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Production of Flowers and Vegetables in Danish Greenhouses
Alternatives to Methyl Bromide

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Contents

Preface

Methyl bromide is listed as a controlled substance in the Montreal Protocol on substances that deplete the ozone layer. The present date for phase out in developed countries is 1 January 2010.

The use of methyl bromide is prohibited in Denmark effective 1 January 1998.

There has been some concern about the total ban of methyl bromide. It has been assumed that the phase out of the pesticide will reduce the viability of some crop production systems. This report describes some aspects of the Danish greenhouse growers' experience. In Denmark, methyl bromide has been used as a soil fumigant, especially for greenhouse tomatoes. The greenhouse growers have changed their growing methods from soil to soilless production, primarily on artificial substrates. The report describes methods used, diseases encountered and some environmental consequences of soilless growing.

It also describes a broad range of further alternatives including inert substrates (the substrate chosen by Danish growers being one of several options), steam sterilisation, use of antagonists etc.

It is our hope that the Danish example may contribute to ease the phase out of methyl bromide.

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The authors

Summary

Methyl bromide (MeBr) will be banned in Denmark effective 1 January 1998. Today almost all greenhouse vegetables and cutflowers are grown in soilless systems which, during the last two decades, have developed very rapidly. The main substrate among Danish growers is inert material, primarily stone wool. A slight increase in tomato yield is observed when changing to soilless substrates. For many other vegetables and flowers no differences in yield have been observed by this change. Soilless growing has some advantages, but the move was accompanied by several unforeseen technical difficulties, many of which have been successfully resolved. Soilless growing does not eliminate root disease, but disease can be held at a low level in most systems. The susceptibility of plants to disease is closely correlated with environmental and nutritional stresses. Environmental controls and good hygienic practices are the most important components of disease control. Soilless systems need frequent irrigation with complete nutrient solutions. They use the same amount of water as soil systems. Used substrate can be returned to the factory and reused in Denmark. Competitive soilless growing relies on the sophistication of growers and extension service together with a high degree of supply security in raw materials.

Sammenfatning

Brug af methyl bromid (MeBr) er forbudt i Danmark fra den 1 januar 1998. Forbuddet medfører at dyrkning i jord vanskeliggøres, og som alternativ dyrkes i dag de fleste væksthusgrønsager og -snitblomster på kunstige dyrkningsmedier, primært stenuld, som de senere år har været gennem en rivende udvikling. For de fleste grøntsager og blomster kan der ikke konstateres forskelle i udbytte, mens der i tomater er observeret en lille udbytte stigning. Dyrkning på kunstsubstrater har visse praktiske fordele, men overgangen fra jord til kunstsubstrat har givet mange uforudsete tekniske vanskeligheder hvoraf mange er blevet løst. Dyrkning på kunstsubstrat løser ikke problemerne med jordbårne sygdomme fuldstændigt, men sygdomstrykket kan holdes på et lavt niveau i de fleste dyrkningssystemer. Sygdomsmodtageligheden af afgrøderne er nært knyttet sammen med dyrkningsforholdene og plantestress. Kontrol af dyrkningsmiljøet og gode hygiejniske forhold er derfor de vigtigste komponenter for at opnå gode resultater på kunstsubstrater. Vandforbruget i dyrkningssystemer med jord og på substrater hvor der anvendes overskudsvanding svarer til hinanden. Efter dyrkningsæsonen kan den anvendte stenuld returneres til fabrikken i Danmark hvor den smeltes om og genbruges, hvilket er med til at reducere miljøbelastningen. En konkurrencedygtig dyrkning på kunstsubstrater afhænger i høj grad af veluddannede gartnere og en veludviklet rådgivningservice sammen med en stor forsyningssikkerhed af råmaterialer.

1 Introduction

Methyl bromide in Denmark

Methyl bromide (MeBr) was introduced as a soil fumigant in Denmark in 1959. It will be banned effective 1 January 1998 due to its effect on the ozone layer (Anon. 1995). Since 1982, MeBr has only been allowed in greenhouses; since 1 January 1996 MeBr has not been allowed in greenhouse tomatoes. Effective 1 January 1998 the ban will be complete.

Use of methyl bromide in open air

In fields, MeBr was used to control potato wart disease caused by *Synchytrium endobioticum* which occurred sporadically; and to control potato cyst nematodes (*Globodera rostochiensis*). The problems of soilborne pests and diseases in open fields are mainly managed with crop rotation, disposal of plant residues and the use of resistant varieties, facilitated by a well-developed agricultural extension service.

Use of methyl bromide in greenhouses

In greenhouses the possibilities for crop rotation are limited and the production of certain crops can be very complicated. The grower must be an expert to make a profit, therefore the same crop is often grown every year in order to exploit the growers expertise and to get full use of specialised expensive technical equipment. These mono-cultural practices lead to a need for soil disinfestation. Furthermore, modern varieties of tomatoes, cucumber and sweet pepper can be very sensitive to attack by diseases, and easily loose 30-40 per cent of the yield if phytosanitary conditions are poor. Lettuce, on the other hand, is not very sensitive to disease attack and can be grown in monoculture for several years without a decrease in yield if the phytosanitary conditions are satisfactory.

In Denmark, MeBr has primarily been used in greenhouse tomato and cut-flower production. In cucumber, it has been used to a lesser degree due to its limited effect on the disease caused by *Phomopsis sclerotioides*. Consequently, cucumber production was transferred to growing on plastic sheets to avoid the spread of this disease and soil disinfestation became unnecessary (Jensen *et al.* 1983). In lettuce the use has been limited because it is necessary to leach the bed with 300-500 mm of water to remove excess bromide which delays the start of the culture. Hence, lettuce growers preferred dazomet, (which has been also been banned in Denmark, effective 1 January 1997). The alternatives to soil disinfestation in greenhouses have thus been either use of artificial substrates or steaming of the soil.

The problems with soilborne pests and diseases in greenhouses are mainly addressed by growing in artificial substrates, either on the floor (edible crops and cut-flowers) or on tables (potted flowers). Growing soilless demands high levels of skill on the part of the growers and of the extension service. Highly specialised equipment and advanced irrigation systems are needed, as well as very high hygienic standards.

Total greenhouse area with edible crops and cut flowers

The total area in Denmark with edible crops and cut-flowers is shown in Fig. 1. In 1986, 170 hectares of floor grown crops were grown. In 1997 this area declined to 118 hectares. This decrease is primarily seen in cut-flowers which have decreased by 73 per cent. The area with edible crops has decreased by 13 per cent over the same period. The reduction in the area with cut-flowers can be attributed to competition from producers in other countries. Most of the reduction was among small holders with outdated greenhouses.

Soil grown area

In 1997, only 13 hectares of edible crops are expected to be soil-grown. The soil-grown area is primarily lettuce (where there is no benefit for the growers to change to inert substrates) or organic grown greenhouses, where no fertilisers are allowed.

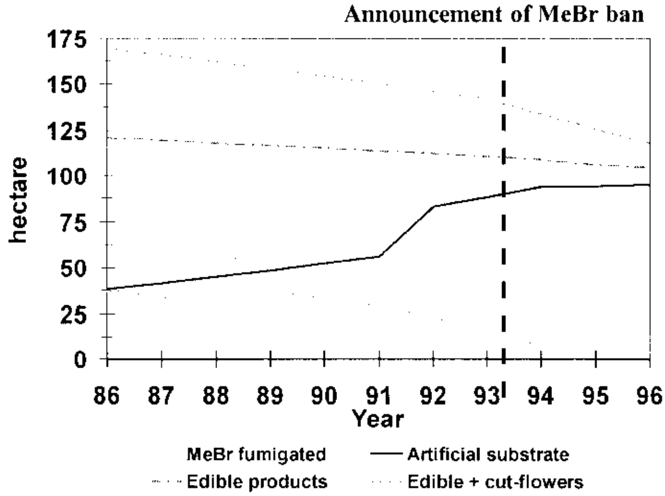

Figure 1
Numbers of hectares treated with MeBr, using artificial substrate and the total area grown with edible crops and cut-flowers. In 1993, when the ban for MeBr was announced 25 per cent of the preciously fumigated area was treated. Many of the growers had already changed to artificial substrates due to economic, phytopathological and ergonomic reasons (Source: Ministry of Environment 1996, Hansen 1997, Holmenlund 1997, Anon. 1996a).

Soilless area

Approximately 88 per cent of area with edible crops are grown soil-less in Denmark today. For cut-flowers, the proportion is approximately 80 per cent. To compare the Danish figures with other European countries; 80 per cent of the vegetables and 30 per cent of the flowers were produced in soilless cultures in the Netherlands in 1993 and 1994 respectively (Rattink 1993, de Kreij 1995). In UK 80% of all commercial cucumber crops are grown on stone wool (Hardgrave and Harrimann 1995), and in Crete less than 1 per cent of the greenhouse area is grown soilless (Manios *et al.* 1995).

MeBr fumigated area

In 1986, 65-70 per cent (38 hectares) of tomato cultures were MeBr-fumigated. The ban on MeBr was announced in 1993, but the fumigated area has been declining since 1989, indicating a decreasing importance of MeBr due to factors other than the proposed ban (Fig.1). In 1997 only 3 hectares are expected to be treated with MeBr (Hansen 1997).

Yield increase

From 1986 to 1996 the average yield in Danish greenhouse tomatoes rose from 31 to 41 kg m^{-2} (Fig. 2). The increase in yield is obtained both in border soil and in soilless cultures and can be attributed largely to new varieties and to developments in fertilisation and irrigation techniques.

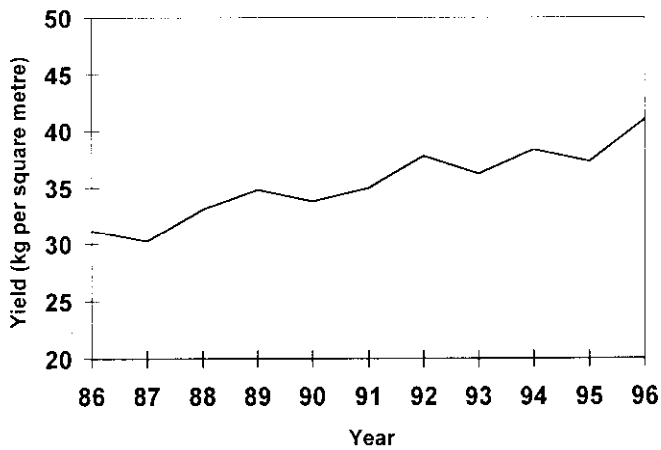

Figure 2
Tomato yield in Danish greenhouses, kg m^{-2}, 1986-1996 (Anon. 1996c).

No direct comparisons have been made in Denmark between soil and soilless cultures, but experience from practice shows that tomato yield in general increases by approximately 2 kg m^{-2} under soilless growing conditions. A higher yield is possible, but due to low market prices, supplementary light from lamps to prolong the growing period is not cost-effective.

A large number of advantages and some disadvantages can be given for growing with soilless culture:

Advantages of soilless growing

- Standardisation of the culture, and the root environment in particular
- Reducing soil infestation
- Elimination of the danger of disinfestant residues in the crop
- Reduction of the energy input for conditioning the root environment in colder climates
- Efficient use of nutrients
- Better control of vegetative and generative plant development
- Earlier and higher production
- Rationalisation of labour (ergonomic)
- Possibilities for culture mechanisation

However, the substrate culture has created environmental problems of its own, including:

Disadvantages of soilless growing

- Disposal of 110-120 m^3 of inert substrates per hectare per year
- Draining of excess water loaded with fertilisers
- Use of plastic for mat wrapping, soil cover, etc.

2 Growing methods

2.1 Soilless culture

Changing from soil to other substrates raises a new set of problems for the grower, different from those growing in border soil. The most important requirement is that the substrate holds sufficient water and air to maintain maximal conditions for root and, therefore, plant growth. In principle, all kinds of materials that do not contain phytotoxic substances can be used as growing substrate (Böhme 1995). Early in the development of soilless growing, straw was used as a substrate, but has subsequently been replaced by artificial substrates such as stone wool (Rockwool®/Grodan®). Grodan® was introduced in 1973 by the Danish Rockwool-Industry as a horticultural substrate, and is the most established product in Denmark (>90 per cent) and most of Europe. Oasis®, Perlite and natural substances such as peat (sphagnum) and coconut husks are also used. Danish growers and their extension service have chosen the inert substrates preferentially because they are physically easier to work with and because it is easier for the research and extension services to establish recommendations and carry out trials on a standardised inert product. Furthermore, the manufacturer supervised the growers in their adoption of the methodology with a package of extension and service early in the transition to soilless technologies. As a result, the growers achieved a reasonable yield the first years they used inert substrates. The experience with soilless culture in cucumber has been transferred to tomatoes as well as to other horticultural crops, such as to cut-flowers.

Growing procedure

The normal growing procedure is to sow seeds in small cubes; to transplant seedlings into propagation blocks and, finally; to transfer plants to the inert growth slabs. The slabs are placed in plastic gullies or in buckets on the floor in the greenhouses and supplied with an irrigation system.

Yield in different substrates

For the best growers only minor differences between substrates are seen in relation to yield (Hardgrave 1994; Hardgrave and Harrimann, 1995 for long-season cucumber; Anon.1996c; Gunnlaugsson and Adalsteinsson 1995 in tomatoes; Andersen 1997b in roses). However, other results have also been observed, e.g. in cucumber, where Maher and Prasad (1995) found a slight advantage in favour of growth substrates with larger water holding capacity (peat and stone wool) compared to other substrates. In multi-year crops soilless systems have an advantage that especially clearing and transplanting are much less labour intensive, than in soil grown cultures.

2.2 Comparison of different growth media

There are several alternatives to soil as growth substrates on the market in Denmark. The different substrates differ in their physical properties giving different conditions for root growth, transport of water and nutrients and consequently biomass production making it difficult for the growers to be expert in more than one substrate. Water cultures are in use, but not common, and some growers report that lower yield and higher disease incidence are the main reason for not growing in water. This chapter gives a short description of the different growth substrates available on the Danish market.

2.2.1 **Inert substrates**

Mineral wool

Mineral wool or stone wool has proven to be an excellent growth medium. It is made of granite or silica, melted at 1600°C and blown into 5μm fibres. The fibres are sold in plastic wrapped slabs (7.5 * 20 * 90 cm (h*w*l)). It has a very high water holding capacity at saturation ($\theta > 0.95$ (da Silva *et al.* 1995)). The hydraulic conductivity has been shown to decrease dramatically with increased suction (Willumsen 1972; da Silva *et al.* 1995). This may become critical and lead to poor uptake of water and nutrients and to rapid development of plant water stress, even when the total volume of water retained by the slab appears to be sufficient for plant transpiration.

The above scenario is not uncommon for the greenhouse growers and plant wilt may be observed even when there seems to be enough water in the medium. The signs of plant stress may be a direct result of extreme reductions in water fluxes towards the roots caused by transient reduction in the hydraulic conductivity (K). The damaging effects of water stress can be avoided by increasing irrigation frequency (da Silva *et al.* 1995).

For hygienic reasons mineral wool is normally used for one growing season and discarded after use which may raise environmental problems (see 6.0 Environmental aspects). To avoid carryover of diseases from one growing season to another the growth substrate can be sterilised with steam (not possible in Denmark for the moment). Steam sterilisation causes some damage which results in a short useful life (2-3 years) (Hardgrave 1995).

Polyurethane-ether and Deroplast-resin

Polyurethane-ether (PUR) and Deroplast-resin can be used as growth substrate too, e.g. Aggrofoam® (a soft polyurethane-ether foam made of industrial remnants) and Oasis® (a hard foam). Polyurethane-ether® has not been widely adopted in Denmark because of lack of support from the manufacturer. Oasis® is a hard foam made from either polyurethane-ether or Deroplast-resin and used to a small extent in cucumber production. Oasis® was produced with CFC-gases, but is now made with vapour and CO_2 (Thygesen 1997).

Soft PUR has a lower waterholding capacity than mineral wool and a lower hydraulic conductivity (Benoit and Ceustermans 1995b; Hardgrave 1995). Hardgrave (1994) reported equal yields in stone wool and soft PUR but noted that the foam needed more frequent irrigation until a strong root system developed. To ensure smooth growth of the roots from the nursing pots into the mat, the PUR-mat must not be too thick, in particularly when growing cucumber (Benoit and Ceustermans 1995b). The low water holding capacity and hydraulic conductivity allows easy control of the moisture content in both spring and autumn, while the mat dries out very quickly at the end of the culture. It is very easily steam-treated under optimal conditions. In trials in the Netherlands, PUR has been reused for up to 10-15 years. Mats that have been treated with steam 6 times showed no loss in yield compared to new ones (Benoit and Ceustermans 1995b).

Pumice/Perlite

Pumice and Perlite are communised volcanic rock that has been used as a substrate, especially in cucumber. It is a biologically inert material. Because of its low water holding capacity beds with pumice have been designed with a 2-3 cm deep water reservoir at the bottom of each bed to ensure adequate water supply to the plants. Irrigation has to be adjusted to give frequent watering with small volumes. Pumice can easily be sterilised with steam or other sterilising agents. Yields in tomatoes grown in pumice and stone wool were similar (Gunnlaugsson and Adalsteinsson 1995).

2.2.2 Organic substrates

Peat and Straw

Organic substrates are biological active and are broken down during the growing season by micro-organisms. Natural substrates often have a high Carbon:Nitrogen relationship (C:N) which is not optimal. The substrate may either bind or release added nutrients making it more difficult to control growing conditions. As they degrade, the oxygen content may decrease lowering yield, especially in fine-ground peat. As the peat breaks down, pH in the substrate is lowered and liming becomes necessary (Hardgrave and Harrimann 1995). High yields are achievable on organic substrates, but highly skilled growers are essential.

2.3 Irrigation and water quality

In soilless cultures only a limited growing volume and a small water reservoir is available for the plants, but the small volume seems not to have any influence on growth. The low volume lowers the buffering capacity in the substrate and may result in a rapid decrease in water content and consequently in the hydraulic conductivity with increasing suction (Wallach *et al.* 1992a; 1992b). Frequent and highly efficient irrigation systems are necessary every hour in critical periods with a high degree of security in continues water supply.

2.3.1 Irrigation systems

Mostly dripwater systems

The most common irrigation system in Danish greenhouses is drip irrigation into the growth slabs, with an outlet at every plant. Only a few water culture systems and no Nutrient Film Technique systems (NFT) are in use. Ebb/flood systems are primarily used in production of potted plants on tables.

Open/closed systems

Irrigation methods may be divided into either open or closed systems. In closed systems excess water is recirculated, eventually disinfested, and reused. There are no apparent differences in yield when different irrigation techniques are used (Willumsen 1996, Schröder *et al.* 1995). At the moment there is no obligatory demands for closed irrigation systems where excess water is reused to prevent surface and ground water contamination in Denmark, as has been mandated in the Netherlands by 2000 (Ratting 1993).

Irrigation with excess water

In Denmark, in commercial greenhouses with tomatoes and cucumber, irrigation with 20-30 per cent excess water is the most commonly used method (run-to-waste). Excess water is used to counter both the potential variations in the irrigation supply and individual plants need for water and fertiliser (McPerson *et al.* 1995, Raviv *et al.* 1995). The discharged water is either used in the fields for irrigation or discharged into the draining system.

Irrigation frequency

The irrigation frequency in soilless systems has to be at least 5-10 times a day, more frequent during the day and less frequent during the night.

2.3.2 Water consumption

Water consumption is equal

Under soil grown conditions excess water is drained into the soil. The amount of water leached depends both on soil type, (porosity, structure, permeability), irrigation interval, water quality and management. With tomatoes and cucumber grown on clay soil, the water consumption is equal to the soilless systems where 20-30 per cent excess water is used. On sandy soil an increase in water consumption may be expected, but little information has been gathered on these differences. In tomatoes, the water consumption is approximately 1000 ±70 litres m^{-2} $year^{-1}$ (Bjerre 1997), giving an average evaporation rate of 3.5 litres m^{-2} d^{-1}. This was also found by Schwarz *et al.* (1996). Cultures grown in slabs typically have 10-11 litres of available water m^{-2}, hence the need for high irrigation frequency.

2.3.3 **Water quality, pH and nutrients**

In soil culture, the soil acts as a sink for many macro- and micro-nutrients. When changing to soilless systems all necessary macro- and micro-nutrients must be added to the irrigation water. Moreover every crop has its own needs that differ throughout the growing season. In most cultures the pH should be around pH 5-6, to dissolve the nutrients in the water and to facilitate their uptake. Precise descriptions of plant needs and regular measurements of the irrigation water are obligatory.

Groundwater of high quality

In Denmark, most irrigation water is groundwater from wells or borings with high drinking quality. Normally, a standard nutrient solution, where all macro- and micro-nutrients are incorporated in the irrigation water serves to meet the target values in the root environment. Irrigation water quality is measured for nutrient content, pH and salinity (EC) at regular intervals in order to formulate an optimised nutrient solution. The control of nutrients is more important when small volumes of substrates per unit of area are used, however very fast regulation of nutrient composition in small water volumes can be achieved.

2.4 The effect of soilless growing on quality and taste

Consumers often link soilless growing of vegetables with poor vegetable quality. They argue that the vegetables do not have their natural aroma and contain more water. A reason for this could be lack of micro-nutrients and/or fast growing vegetables. It is possible to change the salinity of the irrigation water to alter the water content of the vegetables and, perhaps, the aroma, but often this results in lower yield. Because few consumers are prepared to pay a higher price for products with improved taste it is more profitable to produce crops with higher water content.

Sugar/acid ratio

Schnitzler *et al.* (1994) compared the quality of tomatoes from two recirculating irrigation systems to soil grown tomatoes. They used the sugar/acid ratio as an indicator of the taste and they found no differences between the substrates. If the sugar/acid ratio is a satisfactory indicator of taste we may conclude that tomatoes can be cultivated on various substrates, but are best grown close to markets to allow harvesting at optimal ripening stages (close to red-ripe) in order to satisfy taste and other requirements of the consumer.

2.5 Conclusion

Growing soilless is more difficult than growing in soil, but may increase the yield. Highly skilled growers, extension service and technical equipment are needed as well as reliable access to water and all macro- and micro-nutrients for fertilisation. The plant available amount of water is low and high irrigation frequency is needed. There is no evidence for product quality differences among the different growing systems.

3 Phytopathology in Danish Greenhouses

MeBr fumigation was used for reduction of pathogens, pests and weeds. This chapter describes briefly the most important techniques for wilt, root and crown disease management in soil and soilless greenhouse cultures.

3.1 Diseases

The change from growing in border soil to soilless culture has eliminated attack from nematodes but not resulted in disappearance of soil-borne diseases such as *Fusarium*, *Pythium* and *Phythophtora*. For example, *Fusarium oxysporum* f.sp. *radicis-lycopersici* (FORL) which causes Fusarium crown and root rot (FCRR) is found to be the most troublesome disease on tomatoes both in soil and on artificial substrate in Holland (Rattink 1993). FCCR is uncommon in Danish greenhouses. A sterile soil may however not be optimal as a non-sterile soil because the FORL proliferates more rapidly and sporulates more profusely in sterilised soil (Jarvis 1977). The nutrient rich water solution is an ideal environment for the growth and spread of bacteria and fungi. However, bacterial diseases are seldom observed under Danish conditions. The susceptibility to attack by pathogens differs among the different substrates, but severe epidemics are more frequent in water culture than in soil or peat (Forsberg 1991).

3.1.1 Soil systems

Soil systems

In soil or sphagnum the spread of diseases may be suppressed. Patternotte and de Kreij (1993) found that plants in systems with Finnish sphagnum peat (irrigated by an ebb/flood system) showed no disease despite detection of the pathogen in the nutrient solution; however, plants in aeroponic and ebb/flood systems became diseased within a few weeks. They found that *Pythium* was most suppressed in the least decomposed light peat. Hoitink *et al.* (1991) recommended light peat for plug mixes in short production cycle crops. However, suppressiveness of sphagnum peat is variable (Boehm and Hoitink 1992). The fact that chrysanthemums on Finnish sphagnum peat showed no *Pythium* disease symptoms was not attributed to a low pH nor to the presence of humic substances.

3.1.2 Soilless systems

Soilless systems

Several researchers have demonstrated that root pathogens can be disseminated in inert growth media or in water cultures (McPherson *et* *al.* 1995; Lundquist and Svedelius 1991; Hockenhull and Funck-Jensen 1983, Willumsen 1996). With the run-to-waste irrigation systems, McPherson *et al.* (1995) found that the pathogen was largely confined to the point of inoculation, although there was limited evidence of dispersal to occasional plants in individual growth slabs towards the later stages of the trial. In water cultures they found *Phytophthora* dispersed to 93% of the crop in the recirculating water solution, but only a 5% yield reduction was recorded; a similar result was obtained for *Pythium*. Lundquist and Svedelius (1991) studied the fungal flora in four different tomato cultures: one with recirculating nutrient in stone wool beds; one without recirculated nutrient and two water culture systems with biologically active stone filters. The composition of the fungal flora on roots and in the nutrient was quite similar for all systems. Moreover, they found that the content of *Pythium* and *Trichoderma* in drained nutrients from the wool beds was higher than in hydroponic nutrient. Hockenhull and Funck-Jensen (1983) found no severe attack on lettuce by *Pythium* and concluded that severity depends both on the virulence of the pathogen and the quantity of inoculum. Vanachter *et al.* (1983) found that both plant developmental stage and growth conditions had influence on attack by pathogens. Most *Pythium* species mainly infect juvenile or succulent tissues, causing seed rot and pre-emergence damping-off (Yoganathan *et al.* 1980, Hendrix and Campell 1973) Their parasitism is restricted to seedlings or to the feeder roots of older plants which causes them to become stunted and chlorotic. When cells of stems and main roots have developed secondary wall thickenings, infection is restricted to feeder roots.

3.2 Reduction in spread of diseases

Good phytosanitary practices

Good phytosanitary practices are important to avoid the establishment and spread of diseases in greenhouses. In soilless systems where "run-to-waste" and new or sterilised substrates is used, only few and minor problems are seen. Closed recirculating water systems can be perceived as a threat from root pathogens disseminated in the recirculating water solution, which may inhibit greenhouse tomato and cucumber growers from adopting this system. However, in potted plants production on tables, with ebb/flood systems, recirculated water is used with great success. Should the crop be diseased, the growers, in concert with the extension service, have been capable of diagnosing and eliminating further spread of the disease.

3.2.1 Disinfestation of soil

Where border soil is used steaming or use of pesticides is the only alternative for reducing soilborne diseases. Steaming is not economical viable in most cultures, and chemicals such as dazomet have limitations. Furthermore dazomet was banned as of 1 January 1997. Some production systems still use steaming for soil disinfestation. In freesia, for example, border soils are still used because the root temperature in inert media may becomes too high, which hampers flowering. In this case, the growers continue to use soils which are steam disinfested every second year (Andersen 1997b).

Lettuce

Lettuce is a very short-lived crop with 6-7 production cycles per year. Attack by *Pythium* spp. is often seen (Thingaard 1987; Thingaard and Middelboe 1989). Lettuce is grown throughout the greenhouse as opposed to most other crops, which are grown in rows. Satisfactory methods for soilless cultures have been developed and used commercial in several countries, but the Danish growers continue to use border soil, because lettuce is not very sensitive and can be grown in monoculture for several years without a decrease in yield if the phytosanitary conditions are satisfactory. Removal of old plant parts, including the root, may postpone the need for disinfestation. In a trial carried out by DEG in 1996, a yield increase from 72 to 88 per cent among transplanted plants was observed after removal all old plant parts from the previous cropping cycle. The yield increase was attributed to fewer problems with fungi (Anon.1996d). When problems with soilborne pathogens becomes too high, steaming is used.

3.2.2 Disinfestation of substrates

Several horticultural growers have tried to reuse mineral wool slabs for more than one year with out disinfestation. The normal procedure today is however discharging of the slabs after one season.

Steam treatment

Steam treatment of substrates is not used in Denmark due to too few greenhouse within efficient proximity to each other (Andersen 1997a). In the Netherlands and Belgium steaming of used substrates can take place. This is done by a lorry coming around and on which 2 steaming containers and a steam generator is mounted. Steam treatment costs less than half the price of dumping or recycling and remelting the mats in Belgium (Benoit and Ceustermans 1995a).

3.2.3 Disinfestation of recirculating water

Because most greenhouses with vegetables and cut-flowers in Denmark are discharging excess water, there is only limited experience with disinfestation of irrigation water, but to improve security against the establishment of disease and in anticipation of a change to recirculating water systems several methods are under development. Disinfestation can be accomplished by heating, ultra-violet irradiation (UVL), fungicides, iodine, ozone (O_3) or activated hydrogen peroxide. There is also a variety of methods for the reduction of the inoculum density of pathogens including ultra-filtration, micro-filtration, slow sand filtration, addition of antagonists and biofilters. A comprehensive review of different methods is found in Runia (1993).

Pasteurisation

Recirculating water may be heat pasteurised. McPherson *et al.* (1995) used pasteurisation at 95°C for 30 seconds and found it successful in eliminating pathogens. A protocol in which water is held at 25-30°C for at least 24 h prior to high temperature heat treatment has proved successful for eliminating more than 99% of chlamydospores of *F. oxysporum*.

UV-irradiation

Water may be disinfested by treatment with UV-irradiation, particularly in wavelengths of approximately 260nm. UV-irradiation may produce mutants in, or be lethal to fungi (Pomper 1965). Jamart *et al.* (1994) found a dose of $150 mJ/cm^2$ killed all conidia of FORL and root infection decreased to one third of the control. McPherson *et al.* (1995) found a fixed dose of $100 mJ/cm^2$ found UVL proved successful in preventing pathogen dispersal. However, UV-irradiation should be used cautiously if the nutrient solution contains chelated iron; UV-light breaks down the chelate and makes the iron inaccessible to plants (Yoganathan *et al.* 1980). Currently, there are no growers in Denmark who use UV-irradiation of their irrigation water.

Peroxyacetic acid

Several growers who have experienced severe disease in pot plants with recirculating water systems have had success in reducing pathogen populations by adding 0.06 per cent peroxyacetic acid. The actual dose depends on the susceptibility of the plant to non-salient toxic effects. Although the method is successful for disinfestation, the high activity of peroxide and the low pH both corrode equipment, which significantly adds to expense.

Fungicides

Fungicides can be added to the irrigation water to reduce pathogens. In Denmark only Propamocarb (Previcur) is allowed in tomatoes, cucumber and lettuce, but not later than 21 days before harvest. FORL has not been satisfactory controlled by fungicides (Jarvis 1988); used as soil drenches they have limited effectiveness and are economically prohibitive (Tu and Zheng 1994). Jarvis (1988) considered biological control a better alternative.

Iodine

Runia (1994) used iodine against FORL and tomato mosaic virus and found that a concentration of 0.7 ppm completely eliminated conidia of *Fusarium*. However, they also found that the method has an adverse effect on certain elements in the recirculating water particular the trace elements iron and copper. The effect was not caused by iodine itself, but by the carbon in the iodine extraction filter.

Ozone

Ozone (O_3) may be used as a disinfestant of the solution, but is not used by Danish growers.

Biofilters

Biofilters are rarely used in Danish greenhouses although many pot plant growers use recirculating water systems.

Micro-filtration

Filtration of the recirculating water in a sand filter may reduce the numbers of pathogens. Jamert *et al.* (1994) found no significant differences between root-indices for micro-filtered water and controls and McPherson *et al.* (1995) achieved no yield benefit from micro-filtration treatment compared with other disinfestation systems in combination with an ozone unit, but the roots appeared strikingly better than any other treatment.

3.3 Resistant cultivars

Use of resistant cultivars and breeding for resistance are among the most important strategies for reducing disease problems. Several genes have provided durable resistance to most races of *Fusarium* in tomato and are incorporated in horticulturally desirable germplasm. However, new races of the pathogen have been identified (although not in Denmark) and the search for other sources of resistance is ongoing. There has been less success with resistance to pythiaceous organisms, but some root systems show greater tolerance to infection.

3.4 The importance of antagonists

Trichoderma harzianum
Pseudomonas fluorescens

It is very difficult to eliminate established pathogens from soil and from water in inert materials. Hence it is better to have a mixture of non-pathogenic fungi and bacteria in the soil/substrate/water, than a sterile environment which may favour colonisation by aggressive pathogens. Many Danish growers add antagonists to the irrigation water or to potting mixes, primarily isolates of *Trichoderma harzianum*. Several other antagonist have proven useful. *Streptomyces grisei-viridis* and *T. harzianum* controlled FORL (Rattink 1993). Tu and Zheng (1994) demonstrated that *Gliocladum roseum, G. virens, Bacillus subtilis* and *Pseudomonas fluorescens* offered significant control of FCRR. Lemanceau and Alabouvette (1991) have shown the utility of saprophytic isolates of *F. oxysporum* for control of FORL in tomato and flax wilts, presumably by competitive exclusion (Lemanceau *et al.* 1993).

3.5 pH in the growth substrate/irrigation water

pH

To minimise the potential for disease outbreak and to optimise plant growth, the pH of irrigation water should be between pH 5 and 6. Bolton (1980) reported the most severe infection of poinsettia by *P. aphanidermatum* in soilless culture occurred at pH 5.5-7.0. Yogana han *et al.* (1980) found that pH 4.5 favoured the infection by *Pythium* over a pH of 6.5. Funck-Jensen and Hockenhull (1983) found high zoospore production in nutrient solutions between pH 4.0 and 8.0.

Patternotte and de Kreij (1993) found no effect of the pH-level on growth of isolates and on disease development on chrysanthemum in their growing systems.

3.6 Conclusion

Susceptibility of plants to disease is closely correlated with environmental and nutritional stresses. The sophistication of growers and high hygienic conditions in greenhouses are perhaps the most important components of disease control, and in Denmark we are fortunate in that our growers are extremely sophisticated and our greenhouses modern and well kept. The move to soilless systems from soil was accompanied by several unforeseen technical difficulties, many of which have been successfully resolved. Danish growers have foreseen a switch from open irrigation to recirculating water systems, and are actively exploring methods for the disinfestation of nutrient solutions in order to preemptively address anticipated problems. Since sterile solutions may be more easily colonised than non-sterile solutions, perhaps the most important among technical questions that remain is the determination of a method for the selection and encouragement of competitive non-pathogens within recirculating waters; such a method could minimise the necessity and cost of water disinfestation.

4 Management

Growing soilless cultures demands highly skilled growers with a knowledge of fertilisation plans based on chemical composition of the plants and water analysis. Irrigation has to take place very frequently and the growers have to add all necessary macro- and micro nutrients to the irrigation water.

Micro- and micro nutrients in well water

Most Danish irrigation water in greenhouses is ground- or well water. The water contains some nutrients which vary from well to well. In some cases, some micro-nutrients are sufficiently abundant in the water, in others not. Therefore, irrigation water should be analysed before use and at regular intervals. In some water the micro-nutrient content is much higher than the needs of the plants; excess water is needed to avoid accumulation in the growth media. Surface waters from lakes and rivers seldom contain large concentrations of micro-nutrients. These amounts are incorporated in the fertiliser plans. The total salts can be measured by Electrical Conductivity (EC) in milliSiemens cm^{-2}. Most bore and well water in Denmark contains between 0.5-1,0 EC. Rainwater has an approximately EC level of 0.1. The EC in the irrigation water when all nutrients is applied are 2-3, depending on cultivar, the plant age, time of the year etc. Measuring equipment is cheap and standard in all greenhouses using inert substrates to ensure that the total content of nutrients in the irrigation solution is at satisfactorily level. EC measurements are normally carried out 2-3 times a week. EC measurements are also used to control the water content and taste of the fruits.

Electrical Conductivity

Laboratory analysis of nutrients may be essential

Because the plant has different needs during the growing period, the relation between the different nutrients may differ from the added solution. In closed irrigation systems, it is necessary to measure the actual levels of nutrients in the irrigation solution at least every 2-4 week. This can only be determined by laboratory analyses.

Control methods for diseases

Root pathogens may spread rapidly in recirculated solutions. Access to well-equipped diagnosticians is essential in order to rapidly address problems. It is important to regulate root development and the nutrient solution in order to increase security against attack by pathogens. Routine control methods for diseases have been developed (Andersen and Petersen 1990; Thinggaard 1990) and are carried out in Danish greenhouses, with assistance from the extension service.

Fertiliser plans

Nutrient levels in the water must be monitored and adjusted regularly. Often, fertiliser plans cannot be designed by the grower and have to be designed by the extension service.

Control of irrigation systems

The buffering capacity of water and nutrients in the irrigation system is very small compared to growing in border soil. This places high demand for educated growers, continuous access to fertilisers and micro-nutrients, and the infrastructure for repair and replacement of sophisticated equipment within a limit time schedule. Using recirculating water demands the ability to compose optimal nutrient solutions and access to water of good quality.

5 Economy

The transition from border soil to soilless media in tomato has improved yields by approximately 2 kg of tomatoes m^{-2}. These extra kilos must pay for the investments in substrate, for levelling of the floor in the greenhouse and gullies and for grower education. Table 1 shows the annual revenue per m^2 tomatoes. Steam sterilisation of border soils is more expensive (US$ 2.9-3.0 m^{-2} plus transport) than MeBr-fumigation, and is only used under special circumstances. The transition to soilless systems without recirculating water has increased grower income per m^2. Only small difference between disposal and reuse of sterilised substrates are found. Steam sterilisation of used slabs is not possible in Denmark at this time and the prices will probably be higher in Denmark than mentioned in Table 1.

Table 1. *Changes in costs and pay back period for tomato growing in Denmark per m^2 for border soil and soilless growing (prices in US$)*[a].

	MeBr fumigation	Steam sterilisation	Rock-wool®1	Rock-wool®2	Rock-wool®3
Yield increase (2kg)	-	-	2,84[b]	2,84[b]	2,84[b]
Soil, substrate disinfes.	2,00	2,90	-	0,85[c]	-
Costs in growing media	-	-	2,00	0,67	2,00
Discharge of substrate	-	-	0,15-0,2	0,07	0,15-0,2
Saved water-nutrients	-	-	-	-	0,20
Net revenue per season	-2,00	-2,90	0,64-0,69	1,25	0,89-0,94
Investment:					
levelling, and gullies			5,00-8,00	5,00-8,00	d)
Pay back period, years	-	-	2-4	1,4-2	d)

1) Excess water, discharge of substrates for remelting.

2) Excess water, reuse and sterilisation of substrates in 3 years.

3) Investment in closed system.

[a] 1,00 US$ = 6,00 DKK
[b] Sales price DKK 8,50 kg^{-1} = 1,42 US$
[c] Price in Belgium (Benoit and Ceustermans 1995b)
[d] Costs variable due to choice of disinfestation equipment

The annual operating revenue

The annual operating revenue per holding in Danish greenhouses in vegetables and potted flowers is given in Fig. 3. Since 1986, an increasing profit per holding has been observed, with the exception of 1995 when a very low income was obtained due to low market prices. The transition from soil growing to soilless production has not influenced income negatively. Profitability depends more on the actually market prices.

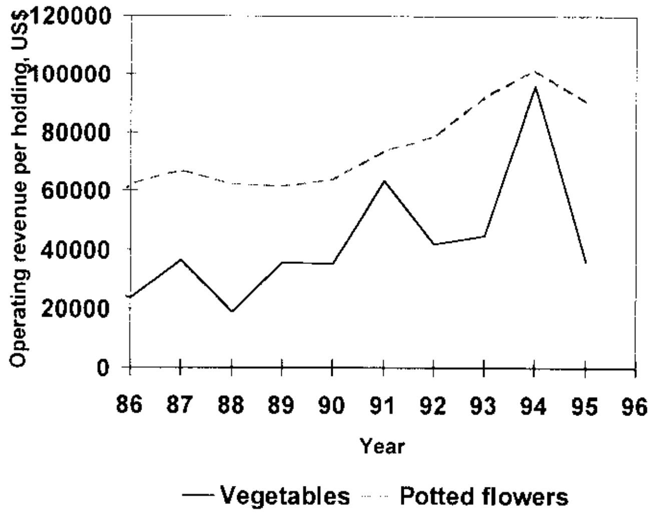

Figure 3
Annual operating revenue in US$ per holding. Since 1986 both vegetables and potted flowers growers have increased their annual revenue, except for 1995 where prices were low (Anon. 1996b).

6 Environmental aspects

The environmental consequences of crop production in green houses have changed. Under soil growing conditions excess water and nutrients is drained into the soil. In open systems this continues. The irrigation systems with slabs do however give the possibility to collect excess water for recycling. The use of inert substrates may be an environmental burden if recycling or proper disposal cannot take place. In Denmark no demands for collecting or recycling of excess drainage water is in force.

6.1 Water

Leaching of nutrients

Danish experiences show that border soil grown tomatoes as an average demand 1 m^3 water m^{-2} $year^{-1}$ independent of the tomatoes are grown in soil or in inert substrates giving a water efficacy of approximately 25 litre's kg^{-1} of tomato. Other irrigation systems (NFT) may have a lower water efficacy per product produced (27-35 litre's kg^{-1}, Schwarz *et al.* 1996). Reuse of water can both save water and nutrients compared to open systems and the pollution from greenhouses can virtually be prevented by adaptation of closed systems. Under normal Danish growing conditions in tomatoes drip irrigation with 20 per cent excess water makes a leaching of approximately 20 per cent of the nutrients. The annual environmental load of nitrogen is then 0.04 kg m^{-2} and 0.008 kg m^{-2} of phosphorous. In places where concern about run-off occurs, Hardgrave and Harrimann (1995) recommends growing in organic substrates because more solution is retained within the slab. In areas where shortage of water and risk of ground- and surface water contamination occurs consideration of the irrigation system should be done.

6.2 Reuse and disposal of substrates

High disposal costs favour reuse

Most soilless substrates can be sterilised and reused, but to minimise labour and the possible spread of soilborne pathogens the growers prefer to use new substrate instead. Polyurethane-ether (PUR) that can be reused several times (Benoit and Ceustermans 1995b), has not been widely adopted in Denmark. The producer of Rockwool® (Rockwool-Industries A/S) collects used substrates in Denmark and the Netherlands for remelting at the factory (Holmenlund 1997). The recycling program has been extended to Sweden, Germany and Great Britain for 1997. In 1996, fifty per cent of the slabs were returned and remelted at the factory at a cost of US$ 0.15-0.20 m^{-2} approximately one tenth of the cost of new slabs). A part of the remaining slabs are discharged at controlled dumping sites, in spite of very high disposal cost (US$ 85-120 ton^{-1}). If the slabs contain no plastic, the Danish greenhouse growers are allowed to spread five centimetre of finely ground inert material on fields every fifth year which is then ploughed into the soil.

6.3 Energy consumption for producing substrates

Energy costs of steaming are equal to soilless systems

The energy cost of producing different substrates varies (Table 2). The energy production cost is highest for Deroplast (Oasis®). Rockwool® and Aggrofoam® have almost the same energy production costs, whereas peat and pumice are low cost materials. There is relative equality among Rockwool®, Aggrofoam® and soil steaming in a cost comparison. If the inert substrates are steamed and reused in the greenhouses, lower energy consumption than steaming the soil every year is possible.

Table 2
Production energy costs to disinfect or to produce growing substrate to one m^2 of greenhouse tomatoes.

	MJ m^{-3} substrate	MJ m^{-2} greenhouse	Source:
Soil steaming	-	108[a]	Andersen 1997a
Peat	50	5	Herbold 1996
Pumice	50	5	Herbold 1996
Aggrofoam®	1000	110	Herbold 1996
Rockwool®	1125	124	Herbold 1996
Oasis®	3300	363	Herbold 1996

[a] Energy consumption for steam disinfestation one m^2 = 3 litres of gasoline.

6.4 Conclusion

Changing from border soil to soilless growing may not change the water and nutrient consumption in well functioning greenhouses using slabs as growing substrate, unless closed recirculating systems are used. NFT irrigation systems have a higher water consumption rate than other closed systems. In areas where water is limited, special attention should be paid to this issue. Inert materials may be an environmental problem in certain areas if reuse or proper disposal does not take place. Steam sterilisation may be a possibility for resolving some environmental problems with inert material. The production energy cost per m^2 for steaming greenhouse soil is the same level as for production of new inert substrates.

7 Conclusions

Banning MeBr has only had minor influence on tomato and cucumber production in Denmark. When the plans for phasing MeBr out were laid down, approximately 83% per cent of the area with tomatoes and cucumber was already grown on other substrates than soil. During the last two decades soilless growing techniques has undergone a very rapid development. In general, a slight increase in yield compared to border growing has been achieved in tomatoes when growing soilless. For many other vegetables and flowers no differences in yield have been observed where soilless growing techniques have been used. The Danish growers have mostly chosen stone wool as their substrate of choice. Stone wool has the same yield potential as other growth substrates.

Susceptibility of plants to disease is closely correlated with environmental and nutritional stresses. The sophistication of growers and high hygienic conditions in greenhouses are perhaps the most important components of disease control. In Denmark we are fortunate in that our growers are extremely sophisticated and our greenhouses modern and well-maintained. The move to soilless systems from soil was accompanied by several unforeseen technical difficulties, many of which have been successfully resolved.

Disposal of used inert growth substances may cause problems, but reuse and remitting to the factory may ameliorate the problem. Reuse and remitting have been accelerated in Denmark by high costs (tax) for disposal at dumping sites.

Peat and pumice have the lowest production energy cost. Soil steaming requires the same energy consumption as production of inert substrates.

In most Danish greenhouses excess water is drained which may be an environmental problem. The amount drained when using slaps of inert materials in open systems is approximately the same size as if the crop were grown in soil. Only in closed systems where water and nutrients are recirculated and reused can this environmental burden be eliminated.

Competitive soilless growing has relied highly on skilled growers and extension service, together with a high degree of supply security in raw materials

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Production of Flowers and Vegetables in Danish Greenhouses

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Alternatives to Methyl Bromide

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Resumé:
Udviklingen i dansk væksthusproduktion af grøntsager og snitblomster er beskrevet i relation til forbud mod brug af methylbromid. Hverken økonomi eller produktionsmetoder er påvirket af forbudet. Konkurrencedygtig produktion afhænger af gode hygiejniske forhold kombineret med kontrollerede vækstforhold, veluddannede gartnere og en veludviklet rådgivning. Da næsten alle grøntsager og snitblomster dyrkes uden jord, lægges der i rapporten især vægt på dyrkningssubstrater, sygdomme og miljøaspekter.

Emneord:
væksthuse; gartnerier; substitution; jord; dyrkningsmedier; økonomi; materialeprøvning; planter; sygdomme; mineralfibre; genanvendelse; desinfektion; brommetan CAS 74-83-9; methylbromid

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