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 20^{th} 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.

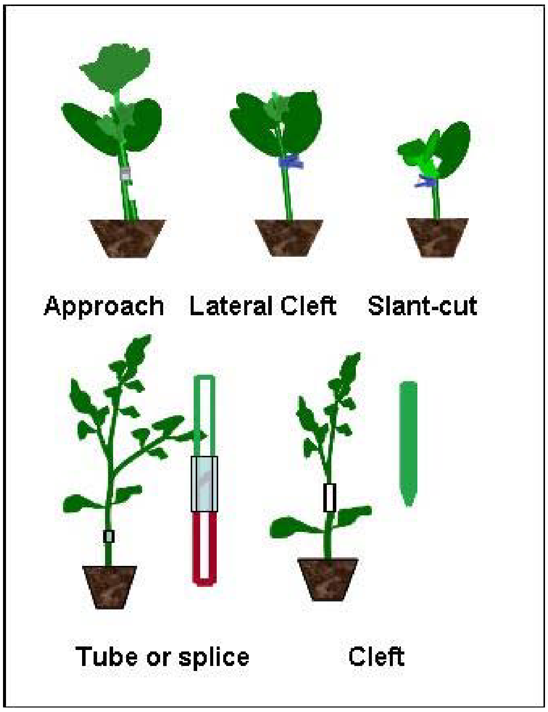

Figure 22: Different grafting techniques

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.	

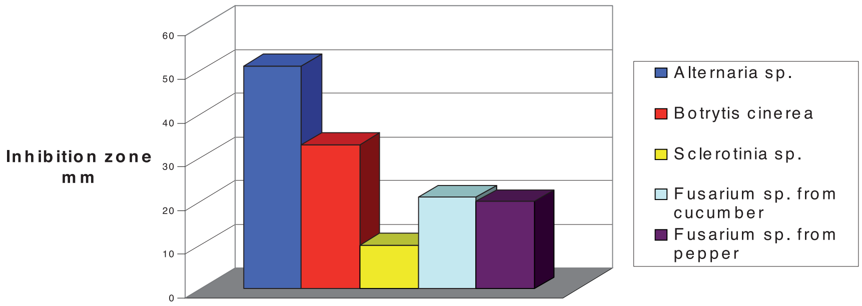

Figure 23: *In vitro* effect of a *Streptomyces griseoviridis* microbiological preparation on different pathogens Source: Hódmez¸ vásárhely, 2001

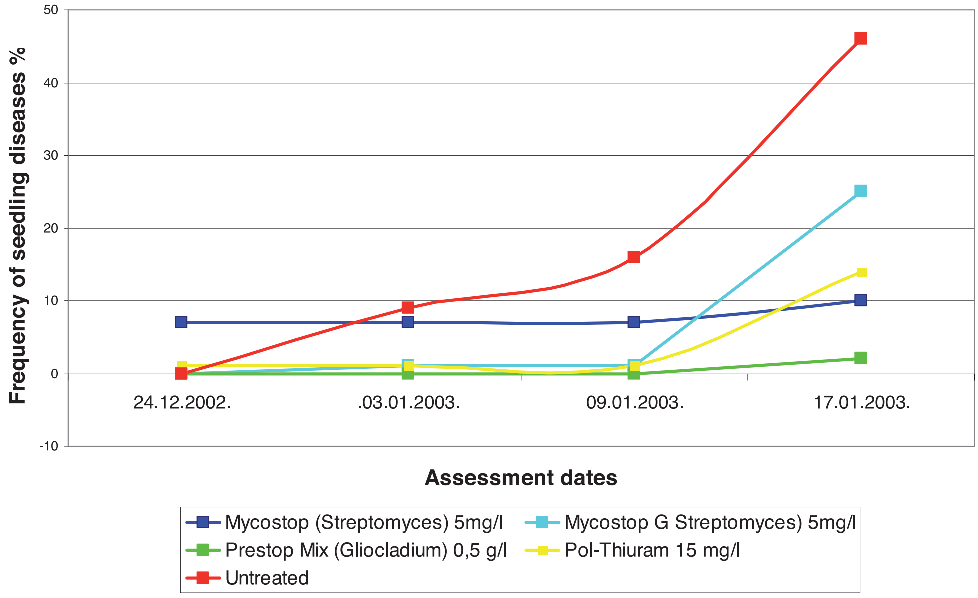

Figure 24: The effect of Mycostop against tomato seedling diseases

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).

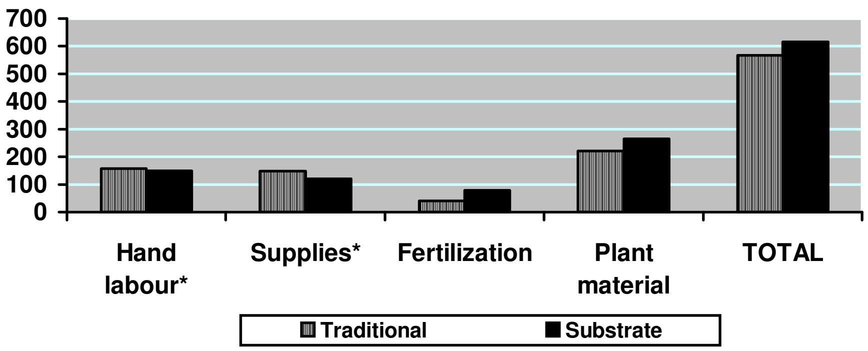

Figure 25: Carnation production costs: traditional vs. substrate (rice hulls). two-year cycle per ha

(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.

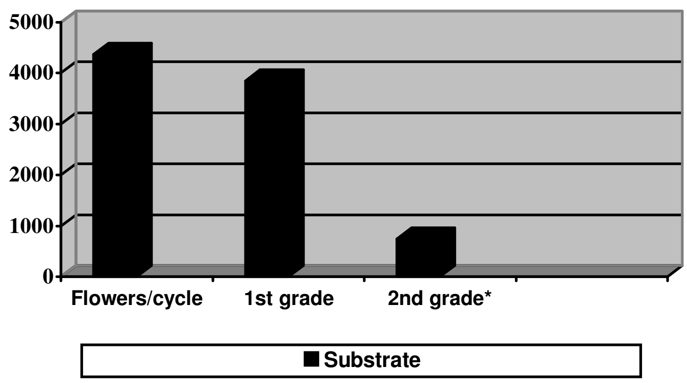

Figure 26: Carnation yield and quality: traditional vs. substrate (rice hulls) per ha: two-year cycle.

(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.

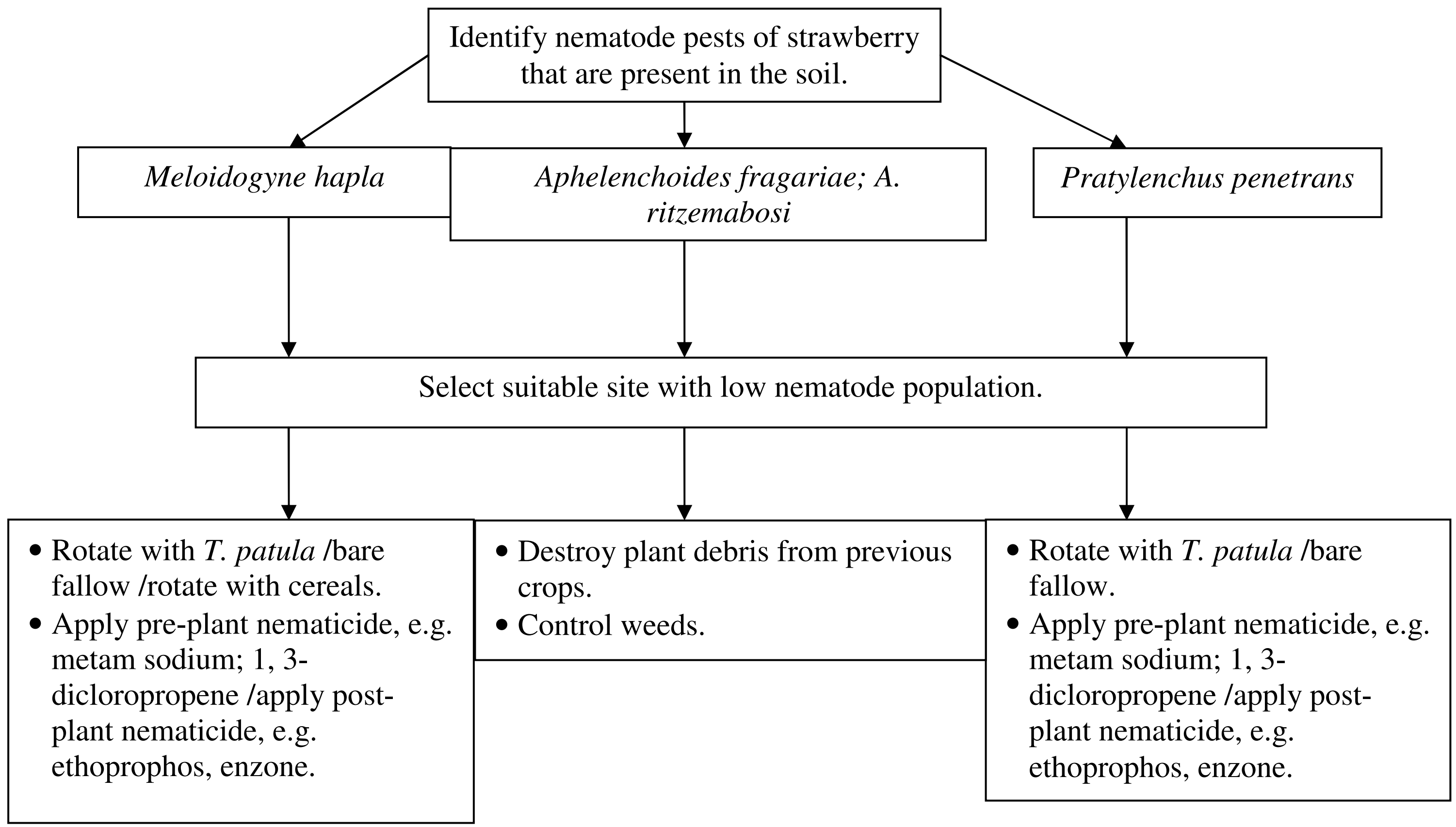

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Figure 27: Integrated management of strawberry nematode pests under moveable poly-tunnels

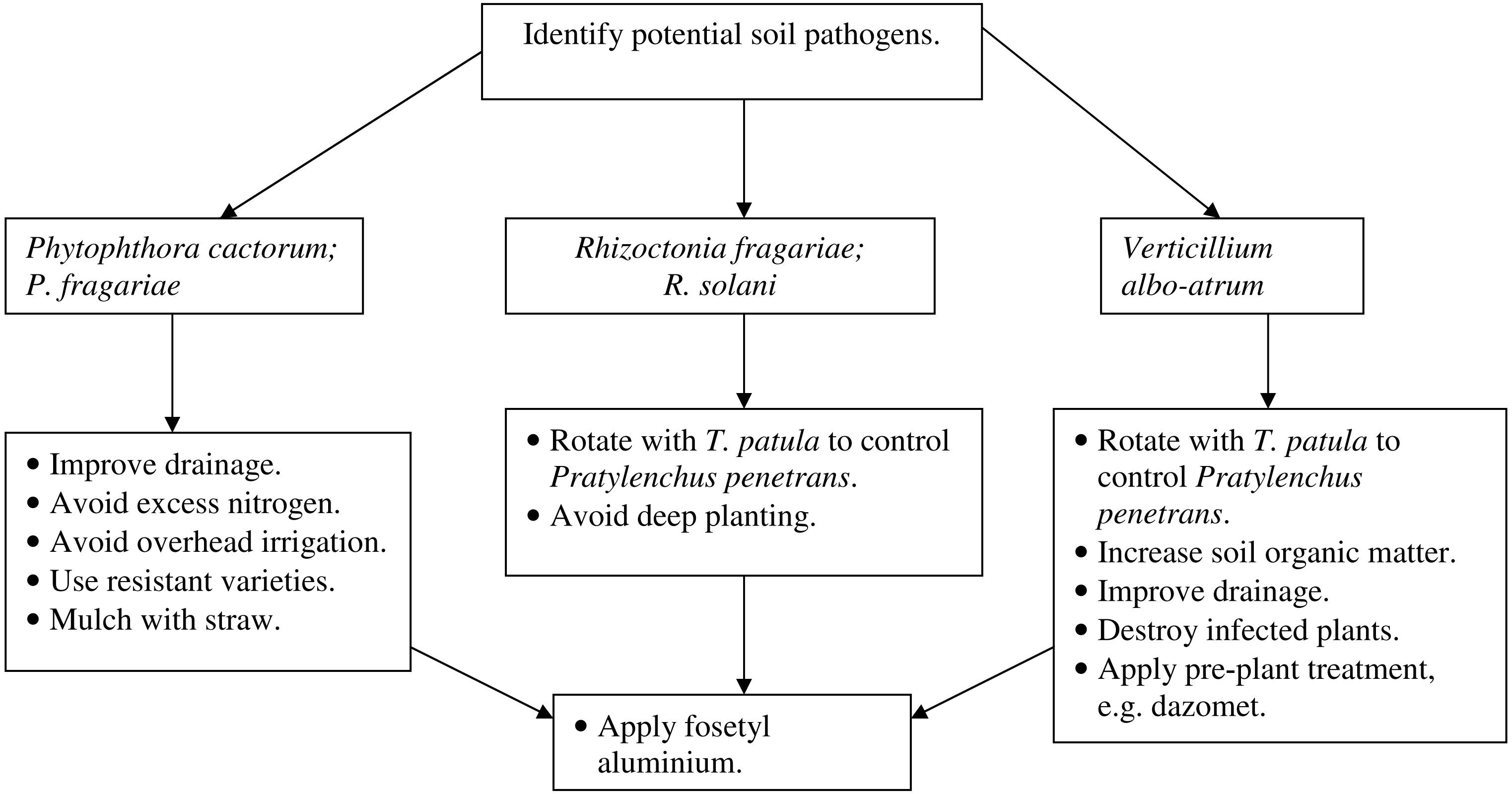

Figure 28 Integrated management of strawberry soil pathogens under moveable poly-tunnels

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.

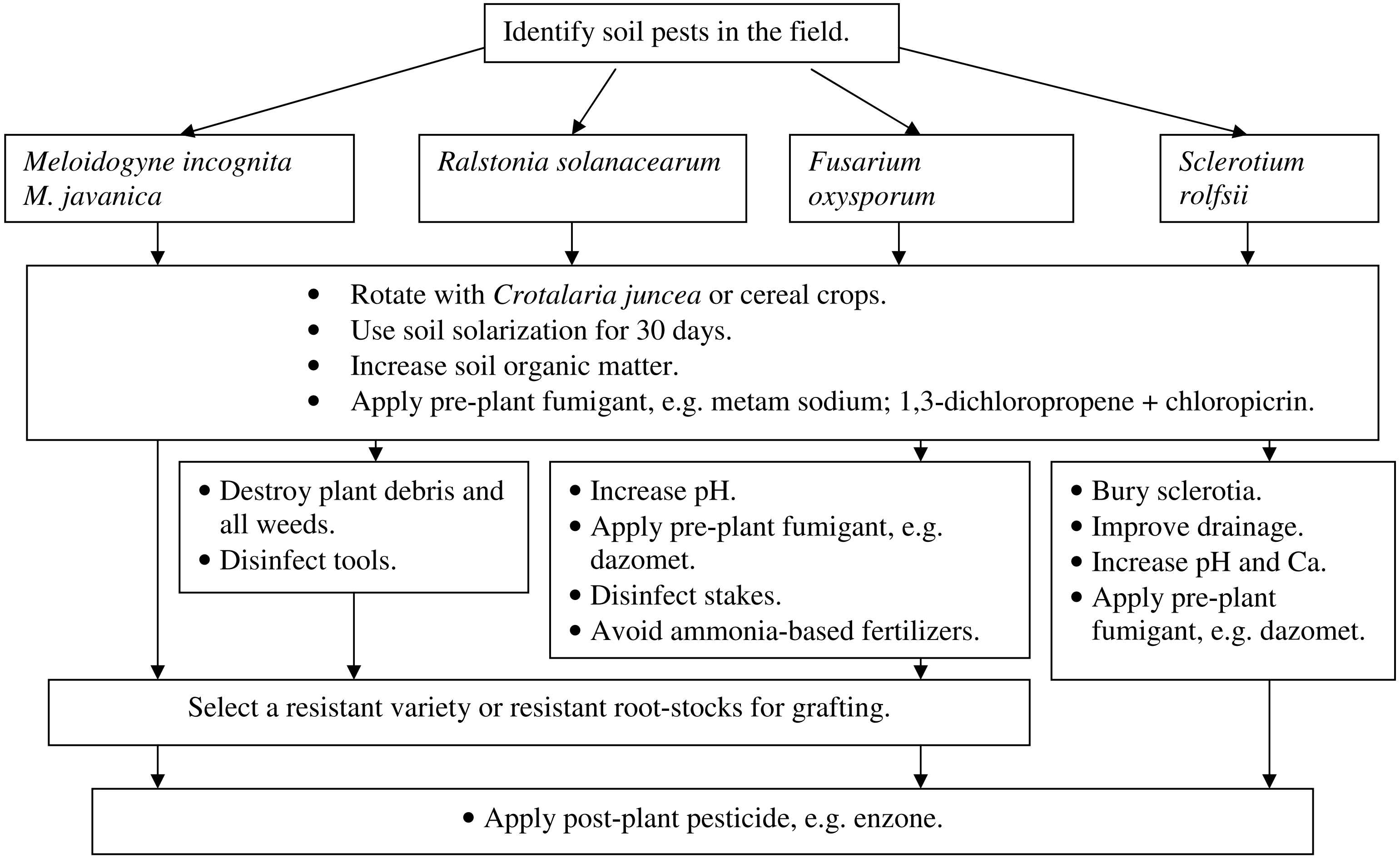

Figure 29 Integrated management of tomato soil pests under moveable poly-tunnels

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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