatives to MB, Spain is using: resistant varieties of substrates, both artificial and natural, such as sand-covered soils in the southern part of the peninsula and the Canary Islands; grafting; biofumigation; crop rotation and fallow; planning of the time for sowing; and preventative measures in seedbeds and chemical controls. Steam is not used because of the high cost. In summer, solarization occurs as a natural phenomenon, but in general, the technique is not widespread among farmers (Bello *et al.*, 1998; Tello, 2000).

In Spain, the successful application of biofumigation has been achieved in strawberries of Andalucia and Valencia; peppers of Murcia and Castilla-La Mancha; cucurbits in Valencia, Castilla-La Mancha and Madrid; tomato in Valencia and the Canary Islands; cut flowers, citrus and fruit trees in Valencia; banana in the Canary Islands; and vineyards in Castilla-La Mancha (Figure 21). Biofumigation has also been recently applied to Swiss chard crops in Madrid and carrot crops in Andalucía and Alicante (López Aranda, 1999; López-Pérez *et al.*, 2003). The most utilized biofumigants have been goat, sheep and cow manure, and remains from rice, mushroom, olive, brassicas, and gardens (Bello *et al.*, 2001; 2003). The cost of biofumigation and its application are not expensive. Its effectiveness in controlling nematodes, fungi, insects, bacteria and weeds is nearly the same as with the use of conventional pesticides. Biofumigation may also regulate viral problems by controlling vector organisms (Bello *et al.*, 2003).

Figure 21: The use of biofumigation in Spain

Solarization is not an effective method when used alone, particularly when the target pests are mobile organisms, such as nematodes. Due to absorbed heat, the nematodes move deeper in the soil, but are brought up to the surface of the soil by ploughing. Solarization has been effective in soils with high organic matter content, when combined with biofumigation, or when used in shallow soils (cucurbits). The period of solarizing soil when combined with biofumigation (biosolarization) should be up to two months if the air temperature is over 40°C (Lacasa *et al.*, 2002).

Grafting aims at soil-borne disease control. The method consists of inserting a susceptible plant on the rootstock of another plant resistant to the target disease. It is used in vegetables for solanaceous plants (tomato, eggplant, pepper) and for cucurbits (melon, cucumber, watermelon). Grafting can compete with MB in production, reliability and price. This technique is widely used in Almería and Valencia to control vascular *Fusarium* wilt in watermelon (Bello, 1998; Bello *et al.*, 1998).

In Spain, tobacco seedbeds can be planted without MB by using the *floating tray technique*, which safely provides high quality seedings at a low cost, with good root systems. The alternative technology consists of trays floating on water in a pool where seedlings are grown. Pools can be located outdoors in plastic micro-tunnels protected by thermal blankets, or indoors in greenhouses. This technique has been used since 1991 in tobacco crops in Extremadura and is an effective alternative to MB (Blanco, 2000).

Biodisinfection: biofumigation and biosolarization

Biodisinfection utilizes crops that release volatile toxic gases. The term "biofumigation" has been applied to the process where volatile toxic gases are released in the degradation process of organic amendments, plant roots and tissues. Released gases are effective against diseases, nematodes and weeds. Incorporation of some brassica or compositae species residues or biomass results in the release of a range of volatile compounds, particularly isothiocyanates, which have herbicidal, fungicidal, insecticidal and nematicidal properties (Bello, 1998; Kirkegaard and Sarwar, 1998; Bello, López-Pérez and García-Álvarez, 2003). In nearly all cases, application of such amendments results in a huge increase in the overall soil microorganism populations, whereas populations of most plant pathogenic microorganisms, and likely some non-pathogenic ones, decrease substantially. The basis for this selective or biodisinfecting effect is not clearly understood, but the term is much preferred over the concepts inferred by biofumigation (MBTOC, 2007).

Organic amendments such as composts, animal and green manures, as well as by-products from agriculture, forest and food industries have been used in many countries to manage certain soil-borne pests (fungi, nematodes and *Orobanche*) in various crops (Goud *et al.*, 2004; Haidar and Sidiahmed, 2006). This alternative is a valid long-term approach to replace the use of pesticides in soil. With a better understanding of the mechanisms by which organic amendments control increases in pathogen populations and of the role of various factors on its effect in soil, there will be wider use of organic amendments in the coming future (Blok *et al.,* 2000; Tenuta and Lazarovits, 2002; Ozores *et al.*, 2005).

The primary mechanisms by which organic amendments reduce pathogens are often chemical in nature. High concentrations of volatile fatty acids (VFA) including formic, acetic and propionic acids, among others, were present in many anaerobically stored organic materials such as liquid swine manure, fish emulsion and some young composts (Conn, Tenuta and Lazarovits, 2005). The generation of these toxicants is greatly affected by soil pH, buffering capacity and organic matter content (Lazarovits *et al.*, 2005).

Biofumigation and biosolarization are easy-to-apply techniques for farmers and technicians. The organic matter as a biofumigant should be in the process of decomposition. The method of application should take into account the need to retain the gases released by the biofumigant during the process of decomposition, for at least two weeks. In fact, its effect in most cases is more biostatic than biocidal. Therefore, it is necessary to prolong its action on pathogens for a certain period of time. A marked herbicidal effect has also been verified. It has been demonstrated that any agroindustrial residue or its mixtures with a C/N ratio between 8 and 20 has a high biofumigating effect. A rate of 50 tonnes ha^{-1} is recommended. However, when problems with nematodes or fungi are very serious, 100 tonnes ha^{-1} should be applied, at a rate that can be reduced by means of cultivation techniques such as application in furrows (Table 16). The biofumigant should be distributed uniformly so that spots of pathogens that could create problems for the crop will not appear. Once the biofumigant is distributed, it should be rototilled for its immediate soil-incorporation. The soil surface should be left smooth with the application of the rototiller's leveller. It is then irrigated, if possible by sprinkling, until the soil is saturated. Irrigation may also be carried out by flooding or drip irrigation. The soil is then covered with plastic for at least two weeks to retain the gases released by the incorporated organic matter (Bello *et al.*, 2001; Bello, López-Pérez and García-Álvarez, 2003).

Table 16: Influence of biosolarization (B+S) on weeds, root-knot nematodes and pepper production in Murcia (Spain)

Treatment	Weeds index	percent plants *M. incognita*	Gall index	Plant height	Commercial production (kg/m^2)
BM 98:2 30 g/m^2	0.04 a	0.00 a	0.0 a	142.0 a	9.4 a
B+S 2nd year (75 t/ha)	0.71 b	53.33 b	2.7 c	144.0 a	8.8 a
B+S 4th year (45 t/ha)	0.33 b	20.0 ab	0.7 ab	145.0 a	8.9 a
B+S 5th year (25 t/ha)	0.17 a	33.33 ab	1.0 b	141.0 a	9.1 a
B+S 6th year (25 t/ha)	0.37 ab	13.3 ab	0.3 a	144.0 a	9.6 a
Control	1.68 c	100.0 c	3.8 d	125.0 b	7.2 b

The cost of biofumigation may reach the same value as MB, especially when animal manure or agricultural residues are transported to great distances. Costs can be reduced when green manure is used, which usually does not exceed US$300 ha^{-1}. Since biofumigation is actually the application of organic amendments, which is normal practice in ICM systems, the cost could be considered zero. Some difficulties could arise at the beginning of the implementation of biofumigation, but with time, the farmer will become more familiar with the method and will choose the best combinations of biofumigants and their ratios (Bello *et al.*, 2001).

ICM is applied in Spain to most of the crops that had been treated with MB, especially tomato and other vegetables, banana, citrus fruits, vineyards and fruit trees. The ICM system is effective in regulating pathogen populations and increasing crop production. Short-cycle (2-3 months) vegetable crops may be used as trap plants in winter. The health and quality of seeds and plants are important elements in ICM. Planting time is established by taking into account temperature changes unfavourable to pathogen development. Resistant plants can also be used; the resistance should be managed appropriately in order to avoid the incidence of more virulent pathogen populations. There are high-yielding vegetable varieties that are also highly susceptible to pathogens in soil. In this case, resistance can be achieved through grafting with highly resistant rootstocks to various soil-borne pests (Bello, López-Pérez and García-Álvarez, 2003).

Discussion and conclusion

In Spain, MB for soil fumigation was mainly applied in strawberries (33 percent), peppers (29 percent), vegetables in general (12 percent), cut flowers (9 percent), tomatoes (5 percent) and other crops (3 percent). Regions with the highest consumption were Andalucía, Murcia, Valencia, Castilla y León and Catalonia. MB is not used in most of the autonomous regions, particularly for tomatoes, which is the major MB-consuming crop in the world.

Various companies and research teams in Spain have paid special attention to the development of new alternatives to MB. The results obtained have been internationally recognized. The biofumigation, solarization, grafting, floating trays for tobacco seedbeds, biological control and ICM are sound alternatives for the replacement of MB, which can also be adapted in other countries. In Spain, the only "critical use of MB" is strawberry nurseries, due mainly to the commercial requirement of treating these plants with the fumigant.

There are alternatives for most of the crops where MB was used. Their implementation depends on the pathogen to be controlled, the crop and the geographical region. Viable alternatives do not necessarily show the same effectiveness as MB, but they are also effective from the technical and economical point of view. In the short term, chemical alternatives will provide enough control of various important pests. However, in the future, the non-chemical alternatives will be more sustainable. Among the non-chemical alternatives, biofumigation is exceptionally convenient, and it can be combined with solarization within an ICM system, which harmonizes cultural practices, crop rotation, grafting and resistant varieties.

Biofumigation is always more economic than MB when local raw materials are used. The ICM system includes: the use of various methods, such as biofumigation with solarization during July–September; rotation with short-cycle crops that act as trap plants; the application of biofumigants, resistant or susceptible varieties grafted on resistant rootstocks; and as a last resort, crops grown on soilless substrates (Bello *et al.*, 1998). Highly qualified farmers and technicians should choose the adequate alternative on a case-by-case basis for making the crop profitable and safe for human health and the environment. Low rates of pesticides with limited environmental risks can also be applied under certain circumstances.

Growers should become aware of the future ban of various soil fumigants and make all possible efforts to identify new alternatives for the control of soil-borne pathogens that affect their crops. Above all, they should no longer plan productions that depend on the use of MB. Alternatives to this fumigant should be applied to keep the quality and profitability of agricultural production at the required level and without any risk to human health and the environment.

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The use of grafting in Spain

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Summary

In Spain, grafting was introduced to combat several diseases such as: tracheomycosis caused mainly by specialized forms of various races of *Fusarium oxysporum* or *Verticillium dahliae*; fungal diseases affecting neck and roots and provoking withering or drying caused by Phytophthora and Pyrenochaeta, among others; diseases caused by phytopathogen nematodes (*Meloidogyne* sp.); and other diseases caused by bacteria due a serious build-up of microorganisms in the soil. Grafting is mainly applied in watermelon and tomato, and, in some areas of the country, in pepper, eggplants, melon and cucumber. The most used grafting methods keep the root system of the cultivar and rootstock during the graft union: *tongue approach grafting*, which is used for cucurbits, mainly watermelon; *lateral cleft grafting* used in watermelon and melon; *cleft grafting* used in solanaceous crops, mainly tomato; *tube grafting* (or *splice grafting*) for tomato and pepper; and *slant-cut grafting* for watermelon, melon and cucumber, a method developed for robotic grafting. The paper also provides details of grafting methods in various vegetables in Spain, their advantages and disadvantages. Grafting is considered another important alternative for the control of soil-borne pests in the country.

Introduction

Grafting consists of uniting two living plant parts so that they grow as a single plant (Hartmann and Kester, 1991) The plant that provides the root is called the “rootstock” and the added piece of another plant is called the “scion” (Janick, 1979). Grafting of vegetable plants is a common practice in Japan, the Republic of Korea, and several European countries. Its main purpose is to control soil-borne diseases and nematodes (Hartmann and Kester, 1991; Lacasa, 2006). When grafting, one tries to avoid contact of the productive plant with the soil, because of the latter’s unfavourable conditions that could inhibit the plant from expressing its full potential and productive characteristics. Grafting is done onto various rootstocks from the same species, genera or family (Louvet, 1974). Sometimes, grafted plants are used even if soil conditions are not adverse, just to increase plant productivity, since the grafted plant is usually more vigorous than the ungrafted one (Lacasa, 2006). It may also be useful to increase fruit size. Grafting on cucurbits was briefly described by Hong (1643–1715) in the Republic of Korea (Lee and Oda, 2000). Grafting was first used commercially in the 20th century for vegetable production in Asia. Grafting of eggplants started in the 1950s, followed by grafting of cucumber and tomato around 1960 and 1970, respectively (Edelstein, 2004).

Grafting of vegetables and fruits

Grafting is commonly used for solanaceous crops (tomato, pepper and eggplant) and cucurbitaceous crops (melon, watermelon and cucumber) in many areas of the world. In Spain, grafting is mainly used in watermelon and tomato, and on some parts of other fruits and vegetables, such as pepper, eggplant, melon and cucumber (Table 17).

Lacasa (2006) considers that grafting was introduced in Spain to combat several diseases, such as: tracheomycosis caused mainly by specialized forms of various races of *Fusarium oxysporum*, *Verticillium dahliae*; fungal diseases affecting neck and roots and provoking withering or drying caused by Phytophthora, Pyrenochaeta and other pathogens; diseases brought about by phytopathogen nematodes (*Meloidogyne* sp.), and others caused by bacteria due to a serious build-up of microorganisms in the soil. Sometimes, grafted plants are used even if soil conditions are not adverse, in order to increase its productivity.

Table 17: Use of vegetables grafting in selected countries

Country	Watermelon	Cucumber	Melon	Tomato	Eggplant	Pepper
Japan	93%	72%	30%	32%	50%	**
Republic of Korea	98%	95%	95%	5%	2%	5%
Greece	100%	5–10%	40–50%	2–3%		
Spain	98%	*	3%	10%	*	**
Morocco	*		*	25%		
Cyprus	80%					
Italy	30%		5-6	*	*	
Israel	70%		**	**		
France		3%	1 000 ha	**		
Netherlands				50%		
Mexico				*		
Guatemala	*		*			
Honduras	*		*			

* No data available ** Starting now

(Source: Miguel, 2004; Camacho, 2007)

Cucurbits and solanaceous grafting techniques applied in Spain can be divided into three basic types (Figure 22):

- grafting techniques that keep the root system of the cultivar and rootstock during the graft union: the *tongue approach graft* for cucurbits, mainly used in watermelon;
- grafting techniques that keep only the root system of the rootstock during the graft union: *lateral cleft grafting* for cucurbits, mainly used in watermelon and melon; *cleft grafting* for solanaceous crops, mainly used in tomato; and *tube grafting* (splice grafting) for solanaceous crops, mainly used in tomato and peppers;
- grafting techniques that remove the entire root system during the graft union with a new root system: *slant-cut grafting* for cucurbits, mainly used in

watermelon, melon and cucumber. This method was developed for robotic grafting.

The grafting calendar depends on several factors such as season and outdoor temperature, the grafting technique applied, and the difference in growth rate between the rootstock and the scion. De la Torre (2005) gives this grafting process schedule for southeast Spain conditions, for several species and grafting techniques (Table 18).

Hartmann and Kester (1975; 1991) have described the developmental sequence of the formation of a graft union as follows:

- cells at the cut surface of both the scion and rootstock die creating a necrotic plate;
- under the necrotic plate, the cambium of both the scion and rootstock produce parenchymal cells termed "callus". Cells in the callus differentiate into a new cambium;
- new xylem and phloem cells are produced in the new cambium establishing a vascular connection between the scion and rootstock.

There are certain environmental requirements that must be met for callus tissue to develop and for achieving a successful graft union (Hartmann and Kester, 1975):

- the temperature should be high enough for rapid cell division and growth;
- high humidity is required to prevent desiccation of the thin-walled, turgid parenchymal cells in the callus. The graft junctions should be isolated from possible infection by pathogens;
- firm support is required to allow proliferation of parenchymal cells in the callus.

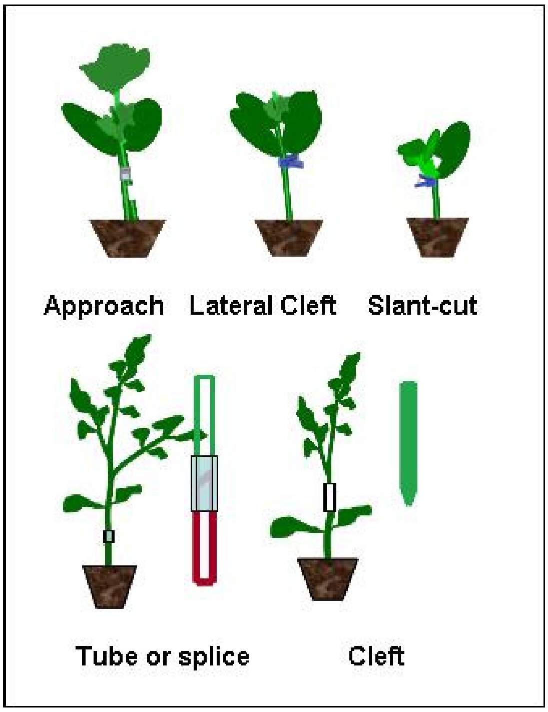

Figure 22: Different grafting techniques

When the variety is rootless at the moment of grafting (lateral cleft, cleft grafting and tube grafting) and the variety and rootstock are rootless at the moment of grafting (slant-cut grafting), it is necessary to strictly control the temperature and relative humidity after the operation to avoid plant dehydration and death before the union with the rootstock.

Table 18: The grafting process duration for conditions in southeast Spain (in days)

Grafting technique	Species	Insertion of cultivar	Grafting	Branch removal	Transplanting
Tube grafting	Tomato -normal plant	2–7	22–27	32–37	42–52
Tube grafting	Tomato -big plant	5–12	27–32	35–50	47–60
Tube grafting	Sweet pepper	0	25–45		45–75
Approach grafting	Watermelon	3–5–7	14–24	25–32	35–55
Lateral cleft grafting	Watermelon	5–7	18–27		35–50
Slant-cut grafting	Watermelon	3–5	15–20		32–45
Lateral cleft grafting	Melon	3–5	16–21		35–40
Slant-cut grafting	Melon	1–3	12–15		30–35
Slant-cut grafting	Cucumber	0–2	9–12		21–28

(Source: De la Torre, 2005)

The most extended grafting techniques in Spain are the *tongue approach graft* for watermelon and the *tube graft* for tomato (De la Torre, 2005):

Tongue approach graft in watermelon

Grafting must be carried out when the rootstock and scion seedlings have the first true leaf. To achieve this, the scion is sown first and the rootstock, between 3 and 7 days later. Grafting is done between 14 to 24 days after the scion is sown, with a razor blade, cut down an angled slit half-way through the stem of the rootstock (2°cm under the cotyledons) and an oppositely angled slit half-way through the stem of the scion; the cut surface must be between 1 and 1.5°cm. The rootstock and scion are joined and kept together with a small grafting clip. Grafted plants are transplanted on a new tray with larger holes and remain in the grafting tunnel or chamber, where humidity, light and temperature can be regulated (22-30ºC, 80-90 percent relative humidity and low light). The tunnel must be ventilated gradually, 7-10 days after grafting, and the cultivar stem must be cut 14-16 days after the grafting. Grafted plants are ready to be transplanted 25-30 days after the grafting.

Tube graft in tomato

Grafting must be carried out when the rootstock and scion seedlings have the same diameter. To achieve this, the rootstock is sown first and the scion, 2–7 days later for production, or 5–12 for large plant production. Grafting is done 22–27 days after sowing for normal plants or 27–32 days for large plants. The rootstock is cut at a slant angle (45–60º) up or under the cotyledons. The grafting clip is attached on the rootstock. The scion is cut in the same way, and then the two cut ends are placed in direct contact; the cutting surface must make full contact. During graft healing, plants are kept in the tunnel or chamber, where humidity, light and temperature can be regulated (20–30ºC, 80-90 percent relative humidity and low light). Plants must be ventilated about three days after grafting: while fusion occurs 6-8 days, then plants are moved to the areas for final adaptation. Transplanting can be done 14–21 days after grafting.

State of development of graft technologies in Spain

In Spain, the use of grafting on vegetables is now increasing. In the past, grafting was mainly used in watermelons, but recently, the use of grafting on tomatoes and peppers has increased, mainly due to new diseases in tomato crops and the prohibition of MB application in pepper crops.

Grafting on watermelon

Watermelon is a traditional, easily managed crop that needs little farm work and is easy to grow. Producers mainly need to focus on pest and disease control. However, one of the problems of intensive cultivation under plastic is the incidence of soil-borne pathogens, particularly *Fusarium* and *Verticillium* wilts and root-knot nematodes. The most important diseases in watermelon are those caused by *Fusarium oxysporum* f. sp. *niveum* (Fon), which is responsible for massive watermelon mortality throughout the world (Brayford, 1992). Although some of the common cultivars of watermelon are resistant to the races 0 and 1 of *Fusarium* (Messiaen *et al*., 1991), all are sensitive to race 2, which is widespread in all watermelon-producing areas. In infested soils, yields are erratic and usually too low. Also, there is a reduction in fruit size (Miguel, 1988). The first methods used in Spain to face the problem of vascular fusariosis were soil and seed disinfection, with unsatisfactory results. Later, starting in the mid-1970s, genes resistant to this fungus were introduced in watermelon crops, but this measure proved insufficient in highly infected soil (Camacho and Fernandez, 2000). The problem was not solved by using various concentrations of all the elements in MB + chloropicrin nor at various doses. The solution to vascular fusariosis was found by grafting watermelons onto rootstocks resistant to this fungus. Grafting watermelon is cheaper, safer and more effective against soil-borne pathogens than the use of MB. In addition, the latter is in the process of being banned worldwide as a consequence of damage to the ozone layer (Camacho and Tello, 2006).

In Spain, the first experiments with grafted watermelon plants were carried out in 1979. Grafted watermelon crops were not grown on a commercial scale until 1985, however, when commercial interspecific hybrids appeared, which has continued until the present with excellent results. In important production areas such as Almeria, Valencia and Murcia, where crops are repeated regularly, 30 million watermelon plants are grafted annually (Hoyos, 2001), comprising around 12 000 ha. At present, almost all watermelon planting is done with plants grafted onto RS841 and Shintoza rootstocks, interspecific hybrids of Cucurbita maxima x Cucurbita moschata. Both of these provide effective protection against most soil-borne pathogens, but not against nematodes (Lee, 2003), which occasionally cause serious damage, especially in late planting. *C. maxima x C. moschata* hybrids are not resistant to *Meloidogyne*; for this reason, if there is a high level of soil infectio, it is advisable to combine grafting with solarization, biofumigation, and nematicide application, or to use another rootstock type, of the genus *Citrullus,* resistant to nematodes (Miguel, 2004).

Grafting on melon

Melons are affected by several soil-borne pests such as nematodes (*Meloidogyne*), fungi (*Fusarium* spp., Gummy, Vine decline) and virus (Melon Necrotic Spot Virus [MNSV], transmitted by soil fungi *Olpidium bornovanus.* The most important soil-borne phytosanitary problems for Spanish melon crops are caused by the fungus *Fusarium oxysporum* f. sp. *melonis* (FOM), *Didymella bryoniae* (Gummy stem blight) and the virus MNSV. Grafting is an effective method to control soil-borne diseases. In particular, vascular diseases caused by *Fusarium* spp. and *Verticillium* spp., nematodes such as *Meloidogyne* spp., MNSV transmitted through a soil fungus *Olpidium bornovalus*. Four races (0, 1, 2, and 1, 2) of *Fusarium oxysporum* f. sp. *melonis* (FOM) have been found in melon. The four races are found in Spain; races 1 and 2 were reported in Almeria by Tello and Gómez in 2000. Miguel (2004) considered than the most important melon pathogens in Spain are *Monosporascus cannonballus* and MNSV. *Monosporascus cannonballus* mainly affects open-air cultivated crops or those with simple protection (under plastic mulch, small tunnel, floating cover) in Murcia, Valencia or Castilla La Mancha, and MNSV affects greenhouse cultivation in Almeria. The incidence of *M. cannonballus* varies from one year to another. Since crop rotation is practised to a certain degree, successively avoiding planting melon in the same plots, the disease becomes unimportant. MNSV is a serious problem in the greenhouses of Almeria, but is no longer a problem when melon is alternated with other crops or when resistant varieties are used.

The development of grafting on melon crops in Spain is very low, mainly because genetic resistance to the most important diseases such as *Fusarium* wilt (Fom 1 and Fom 2 gene) or MNSV (nsv gene) has been introgressed into commercial varieties. The low development of grafting on melon is due to other reasons such as problems with graft-scion incompatibility or fruit size. Late graft-scion incompatibility has been found on Spanish green melon type. Lower fruit quality has been found with the Cantaloupe and Galia type; grafting plants produce larger fruits. These larger Cantaloup or Galia fruit sizes are not appreciated in the European market. The increase in fruit size induced by grafting on this types or melons is a problem when the destination market is Europe, but not when is North America, mainly due to consumer preferences for larger-sized cantaloupe (muskmelon) type in North

America. Grafting is now being developed as an alternative to MB for the control of soil-borne diseases in Central American melon crop production. Grafting onto melon (*Cucumis melo*) can be of benefit when the pathogen to control is *Fusarium* wilt (FOM), as long as the rootstock is resistant to the strains of the pathogen present in the soil (Miguel, 2004) or MNSV. As long as there is good compatibility between the rootstock and the scion variety, grafting onto hybrids of Cucurbita (*C. maxima x C. moschata*) also enables control of *Phomopsis sclerotioides, Monosporascus cannonballus* and MNSV, in addition to *Fusarium* wilt (all races). In the event of soil infection by nematodes (*Meloidogyne* spp.), it is necessary to combine grafting with other techniques (nematicide use, solarization + biofumigation, crop rotation) in order to reduce their population (Miguel, 2004).

Grafting on cucumber

In Spain, the development of grafting on cucumber crops is very low mainly because the incidence of important soil-borne disease is low, so there has not been any special motivation for grafting. In December 1999, root and stem rot was observed on greenhouse-grown cucumber plants in Almeria, using rock wool cultures. In 1999 and 2000, the disease was found in eight additional greenhouses (14 ha). The fungus was identified as *Fusarium oxysporum* f.sp. *radicis cucumerinus* (Moreno *et al*., 2001). Experimental trials of substrate disinfestation have been carried out in Almeria by Tello and collaborators (Dr. Añaños' doctoral thesis). All of these trials were carried out in commercial greenhouses using perlite cultures. The main goal of the studies on cucumber was to find a profitable biological (grafting), physical (solarization), chemical (Metam sodium, 1,3 Dichloropropene and Chloropicrin) or physical and chemical (Metam sodium + solarization) control method of the disease.

Only good control of the disease was achieved when plants were grafted on interspecific hybrids of *Cucurbita maxima* x *Cucurbita moschata*; incidence of the disease in other treatments (physical, chemical and their combination) was important.

Grafting on tomato

Until 2000, grafting on tomato was developed poorly. This situation was due to several factors, the same ones invoked by Tello to explain why the use of MB had never been widespread in tomato cultivation in Spain. This arguments were: (i) the stability of resistance genes to *Fusarium oxysporum* f.sp *lycopersici* (FOL), *Verticillium* and *Meloidogyne* over the last 20-25 years; (ii) crop handling (sand-covered soil) in Almeria; and (iii) the use of other disinfectants (metam sodium and 1,3-dichloropropene) (Tello, 2002).

Soil-borne pathogens cause severe disease problems on tomato crops around the world: three reported races of *Fusarium* wilts (*Fusarium oxysporum f .sp. lycopersici*) – race 3 reported in Australia in 1978 and later reported in America; *Verticillium* wilts (*Verticillium dahliae*, races 1 and 2), Bacterial canker (*Clavibacter michiganense*); Bacterial speck *(Pseudomonas syringae p.v tomato*); Root-knot nematodes (*Meloidogyne* spp.); and corky root (*Pyrenochaeta lycopersici*).

Grafting on tomato has been carried out in France for many years. It has mainly been used to prevent corky root – caused by *Pyrenochaeta lycopersici* (Beyries, 1974) – a serious disease in the greenhouse to which tomato varieties have no effective resistance (Miguel, 2002). Contrary to other countries, corky root has never represented a serious soil problem in greenhouse tomato cultivation in Spain. Similarly, up to now, FOL has never had special incidence in cultivation on substrate (Tello, 2002; Miguel, 2002). Therefore, there has not been any particular motivation for grafting with the varieties that usually afforded resistance to FOL, *Verticillium* and nematodes. Formerly, grafting was only practised on non-resistant varieties with special commercial value (Miguel, 2002).

The situation changed radically at the end of the 1990s, *when collapse* appeared, an alteration that seemed to involve PepMV and *Olpidium* (Lacasa and Guerrero, 2002). In 1999–2000, the losses caused by collapse exceeded € 9 million because there were almost 1 500 ha of tomato grown with more than 50 percent of the plants affected (Contreras *et al.*, 2003).

The epidemiological preliminary studies of the collapse syndrome found that the PepMV infection of the plants was the common element in all the greenhouses where withering and collapse were detected. The epidemic association showed that the presence of the virus was a necessary but insufficient condition for the manifestation of the lethal syndrome. Later, it became known that, in addition to the viral infection, environmental circumstances had to be combined and, less importantly, the handling of the crop also had an influence in the syndrome expression (Lacasa, 2006). The presence of *Olpidium brassicae* in tomato roots seems to be frequent; no plant alterations have been mentioned in reference to this fungus. Nevertheless, the results obtained by inoculating with the virus and the fungus have led to considering that there may be a possible contribution of the fungus in the expression of the collapse, which affects the intensity of the syndrome (Guerrero *et al*., 2004; Lacasa, 2006).

The preferred rootstocks are the interspecific hybrids *Lycopersicum esculentum x L. hirsutum*, which are resistant to a wide range of pathogens such as: *Fusarium oxysporum* f.sp *lycopersici; F. oxysporum* f.sp *radicis-lycopersici*; *Verticillium dahliae; Pyrenochaeta lycopersici; Meloidogyne* sp. and “collapse” (probably Pep MV + Olpidium) (Miguel, 2004). These hybrids are not actually resistant to the virus PepMV: in Murcia, Lacasa and Guerrero (2002) show how the grafted plants are also infected and show withering symptoms, but grafted plants did not show, or showed only low percentages of, collapse, even carrying the virus and showing symptoms in leafs and fruits. The concentration of the virus in the grafted plants was significantly less than in the ungrafted ones. There was a greater reduction in the proportion of plants with withering symptoms in grafted plants than in non-grafted ones; the incidence of withering and collapse were higher when the grafting point was covered by soil on grafted plants.

Lacasa (2006) estimated that more than 30 million tomato grafted plants were used in Murcia in 2005, the principal justification being collapse control.

In 2006, another new phytopathological problem was detected on tomato. *Phytophthora parasitica* was found on new cherry tomato productions areas in Granada and Almeria. Field trials done by Tello and collaborators revealed grafting as the best approach to control Phytophthora root rot on tomato; biofumigation under cold conditions (winter months) did not reduce its incidence. Grafting combined with good irrigation practices and water management reduced the severity of the disease. Better results in grafted plants were reported when the grafted point was as high as possible in order to avoid direct contact with the soil.

Grafting on pepper

Most greenhouse pepper production is allocated in the southeast of Spain, in the province of Almeria (8 000-9 000 ha) and Murcia-Alicante (1 800-2 000 ha). There are differences in crop managements between those production areas. In Almeria, pepper crops are established in the summer and in the end of winter. The plants are produced mainly in the artificial soil, “enarenado” (sand-covered soil) and incidence of soil-borne disease is very low. Sand-covered soil culture also represents an effective tool to control soil-borne pests and diseases. Crop rotation is commonly practiced in Almeria. The situation in Murcia and Alicante is different, however: pepper cycles are longer (9-10 months) and no crop rotation is practised.

In Murcia and Alicante, pepper crops are established in the autumn. The plants are produced mainly in natural clayey soils and the incidence of soil-borne disease is common in the area. Several experimental trials of soil disinfestation have been carried out on Murcian sweet pepper crops by Lacasa and Guerrero (2002). All of these trials were carried out in greenhouses, some of which were commercial. The main goal of the studies on pepper was to find a profitable biological or chemical alternative to MB, and determine if it could reduce soil-borne disease incidence, mainly *Phytophthora* pepper stem rot, root-knot nematodes and soil deterioration. There were no differences between the yields from treatments with MB, and biofumigation plus solarization when assays were done for six years, and the amount of manure applied was progressively reduced. Grafting was assayed to improve nematodes control. Bello *et al.* (2001) concluded: “The use of grafting in long cycle crops, such as pepper, is of great interest, because important fungi and nematode infections can appear in the final months of cultivation. The grafted plants can maintain in time the efficacy of biofumigation and chemical treatments.”

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Biological agents for the control of soil-borne pests

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Summary

Microbiological agents should not be used alone to control soil-borne pathogens and nematodes. It has been observed that their use combined with other strategies may help to provide the necessary control. Since manufacturing and registration of microbiological agents are very expensive processes, they should be applied only in high-value crops, which can pay back the investment of the application. The advantages of the use of these agents are that they are non-toxic to humans, animals and several useful organisms, do not normally cause pest resistance, and can be applied effectively in IPM. In Hungary, some of these microbiological agents are Mycostop based on *Streptomyces griseoviridis* K61 for the control of damping-off and Fusarium wilt, or Koni based on *Coniothyrium minitans* K1 against Sclerotinia rot, Trichodex WP (*Trichoderma harzianum* T-39) used in strawberry, raspberry, grapevines, tomato, cucumber, lettuce, ornamentals under greenhouses against Botrytis rot.

Introduction

Due to the expansion of greenhouse crop production and the need to completely phase out the use of MB, various microbiological agents can be applied for the control of soil-borne pests as part of the IPM system. The integration of such agents will undoubtedly assure a healthy production with less chemical inputs and environmental pollution.

Important soil-borne diseases in greenhouse crops in Hungary

The most important fungal diseases in vegetables are damping-off caused by various pathogens (*Pythium* spp., *Rhizoctonia solani, Fusarium* spp., *Alternaria* spp., *Phytophthora* sp.), white mould (*Sclerotinia sclerotiorum, Sclerotinia minor*), grey mould (*Botrytis cinerea*), Fusarium wilt (*Fusarium* spp.), Verticillium wilt (*Verticillium dahliae, Verticillium albo-atrum*), brown and corky root rot (*Pyrenochaeta lycopersici*), foot rot diseases (*Pythium* spp., *Phytophthora* spp., *Thelaviopsis basicola*) and late blight disease (*Phytophthora* spp.).

Some bacterial diseases are also important, such as: *Clavibacter michiganensis* spp. *michiganensis, Xanthomonas campestris. pv. vesicatoria, Pseudomonas syringae, Erwinia carotovora* and *Pseudomonas caryophyll.*

Damping-off is probably the most dangerous disease for seedlings sown in seedbeds, where the pathogen spread fast. Fusarium wilt is a typical vascular disease generally affecting all crops, while Verticillium wilt is not frequent. White and grey mould disease caused by *Sclerotinia* sp. affects Chinese cabbage and pepper. The sclerotia of this pathogen are able to survive in soil for a long time. It is also resistant to various fungicide treatments. *Botrytis* sp. affects tomato, while powdery mildew is a frequent disease on tomato and on cucumber leaf caused by *Erysiphe cichoracearua* and *Sphaerotheca fuliginea*, respectively. This mildew is caused by *Leveillula taurica* on pepper.

Biological control of diseases

There are several organisms identified for biological control of pathogens causing plant diseases. The mechanism of action of these microorganisms may be due to an antagonistic effect, hyperparasitism against the pathogens, or competition for the ecological environment. The mechanisms of action are as follows:

- penetration into the rhizosphaeres of the treated plants and colonize them before the pathogen can reach the plant;
- rapid reproduction of antagonists or hyperparasites if there is sufficient soil moisture;
- extraction of substances with an antibiotic effect able to inhibit the development of the pathogen without actually killing it;
- successful competition with the pathogen for the available nutrients and life space, and finally suppress the development of the pathogen;
- extraction of enzymes able to kill the cells of the pathogen by lysis effect.

In addition, in some cases, the applied antagonist could induce an acquired resistance in the plant against the pathogen. Furthermore, the applied antagonists in several cases stimulate the development of the crop.

Feasibility of the use of microbiological agents

It has been shown that the use of microbiological agents alone is not effective for the control of plant diseases. Their use is recommended in combination with other control strategies. Steaming or solarizing the soil and later applying the microbiological preparation seems to be the best option.

Manufacturing and registration of microbiological agents are very expensive processes, and should therefore be applied only in high-value crops, which can pay back the investment of the application. It is advisable to use these microbiological agents in protected vegetables and ornamentals in greenhouses for the control of soil-borne diseases or nematodes.

The use of these agents has the advantages of not being toxic to humans, animals and several useful organisms (some verification is usually required); and not causing pest resistance. Moreover, they can be effectively applied in IPM and do not require a waiting period between the application and harvesting. However, they have also some disadvantages: in most cases, microbiological control is less effective than chemical control; manufacturing, formulation and registration of preparations are expensive; the cost is too high; the registration procedure is usually long, complicated and expensive; and these agents can be applied efficiently and economically only in protected areas where living conditions of the applied agents are ensured.

Microbiological agents tested in Hungary against diferent pathogens

In the EU, some bioagents are registered for the control of plant pathogens (Table 19). As a member of the EU, Hungary should comply with the rules on this matter. Indeed, some products have been developed and are based on useful microorganisms (Table 20). The main products are Mycostop, Koni and Trichodex.

Mycostop is based on *Streptomyces griseoviridis* K61. It is produced by Verdera Oy (Kemira Oy) (SF) and is recommended for its use in: carnation, gerbera against Fusarium wilt, in potted and cut flowers againts root and foot rots, and wilt diseases, in bedded flowers against damping-off, in vegetables, ornamentals, pepper seedling production and transplants, and in melons for the control of damping-off and Fusarium wilt. For the control of damping-off, the following is recommended: seed treatment at the rate of 5-10 g/kg of seeds; for the control of root and foot rot, the bioagent can be applied at 0.1 kg/ha/1 000 litres of water for soil drenching, or 1 kg/ha (0.1 g/m^2) sprayed on the soil or as a seedling cube in 3 000 litre/ha of spray volume for soil drenching; it can also be applied at a rate of 1 kg dissolved in 25 litres of water for 1 tonne of seeds. This biopreparation's effect on various pathogens is given in Figure 23, and its effect against seedling diseases of tomato in Figure 24

Koni is based on *Coniothyrium minitans* K1 and manufactured by Biovéd Bt. (Hungary). It is used in cucumber, tomato, lettuce, pepper, carrot, parsley, protected ornamentals, annual flowers, sunflower, rape and soya against Sclerotinia rot applied at 5-8 kg/ha.

Trichodex WP is based on *Trichoderma harzianum* T-39 and manufactured by Makteshim (Israel). It is used in strawberry, raspberry, grapevines, tomato, cucumber, lettuce and ornamentals in greenhouses against Botrytis rot applied at 2 kg /ha. The effectiveness of various treatments based on Trichodex on pepper are shown in Table 21.

Table 19: Registered microbiological active ingredients against plant pathogens according to Annex I of 91/414/EEC Council Directive

Agent	Registered for
Agrobacterium radiobacter K 84	Crown gall disease
Bacillus subtilis IBE 711, Cohn 1872, QST 713 (=AQ 713)	Soil-borne fungal pathogens
Phlebiopsis gigantea	*Heterobasidion* root and butt rot
Pythium oligandrum	Damping-off
Streptomyces griseoviridis K61	Soil-borne pathogens
Trichoderma harzianum KRL-AG2	Soil-borne pathogens
Trichoderma polysporum ATCC 20475	*Heterobasidion* root and butt rot
Trichoderma viride	Soil-borne pathogens and *Heterobasidion* root and butt rot
Verticillium dahliae Kleb.	Dutch elm disease
Coniothyrium minitans CON/M/91-08	White rot disease (*Sclerotinia*)
Gliocladium catenulatum J1446	Soil-borne pathogens
Pseudomonas chlororaphis	Soil-borne pathogens
Paecilomyces lilacinus strain 251	Root-knot nematodes

Table 20: Registered biological agents for soil-borne pest control in Hungary

Antagonists	Target pathogens	Registration in Hungary as a plant protection agent
Agrobacterium radiobacter	Crown gall disease	
Arthrobotrys oligospora	Root-knot nematodes	
Bacillus subtilis	Soil-borne pathogen fungi	
Conyothirum minitans	White mold (Sclerotinia rot)	KONI
Gliocladium catenulatum *G. virens*	Soil-borne pathogen fungi	
Pseudomonas fluorescens *P. putida*	Soil-borne pathogen fungi	
Streptomyces griseoviridis	Soil-borne pathogen fungi	MYCOSTOP
Trichoderma spp.	Soil-borne pathogen fungi	
Trichoderma harzianum	Grey mould disease	TRICHODEX
Pythium oligandrum	*Pythium* spp.	

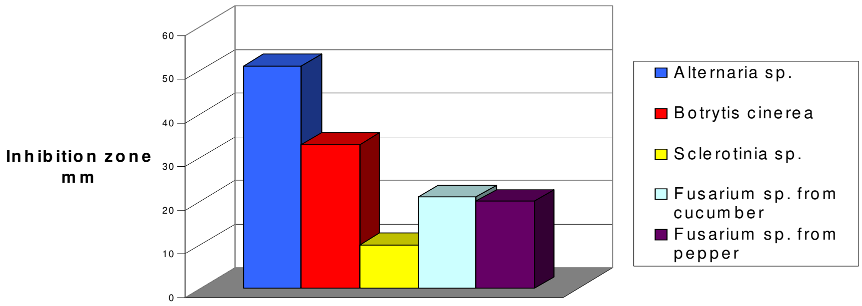

Figure 23: *In vitro* effect of a *Streptomyces griseoviridis* microbiological preparation on different pathogens Source: Hódmezővásárhely, 2001

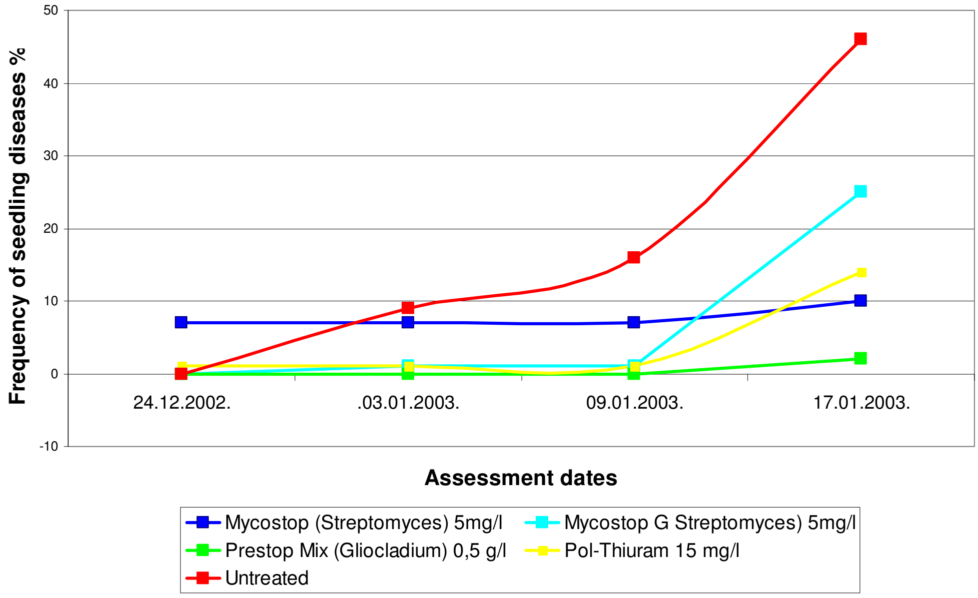

Figure 24: The effect of Mycostop against tomato seedling diseases

Conditions for the application of biological control agents

The most important aspect here is that the microbiological agent should reach the plant site to exert its effect against the pathogens. Normally, it should reach the plant roots and colonize the rhizosphere.

Biocontrol agents behave better in soil with neutral or slightly alkaline pH, low salt content, and good organic matter and nutrients content. The agents survive only in anaerobic conditions.

The quality of the preparations of microbiological agents should be regularly controlled, and the products should be stored and handled according to the recommendations given on the labels.

Table 21: Use of *Trichoderma* spp. in pepper, 1987

Treatments (with different strains)	Rates, mode of application	Plants infected by soil-borne diseases (%)		Additional income with respect to the standard (%)
		Fusarium sp.	*Sclerotinia* sp.	
TS-2	Application of 108 cfu/m^2 at planting + drenching monthly (6x)	1.2	8.7	23.8
T-14	Application of 108 cfu/m2 at planting + drenching monthly (6x)	5.87	8.53	24.7
Standard control	Ronilan WP 0.1 %, Sumilex WP 0 .1 %, Orthocid 50 WP 0.2 % (a total of 8 treatments)	5.87	15.6	-

Alternatives to methyl bromide in protected horticulture with special reference to floriculture – the IPM approach

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Summary

This paper describes the importance of IPM for the replacement of MB as a soil fumigant. The major components of IPM are pest monitoring; control by exclusion (plant quarantines and revisions, and disease-free plant material); cultural control, which includes weed control and other plants that act as alternate hosts; and crop rotation. Whenever possible, there should be good ventilation of growing areas for reducing diseases, keeping greenhouse covers in good condition, using the right N fertilizers and adequate irrigation to discourage pest development, and restriction of the passage of workers. Other major components are: physical control, consisting of the use of insect traps (yellow, blue) to reduce and monitor insect populations, rogue diseased plants, and treat localized infestations to reduce pest or disease pressure; soil sterilization with steam before planting; and disinfection of shoes and tools, etc. to avoid the dissemination of some pests, soilless substrates, and solarization. Other major IPM components include genetic control through the use of resistant varieties; biological control through the use of available biopesticides, soil amendments and other beneficial organisms; and chemical control through the rational use of pesticides of low risk to the environment.

Introduction

The growers need to adopt a new approach for replacing the use of MB as a soil fumigant for growing flowers. There is no single alternative able to replace MB, which means that an integrated system, consisting of various alternatives, should be adopted for reducing the incidence of Diseases.

In different parts of the world, several alternatives to MB are already available for their use in the cut flower and ornamental plant sector, some of them having showed excellent results. Depending on circumstances related to environmental conditions, supplies and infrastructure, among others, one of these alternatives would be more suited for a particular grower. However, the best option is to combine them in a programme for the best results. In simple terms, the IPM approach is the answer.

Integrated Pest Management (IPM)

In essence, IPM consists of using all possible resources – not chemical control alone – to reduce and prevent the incidence and effects of a given disease or pest. The most important components of IPM are crop sanitation, disease-free plant material, physical and cultural controls, disease-or pest-resistant varieties, and monitoring and recording disease occurrence. All of these contribute in some way to pest reduction and help minimize the use of chemical pesticides. IPM is currently the only real and long-lasting solution for the control of severe diseases and pests attacking many crops.

It is essential to detect pests and diseases at the earliest possible stage, treating foci as soon as they appear and using options other than chemical control whenever possible. IPM requires a grower’s understanding of the life cycle of the pathogen, its epidemiology and dissemination, surviving forms, alternate hosts and other data.

In its practical application, IPM leads to excellent technical and economical results, because it may bring substantial savings both in natural resources and in costs. The main components of IPM appear in Table 22.

For protected horticulture and floriculture, which are generally characterized by high investment and require high-quality produce for maintaining profitability. The alternatives shown below have proven to be feasible in different cropping situations and environments. Economic and technical feasibility, however, is influenced by many factors and should therefore be validated on a case-by-case basis.

Steam sterilization (pasteurization)

Pasteurization or steam sterilization of the soil is a process by which pests, diseases and weeds present in the soil are killed by heat at a given time. In simple terms, this involves injecting or diffusing hot water vapour into the soil with the aid of a boiler and conductors. As a general rule, it is recommended to carry out treatment so that the coldest spot in the soil or substrate is maintained at 70 to 80°C for half an hour. If carried out properly, steam is probably the best alternative to MB, proving equally effective.

Many variables influence the success and cost-effectiveness of steam, for example, the boiler and diffusers used, soil type and structure, and soil preparation. The depth or volume of soil or substrate to be treated directly influences costs of this alternative. Steam can be made economically feasible when disease incidence is kept at a low level and when it is part of an integrated management system. Advanced growers can even perform strip treatment (growing beds only), saving 40 percent of the costs. Some problems associated with steaming may arise, such as accumulation of soluble salts (particularly manganese), ammonium toxicity and recontamination.

Table 22: The main components of Integrated Pest Management

1. Monitoring (scouting)
- Human resources – trained personnel for the detection and identification of pest problems in the field
- Mapping – identification of affected areas (foci) and pests or diseases as soon as possible
- Collecting information – establishment of an action threshold, interpreting results
- Evaluation and decisions on whether, when and where to apply control measures, which may range from "no action" to pesticide use; creating a pest or disease history

2. Control by exclusion
- Plant quarantines and revisions of all plant material entering into production areas
- Disease-free plant material, which includes propagation facilities

3. Cultural control
- Elimination of weeds and other plants that act as alternate hosts
- Crop rotation – when possible
- Good ventilation for reducing diseases (caused by fungi, for example)
- Maintenance of greenhouse covers in good condition and clean growing areas
- Selection of the right N fertilizers and watering practices that discourage pest development
- Restriction of the passage of workers and vehicles from diseased to healthy areas

4. Physical control
- Insect traps (yellow, blue) to reduce and monitor populations
- Screens and other barriers that restrict insect entrance
- Aspirators or vacuum cleaners that trap flying insects
- Rouging of diseased plants and treating of localized infestations to reduce pest or disease pressure
- Soil sterilization with steam before planting
- Disinfestation of shoes, tools and other means by which problems can be disseminated
- Soilless substrates
- Solarization

5. Biological control
- Biopesticides (those already commercially available)
- Biocontrol agents (those which have proven successfully)
- Incorporation of compost and/or beneficial organisms (*Bacillus, Trichoderma,* Actinomyces and others) to the soil.

6. Genetic control
- Resistant varieties to pests and diseases (e.g. fusarium wilt of carnations)

7. Chemical control
- Soil fumigants (metham sodium, dazomet, 1,3-dichloropropene plus chloropicrin) and specific pesticides (fungicides, nematicides)
- Disinfectants (to prevent pest or disease dissemination)

Soluble salt accumulation may be prevented with the correct temperature during the appropriate length of time, avoiding overheating. To prevent recontamination, only disease-free plant material should be used; treated areas should be replanted as quickly as possible, ideally as soon as the soil cools off. Also, hygienic measures that help prevent disease dissemination should be observed. Just like fumigants, steam is a biocide, killing all living organisms within the soil. To correct this problem, compost and/or beneficial organisms such as *Trichoderma* and beneficial bacterial cultures are added right after steaming.

Costs of steaming can be reduced by keeping disease incidence low through IPM, which renders heating the soil to a depth of 25–30°cm sufficient for adequate pest control.

If not done properly, however, steam sterilization can end up being a frustrating and extremely costly experience. As stated above, the main concern is the depth at which steam has to be injected, which greatly influences fuel and energy costs. This further illustrates the importance of preventing disease spread and build-up, which can only be achieved efficiently through IPM. Additionally, incompletely sterilized soils where some inoculum of the disease agent is left, provide an optimum environment for reproduction in the absence of normal competition from other organisms.

Steam has other benefits over fumigants: the latter usually require a waiting period, sometimes at least 30 days, before replanting can occur, while steamed soils can be replanted immediately. This fact alone adds one whole month of flower production to steamed areas, representing, for example, about 135 000 exportable carnation flowers per hectare.

Compost

Compost is not only an excellent fertilizer, but also contains high amounts of beneficial organisms that prevent and help control soil-borne diseases. In addition, it contributes to restoring natural soil flora and increases water retention capacity. Compost enriched with beneficial organisms such as *Trichoderma* provides very good control of soil fungi such as *Phoma* and *Pythium*. Growers incorporating compost to the soil and following a strict IPM programme have been able to produce highly profitable yields without any other soil sterilization.

Compost is becoming very popular in many countries such as Kenya, Brazil, Costa Rica, Colombia, Ecuador and Zimbabwe because of its benefits and the fact that, in flower farms, there is large amount of flowers refuse that can be used for composting. The latter is a simple process that should be carried out carefully. Table 23 summarizes the necessary steps for composting.

Environmental conditions (temperature, pH, oxygen aeration, humidity) are of great importance in composting. Depending on the plant types processed, composting may last between four and five months.

As soon as composting starts, the temperature inside the piles will rise, reaching around 60°C. This leads to a natural pasteurization process, killing most of the harmful fungi or bacteria that may be present in the plants, which is an additional benefit.

Table 23: The composting process

Process	Comments
1. Chop (cut) plant material	Small uniform pieces will decompose more rapidly and evenly. Size, however, depends on the amount of water in the plants and the machinery available.
2. Build piles	Make layers starting with sand or another material providing good drainage. Follow with alternate layers of plant material, rice hulls or other porous material such as sand for good aeration, and a source of nitrogen such as cow or pig manure; if unavailable, as is sometimes the case in Turkey, a liquid formulation of nitrogen and even urea also brings good results.
3. Cover	Place polyethylene film directly on top of piles or place piles under a plastic roof. Some growers place piles out in the field. This step aims at keeping a good level of humidity inside the piles. If the location is rainy, a roof is a good idea. If film is used, holes should be opened to allow for gas exchange.
4. Turnover	Turn over the compost about every four weeks according to temperature evolution. This is essential to ensure proper aeration of piles.
5. Harvest	Harvest should be done after three or four turnovers (about three or four months), according to flower type and environmental conditions.

The above processes require important considerations within a company's infrastructure. There should be an adequate, ample and well-aerated site reserved for chopping the plants where compost piles can be placed, and above all, an excellent waste classification programme. Materials of different origin – plastics, wires, rubber bands and others – will obviously not decompose, may cause problems further along the process and should be separated. A soil health management system based on compost incorporation is described in Table 24.

Table 24: Health and nutrition management of chrysanthemum production with compost

• Quantity of compost applied	20–30 tonnes/ha
• Frequency of application:	Pre-plant (every 16 weeks)
• Beneficial organisms (suspension)	50 litre/ bed of 30 m^2
• % susbstitution of chemical fertilizers (per cycle):	50%
• Water retention capacity:	Increased by 30–40%
• Soil sterilization:	None, except for sporadic disease foci, which are treated with steam or specific pesticides.
• General cost reduction:	15–20%
• Estimated cost per ha	US$$4 950 (MB was calculated at US$5 600)

(Source: Jaramillo and Valcárcel, pers. comm., 2004, Jardines de los Andes, Bogotá, Colombia)

Soilless substrates

Production of cut flowers and propagation materials in substrates is rapidly expanding in developing countries, especially since growers have started to find and successfully adapt locally available, cheap substrates such as rice hulls, coir, sand and composted bark. An estimated 40 percent of all carnations produced in Colombia (around 500 ha) are presently produced in substrates. Although setting up a soilless production system is expensive – around 47 percent more than traditional ground beds – growers are able to compensate the extra cost through significantly better yields (20–25 percent) that result from higher planting density, optimum plant nutrition, and better pest and disease control (Figure 25).

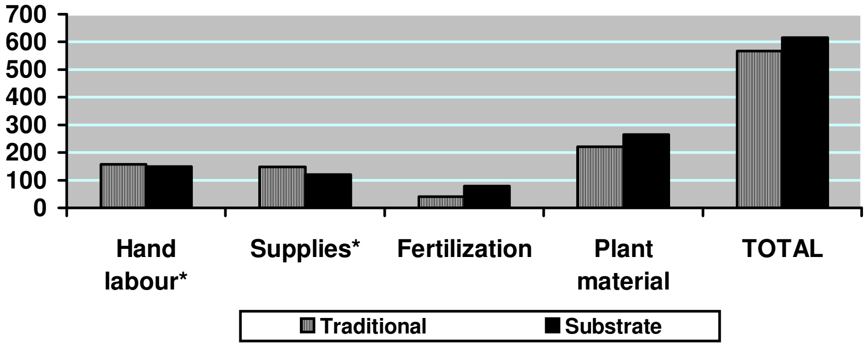

Figure 25: Carnation production costs: traditional vs. substrate (rice hulls). two-year cycle per ha

(Source: La Gaitana Flowers, 2004)

Note: Figures in US$100.

*Includes herbicide application and fumigation with Telone C-17.

Production costs are about 8 percent higher when growing in substrates than int raditional production in ground beds, where the soil is fumigated with Telone C-17. However, when yields and quality are considered (Figure 26), it is clear that more and better quality flowers are harvested, and the higher investment pays off.

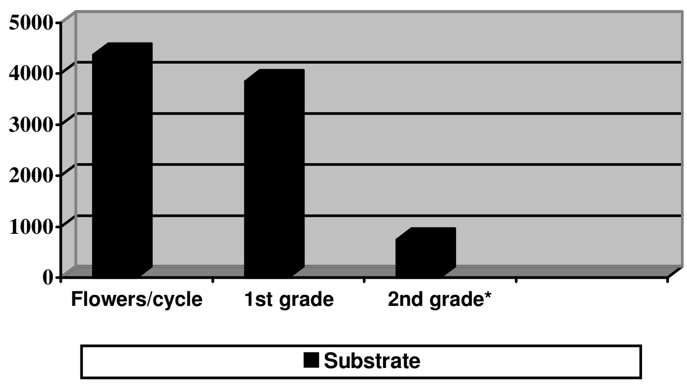

Figure 26: Carnation yield and quality: traditional vs. substrate (rice hulls) per ha: two-year cycle.

(Source: La Gaitana Flowers, 2004)

Figures in US$1 000.

*Includes non-exportable flowers.

A simple example relating to roses production in substrates is shown in Table 25. While investment for substrate production is substantially higher, so are yields and quality of flowers obtained. Even though the production cycle is shortened, this is not considered a drawback by growers since the market is constantly requiring new varieties.

Table 25: Comparison of traditional rose production in ground beds
with production in rice-hull substrate

	Ground beds	**Substrate**
Plant density	60 000 plants/ ha	86 000 plants/ ha
Set-up cost/ 30 m^2 bed	U$57	U$80
Yield	1.2 million flowers/ year	1.5 million flowers/ year
Production cycle	5–8 years	3 years

(Source: Flores Sagaró, 2002)

Commercial production in substrates is a clear trend in most Latin American countries where commercial floriculture is important, for example, Brazil, Ecuador and Colombia. It is also becoming important in Africa, for example, in Kenya and Uganda. It does pose new challenges, however, associated with water and nutrition management, pest and disease control, and the environment, since the nutrient solution should be re-circulated in order to avoid soil and groundwater contamination.

Solarization

Solarization is a process through which the soil or substrate is rid of harmful organisms by covering it with clear plastic and allowing it to heat under natural solar irradiation. One of its drawbacks for intensive production systems such as floriculture is the long period of time (28 to 40 days) that the soil needs to remain fallow during treatment. In Brazil, however, an economical device has been devised – the “solar substrate collector” – that is ideal for treating substrates and based on the principle of solarization. In other countries such as Israel, Jordan, Turkey and Morocco, where ideal conditions for this alternative prevail (sufficient periods of time with high and intensive irradiation), the system is used with much success for horticultural crop production.

Fumigants

Trials and experiences with soil fumigants in floriculture have shown that their effectiveness varies with factors such as the pathogens to be controlled, soil characteristics and crop species. These chemicals have been used combined or implemented with other options such as steam, in several cases with variable results.

Several fumigants are being evaluated as alternatives to MB, both by commercial growers in many countries, as well as in several demonstration projects conducted by the implementing agencies of the Montreal Protocol.

The most promising results have been obtained with metam sodium, dazomet and 1,3 dichloropropene + chloropicrin. Presently, performance and efficiency of these fumigants are being enhanced through new formulations, improved application methods and a combination with other alternatives.

However, alternative fumigants, just like MB, have uncertain long-term suitability of use. While they may not damage the ozone layer, they nonetheless present human health hazards and risks to the environment, such as the potential to contaminate groundwater, their residual activity in soil and water, inconsistency of effectiveness, and others. These factors have led and may further lead to restrictions on their use, and will certainly reinforce the need to opt for an IPM that does not rely on chemicals alone.

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Integrated soil pest management in protected environments

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Summary

Soil IPM strategies offer a more environmentally friendly alternative to the routine use of MB. Suggestions are made for managing soil pests of strawberry fruit and tomato under moveable poly-tunnels and in glasshouse crops, using the pest's biology and host range as the starting point for developing integrated strategies, which minimize the use of chemical pesticides. The success of such strategies will depend on regular pest monitoring, opportunities to increase plant diversity and the strict enforcement of good hygiene practices.

Introduction

The phasing-out of MB provides a golden opportunity for farmers to be more innovative in their approach to pest management. This new approach should involve an understanding of the biology and host range of each of the economically important pests that pose risks to a given crop. An awareness of the life-cycle, optimum environmental conditions for rapid multiplication, and the modes of dispersal and survival for each pest will lead to the development of a range of management practices (in some cases that combine non-chemical with chemical) that are detrimental to the pests while benefiting organismsthat are antagonistic to them.

The biology and host range of soil pests in protected environments

The most damaging soil pests that can affect crops grown in protected environments in Europe are species of nematodes, fungi, bacteria and weeds. Root-knot nematodes, *Meloidogyne* spp., root lesion nematodes, *Pratylenchus* spp. and foliar nematodes, *Aphelenchoides* spp., are the most economically important and commonly occurring nematode pests of fruit and vegetable crops. The most damaging soil pathogens affecting these crops include: damping-off fungi, *Pythium* spp; the vascular wilts, *Fusarium* spp. and *Verticillium* spp.; the leaf blights, *Alternaria* spp. and *Phytophthora* spp.; the root rots, *Pyrenochaeta* sp. and *Rhizoctonia* spp.; the stem rots, *Sclerotium rolfsii* and *S. sclerotiorum*; anthracnose, *Colletotrichum* spp.; and bacterial wilt, *Ralstonia solanacearum*. The biology and host ranges of these soil pests are summarized in Table 26 and Table 27.

Root-knot nematodes

There are three species of root-knot nematode that are common in Europe: *Meloidogyne hapla, M. javanica* and *M. incognita*. *Meloidogyne hapla* is known as the northern root-knot nematode because it is adapted to the cooler temperatures of northern Europe. The mature female feeds directly from the phloem tissue, causing the roots to swell. Its life-cycle is completed in ten days at 20ºC and each female lays up to 500 eggs; however, it can survive temperatures as low as minus 15ºC during the winter, but not above 27ºC in summer. This nematode prefers to infest hosts such as strawberry, carrot, tomato, potato, sugar beet and rose. Dispersal is through soil water and via dirty implements.

M. javanica and *M. incognita* are the two economically important root-knot nematodes that commonly occur in southern Europe. They are often found in mixed populations. The females are endoparasites and produce large swellings or galls during intra-cellular feeding. Both species can complete their life-cycles within six days at 30ºC and produce more than 1 000 eggs per female, but they are unable to survive for long periods where soil temperatures drop below 10ºC. They have an extremely wide host range, which includes all Solanaceae, Cucurbitaceae and most legume crops. They are dispersed in irrigation water and by dirty implements. Root-knot nematodes provide entry for many soil-borne pathogens, particularly those causing root rots and vascular wilt diseases.

Root lesion nematodes

Pratylenchus penetrans is one of the most important root lesion nematodes in Europe. This nematode is a migratory endoparasite, moving in and out of the host plant's roots, leaving a trail of necrotic tissue in its wake. It has a life-cycle of 30 days at 30 C and can survive temperatures as low as minus 12ºC. Its main hosts are strawberries, raspberries and potatoes, and dispersal methods include soil water, infested plant parts such as roots, tubers, bulbs, corms and cuttings and dirty implements. Strawberry roots damaged by *P. penetrans* are liable to infection by *Rhizoctonia* spp. and *Verticillium albo-atrum*.

Foliar nematodes

Aphelenchoides fragariae and *A. ritzemabosi* infect the leaves and crowns of strawberry plants, causing a crumpled, distorted appearance. The life-cycle of these nematodes is 10 days at 18ºC and they can survive temperatures as low as minus 20ºC. They are also able to survive in the soil as fungal feeders; however, these nematodes are rarely found in soil after three months in the absence of a plant host. Other hosts include ferns, and flowering plants belonging to Liliaceae, Primulaceae and Ranunculaceae. All plants showing symptoms of this pest should be destroyed, and strawberry runners used in commercial production should be certified free of *Aphelenchoides* spp.

Damping-off fungi

Pythium spp. are soil-and water-inhabiting organisms traditionally treated as fungi. These fungi can live as saprobes and as general pathogens with limited specific host ranges. Several species of *Pythium* often occur together in one disease syndrome such as damping-off, root rots and plant decline. They can attack plant parts close to the soil level. Other fungi, nematodes and bacteria can also be part of the damping-off syndrome. The damping-off syndrome decimates nursery beds and is difficult, if not impossible, to eradicate. A new site must be prepared taking care not to introduce any soil, plants or implements that have been in contact with the contaminated bed. In the right conditions, seedlings of all plants are vulnerable to infection by the damping-off fungi. *Pythium* spp. can infect substrate culture and hydroponic systems if high levels of sanitation and hygiene are not implemented. Decontamination is expensive, with a loss of crop and downtime for thorough cleaning and sterilization of equipment and systems.

Vascular wilts

Fusarium spp. are a large group of fungi found worldwide. This group contains species that are saprobes, general pathogens and pathogens that will only infect a specific or closely related group of hosts. These fungi are soil-borne and can survive as saprobes in plant debris; they can also be dispersed through contaminated seed. Further, they can occur in disease complexes or syndromes (e.g. damping-off) and produce compounds (mycotoxins) that are toxic to plants and animals. The continuous cropping of a disease-prone host leads to the development of “wilt sick soil”, for which crop rotation has little or no control. *Fusarium oxysporum* is the most economically important species. This species has many variants, referred to as “special forms” that differ in pathogenicity. These special forms usually have a very narrow host range and sometimes consist of different races, which can have different geographical distribution. Their presence or absence can determine whether a particular crop can be grown.

Verticillium spp. are root and soil inhabitants. The two most economically important species are *Verticillium albo-atrum* and *V. dahliae*. *V. albo-atrum*, which will attack a large variety of mostly temperate crops and cause serious disease at 24ºC; the severity of symptoms decline above this temperature. This fungus does not produce survival or over-wintering structures and declines rapidly in the absence of a suitable host. Some control can be achieved through fallow or crop rotation. Some hosts do not display the characteristic wilt syndrome when the fungus invades the vascular system (e.g. hops).

V. dahliae will also attack a wide range of hosts and causes severe disease at up to 28ºC. It is more harmful in warm-temperate climates. This fungus produces survival structures (microsclerotia) and can survive much longer in the soil than other species of *Verticillium. V. dahliae* invades the plant vascular system, but the characteristic wilt syndrome does not always appear.

Leaf blights

Alternaria spp. cause economically important diseases, especially in enclosed environments (protected cropping systems), mostly as necrotic lesions on the upper parts of herbaceous crops. These fungi can survive on crop debris and poor quality seed from a contaminated crop will carry over infection to the new crop. *A. solani* causes early blight and fruit rot on tomato and early blight and tuber rot on potato. Some *Alternaria* spp. have been found to produce toxins that can cause serious damage on specific hosts under the right conditions.

The genus *Phytophthora*, like the genus *Pythium*, are soil-and water-borne organisms traditionally treated as fungi. Only two species, *P. infestans* (potato blight or potato late blight) and *P. phaseoli* (bean blight), have truly airborne dispersal structures (sporangia). Some species have a significantly saprobic phase and are not plant pathogens to any economic degree. *Phytophthora* spp. are either non-specialized (plurivorous) or only attack specific hosts. Infection is followed by a rapid necrosis of the plant organ attacked. Death of a plant (including woody perennials) may result from extensive root necrosis, stem cankers, cortical rots or complete foliage destruction. *Phytophthora* species fall into three groups of optimum temperatures for growth and infection capabilities: the ranges (15–22ºC; 20–28ºC; 25–32ºC) are reflected in the geographical distribution of these fungi. Some *Phytophthora* species have special forms that attack individual hosts with devastating results, for example, *P. capsici* f. sp. *capsici* on *Capsicum* (red peppers).

Root rots

Pyrenochaeta lycopersici is a soil-borne pathogen that causes tomato corky root or brown root rot. In Europe, it is usually found in protected, especially glasshouse cultivation and causes considerable problems in tomato crops grown in close succession. The fungus also causes disease in tobacco and other plants, It has not been found in the tropics and distribution appears to be restricted to temperate and warm temperate regions of the northern hemisphere.

Rhizoctonia spp. are soil-borne fungi. The most economically important member of this group, *Rhizoctonia solani* (*Thanatephorus cucumeris*), is a non-specialized soil inhabitant found in different ecological forms and different pathogenic patterns (aerial, soil surface and subterranean). This fungus causes seed decay and is often found as part of the damping-off. Stem lesions and canker; root and above-ground rots; leaf web and thread blights and storage rots are the common symptoms. After invasion by the fungus, a greyish mycelial (thread-like mat) can be observed covering plant parts in wet conditions.

Stem rots

Sclerotium rolfsii is a non-specialized but important plant pathogen that causes southern blight or stem rot. The fungus inhabits the soil and has characteristic resistant survival structures (sclerotia) that resemble mustard seeds. The sclerotia have a long but variable survival time and on germination, infect plants directly. The fungus is most frequently found in moist warm conditions, which can ideally be provided in protected cropping systems.

Sclerotinia sclerotiorum is another non-specialized pathogen that attacks vegetables and other crops under cool moist conditions. The fungus causes a cottony or watery soft rot in protected and open-field systems, and causes a post-harvest condition known as white mould. Root /lower stem infection occurs from directly germinating sclerotia in the soil and causes damping-off and wilt. Infection can also occur through airborne ascospores (sexual spore form) on unwounded soft tissue such as flowers and can also be transported by pollen from infected flowers. Infected seed and weeds can be sources of inoculum and sclerotia in the soil, which ensure inoculum survival from season to season, and a heavy infection potential can build up over a few seasons if the disease is unchecked and sanitation measures are not implemented.

Anthracnose

Colletotrichum spp. are best known for causing disease symptoms described as anthracnose and can occur to a devastating level on fruit, leaves and stems. Field infection can be latent (not obviously diseased) and symptoms only appear during post-harvest. These fungi are non-specialized and conidia (asexual spores) produced in a saucer-shaped fruitbody (acervulus) are dispersed through water splash. The acervuli appear as little black dots and the conidia can sometimes be seen as pinkish slimy masses on the top of them. The acervuli are grouped together in sunken irregular-shaped necrotic (areas of damaged or dead tissue) lesions on fruit, leaves and stems. *C. acutatum* causes considerable problems in strawberry cultivation in Europe and is a quarantine pest in the United Kingdom. *C. capsici* is seed-borne and causes disease on *Capsicum* (red pepper) in warm temperate regions. *C. coccodes* mainly causes anthracnose in tomato fruit; black dot on potato and tomato roots; aubergine and red peppers are also attacked. This fungus is a soil inhabitant, and serious root infection is due to a high inoculum in soil. The most well known of this genus, *C. gloeosporioides* (*Glomerella cingulata*), is the most problematic one in the tropics and subtropics, and may occasionally cause problems in protected systems in warm temperate regions.

Bacterial wilt

Ralstonia solanacearum (formerly *Pseudomonas solanacearum*) is a gram negative rod-shaped bacterium and the only truly soil-borne bacterial plant pathogen. Infection can also occur through seed and diseased foliage. This bacterium causes wilt and brown rot in many crops in temperate, warm temperate, subtropical and tropical regions worldwide. Infection is systemic in the vascular system, producing a wilt of part or all of the plant. Other symptoms may occur, with or without wilting, and include browning of the vascular tissues, bacterial ooze from cut stems; stunting and chlorosis of plants.

Three races, several subraces and biovars (biological varieties) have been identified and infect different hosts in different temperature ranges. Race 1 affects tobacco, tomato, potato, aubergine, diploid banana and many other solanaceous crops and weeds, and has a high temperature optimum (35–37°C). Race 2 affects triploid bananas (causing Moko disease) and *Heliconia* spp., and has a high temperature optimum (35–37°C). Race 3 mainly affects potatoes and tomatoes with lesser virulence to other solanaceous crops. Pelargonium can also be affected. Solanaceous weeds host the disease and can serve as reservoirs.

Weeds

The most common weed species in protected systems are sedges (Cyperaceae). Broad-leaved weeds can also cause problems in some circumstances. Removal is necessary before the weeds start in order to seed to prevent build-up of inoculum in the soil.

Organic mulches and composts may be contaminated with weed seeds when they have not been killed off during the preparation processes. Weeds are also alternate hosts to many of the soil-borne pests that can infect protected systems.

A combination of soil solarization for a minimum of 15 days and application of metam sodium, 1,3,D plus chloropicrin and dazomet will control weeds in a pre-planting situation.[2]

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[2] Further information concerning these and other pests can be found in CABI's Crop Protection Compendia: www.cabi.org/compendia/cpc.

Sampling for soil pests

The first step in getting to know the range of pests that occur naturally in a particular soil or planting medium is to take soil and root samples so that the nematodes and pathogens that they contain can be extracted and identified by suitably qualified scientists. This should be done on a regular basis, usually towards the end of each cropping season, particularly where the same or closely related crops are grown in succession.

Sampling for soil nematodes

The best time for samples is just prior to harvest time, when the nematode populations are at their peak. Several samples, each of approximately 200 g of rhizosphere soil, should be taken from depths of 10–30°cm and at random from several different parts of the field. The peripheral, feeder roots of crop plants (and of weed hosts, where appropriate) should also be collected and included with the soil. This material should be bulked in a thick plastic bag, carefully labelled with the date, current crop and cropping history, and stored at 5–10ºC, out of direct sunlight, until they can be processed and examined microscopically. In areas where poor growth such as stunting and chlorosis are observed in the crop, the soil and root samples should be collected in a separate bag so that the nematode populations can be compared with those that were collected from around healthy crops. This sampling technique can be used to estimate population levels of all soil and root nematodes: in the case of root-knot nematodes, *Meloidogyne* spp., the juvenile stages that are found in the soil can be used to estimate population levels. The mature females, which are embedded in the roots, are used to identify this nematode to species level. The uprooting of mature plants at harvest time can give a good estimation of root-knot nematode damage, especially if a rating system is used that enables the amount of root galling to be scored out of 10 (Zek, 1971). Adult and juvenile stages of the nematode *Pratylenchus* spp. are present in both roots and soil; the adult stages of male or female are required for species identification.

In the case of foliar nematodes such as *Aphelenchoides* spp., the affected plant material must be examined to confirm the presence of adult and juvenile stages of the nematodes.

Sampling for soil pathogens

Sampling can either be of the growing medium (soil, substrate) or of the diseased plants. The growing medium sampling should be undertaken before planting if contamination is suspected, or after a few years of succession cropping to check potential disease build-up. Soil samples of approximately 200 g should be taken from the rhizosphere at depths of 5-20°cm, at random from the cropping area. The soil can be bulked in a plastic bag and labelled with the date, crop and cropping history, and stored at 5–10ºC, out of direct sunlight, until they can be processed. Soil can be processed using a variety of techniques to determine the inoculum load of a particular pest organism and involves sending the samples to a laboratory equipped to undertake such screening.

Infected plants can either be examined by an experienced person or sent to a laboratory equipped to undertake such analysis. The symptoms on the leaves may not necessarily appear where the infection has started; e.g. since root rots can cause foliage to wilt, it is useless to examine the foliage because the problem is in the roots. Uprooting an infected plant and examining the roots for signs of disease are the first steps. If the roots are healthy, then the stem is examined externally for signs of rot at the stem base and then by cutting the stem lengthways to look for signs of internal staining. Infections by fungi usually result in an obvious brown staining of the vascular system. Infections by bacteria are more difficult to determine as the brownish staining is much less obvious. Plants with suspected bacterial wilt can be carefully uprooted and a portion (approximately 5-10°cm in length) of the stem from above the root placed in a vessel containing clean water. If bacteria are present, then a fine film will flow out of the cut end of the stem and can be observed by carefully holding the vessel up to the light. Care must be taken not to squeeze the stem during these processes as stem contents flowing out can be confused with bacterial streaming by the inexperienced observer. Foliage diseases are easiest to observe as lesions can usually be seen on the foliage and often on the stem as well (e.g. anthracnose; downy and powdery mildews; rusts and smuts; leaf spots). If the disease is new, then professional help must be sought to determine the problem and for advice on the control strategy. Plant material collected for examination must be wrapped in paper; newspaper is an excellent choice and is readily available. Plastic must not be used because it causes the plant material to sweat, and saprobic fungi and bacteria will rapidly overgrow the material making it useless for examination. Plant material must be examined as soon as possible because some causal organisms die out rapidly and cannot be isolated to complete the diagnosis (Waller and Ritchie, 2001; Ritchie, 2003).

Table 26: Optimum conditions for rapid build-up of nematode populations

Nematode	Life-cycle	Optimum soil conditions				Min. temp. ºC	Dispersal mechanism	Preferred hosts
		Texture	SOM	pH	Moisture			
Aphelenchoides fragariae *A. ritzemabosi*	10 days @ 18ºC	All	High	4–8	Med.-high	-20	Soil (<3 months), infested plants and seed	Strawberry, ferns, members of Liliaceae, Primulaceae and Ranunculaceae
Meloidogyne javanica *M. incognita*	6 days @ 30ºC	Sandy	Low	4–8	High	10	Soil water, dirty implements	All solanaceous, cucurbits and legume crops
M. hapla	10 days @ 20 C	Sandy	Low	4–8	High	–15	Soil water, dirty implements	Strawberry, carrot, tomato, potato, sugar-beet, rose
Pratylenchus penetrans	30 days @ 30ºC	Sandy	Low	4–8	High	–12	Soil water, infested plants, dirty implements	Strawbery, raspberry, potato

Table 27: Optimal conditions for rapid build-up of soil pathogens

Pathogen	Temp. ºC	Optimal soil conditions				Air humidity	Dispersal mechanism	Preferred hosts
		Texture	SOM	pH	Moisture			
Alternaria solani	24–29	All	All		High	High	Seed, infected plants, splash, soil water	Solanaceae
Colletotrichum spp.	20–24	All	All		High		Rain, overhead irrigation	Solanaceae, strawberry
Fusarium oxysporum	28	Sandy	Low	4-6	High		Seed, stakes, soil	Solanaceae
Pyrenochaeta lycopersici	15–20; 26–30	All	All		High		Chlamydospores , soil, dirty implements	Solanaceae; cucurbits
Phytophthora infestans	18–22	All	All		High	91-100%	Splash, soil water, infected plants	Solanaceae
Pythium spp.	25–30	All	All		Med.-high		Soil, water, dirty implements	Most herbaceous plants
Rhizoctonia fragariae	18–28	All	All		High		Sclerotia, host debris	Strawberry
Ralstonia solanacearum	27; 35–37	Clayey	Low		High		Soil water, infected plants, dirty implements	Solanaceae
Sclerotium rolfsii	30–35	All	Low	<7	High	High	Seeds, soil	Most herbaceous plants
Sclerotium sclerotiorum	20–24	All	Low		High	High	Seeds, soil	Most herbaceous plants
Verticillium albo-atrum	20–24	Sandy	Low	6–8	High		Infected plants, soil	Most herbaceous plants
Verticillium dahliae	24–28	Sandy	Low	6–8	High		Infected plants, soil	Most herbaceous plants

Integrated management of strawberry soil pests under moveable poly-tunnels

Figure 27 and Figure 28 show an integrated approach to pest management in strawberry fields under moveable poly-tunnels.

Poly-tunnels should be sited in areas where there are low numbers of plant-parasitic nematodes. In the case of strawberry, this means avoiding areas that have high populations of either *M. hapla* or *P. penetrans*.

The populations of *M. hapla*, *P. penetrans*, *Aphelenchoides* spp., *Verticillium* spp. and some weed species will decline where there is a bare fallow for more than three months during the growing season or where there is rotation with cereal crops (CPC, 2006). However, populations of *P. penetrans* can be reduced to almost zero by rotating with the catch crop, African marigold, *Tagetes patula* (Evenhuis, Korthals and Molendijk, 2004). The absence of *P. penetrans* will, in turn, reduce the rate of infection by *Rhizoctonia* spp. and *V. albo-atrum*. Rotating with *T. patula* will also control *M. hapla* down to an acceptable level (Runia, 2004).

High levels of soil organic matter will increase the diversity of micro-organisms that are antagonistic to root-feeding nematodes and *Verticillium* spp. The incorporation of large amounts of organic matter into the soil will therefore contribute to the control of these pests. The planting area should be well drained to avoid *Phytophthora* and *Verticillium* infections; all plant debris and alternate weed hosts should be removed to discourage the survival of A*phelenchoides* spp. and *Verticillium* spp.

Where pest levels remain high, recommended pre-plant fumigant treatments that are effective against most soil pests affecting strawberry are: metam sodium, applied by rotary spading injection, or 1,3-dichloropropene + chloropicrin through drip irrigation, under plastic mulching. The latter mixture is said to be ineffective against *Phytophthora* spp., however (Runia, Molendijk and Evenhuis, 2007). Dazomet granules are partially effective against nematodes, fungi and weeds.

Healthy, certified planting material should be used at all times to escape *Aphelenchoides* infection. Resistant strawberry varieties are available against *Phytophthora* spp. Deep planting should be avoided to guard against *Rhizoctonia* spp. Avoiding overhead irrigation, excessive use of nitrogen and mulching with straw will also discourage *Phytophthora* infections.

Organophosphate nematicides such as ethoprophos or the fungicide fosetyl aluminium may be applied around the roots of growing crops, where necessary. Weeds can be controlled by herbicides such as butralin, napropamide, pendimethalin, quizalofop-P, sethoxydim, chlorthal or dimethyl ester.

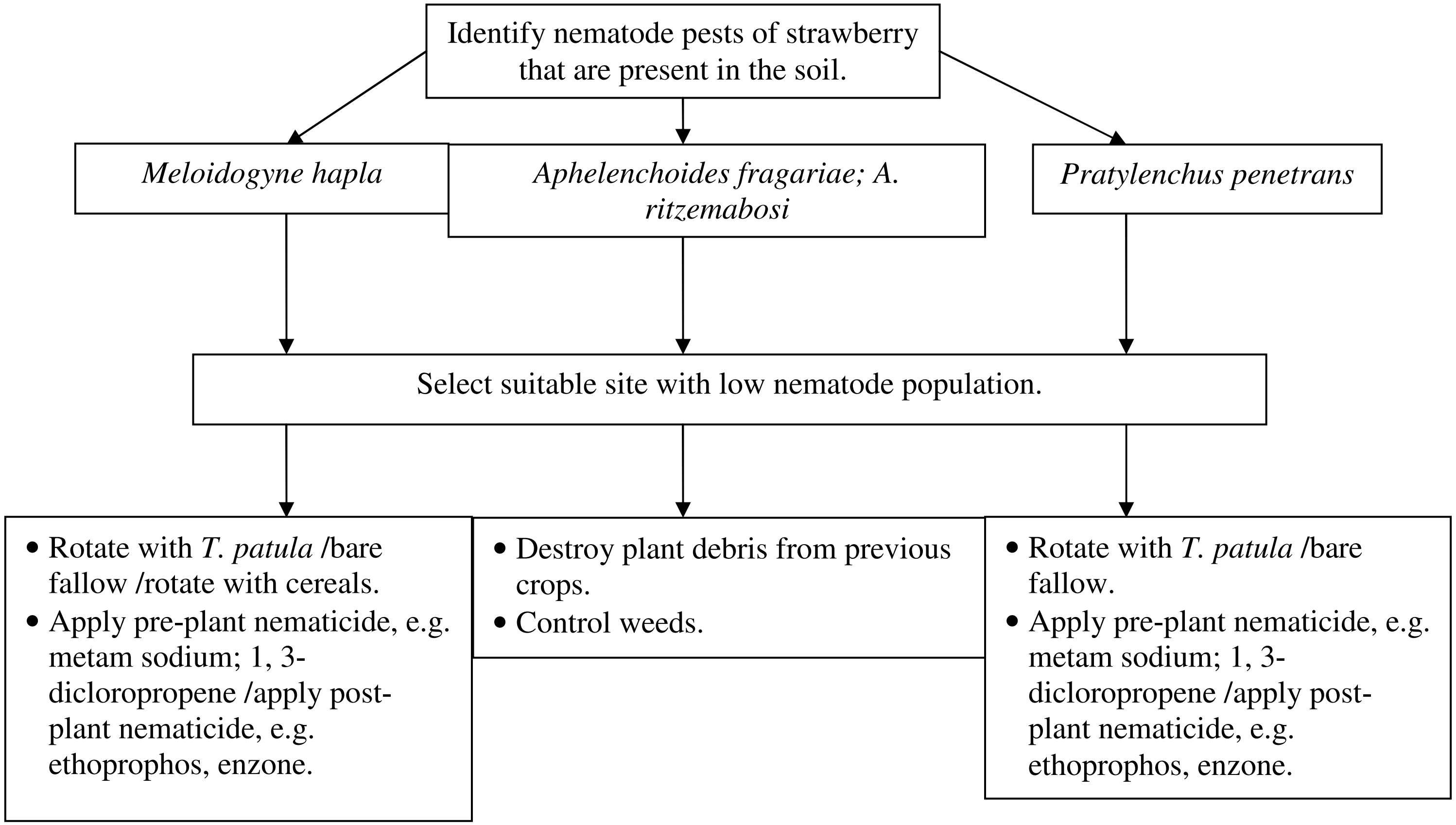

Figure 27: Integrated management of strawberry nematode pests under moveable poly-tunnels

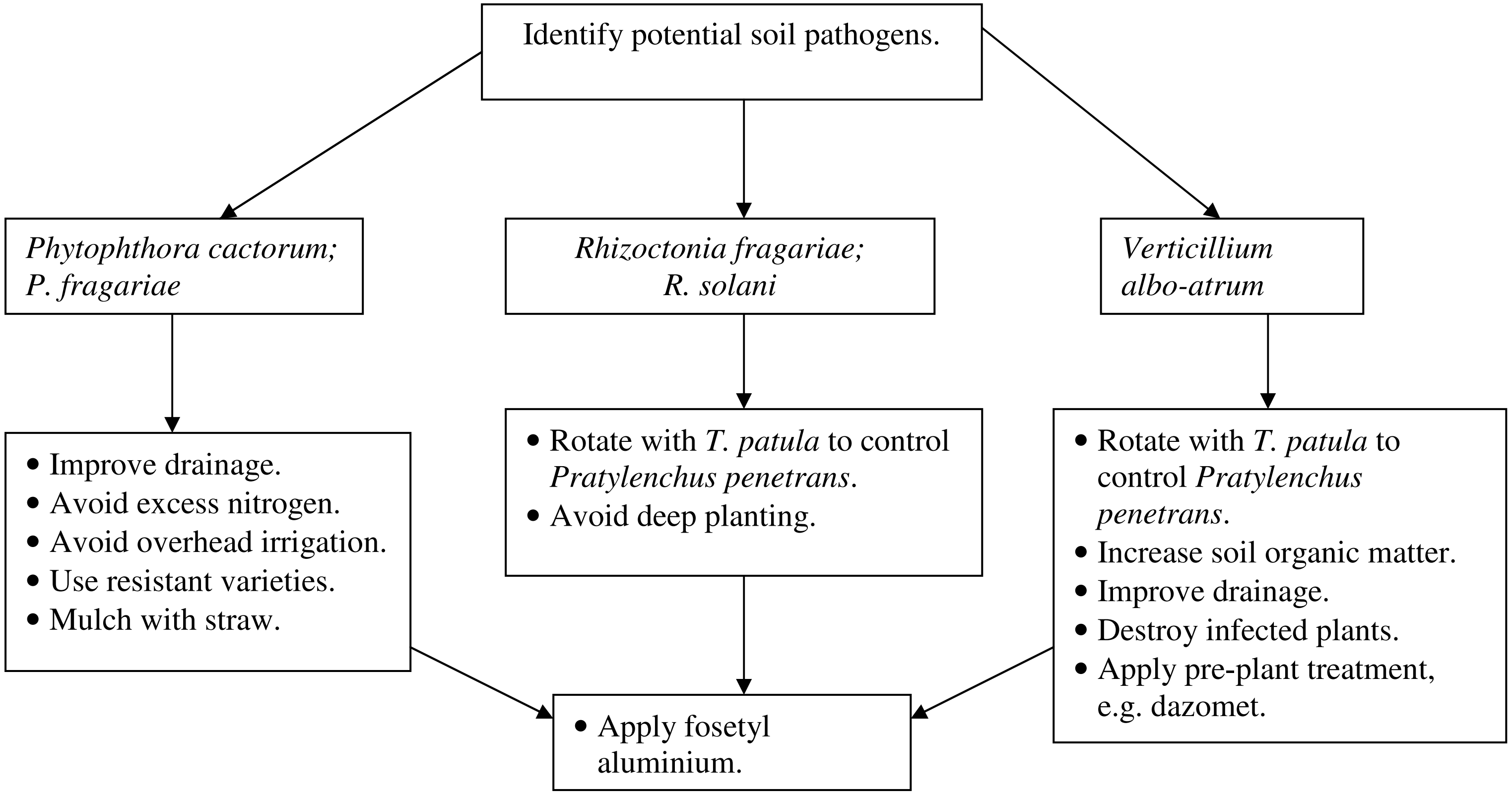

Figure 28 Integrated management of strawberry soil pathogens under moveable poly-tunnels

Integrated management of tomato soil pests under moveable poly-tunnels

Figure 29 shows an IPM system to control soil pests of tomato in the field and under moveable poly-tunnels.

The most damaging nematode pests of tomato in southern Europe are the root-knot nematodes, *M. javanica* and *M. incognita,* while soil-borne pathogens such as *Ralstonia solanacearum,* which causes bacterial wilt*, Fusarium oxysporum,* which causes vascular wilt, and *Sclerotium rolfsii,* which causes stem rot, are widespread across Europe. Interactions between *Meloidogyne* spp. and *R. solanacearum* or *Fusarium* spp. are common, and there is some evidence of synergism between them (Sikora and Carter, 1987).

In southern Europe, where *M. javanica* and *M. incognita* are endemic, rotation with sunhemp, *Crotalaria juncea* is recommended. This green manure crop suppresses root-knot nematodes through the production of toxic root exudates and by being incorporated into the soil where it increases organic matter, thereby providing a food source for antagonistic organisms (Valenzuela and Smith, 2002). Liberal application of amendments of chicken manure also encourage *Meloidogyne* antagonists (Karanja *et al*., 2001). Increasing soil organic matter will reduce the incidence of other soil pathogens, especially *Sclerotium sp.* Rotation with non-hosts, such as cereal crops, will lead to reduced populations of all soil pests of tomato.

Soil solarization for 30 cloudless days will control many soil pathogens, including *Fusarium*, spp., *Verticillium* spp. and *Sclerotium.* (EC, 2006).

Effective pre-plant fumigants to reduce soil pests are metam sodium, 1, 3-dichloropropene + chloropicrin and dazomet. The application rates of these chemicals can be reduced by 50 percent if combined with soil solarization for at least 15 days. This combination will control nematodes and weeds as well as soil fungi.

Additional measures can be taken to reduce the incidence of soil pathogens: improving drainage; using non-ammonia-based fertilizers; deep ploughing to bury sclerotia; destroying plant debris and weeds to discourage bacterial wilt; increasing soil pH; adding calcium to avoid *Sclerotium* and *Fusarium,* and disinfecting stakes and all farm implements.

There are several commercially available tomato varieties that are resistant to one or more of the following soil pests: *M. javanica, M. incognita, Fusarium oxysporum Verticillium race 1; Oidium neolycopersici; Pyrenochaeta lycopersici, Alternaria* spp. *Phytophthora infestans* and *Pseudomonas syringae* (Lindhout, 2005). These varieties can be used to produce whole plants or root-stocks to be grafted with scions of other varieties. It should be noted that resistance to root-knot nematodes will break down above 26ºC and in soils where there are high populations of these pests.

Enzone can be applied as a post-plant treatment to control root-knot nematodes, soil fungi and weeds.

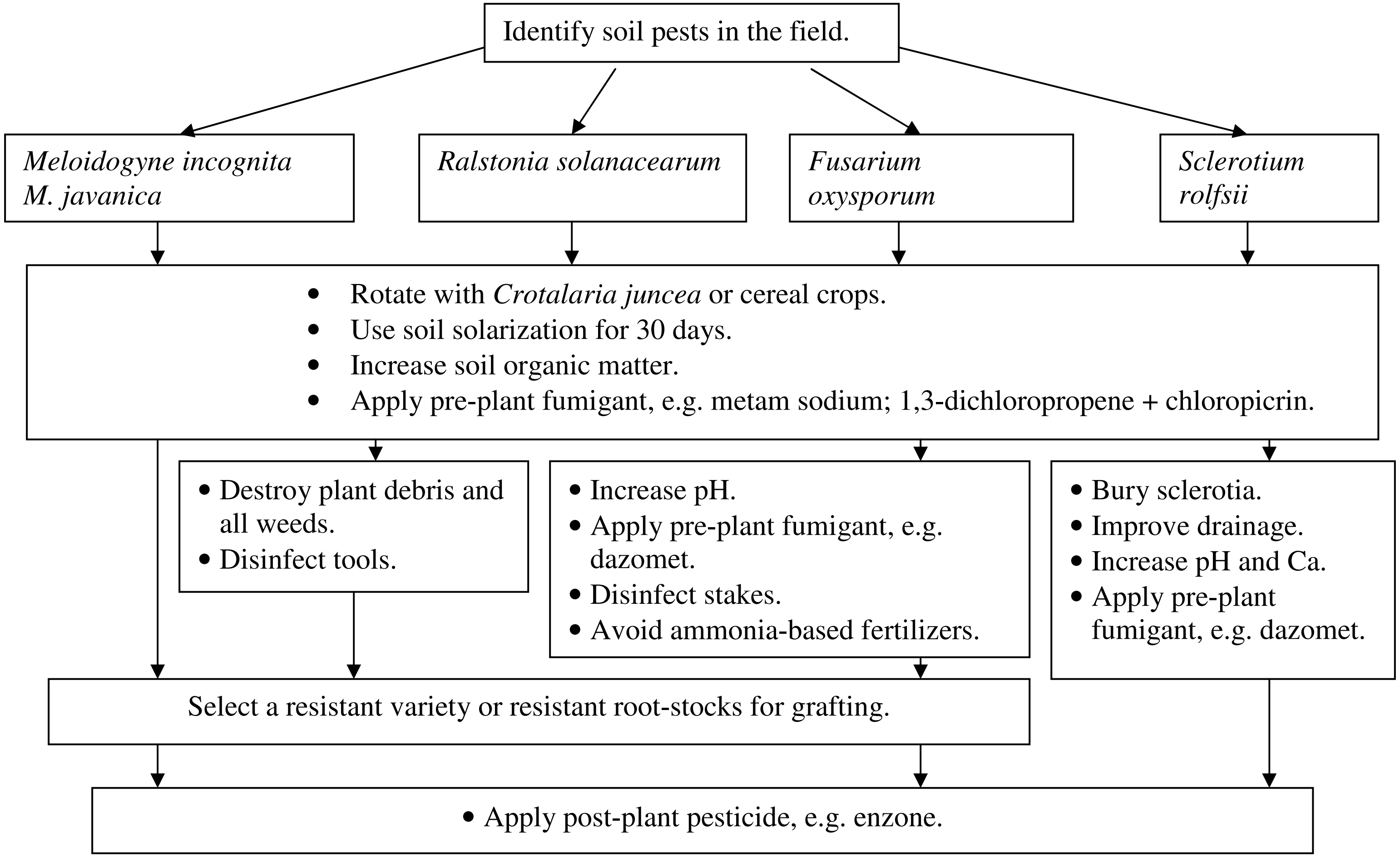

Figure 29 Integrated management of tomato soil pests under moveable poly-tunnels

Integrated management of glasshouse soil pests

Protected cropping environments are ideal for the rapid build-up of economically important pests. In the past, the ease of fumigating pests with MB often led to the neglect of sanitation and hygiene as part of good agricultural practices. These practices are of great importance, since prevention is more efficient and economical than spending time and money on solving pest problems. Simple and effective measures need to become part of the daily routine of protected environment management: using certified planting material to avoid pest introduction; disinfecting cultivation implements and footwear before moving between protected environments; spot weeding by hand, using spot application with a systemic herbicide or using "hot-lance" equipment to prevent seed formation or weeds providing alternative hosts for pests; sterilizing containers and substrates between crops; and removing crop debris to avoid pest carryover.

Currently, the most appropriate method of soil disinfection for intensive glasshouse production is steam sterilization. Various steam-producing systems have been devised that ensure that the soil is exposed to 70ºC for at least 30 minutes in order to kill all soil pests, including nematodes, fungi, bacteria and weed seeds (Bollen, 1981). A new method requiring much less energy is also being developed, which uses hot air to sterilize soil (Runia, Molendijk and Evenhuis).

The use of soilless substrates or hydroponic systems will completely exclude root feeding nematodes as long as seedlings are raised in sterile media. If substrates are to be re-used, they should be subjected to solarization or fumigated with metam sodium. Pathogenic fungi and bacteria can be eradicated by ensuring that substrate containers and irrigation lines are disinfected regularly. Sanitation and hygiene are paramount in hydroponic culture that uses re-circulation systems since the introduction of fungi, such as *Pythium*, or bacteria, such as *Ralstonia*, will make it necessary to close down the system and undertake a complete sterilization of all piping, containers and substrates.

Seed should be treated to exclude all seed-borne pathogens using one or more of the methods listed in Table 28 (Allison, 2002) and sown into sterile media.

Table 28: Seed treatments

Treatment	Target pests
Hot water (Tomato seed: 25 mins. @ 50 ºC)	*Colletotrichum*, spp. Bacterial spot, Bacterial canker, *Phoma* spp.
Bio-priming with *Pseudomonas fluorescens*	*Pythium* spp., Downy mildew
Streptomycin	Bacterial spot
Trisodium phosphate + sodium hypochlorite	Surface viruses
Metalaxyl/ Cymoxanil	Downy mildew
Thiram	*Pythium* spp.

The addition of *Trichoderma harzianum* to sterilized soils and substrates will protect plant roots from infection by pathogenic fungi. Continuous monitoring of temperature and humidity, and the application of optimum levels of plant nutrients will ensure that plants remain healthy and resist infection.

Conclusion

Good IPM strategies seek to minimize pesticide use in order to protect the environment, while providing a high economic return for the farmer. The effectiveness of an IPM strategy depends on the grower's knowledge of the biology and host range of the prevailing and potential pests, and his/her ability to monitor them on a regular basis. Pest fact sheets and an identification service should be available locally to support in this process.

The greater the crop diversity, the more opportunity there will be for the introduction of successful IPM strategies. Unfortunately, many crops that are in high demand, such as tomato, aubergine, sweet peppers, chilli and potatoes, belong to the Solanaceae family and thus share the most serious pest problems in terms of soil nematodes and pathogens. Furthermore, root-knot nematodes (*M. incognita, M. javanica*) have an even wider host range. In addition to solanaceous crops, they also attack plants belonging to the Cucurbitaceae (cucumbers, squash and melon) and Leguminosae (beans) families. It is therefore extremely difficult for the horticulturalist to reduce his or her reliance on chemical pesticides in soil-based cultivation systems unless there is an opportunity to rotate with non-hosts or catch crops. In areas where the location of small poly-tunnels can be shifted after one or two seasons, sites with low soil pest populations should be selected, and emphasis should be on integrated systems that include the use of solarization and resistant/grafted varieties. In protected environments, where soil is routinely sterilized or soilless cultures are maintained, there is ample scope to prevent infection through strict hygiene.

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Technical Meeting on Non-Chemical Alternatives for Soil-Borne Pest Control

Programme
26-28 June 2007, Hungary

Day 1
26 June

9.00	Opening of the meeting: Jerôme Malavelle, UNEP, Coordinator of the CEIT Methyl Bromide project Maria Kadlecikova, FAO Subregional representative for Central and Eastern Europe	
9.15	The phasing out of methyl bromide	Robert Toth
9.30	Non-chemical alternatives to methyl bromide for soil-borne pest control	Ricardo Labrada
9.50	Hydroculture in Hungary	Alfred Forrai
10.10	Growing in containers in Hungary	Daniel Tompos
10:20	Farmers training on alternatives for soil-borne pest control in Hungary	Ferenc Baglyas
10.30	Coffee break	
10.50	Biological pest control at Arpad-Agrar	Ákos Zentai
11.10	Grafting as an alternative for vegetable production in Hungary	Laszlo Kovacs
11.30	Discussion	
12.15	Lunch	
14.00	Non-chemical alternatives used in Bulgaria	Georgi Neshev & Stoyka Masheva
14.45	Non-chemical alternatives for soil uses on horticultural production in Poland	Czeslaw Slusarski & S.J. Pietr
15.30	Coffee break	
15.45	Nematode control strategy (NCS) and physical soil disinfestation methods used in the Netherlands	Willemien Runia
16.30	Biological agents for the control of soil-borne pests	Dormannsné Erzsébet
17.15	Discussion	
17.45	End of Day 1	

Day 2
27 June

9.00	Use of soilless substrates	W.H. Schnitzler
9.45	Soil solarization: an environmentally-friendly	Baruch Rubin

	alternative	
10.30	Coffee break	
10.45	*The use of biofumigation in Spain*	Antonio Bello
11.30	FAO database HORTIVAR	Wilfried Baudoin
12.15	Lunch	
14.00	The use of grafting in Spain	Fernando Diánez
14.45	Integrated soil pest management in protected environments	Sam Page
15.30	Coffee break	
15.45	Alternatives to methyl bromide in protected horticulture with special reference to floriculture – the IPM approach	Marta Pizano
16.30	Discussions	
17.30	End of Day 2	

Day 3
28 June

7.00	Field visit to Arpad –Agrar Rt, Szentes: - Visit Szentes-Szentlaszlo plant. - Small buffet. - Visit to the glasshouses. - Lunch
13.30	Travel to Szeged, to visit Floratom plant (about 50 min.from Szentes).
16.00	Return to Budapest

29 June

Return of the participants to their countries of origin

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