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

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Summary

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

Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

Available non-chemical alternatives for soil-borne pest control

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

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

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

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

Soilless substrates

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

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

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

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

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

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

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

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

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

Heating and steam

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

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

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

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

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

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

Biological control agents

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

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

Table 2: Main microorganisms used for biological control in soil

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

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

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

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

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

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

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

Resistant cultivars and grafting

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

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

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

Organic amendments and biofumigation

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

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

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

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

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

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

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

Soil solarization

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

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

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

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

Use of plant covers

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

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

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

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

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COUNTRY REPORTS

Non–chemical alternatives used in Bulgaria

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Summary

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

History of greenhouses in Bulgaria

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

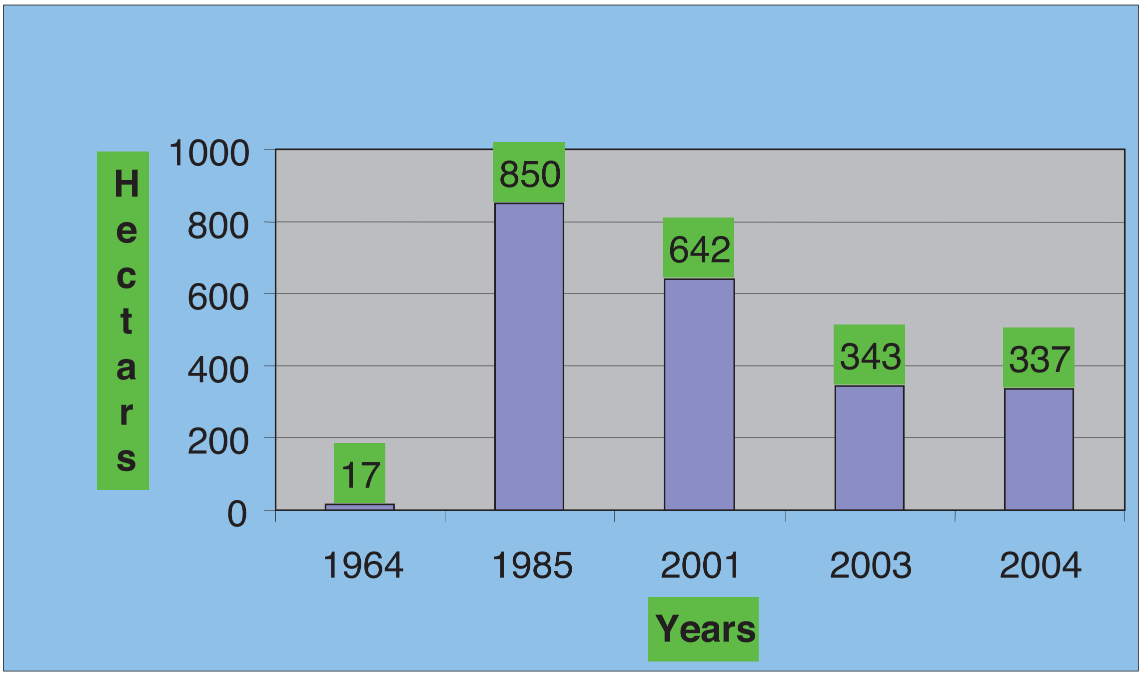

Figure 3: Glass greenhouse area in Bulgaria 1964–2004

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

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

Cultural practices

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

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

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

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

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

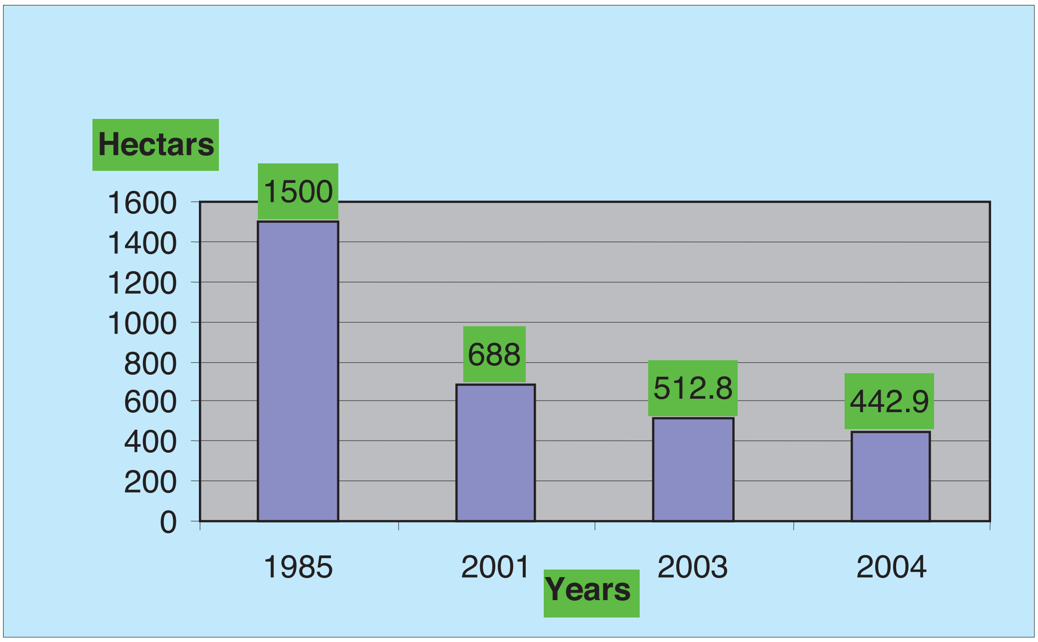

Figure 4: Plastic Greenhouses in Bulgaria

Physical methods

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

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

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

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

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

Biological control

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

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

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

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

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

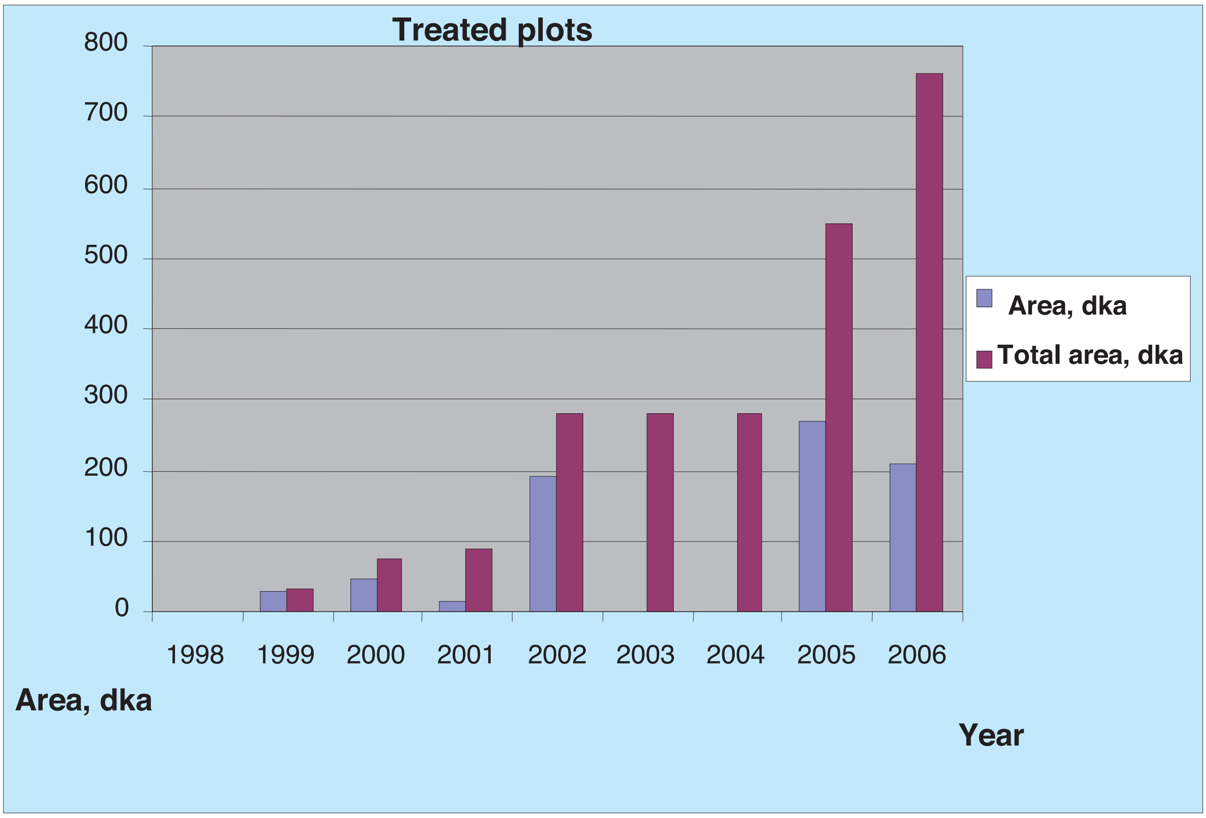

Figure 5: Diagram of the treated plots in dka applying both methods starting from 1999 to the present

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

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

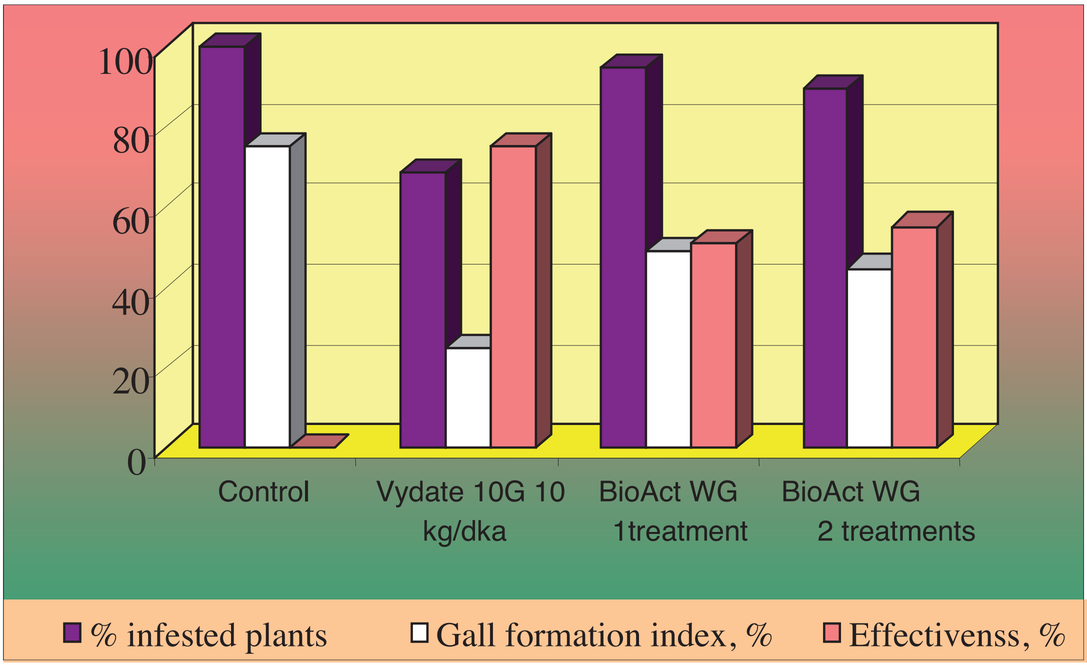

Figure 6: Action of bioproduct BioAct WG compared with Vydate 10G

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

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

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

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

Hydroculture in Hungary

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Summary

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

Vegetables production

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

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

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

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

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

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

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

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

Ornamentals

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

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

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

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

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

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

Grafting as an alternative for vegetable production in Hungary

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Summary

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

Vegetable production in Hungary

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

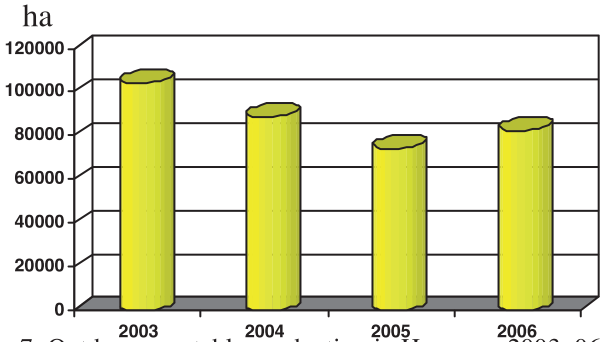

Figure 7: Outdoor vegetable production in Hungary, 2003–06

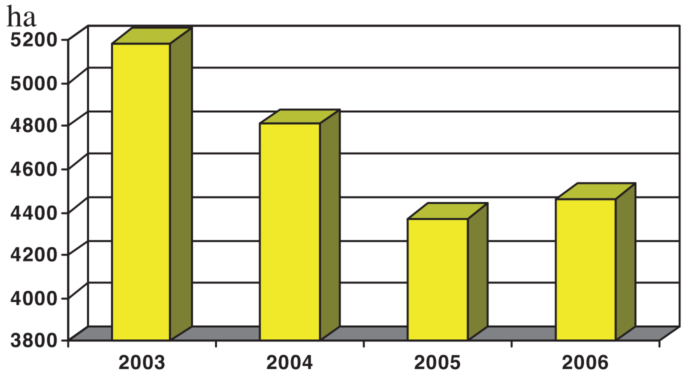

Figure 8: Greenhouse (glass + plastic) vegetable production in Hungary, 2003–06

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

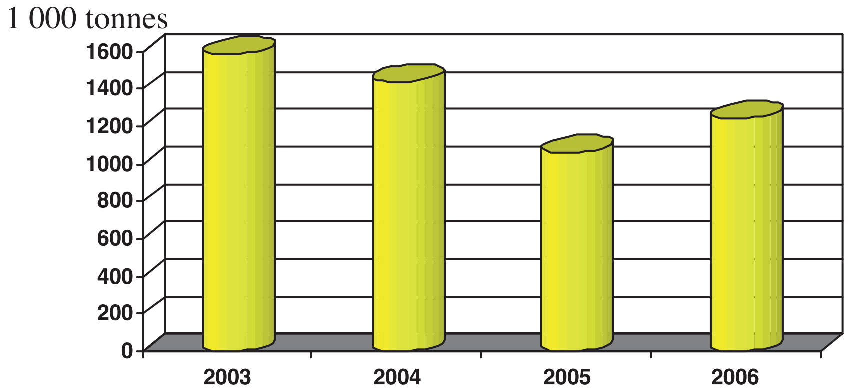

Figure 9: Vegetables production in Hungary in the open field, 2003–06

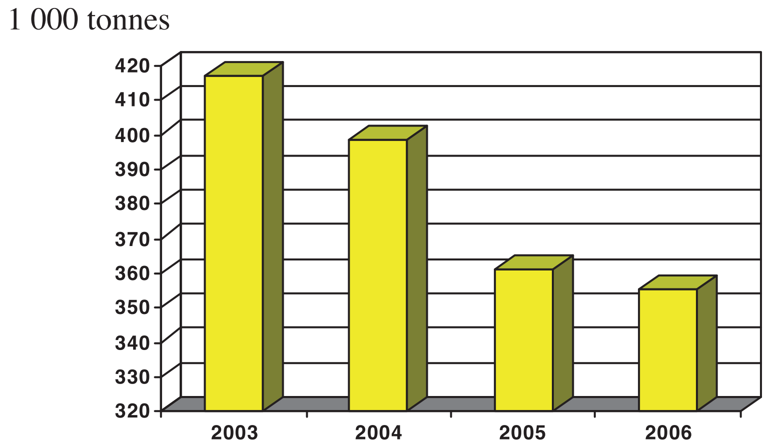

Figure 10: Vegetables production in Hungary in glass and plastic greenhouses

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

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

Grafting

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

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

Table 4: Pepper plants grafted vs. own-rooted

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

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

Table 5: Tomato plants grafted vs. own-rooted

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

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

Table 6 Watermelon grafted vs. own-rooted

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

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

Growing in containers in Hungary

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Summary

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

Introduction

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

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

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

Available substrates in vegetable production in Hungary

Bog-peat

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

Low moor peat

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

Coconut fibres

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

Perlite

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

Fired clay granules

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

Sand

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

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

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

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

Pots applied in Hungary

Buckets

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

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

Plastic containers

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

Other plastic pots and boxes

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

Table 7: Mixed substrate used in Hungary

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

Polystyrene buckets and boxes

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

Polyethylene sacs

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

Biological pest control at Arpad-Agrar

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Summary

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

Introduction

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

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

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

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

Problems of chemical crop protection

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Summary

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

Characteristics of training

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

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

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

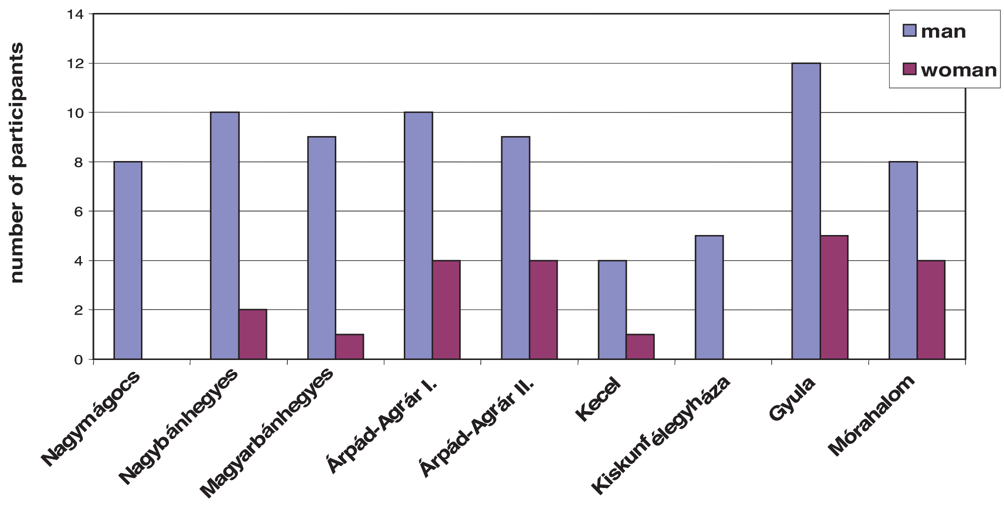

Figure 11: No. and gender of participants in the FFS

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

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

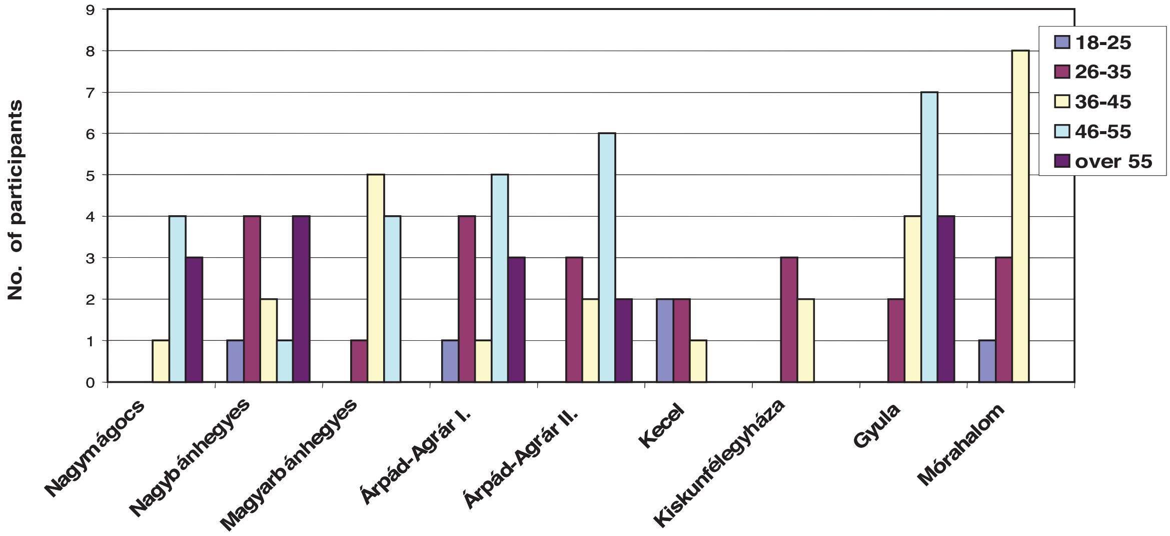

Figure 12: The age of FFS Participants

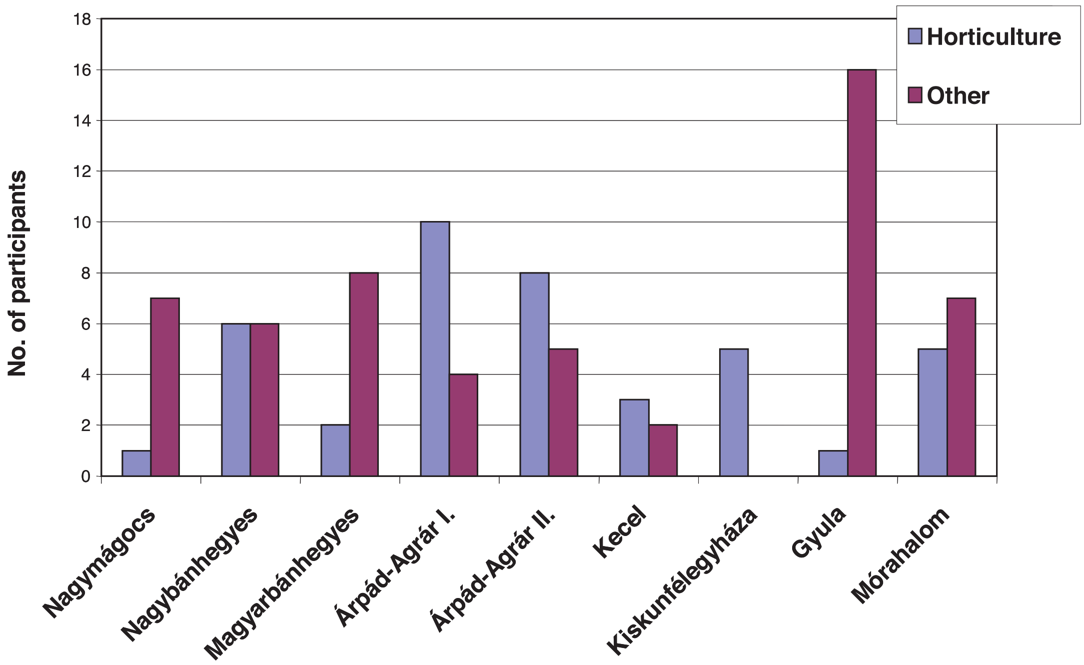

Figure 13: Participants in the FFS according to their areas of specialization

Conclusions

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

Table 8: FFS conclusions

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

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

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Summary

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

Introduction

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

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

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

Past and current alternative methods in protected cultivation in Poland

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

Cultural methods

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

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

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

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

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

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

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

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

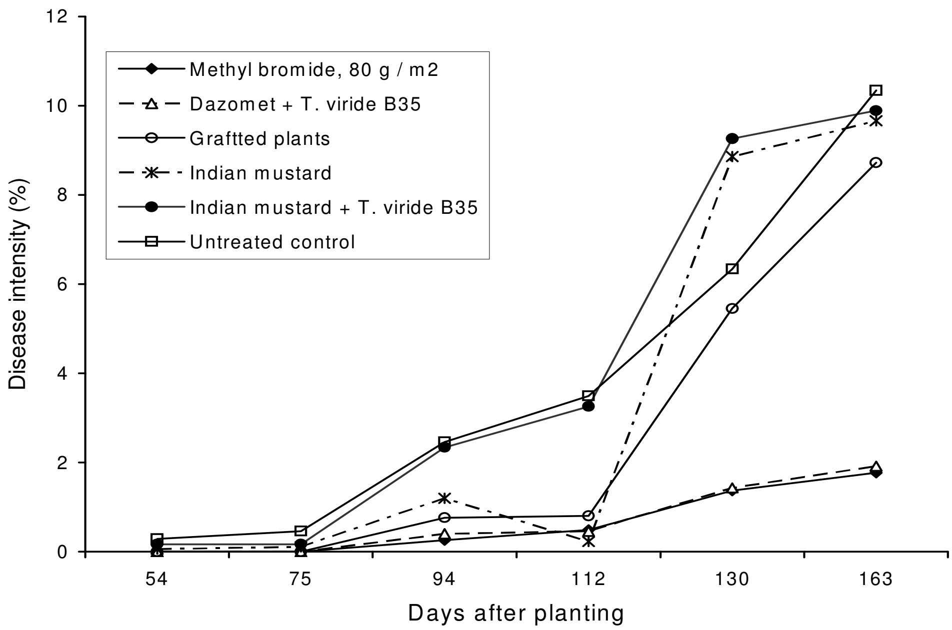

Table 9: The efficacy of preventive application of chemical and biological treatments in greenhouse cucumber grown as a fourth crop on re-used rockwool slabs (autumn cultivation)

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

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

Use of grafted plants and resistant cultivars

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

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

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

Biological control

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

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

Table 10: Commercially available biocontrol agents in Poland

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

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

Organic amendments and natural products

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

Table 11: Commercially available natural plant protection products in Poland

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

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

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

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

(Source: Skrzypczak and Orlikowski (1998)

Heat treatment

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

Combined application of non-chemical alternatives with chemical alternatives

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

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

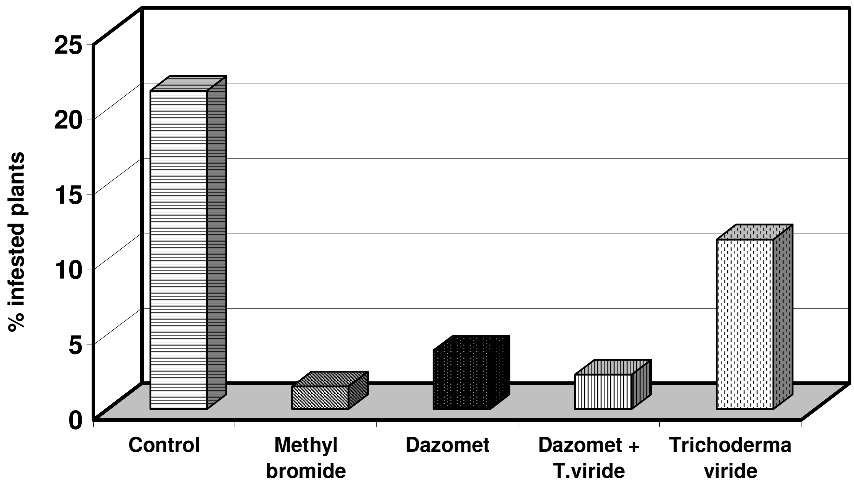

Figure 15: The influence of chemical, biological and integrated control of *Verticillum Dahliae* on final diesease incidente in bell pepper plants (mean of six trails)

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NON-CHEMICAL ALTERNATIVES AND IMPLEMENTATION METHODS

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

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Summary

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

Introduction

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

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

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

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

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

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

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

Nematode control strategy

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

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

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

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

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

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

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

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

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

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

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

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

Additional measures

Black fallow

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

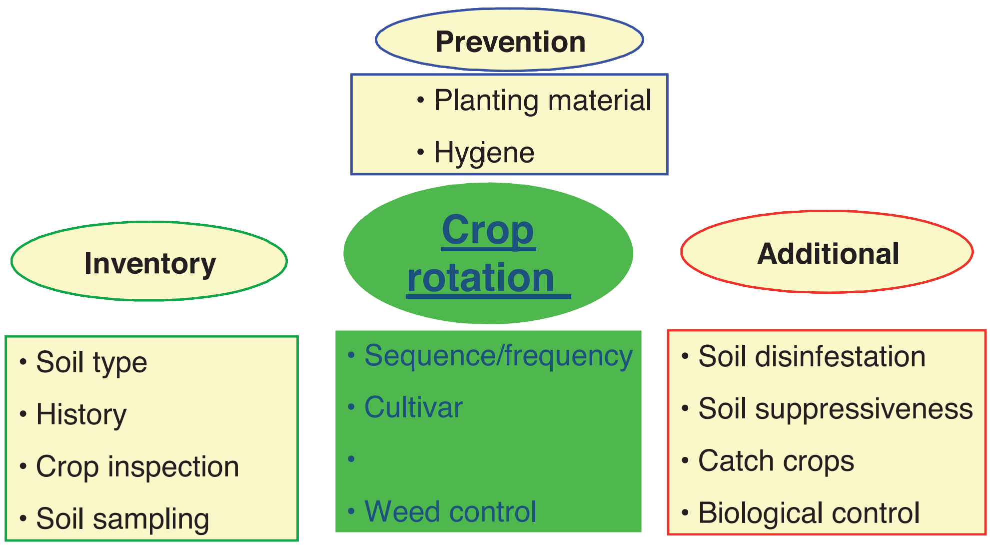

Figure 16: Nematode Control Strategy

Catch crops

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

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

Soil disinfestation

Anaerobic composting

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

Inundation

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

Steam sterilization

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

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

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

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

Hot air treatment (Cultivit®)

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

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

Chemical soil disinfestation

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

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

Concluding remarks

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

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

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

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Use of soilless substrates

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Summary

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

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

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

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

Introduction

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

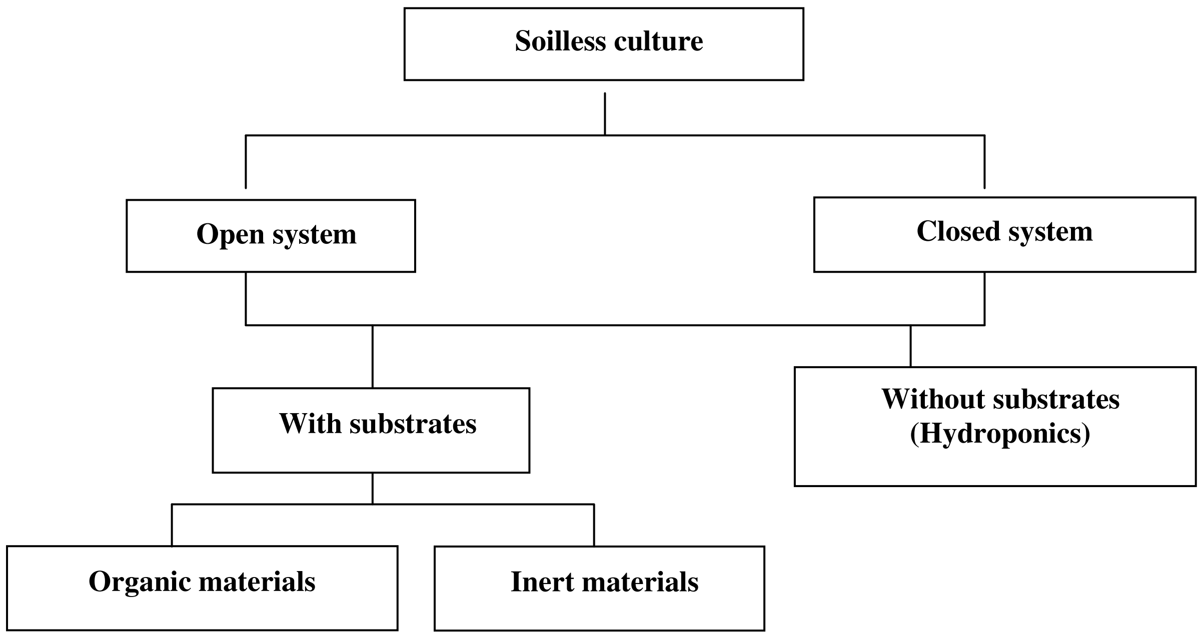

Figure 17: Systems available for soilless cultivation

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

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

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

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

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

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

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

(Source: Schröder and Lieth, 2002)

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

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

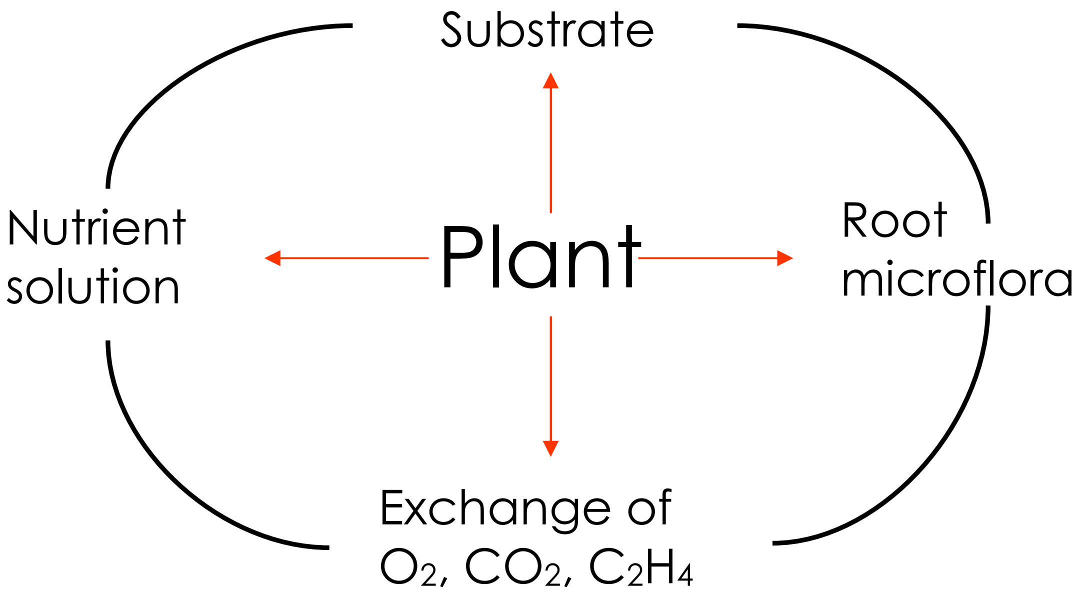

Figure 18: The matrix for good plant development in hydroponics

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

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

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

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

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

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

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

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

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

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

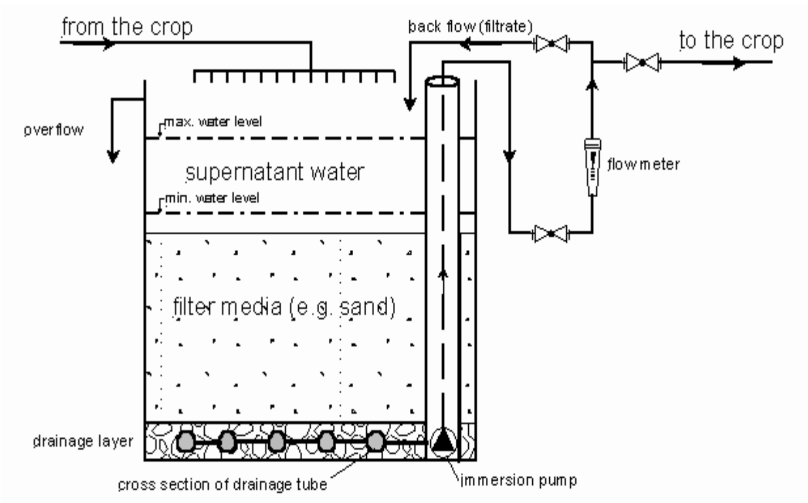

Figure 19: Set-up of slow filtration according to Wohanka

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

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

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

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

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

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

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

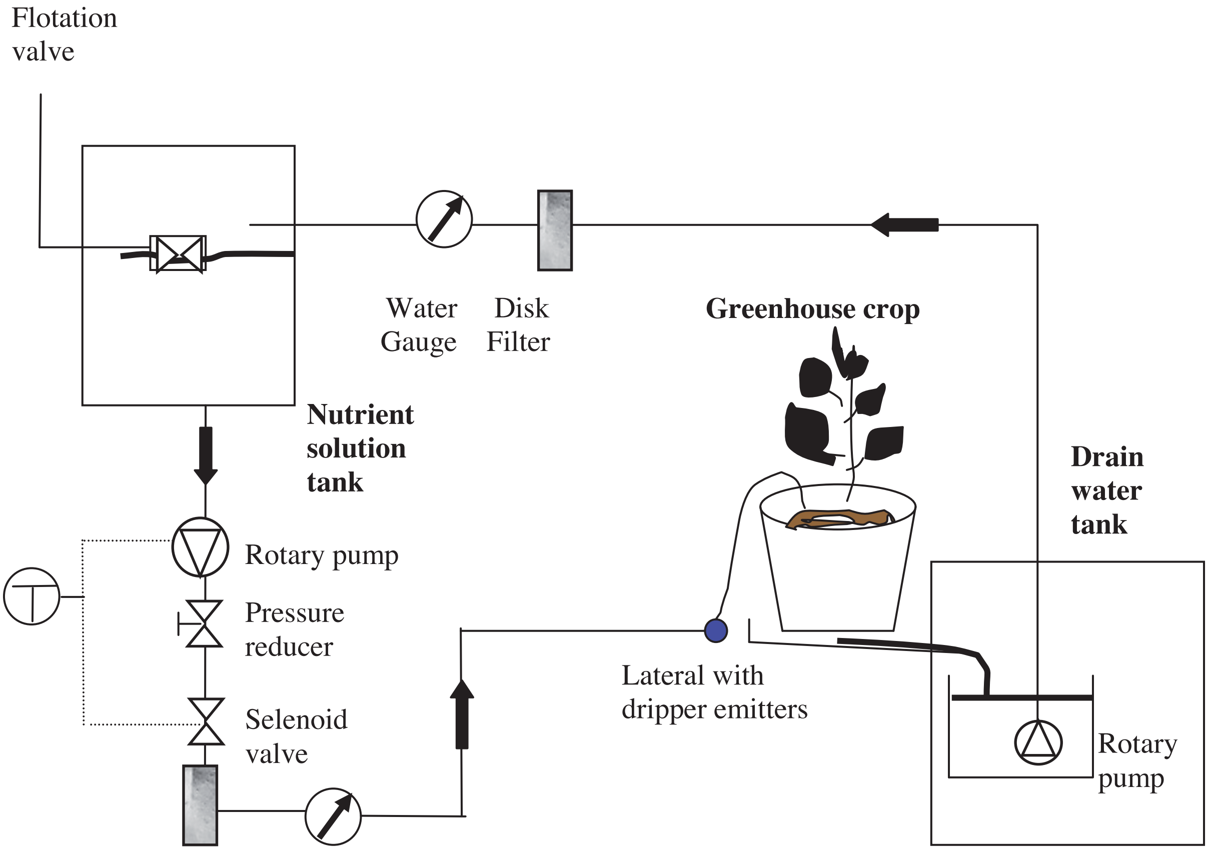

Figure 20: The technical installation for the recirculation of nutrient solutions with manual adjustment nutrients according to measured pH and EC values

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

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

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