Environment Modification for Disease Management

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Maria Lodovica Gullino and Angelo Garibaldi

Abstract

Florist's crops are often grown under protection and, at least in some countries, in sophisticated greenhouses which permit control of the environment. In the warmer climates, they are also grown outdoors, thus with more limitations in environmental control. Understanding the effects of environmental parameters on pathogens makes environmental manipulation for disease control feasible. In some cases, the manipulation of the environmental parameters by itself permits effective reduction of the incidence of several diseases. Frequently, such manipulation of environmental parameters permits reduction of further interventions. This chapter considers the manipulation of temperature, RH, soil moisture, pH, and light as well as the solutions that can be applied in the case of soilless cultivation.

Keywords

Temperature • Relative humidity • pH • Light • Soilless cultivation • Foliar diseases • Soil-borne diseases

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M.L. Gullino (✉)
Centre of Competence Agroinnova, University of Torino, Grugliasco, Italy

DISAFA, University of Torino, Grugliasco, Italy
e-mail: marialodovica.gullino@unito.it

A. Garibaldi (✉)
Centre of Competence Agroinnova, University of Torino, Grugliasco, Italy
e-mail: angelo.garibaldi@unito.it

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1 Introduction

Florist's crops are often grown under protection and, at least in some countries, in sophisticated greenhouses which permit control of the environment (Castilla 2013). However, some crops, particularly in the warmer climates, are grown outdoors, thus with more limitation in environmental control.

This chapter will mostly deal with greenhouse crops, which are the ones most potentially influenced by modification of the environmental conditions. However, some of the approaches described can be applied, though at a lesser extent, to field grown crops. Understanding the effects of environmental parameters on pathogens makes environmental manipulation for disease control feasible. In some cases, the manipulation of the environmental parameters by itself permits effective reduction of the incidence of several diseases. Frequently, such manipulation of environmental parameters permits reduction of further interventions.

In this chapter the manipulation of temperature, RH, soil moisture, pH, and light will be considered as well as the solutions that can be applied in the case of soilless cultivation. The manipulation of mineral nutrition and the management of the irrigation water are not considered since they are already covered in other chapters.

2 Environmental Factors Favorable to Disease Development

The main environmental factors influencing plant growth and disease development are temperature (of both air and soil), relative humidity (RH), soil moisture, pH and mineral nutrition, dew, and, to a lesser extent, air movement and light (day length and intensity).

Pathogens often have well-defined temperature *optima* for infection, colonization, and disease development, with differences existing among pathogens as well as for the different phases of the infection process. Very often the most favorable temperature for a pathogen is very close to the temperature *optimum* for crop growth, so that little can be done by growers in terms of temperature manipulation. However, sometimes slight changes in temperature will result in a strong influence on disease development. This can happen, for instance, in the case of Verticillium wilt caused by *V. albo-atrum* and *V. dahliae:* temperatures higher than 25 °C permit reduction of disease severity in several crops. Growth and sporulation of *Botrytis cinerea*, the causal agent of gray mold, are inhibited by temperatures higher than 30 °C: increasing air temperature can help to reduce gray mold incidence in the case of crops tolerating temperatures higher than 30 °C (Trolinger and Strider 1985). The incidence of Fusarium wilt of carnation, caused by *Fusarium oxysporum* f. sp. *dianthi*, can be reduced at air temperatures lower than 15 °C, while symptoms are severe at temperature higher than 20 °C (Fletcher and Martin 1972; Nelson 1961). Also soil or substrate temperature can influence disease development. *Fusarium oxysporum* f. sp. *dianthi* on carnation is less severe at temperatures of 21 °C or lower, and symptoms are absent at soil temperatures of 10-16 °C. Also Fusarium wilt of Paris daisy (*Argyranthemum frutescens)*, caused by *Fusarium oxysporum* f. sp. *chrysanthemi*, is most severe at soil temperatures higher than 20 °C (Angelo Garibaldi, unpublished).

Generally, warm air and soil temperature and high RH favor the development of bacterial wilts. In the case of bacterial blight of geranium, caused by *Xanthomonas hortorum* pv. *pelargonii* (formerly, *Xanthomonas campestris* pv. *pelargonii*), symptoms develop in 7 days at 27 °C and in 21 days at 16 °C; symptoms are enhanced between 21 and 23 °C, while they are suppressed at 10–15 °C or at 32–38 °C (Campbell 1985). While temperatures lower than 27 °C, at RH lower than 80%, reduce the severity of bacterial blight of chrysanthemum, incited by *Erwinia chrysanthemi* (Campbell 1985).

Air temperature has a direct effect on RH, which, in turn, has a strong influence on the development of foliar pathogens. Heating and ventilation inside a greenhouse permit the establishment of conditions less favorable to infection and sporulation. Diseases such as gray mold, downy mildew, rusts, many foliar spot diseases, and bacterial blight, all dependent upon deposition of water on the plant surface, can be easily controlled or, at least, reduced, by heating and/or ventilating. Although heating requires energy consumption, computerized monitoring systems permit adjustment of RH avoiding excessive use of heat and ventilation. It is advisable to maintain RH at 85% or below because RH at the leaf surface is likely to be 10% higher. Most fungal spores, except those of powdery mildews, can germinate at 95% RH.

Also the covering material (plastic or glass) might affect disease severity; for instance rust caused by *Uromyces caryophyllinus* and leaf spot by *Alternnaria dianthi* are more severe on carnation grown under plastic. On the contrary, rose powdery mildew, incited by *Sphaerotheca pannosa*, is more severe under glass. In all cases, the presence of higher RH values under plastic is responsible for such responses (Garibaldi et al. 1976).

Soil wetness can affect the development of some diseases, especially those caused by pathogens with a motile zoospore stage, such as *Olpidium*, *Pythium*, *Phytophthora*, etc. Epidemics of damping off caused by *Pythium* spp. and of basal rot caused by *Phytophthora* spp. are quite common at the nursery level for many ornamental crops, such as gerbera, rhododendron, and skimmia. In soils which are too wet also healthy roots do not function well because of low oxygenation, thus increasing the effect of root rot. Zoospore producing pathogens find the best situation for spreading in closed soilless systems and diseases caused by *Pythium* spp. and *Phytophthora* spp. are quite common (Gullino and Garibaldi 2007; Jarvis 1992; Stanghellini and Rasmussen 1994).

Wilt of gerbera, caused by *F. oxysporum* f. sp. *chrysanthemi*, is more severe on plants grown in soilless systems than in soil. Maintaining the pH of the nutrient solutions at values higher than 6.0 reduces the spread of the inoculum of the causal agent (Garibaldi and Gullino 2012).

Although day length and light intensity do not have a direct effect on disease development, a combination of radiation with RH and other factors might affect the expression of certain diseases.

Alteration of the solar radiation inside the greenhouse can influence disease development, not only because of the effect on the spectral composition of the radiation with consequences on spore formation but mainly because plants grown at high density are more susceptible to diseases in the presence of reduced light levels (Louvet 1984). The modification of the spectral characteristics of greenhouse covers permits reduction of the incidence of foliar diseases and also protects crops from insects and insect-borne virus diseases (Raviv and Antignus 2004). A complete or partial absorption of solar UV radiation may interrupt the life cycle of fungal pathogens and/or alter the visual-based behavior of many insects and might play a role in pest and disease management. In the case of greenhouse grown roses, a supplementary radiation with low levels of UV suppresses the development of powdery mildew, incited by *Podosphaera pannosa* (Kobayashi et al. 2014).

The increase in temperature in the greenhouse, the prevention of agrochemical loss from rain, and the filtering of UV light of the plastic covering help to increase the efficiency of the fungicide treatments. However, an increased risk of phytotoxicity as a consequence of an increase in temperature should also be considered (Urban 1997).

It is also important to notice that some environmental parameters might also affect biocontrol agents or, more generally, the microorganisms that, at the phyllosphere or rhizosphere level, might play a role in the control of some pathogens.

3 Monitoring and Control of Environmental Parameters Under Greenhouse Conditions

In the case of greenhouse crops, growers have the unique possibility to exert some control over the environmental conditions in which crops are grown. Monitoring the environment and controlling it in order to avoid pests and diseases has long become an important component of greenhouse management: indeed, plant production under protection offers opportunities for specific control of climatic factors, both for optimization of plant growth and for integrated control of pathogens. In a closed system such a greenhouse, simple management practices can be adopted that are more difficult in an open field.

Disease control by specific climate management is most promising for pathogens which have critical climatic requirements for specific stages of development. Once the environmental parameters that influence pathogens are understood, they can be more precisely regulated. Monitoring is important, since it permits precise control of environmental parameters in order to reduce disease development using computerized systems, which also save energy and reduce production costs. Disease management is greatly enhanced by monitoring and controlling temperature, light, humidity, water, ventilation, carbon dioxide, and crop nutrition. Of these factors, manipulating the interactions of temperature and humidity is probably the most important in the control of foliar diseases, while rhizosphere moisture and temperature are the most important for root and wilt diseases.

In the presence of high humidity, guttation can occur from leaves and pruning wounds. A repeated cycle of guttation and drying can lead to injury by phytotoxic salts that creates infection points for necrotrophic pathogens. Dew deposition in the greenhouse favorable for downy mildews, rusts, and *Botrytis* blight is common on cool nights following warm, humid days. Regulating day and night atmospheres is important for disease control and also helps in reducing the total amount of chemicals sprayed (Hausbeck and Moorman 1996).

Botrytis cinerea on fuchsia was managed with specific climate and/or ventilation management; in particular, controlled dehumidification combined with a drop of temperature in the morning, and with a supplementary direct ventilation to decrease air humidity within the canopy, reduced stem blight to one third and sporulation on necrotic leaves to half of that in the corresponding control (Friedrich et al. 2005). Avoiding temperatures conducive to *Phytophthora infestans* and reducing moisture reduced late blight on petunia (Becktell et al. 2005b), with a reduction in fungicide use (Becktell et al. 2005a). On rose, *Peronospora sparsa* is now much less important than in the past, due to the possibility of better control of greenhouse RH as well as the availability of effective chemicals (Garibaldi and Gullino, unpublished results)..

Controlling RH and lighting reduced powdery mildew development and increased the vase life of cut flowers (Mortensen and Gislerød 2005). Temperatures higher than the optimum (21 °C) for the disease reduced powdery mildew severity in poinsettia (Byrne et al. 2000).

In the case of anthracnose of azalea, caused by *Colletotrichum acutatum*, keeping leaf wetness duration lower than 12 h when temperatures exceed 15 °C helps in managing the disease, which can be serious on some cultivars (Bertetti et al. 2009) (Fig. 1).

Beside controlling temperature and RH in order to reduce foliar diseases, it is necessary to ensure that water is lost from the crop by the normal physiological processes and that evaporation occurs from all other surfaces of the greenhouse. This is achieved through heating and ventilation but at a considerable cost. Ausburger and Powell (1986) provided data on the cost of humidity management.

All heat saving techniques should be adopted, although in some cases, for example, using thermal screens can create longer periods of high RH which can increase disease risk. In some cases, e.g., for gray mold management, ventilation alone helps in minimizing the risks of epidemics by permitting good air movement.

Root-zone or soil heating can be accomplished with either floor or bench heating systems. Such a long-standing grower practice to improve plant growth can have a positive effect in reducing the severity of certain pathogens. Bottom heat, a traditional means of avoiding root rots incited by species of *Phytophthora*, *Pythium* and *Rhizoctonia*, is enhanced in cutting and seedling trays with upward air movement between the young plants.

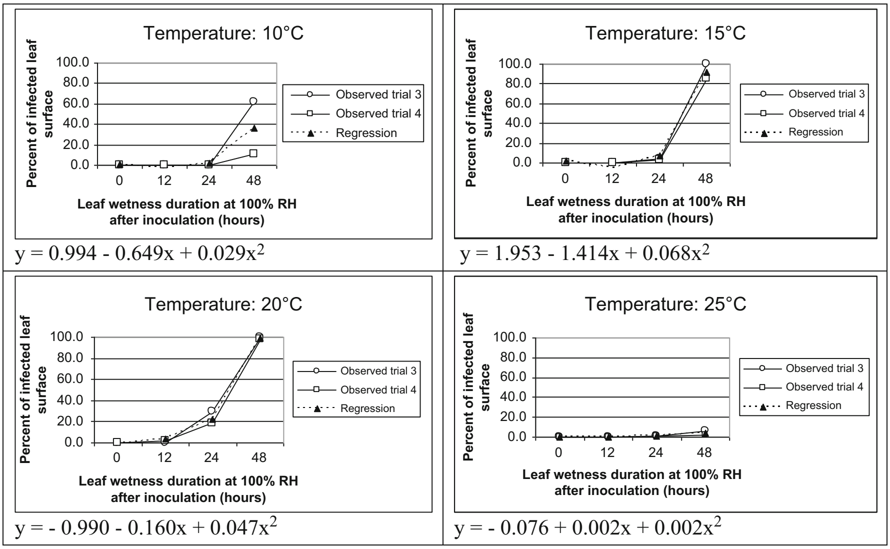

Fig. 1 Effect of leaf wetness duration on severity of anthracnose caused by *Colletotrichum acutatum* on *Rhododendron azalea* cv. Palestrina. For each temperature tested, data obtained showed similar variances with the Levene test. Thus, leaf wetness duration and severity can be related by using a single equation obtained by regression analysis as shown at the base of each graph. There were no symptoms on inoculated plants maintained at 5 °C and 30 °C (With permission from Bertetti et al. 2009)

Development of Fusarium root and crown rot incited by *Fusarium hostae* in container-grown hostas is affected by the type of wounding that occurs during propagation, container mix content, watering schedule, and temperature; peat or peat-bark container mix reduced disease incidence and severity, and disease was higher on plants growing in a dry-container mix and at moderate (20–25 °C) temperatures (Wang and Jeffers 2002).

The application of lime to the medium increases the pH and suppresses Fusarium wilts (Elmer 2012). This has been observed in the case of carnation (Engelhard 1979), chrysanthemum (Engelhard and Woltz 1973), and also on gerbera (Garibaldi, unpublished).

Altered greenhouse and bench design can improve air movement, thus reducing the risk of diseases. Through-the-bench air movement is, perhaps, the most neglected and simplest means of reducing seedling rots in tangled plant masses. A modest degree of spatial isolation, such as maintaining a distance of at least 10 m to fields where lilies were grown in the previous year, proved effective in reducing Botrytis leaf blight in lily. Such simple cultural practices were more effective than other cultural practices aimed at reducing survival of sclerotia (such as removal of crop residues and crop rotation) and was particularly effective when combined with the use of a relatively resistant cultivar (De Kraker et al. 2005). In the case of bulb crops, plant density can also consistently influence Fusarium wilt severity.

According to Price (1975a), since the different *formae speciales* of *Fusarium oxysporum* causing wilt on bulb crops have limited capability to grow in the soil, the spread of wilts to nearby bulbs occurs through the roots. Infection also occurs via wounds and bruises when the operations of digging, cleaning, and grading bulbs take place (Price 1975b), so that all practices which reduce contact among bulbs reduce wilt severity (Gullino 2012).

All factors reported above can be controlled to a greater or lesser extent according to how available sophisticated greenhouse structures and the equipment are.

Although light can affect spore germination for some pathogens, this has not been used often for the control of diseases. Shading is often used by growers when crops are wilting, but the effect of this practice is mostly on temperature rather than on light intensity. In the case of root rot of lavender, caused by *Phytophthora nicotianae* var. *parasitica* with a high level of rot incidence, a ≥50% reduction in rot incidence was achieved by growing plants under shade. Maintaining plants under shade provided sufficient root rot control for practical cultivation conditions (Minuto et al. 2001) (Table 1). The effect was linked to a reduced heating effect of black pots used by growers.

Proper management of RH, light intensity, and photoperiod has a significant impact on powdery mildew development on rhododendron. Particularly, RH was important both during spore germination and later during colony development, with disease development being adversely affected by reducing RH from 100 to 70 and 85%. Light intensity and photoperiod both had considerable effects on the induced resistance response of the host (Kenyon et al. 2002). Shading strongly increases the severity of powdery mildew, caused by *Golovinomyces cichoracearum* on aster (A. Garibaldi, unpublished).

4 Cultural Techniques, Including Soilless Media

Under greenhouses, growers have powerful management tools for production, many of which could significantly affect the epidemiology or severity of some diseases. The use of hydroponic, soilless cultures and artificial substrates have been gaining popularity for a number of years, particularly for high value crops such as rose, carnation, gerbera, basil, and lettuce. Soilless cultivation permits starting a production cycle completely free of pathogens. It also permits eradication of pathogens present in the recirculating nutrient solutions (Van Os et al. 2012). Although such cultural systems are ultimately intended to reduce production costs and maximize profits, precise environment and nutrition controls pushing plants to new limits of growth and productivity can generate chronic stress conditions, difficult to measure, but apparently conducive to diseases caused by pathogens such as *Penicillium* spp. or *Pythium* spp. The spread of diseases in soilless cultivation systems can be solved by adopting proper disinfection methods for the recirculating solution, such as slow sand filtration. Moreover, preventative methods to make plants less susceptible to diseases as well as the use of diagnostic tools permit a fully integrated approach in such systems (Van Os et al. 2012).

Table 1 Effectiveness of different growing conditions of lavender on root rot, caused by *Phytophthora nicotianae* var., expressed as percent of dead plants at two dates, June 26 and August 21, 1996 (With permission from Minuto et al. 2001)

Number and site[a]	Pot, volume (l)	Substrate[b]	Substrate inoculation	Fungicide treatment	Percentage of dead plants at June 26 and	August 21
1. S	Clay, 2	L	+	–	33.8	62.0
2. S	Clay, 2	HC	+	–	15.2	27.0
3. S	Clay, 2	HP	+	–	27.5	46.3
4. S	Clay, 2	L	+	+	26.3	46.4
5. S	Clay, 2	HC	+	+	19.3	31.3
6. S	Clay, 2	HP	+	+	14.7	23.3
7. S	Clay, 2	L	–	–	2.0	3.3
8. S	Clay, 2	HC	–	–	0.0	0.0
9. S	Clay, 2	HP	–	–	0.0	1.3
10. S	Clay, 2	L	–	+	3.8	3.8
11. S	Clay, 2	HC	–	+	2.0	2.0
12. S	Clay, 2	HP	–	+	1.9	1.9
13. S	Plastic, 2	L	+	–	22.1	55.2
14. S	Plastic, 2	HC	+	–	27.5	54.5
15. S	Plastic, 2	HP	+	–	27.4	46.3
16. S	Plastic, 2	L	+	+	18.3	39.7
17. S	Plastic, 2	HC	+	+	42.2	63.4
18. S	Plastic, 2	HP	+	+	29.1	44.2
19. S	Plastic, 2	L	–	–	7.4	18.9
20. S	Plastic, 2	HC	–	–	0.0	2.0
21. S	Plastic, 2	HP	–	–	1.3	3.4
22. S	Plastic, 2	L	–	+	7.2	12.2
23. S	Plastic, 2	HC	–	+	1.4	2.7
24. S	Plastic, 2	HP	–	+	0.7	0.7
25. O	Clay, 2	L	+	–	22.4	48.4
26. O	Clay, 2	HC	+	–	18.4	55.0
27. O	Clay, 2	HP	+	–	59.9	85.8
28. O	Clay, 2	L	+	+	44.3	83.7
29. O	Clay, 2	HC	+	+	74.1	90.8
30. O	Clay, 2	HP	+	+	65.4	93.3
31. O	Clay, 2	L	–	–	3.5	16.7
32. O	Clay, 2	HC	–	–	0.0	23.0
33. O	Clay, 2	HP	–	–	0.7	20.5
34. O	Clay, 2	L	–	+	9.1	31.7
35. O	Clay, 2	HC	–	+	1.4	50.1
36. O	Plastic, 2	HP	–	+	9.2	49.8
37. O	Plastic, 2	L	+	–	14.6	34.2

(*continued*)

Table 1 (continued)

Number and site[a]	Pot, volume (l)	Substrate[b]	Substrate inoculation	Fungicide treatment	Percentage of dead plants at June 26 and August 21	
38. O	Plastic, 2	HC	+	–	36.3	65.7
39. O	Plastic, 2	HP	+	–	39.4	64.4
40. O	Plastic, 2	L	+	+	16.3	58.0
41. O	Plastic, 2	HC	+	+	26.1	60.8
42. O	Plastic, 2	HP	+	+	55.0	85.7
43. O	Plastic, 2	L	–	–	5.5	75.2
44. O	Plastic, 2	HC	–	–	0.0	55.1
45. O	Plastic, 2	HP	–	–	0.0	71.8
46. O	Plastic, 2	L	–	+	5.1	63.4
47. O	Plastic, 2	HC	–	+	2.6	78.1
48. O	Plastic, 2	HP	–	+	0.0	72.5

[a]*S* shaded, *O* open field
[b]*L* light, with perlite, *HC* heavy, with clay, *HP* heavy, with pomix

Closed recirculating soilless systems represent an interesting environment for exploiting innovative disease management options. For instance, increasing the value of electrical conductivity of the nutrient solution, use of potassium silicate amendments, and the combination of both have proven effective against a number of foliar and soil-borne diseases, such as powdery mildews, downy mildews, several leaf spots, and Fusarium wilts (Gullino et al. 2015). Silicon provided at least partial control of powdery mildews of greenhouse crops as well as of brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotinia homeocarpa*), and gray leaf spot (*Magnaporthe grisea*) on turfgrass (Bélanger et al. 1995; Brecht et al. 2004; Uriarte et al. 2004). When associated with a higher level of electrical conductivity, potassium silicate provides very interesting results. Under these conditions, in addition to the deposition of amorphous silica in the cell wall, there could be an increase in the production of lignin due to the presence of NaCl that could contribute to limiting the penetration of the pathogen within the plant cell, especially in the presence of foliar pathogens (Gullino et al. 2015). The effects of electrical conductivity to induce resistance against *Fusarium oxysporum* f. sp. *cyclaminis* on cyclamen have been documented by Elmer (2002); plants of cyclamen inoculated with the pathogen and treated with chloride salts showed a better growth and fewer wilt symptoms. The possibility of applying silicon as well as of manipulating the electrical conductivity to ornamental crops grown hydroponically is interesting because this type of cultivation is becoming more important and there is a scarcity of registered fungicides (Garibaldi et al. 2012).

Soilless systems also permit better manipulation of the microbiological conditions through microbial optimization with the application of microorganisms able to colonize the rooting system of plants grown under a strictly controlled environment.

Table 2 Effect of the application of selected antagonistic fungal strains into different closed soilless growing systems on the suppression of gerbera root rot incited by *Phytophthora cryptogea* (with permission from Garibaldi et al. 2003)

Treatment				Percentage of diseased plants at							
Soilless system	Slow sand filtration	Addition of antagonists	Inoculation of *P. cryptogea*	1/29		3/16		4/17		5/23	
Closed	Yes	No	Yes	0.0	a[a]	0.0	a	5.6	ab	11.1	b
Open	No	No	No	0.0	a	3.2	ab	5.3	ab	12.6	b
Closed	Yes	*Fusaria*	Yes	0.0	a	0.0	a	0.0	a	1.9	a
Closed	No	No	Yes	0.0	a	7.6	b	9.1	b	22.8	c
Closed	Yes	*Trichoderma*	Yes	0.0	a	0.0	a	0.0	a	2.1	a
Closed	UV	No	Yes	0.0	a	0.0	a	0.0	a	9.0	b

[a]In each column means followed by the same letter do not significantly differ according to Duncan's Multiple Range Test ($P = 0.05$)

Slow sand filtration combined with the application of different antagonistic strains of *Fusarium* spp. and *Trichoderma* spp. proved effective against *Phytophthora cryptogea* in gerbera (Tables 2, 3 and 4) (Garibaldi et al. 2003).

Suppressiveness of reused substrates adopted in soilless cultivation represents a very interesting feature, with many possible practical applications (Clematis et al. 2009). Antagonistic microorganisms, isolated from soilless systems and better adapted to this cultural system, have already been selected and proved effective against Fusarium wilt of rocket (Srinivasan et al. 2009), while strains of *Trichoderma* spp. isolated from soilless systems controlled *Pythium ultimum* on cucumber (Liu et al. 2009). This new development of biological control could also be interesting in the case of ornamentals.

Although interesting for field crops and also for vegetables, the widespread use of organic amendments for disease control is still not being practiced in the case of ornamental crops, due to many factors such as the type of amendments, the lack of standardization, the inconsistency in their efficacy, and the complexity of their use. A gap between good results observed in the laboratory and greenhouse compared to the few promising results in the field is still relevant today, as mechanisms of action are largely unknown and risk for ornamental production is too high compared to other disease control strategies.

5 Substrate and Compost Suppressiveness

Certain soil-borne diseases do not occur or are less severe in some soils that are referred to as suppressive. In many cases, suppressiveness had a microbiological origin that was destroyed by steaming. Some bacteria and/or fungi indigenous in these soils have been shown to be responsible for suppression of Fusarium wilt pathogens. The most efficient were identified as *Pseudomonas* and *Alcaligenes* in the USA and as *Fusarium* spp. in France and Italy. Antagonistic *Fusarium* spp., isolated from the rhizosphere of carnation

Table 3 Effect of the application of selected antagonistic fungal strains into different closed soilless growing systems on the production of flowers per healthy gerbera plant (With permission from Garibaldi et al. 2003)

Treatment				Number of flowers per healthy plant at											
Soilless system	Slow sand filtration	Addition of antagonists	Inoculation of *P. cryptogea*	1/23		2/5		3/1		3/30		4/23		5/10	
Closed	Yes	No	Yes	1.5	a[a]	2.5	a	4.2	a	6.9	a	15.9	ab	17.8	b
Open	No	No	No	1.5	a	2.4	a	4.2	a	7.5	a	12.9	ab	14.8	b
Closed	Yes	*Fusaria*	Yes	1.4	a	2.3	a	4.7	a	7.3	a	10.0	ab	11.8	c
Closed	No	No	Yes	1.2	a	2.1	a	3.6	a	5.7	a	8.4	b	9.4	c
Closed	Yes	*Trichoderma*	Yes	1.7	a	2.7	a	4.9	a	7.6	a	10.5	ab	11.9	c
Closed	UV	No	Yes	1.2	a	2.5	a	8.6	a	14.7	a	22.5	a	28.8	a

[a]In each column means followed by the same letter do not significantly differ according to Duncan's Multiple Range Test ($P = 0.05$)

Table 4 Effect of the application of selected antagonistic fungal strains into different closed soilless growing systems on the production of gerbera flowers/m^2 (From Garibaldi et al. 2003)

Treatment				Number of flowers/m^2 at											
Soilless system	Slow sand filtration	Addition of antagonists	Inoculation of *P. cryptogea*	1/10		2/5		3/1		3/30		4/23		5/10	
Closed	Yes	No	Yes	3.5	a[a]	12.1	a	19.1	A	27.9	a	35.1	a	40.7	a
Open	No	No	No	2.7	a	11.0	a	17.3	A	28.1	a	39.9	a	47.4	a
Closed	Yes	*Fusaria*	Yes	4.2	a	10.8	a	20.4	A	30.3	a	40.8	a	47.8	a
Closed	No	No	Yes	2.6	a	9.0	a	12.3	b	16.6	b	21.5	b	24.0	b
Closed	Yes	*Trichoderma*	Yes	3.3	a	12.3	a	19.5	a	28.2	a	37.4	a	42.0	a
Closed	UV	No	Yes	2.6	a	10.7	a	16.4	a	25.4	a	37.5	a	45.8	a

[a]In each column means followed by the same letter do not significantly differ according to Duncan's Multiple Range Test ($P = 0.05$)

plants grown in suppressive soils, did show high rhizosphere competence as compared with saprophytic nonantagonistic *Fusarium* spp. isolated from the same soils. When applied to soil and substrates they control Fusarium wilts on crops such as tomato, basil, carnation, cyclamen, and bulb crops (Gullino and Garibaldi 2007). Strains of *Trichoderma viride* showed good antagonistic activity against Fusarium wilts and have been used in chrysanthemum. Soils suppressive to *Rhizoctonia solani* are correlated with the presence of large amounts of *Trichoderma* spp. (Chet 1987).

Suppressiveness has also been found for substrates used in floriculture; in this case often microbiological and physical causes co-exist (Pugliese et al. 2015). Sphagnum peat mixes can naturally suppress diseases caused by soil-borne pathogens, but within a few weeks after potting they become conducive to diseases (Hoitink and Boehm 1999). Bacteria and fungi contribute to the suppression of root rots and wilts in peat mixes (Tahvonen 1993). Light peat decomposes in pots during production and the disease suppression effect is lost; amendment of decomposed peat mixes with microorganisms should consider the decomposition state (Hoitink and Locke 2012). Mixing light peat with more decomposed peat, at a 1:1 ratio, provides professional sphagnum potting mixes capable of providing, through suppressiveness, control of soil-borne pathogens for most greenhouse crops (Hoitink and Boehm 1999).

In the case of substrates, when hardwood bark (composted or not) is used, improved plant growth is generally observed, especially in potted plants. Suppressiveness and improved vigor of plants in such bark substrates result from the physical characteristics of bark composts and from higher levels of antagonists supported by these composts (Hoitink and Boehm 1999). Such peat mixes also support well the introduction of biocontrol agents or the addition of composts (Hoitink and Locke 2012).

During the past two decades various composted organic wastes have partially replaced peat in container media used for the production of ornamentals. Recycling of these wastes has been adopted for economic and production reasons. The cost of composts can be lower than that of peat. Production costs may also be decreased because some of the compost-amended media, and particularly those amended with composted bark, suppress major soil-borne plant pathogens, thus reducing plant losses and avoiding the use of fungicides (Hoitink and Boehm 1999). Additional research is showing that the use of composted materials can suppress soil-borne pathogens (Noble and Coventry 2005; Termorshuizen et al. 2006). To improve the consistency of disease control using composts, biological control agents (BCAs) have been added to compost amendments; composts can provide a food base for BCAs of soil-borne pathogens. Results indicate that mixtures of bacterial and fungal BCAs are more effective than single BCAs in inducing suppression of *Rhizoctonia* and *Pythium*. Compost amendments could, therefore, be used in flower nurseries as partial substitutes for peat substrates in the production of ornamentals with consequent advantages in terms of money and production. Growing mixes fortified with *Trichoderma hamatum* 382 controlled Botrytis blight on geranium (Olson and Benson 2006) and begonia (Horst et al. 2005). The same BCA added to potting mixes controlled Fusarium wilt of cyclamen (Hoitink and Locke 2012).

Although composts may not control diseases to a level that will replace the use of fungicides, their integration into current disease management practices may reduce the use of fungicides. This has been shown for instance in the case of suppression of dollar spot (*Sclerotinia homeocarpa*) on turfgrass (Boulter et al. 2002a, b). Increasing the use of compost as a potting substrate for plants would contribute to the recycling of wastes and to reducing the use of nonrenewable fertilizers. Compost is also interesting as a peat substitute, in particular after recent increasing concern about the environmental impact of peat extraction and the damage to peat lands natural habitats by the horticulture industry (Silva et al. 2007). The suppressive capacity of compost against soil-borne pathogens has been demonstrated in several studies leading to greater production efficiency and reduced nontarget effects (Garibaldi 1988; Hadar 2011; Hoitink and Boehm 1999; Hoitink and Fahy 1986; Noble and Coventry 2005). Compost was demonstrated to be the most suppressive material, with more than 50% of cases showing effective disease control, compared to other amendments such as crop residues and peat (Bonanomi et al. 2007). In container experiments using soil or sand, compost derived from green wastes and/or dairy cow manure generally showed a suppressive effect on *Pythium* species and *Rhizoctonia solani,* but the results did not necessarily translate into the field (Noble and Coventry 2005). Compost suppressiveness was dependent on the type of wastes used. Low rates of compost in growing media are generally indicated in order to avoid negative growth effects and phytotoxicity caused by high pH and electrical conductivity and other phytotoxic compounds present in composts (Sullivan and Miller 2001). However, it is generally necessary to include at least 20% v/v of compost in containers in order to observe a suppressive effect. Cases of increase of disease severity caused by composts used in containers have also been reported. A 50% spruce bark compost increased black root rot caused by *Thielaviopsis basicola* in poinsettias and Fusarium wilt of cyclamen, compared to a peat substrate (Krebs 1990). Highly saline composts were reported to enhance Pythium and Phytophthora diseases, while composts with higher nitrogen or ammonium content enhance Fusarium wilts (Hoitink et al. 2001). Among soil-borne pathogens, *Rhizoctonia solani* is considered to be the most difficult one to control with compost (Bonanomi et al. 2007; Scheuerell et al. 2005). Variability also depends on the pathosystem (Termorshuizen et al. 2006). Success or failure of compost for disease control depends on the nature of the raw materials from which the compost was prepared, on the composting process used, and on the maturity and quality of the compost (Termorshuizen et al. 2006). Control of soil-borne diseases with organic amendments must be viewed not as a stand-alone management approach but rather as part of a systems approach where several aspects of the impact of crop production practices on resident soil microbial communities are addressed. New approaches to monitor how microbial community structures in soil change as a result of organic amendment may lead to a better understanding of which changes in microbial communities are responsible for conferring the disease suppressive effects. This may eventually lead to improved and more reliable disease control resulting from organic amendment of soil, sand, or peat, both in container crops in greenhouses and in the field.

6 Concluding Remarks

Monitoring the environment and controlling it to keep plants disease-free has become a fundamental part of greenhouse management. Once the environmental parameters that influence pathogens and biocontrol organisms are understood, they can be more precisely regulated. Because of differences in climate, some of these strategies can be more easily and effectively applied in countries where greenhouses are more sophisticated. For instance, in Europe the structures most adapted to environmental control are located in the northern countries: under such conditions the adoption of proper techniques very often permits reduction of the severity of most foliar diseases.

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