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Maintaining soil health for crop production in organic greenhouses

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ABSTRACT

Organic production in intensive greenhouse operations, while maintaining soil health and sustainability, is a challenging task. Organic greenhouse crops must be rotated, but the rotations are short, so that rapid buildup of pest and pathogen populations can occur to levels causing significant damage. Heavy soil infestations together with the need to maintain profitable production forces the farmer to use effective control measures, while trying to maintain soil health and quality. If resistant cultivars or cultivars grafted on resistant rootstocks are not available, some form of soil disinfestation may be needed to eliminate the majority of root pathogens and pests in the soil. Soil steaming creates a "biological vacuum" that is prone to re-invasion by pathogens and pests. Selecting a soil treatment that preserves the biological equilibrium in soil, enhances the development of natural disease suppressiveness and provides an increased growth response is preferred. This is especially important for intensive organic greenhouse production, where a healthy soil is a prerequisite for the profitable production of healthy crops. Soil health can be promoted by aerobic soil disinfestation ("biofumigation"), anaerobic soil disinfestation, solarization, and a combination of these treatments. Here, we present a variety of strategies and approaches for the promotion of soil health and disease suppression in organic greenhouses.

1. Introduction

Greenhouse production of edible and ornamental crops is geared towards extending the cropping season, under optimal and stable environmental conditions, such as temperatures and relative humidity. Indoor production prevents adverse conditions such as extreme temperature conditions and precipitation. However, such a system is energy-demanding during cold weather. The most important greenhouse production areas are in Europe (in particular The Netherlands and the Mediterranean region), Canada, Mexico, and the USA (primarily California and Florida). Greenhouse crops may be grown on raised beds or on benches using organic growing substrates (mix of peat, composts). Hydroponic systems, is allowed in the USA but prohibited in Canada. Natural soil is not mandatory in Canada.

Organic greenhouse production is still a small sector of the organic production industry and constitutes only a small proportion of total greenhouse production. For example, The Netherlands has more than 5000 ha of conventional and only about 100 ha of organic vegetables produced under glass (Meijer, 2009; Dorais and Alsanius, 2015). The greenhouse structures range from very simple unheated plastic houses (called 'high tunnels' in the USA) to fully-automated temperature and humidity controlled glasshouses, and may range in size from a hundred to ten thousand m^2 (Greer, 2000; Platform Biologica, 2000). Plastic houses are quite common in the Mediterranean region to grow early-season, lucrative crops.

The basic principles and rules for organic field production also hold for organic greenhouse horticulture. In particular, the following principles are applicable:

1. To grow vegetables and herbs in soil, on raised beds or on benches using organic growing substrates (mix of peat and composts).
2. To maintain and improve soil fertility for long-term productivity.
3. To make maximal use of natural processes and rhythms (biological regulation of diseases and pests, availability of nutrients, and the use of natural daylight).
4. To make maximal use of renewable resources and energy sources; and
5. To prevent environmental pollution during production.

In certified organic greenhouses in Europe, plant production must take place in natural soil, not in artificial substrates or hydroponics. Organic plant production in soil-less substrates such as peat

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Fig. 1. Organic tomatoes grown along vertical ropes in a greenhouse in The Netherlands.
Note: The long leaf-less stems that are folded horizontally. The plants are lowered weekly after removal of the older leaves (photograph by Wim Blok).

or compost is only allowed in the EU when the plants are sold in the pots in which they were raised (van Bruggen, 2015). The substrates must have a biological origin and preferably be renewable. Peat products are allowed, but not recommended from commercial considerations, due to the finite supplies of peat. Peat is therefore being replaced by alternatives like coco peat or compost. In the USA; however, organic vegetables may be produced in organic substrate media, as long as they are organically certified (Greer and Diver, 2000).

Only very profitable crops are produced in greenhouses. These are mostly vegetables and herbs. The main vegetable crops grown in greenhouses are tomato, cucumber, sweet pepper, eggplant, lettuce, and mixed greens. For the production of greenhouse vegetable crops like tomato, cucumber, eggplant and sweet pepper mostly indeterminate varieties are used (Gravel et al., 2010; Hasna et al., 2009; van Bruggen, 2015). Individual plants are supported with ropes or stakes. When they are held up by ropes, the bottom leaves are removed regularly and the tops can be lowered over time (Fig. 1). The selected cultivars for organic production are mostly the same as those used in conventional greenhouses. The most common herbs grown in organic greenhouses are fresh culinary herbs like basil, chives, cilantro, dill, mint, parsley and sage, but also dried herbs like oregano, rosemary and thyme (Greer, 2000). Fragrant and aromatic herbs, such as lemon balm and lavender, are sometimes produced in greenhouses. Medicinal herbs (e.g., *Echinoa* sp. and *Aloe vera*) are usually grown outside, but sometimes also in the greenhouse. Some herbs cannot be grown outside in temperate climates because they require a long growing period, e.g., rosemary. Herbs are marketed as fresh-cut products or in pots with special potting mixes made for the organic industry. This review will be focused on organic vegetable production.

Quality products and stable market supplies are crucial for the success and maximum profit of greenhouse crop production. Hence, technology intends to accomplish precise environmental and nutritional control under intensive production. These in turn push plants to new limits of growth and productivity, for example 400 tons of tomatoes per hectare in nine months, which requires large amounts of organic fertilizer (van Bruggen, 2015; van Bruggen et al., 2015b,c). Organic greenhouse crops must be rotated, but the rotations are short (two or three years) and subsequent crops may be susceptible to the same pathogens and pests (Hasna et al., 2009; van Bruggen, 2015c). Thus, pathogens and pests can establish and cause damage, if the soil and the entire environment is not properly managed to reduce this risk. The long production season and the short period between cropping make the control of pests and diseases in protected crops challenging (Gullino et al., 1999).

2. Common soilborne diseases and pests in organic greenhouses

Soilborne pests (pathogens, arthropods and weeds) can cause heavy losses in greenhouse production, affecting both yield and quality. The narrow rotation practice causes rapid buildup and enrichment of pest populations in the soil to levels which force the farmer to use effective control measures. This is even more so for organic than conventional greenhouse production, despite the maintenance of soil quality in organic greenhouse production through crop rotation (although limited), organic amendments and other means that are available for mitigating soilborne pathogens according to organic standards.

The most common soilborne diseases that occur in greenhouse-produced plants are root rots, wilts, root knot nematodes and nematode-transmitted viruses (van Bruggen, 2015). Because crop rotations may be minimal, soilborne diseases are generally more severe in organic than in soilless conventional greenhouse production. In particular, root knot nematodes, which have a very wide host range, may build up to unacceptable levels (Klein et al., 2012; van Bruggen and Semenov, 2015; van Bruggen et al., 2015b). The most important root diseases are corky root of tomato and cucumber caused by *Pyrenochaeta lycopersici* (Giotis et al., 2009; Hasna et al., 2009; van Bruggen et al., 2015b; Vitale et al., 2011) and tomato root rot caused by *Fusarium oxysporum* f. sp. *radicis-lycopersici* (Ozbay and Newman, 2004). *Sclerotinia sclerotiorum* can be problematic on small vegetables like lettuce (Baysal-Gurel and Miller, 2010). Phytophthora root rot is common on pepper and herbal plants (Greer, 2000). Verticillium and Fusarium wilt can be devastating when resistant cultivars are not used (Giotis et al., 2009).

Many bacterial diseases are seed-borne, and can become problematic when transplants are used from a non-reputable source. Vegetable seedlings are produced at very high densities and the slightest seed contamination can result in epidemic spread due to the use of a fine mist to produce transplants. A typical example is bacterial canker (*Clavibacter michiganensis* subsp. *Michiganensis*) of tomato which can be especially problematic, because the pathogen can be present on symptomless plants, but can become systemic and induce symptoms under favorable (humid and warm) conditions (Miller and Broome, 2012). *Clavibacter* survives readily on plant debris. The best control is prevention by using certified pathogen-free seed and transplants. In addition to this pathogen, *Ralstonia solanacearum* could be accidentally introduced and cause wilt of solanaceous crops. *R. solanacearum* race 3 biovar 2 is a quarantine organism in the USA and Europe and will need to be eradicated if discovered (Messiha et al., 2007). *R. solanacearum* race 1 is endemic in many tropical and some subtropical areas, and can be devastating in affected greenhouses.

In addition to fungal and bacterial diseases, soilborne virus diseases such as Cucumber Green Mottle Mosaic virus (CGMMV) can be quite important in organic greenhouse production (Miller, 2011). Some virus diseases and most viroid diseases are seedborne and/or mechanically transmitted (Miller, 2011). Many other viruses and viroids can become problematic, but little has been published about these pathogens in organic greenhouse production.

Many soilborne pathogens have multiple mechanisms of survival and dissemination, resulting in multiple sources of inoculum, all of which have to be identified and managed to maintain soil and crop health. The source of infestation of soilborne pathogens includes primarily the soil inoculum. However, other sources are