we find ourselves putting on the drip irrigation three times a day. Working on the theory of a little and often. If we give them just one long blast of water then we find the water just runs out of the bottom of the pot and is wasted. Staff personnel include a mixture of full-time college-educated nursery people, students, part-time labor, and press-ganged family.

LITERATURE CITED

Dunn, N.D. 1995 The use of hot callusing for bench grafting. Comb. Proc. Intl. Plant Prop. Soc. 45:139.

Control of Botrytis During Plant Propagation

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INTRODUCTION

Diseases caused by species of *Botrytis* (Table 1) are probably the most frequent and widely distributed diseases of nursery plants, with *B. cinerea* being the most common. Symptoms of *Botrytis* diseases generally appear as blights or rots of various plant tissues. Under humid conditions the characteristic gray cottony sporulating mycelia appears, thus the common name of gray mold. In addition, symptoms can consist of leaf spots and cankers. Diseases caused by *B. cinerea*. are also some of the most difficult diseases to control due to the pathogen's prolific asexual reproduction, ability to survive as a saprophyte, and the continuos susceptibility of plants to infection.

PATHOGEN BIOLOGY

Botrytis spp. have an extremely complex life cycle (Fig. 1) that involves sexual and asexual reproduction, and the abilities to survive indefinitely as a saprophyte on organic material, to remain latent on infected plants, and sporulate at any point in its life cycle. In addition, *Botrytis* spp. are extremely genetically variable due to multinucleate hyphae and spores, the heterokaryotic (both male and female) nature of some strains, and sexual recombination. However, *Botrytis* spp. tend to be weak pathogens, usually requiring an exogenous nutrient source (e.g., insect frass, senescent tissue, wounds, etc.) or a compromised host for successful infection.

Dispersal is mainly through the dissemination of airborne conidia from sporulating mycelia. Dispersal can also occur through ascospores, dispersion of infected debris, insects, and mechanical transmission. Conidia are released during rapid changes in relative humidity accompanied by air movement or water splashing. Generally, peak spore release is associated with activity in the greenhouse (e.g., watering plants, moving plants, leaf removal, etc.). Once released, conidia land on plant tissues where they can remain dormant or germinate if conditions are favorable. They require RH > 93% or free water and an exogenous nutrient source to germinate. Germination can occur between 32 and 79°F, with an optimum of 68°F for *B. cinerea*. Infection and disease development can occur at 32 to 95°F.

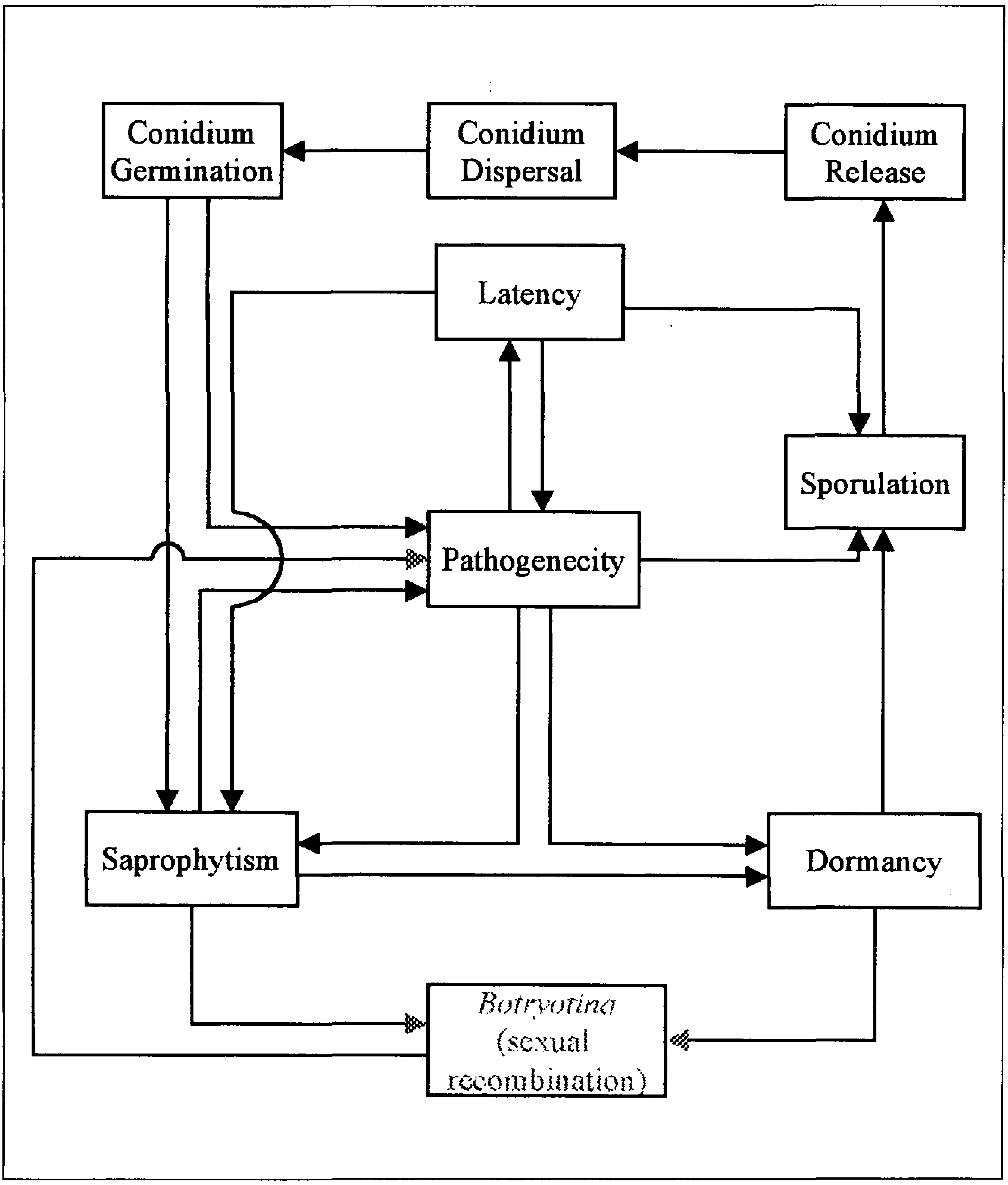

Figure 1. The life cycle of *Botrytis* species. The principle means of *Botrytis* survival and dissemination is in bold. The conidium is an asexual spore. Saprophytism is the growth and survival on dead organic material. Pathogenecity is when *Botrytis* has infected plant tissue but symptoms may or may not be visible. Latency is a state where the pathogen is either no longer actively growing in the infected plant tissue or there no symptoms expressed.

At any time during the infection process *Botrytis* can enter a state of latency where the pathogen no longer grows. The cause of latency is not understood but is thought to be associated with plant susceptibility or changes in environmental conditions.

PREDISPOSITION

Numerous factors can predispose plants to infection by *Botrytis* (Table 2), the most important being senescent tissue and wounds. Nutrients that become available on

Table 1. Species of *Botrytis* and major host plants[1].

Botrytis species	Hosts
B. allii, B. sphaerosperma	*Allium* spp.
B. anthophila, B. spermophila	*Trifolium* (clovers)
B. cinerea	most dicotyledons, many monocotyledons, and some Pteridophyta
B. elliptica	Lily
B. fabae	Leguminosae
B. tulipae	Tulips
B. narcissicola, B. polyblastis	Narcissus
B. paeoniae	Peony
B. gladiolorum	Gladiolus
B. convoluta	Iris

[1]Host range of individual *Botrytis* species is not always exclusive of other taxa.

Table 2. Factors that predispose plants to infection by *Botrytis*.

Plant fertility
Low calcium, phosphorus, or potassium increases susceptibility
Ammonium nitrogen increases susceptibility compared to nitrate nitrogen
Keep fertility in balance so plant sugars stay in balance (<50% total carbohydrates) to dry weight

Nutrients on leaves
Pollen, insect frass, other organic compounds

Fungicide applications
Zineb increases sugar exudation and stimulates mycelial growth

Leaf damage
Insect feeding, mechanical, chemical or salt/fertilizer burn,

Wounds

Water stress (either too much or too little)

Low light

Senescent tissue

Temperature (cold or heat) injury

senescent tissue and wounds stimulate germination of *Botrytis* and serve as an energy reservoir to infect healthy tissue. Thus, measures that reduce the presence of senescent tissue and wounds greatly reduce *Botrytis* infections. Fertility management is another critical factor that can predispose plants to infection by *Botrytis*. Plants need a balanced fertility program such that nutrients are neither in excess or deficient. Nutrients of particular concern are N, P, K, Mg, and Ca.

CONTROL MEASURES

No one control measure is going to give effective control of *Botrytis* diseases during plant propagation. Control will be dependent on the integration of cultural methods, pesticide (biological or chemical agents) applications, and environment control into a holistic management system so that many pathways of the life cycle are disrupted. An example system is presented in Table 3.

Cultural Control. Cultural control of *Botrytis* is mainly through sanitation and the manipulation of environmental parameters. Use of resistance varieties, fertility management, keeping mother plant's architecture open, placing a physical barrier (e.g., a white plastic disk) on the soil surface to prevent leaf contact, are also useful cultural control measures.

Sanitation consists of roguing infected and senescing plant tissue and removing plant debris from on and under benches. Rogued material should be disposed of immediately into covered containers. This material should then be burned or moved off site. Do not have cull piles near air intakes or doors for the greenhouse. The use of clean propagation media and source material are also part of the process.

Preventing latent infections in mother plants and plants placed in cold storage should be a major focus during their production. All of these sanitation practices attempt to reduce the *Botrytis* spore load in the greenhouse, and thus reduce chances for infection.

Environmental parameters can be manipulated in order to reduce the ability of those *Botrytis* spores that do land on susceptible tissue to infect. The relative humidity, temperature, and light can be manipulated to make the greenhouse environment less favorable for *Botrytis* infections.

Relative humidity within the plant canopy should be maintained below 90%. This can be accomplished through plant arrangement (adequate spacing and orient rows parallel to air currents), ventilation, heating of the house at critical times (sunset), avoiding overhead irrigation or irrigating at times when free water on leaves does not dry quickly, and maintaining good air circulation. Air circulation is used to reduce humidity in the canopy and homogenize air temperature within the greenhouse. Care must be taken to ensure that the leaf flutter is minimized so that mechanical damage to leaves does not occur.

Temperature should be adjusted to optimize growth of the plants without respect to what temperature is favorable to *Botrytis*. Temperature fluctuations should be avoided and the night time cooling should be minimized to reduce the probability of dew forming on leaves or increasing humidity. An alternative to raising the temperature at night would be to increase other measures to reduce humidity (i.e., ventilate and heat for a few hours at sunset).

Light intensity and wavelength can be manipulated in order to reduce infection of *Botrytis* either directly or indirectly. Greenhouse covers that block ultraviolet light

Table 3. An example of an integrated *Botrytis* management system for mother plants and cuttings.

Mother Plants
General
Keep humidity below 90% and foliage dry
Force air heating under bench
Drip irrigation
Air circulation
Space between plant
Open plant architecture
Vent and heat house around sunset
Harvesting
Rogue infested material 24 h before harvest
Take cuttings in the morning before house heats up and humidity drops
After Harvesting
Reduce humidity to < 60% for 24 h
Apply a control measure immediately after completed harvesting
Maintain optimum fertility
Plastic shield covering soil in pots
Rogue diseased and senescent tissue
Control insects
Cuttings
Steam clean propagation bench and any area cuttings will be handled
Allow cuttings to dry before placing under mist
If cutting will survive, heat treat by dipping into 122°F water for 20 to 40 sec.
Daily rogue infected cuttings
Treat with control measure immediately after harvesting or sticking.
Keep cuttings from different days or hosts with different susceptibilities separate

enhance the blue/UV ratio that inhibits sporulation by *Botrytis*. While this effect can result in an 80% reduction in sporulation, there is a high degree of variability among *Botrytis* isolates. A more practical approach is the use of long-wave infrared absorbing coverings which help to hold heat inside the greenhouse during the night, thus reducing changes in relative humidity.

Chemical Control. There are numerous fungicides available for application to ornamental and nursery crops, however, resistant *Botrytis* populations have also been developed (Table 4). Chances are that if you have been using a compound for several years without rotation resistance has developed and you should choose a compound from a different fungicide class.

Effective use of chemical pesticides depends on the thorough coverage of plant tissue, particularly within the plant canopy. These tissues are probably more susceptible to infection due to the presence of debris of the leaf surface and senescing tissue. In order to manage resistance development, it is extremely important to use mixtures (preferable) or rotate with different classes of chemicals. Some pesticides on the market are ready mixes of two different fungicide classes (e.g., Benefit, Duosan). Alternating or mixing chemicals when you have a population that is resistant to one of the compounds does little to reduce resistance build-up, since you will be selecting for a population that is resistant to both compounds. Once resistance to a compound is present, there is little utility in continuing to employ that compound in your management program. There are some laboratories that will test *Botrytis* isolates for resistance to pesticides (e.g., Plant Disease Clinic, Oregon State University).

Biological Control. The use of biological control agents in the production of ornamental and nursery crops is gaining strong interest due to improved efficacy and reduced re-entry intervals (usually < 4 h). However, the effective utilization of

Table 4. Fungicides[1] labeled for use against diseases caused by *Botrytis* on ornamental and nursery crops in the United States[2].

Class	Common	Trade Name Examples	Resistance
Aromatic hydrocarbons	DCNA or Dichloran	Botran	No
Chloronitrile	Chlorothalonil	Daconil, Exotherm Termil	No
Benzimidazole	Benomyl, Thiophanate-methyl	Benlate, Cleary's 3336, TopsinM	Yes
Dicarboximide	Iprodione, Vinclozolin	Curalan, Chipco Ornalin, Touche	Yes
EDBC's ethylenebis-dithiocarbamates	Mancozeb Maneb	Dithane, Manzate 200, Maneb	No
EBDC-like	Ferbam, Thiram, Ziram	Ferbam, Thiram, Granuflo	No
Fatty Acids	N-alkyl fatty acids	Physan, Triathlon	No
Hydroxyanilide	Fenhexamid	Decree	Yes
Inorganic compounds	Copper hydroxide	Kocide, Champion,	No
	Copper Sulfate	Phyton	No
	Sulfur	Sulfur, Mylox	No
	Sodium bicarbonate	Armicarb	No
Oils	Petrolium distillate	JMS Stylet Oil	No
Phenylpyrroles	Fudioxonil	Medallion	No
Phthalimides	Captan	Captan	Yes
Other	PCNB	Terraclor, TurfPro	No

[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of the products or vendors that may also be suitable.

[2] Legal uses of many pesticide are constantly changing, therefore always obtain and read a current table prior to using a product.

Table 5: Biological control agents for *Botrytis* registered by the U.S. Environmental Protection Agency for application to ornamentals in the United States.

Common Name	Organism and Strain	Target	Use	Company
Mycostop	*Streptomyces griseoviridis* strain K61	*Fusarium* spp., *Alternaria brassicola*, *Phomopsis* spp., *Botrytis* spp., *Pythium* spp., and *Phytophthora* spp.	Can be applied as seed treatment, transplant or cutting dip, and soil spray or drench.	AgBio Development Inc. Westminster, CO Tel: 303-469-9221 Fax: 303-469-9598
Prestop	Gliocladium catenulatum strain J1446	*Alternaria*, *Botrytis*, *Cladosporium*, *Didymella*, *Fusarium*, *Helminthosporium*, *Pencillium*, *Plicaria*. *Pythium*, *Phytophthora*, *Rhizoctonia*, and *Verticillium*.	Can be applied as seed treatment, transplant or cutting dip, and soil spray or drench.	AgBio Development Inc. Westminster, CO Tel: 303-469-9221 Fax: 303-469-9598
TopShield	*Tricoderma harzianum rifai* strain KRL-AG2	*Botrytis*	Foliar spray with a surfactant	BioWorks Geneva, NY Ph: (315) 781-1703 Fax: (315) 781-1793

[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of the products or vendors that may also be suitable.

[2] http://www.bioworksbiocontrol.com

Table 6: Biological control agents for *Botrytis* that should be registered by the U.S. Environmental Protection Agency for application to ornamentals in the near future.

Common Name	Organism and Strain	Target	Use	Company
Serenade[1]	*Bacillus subtilis*	Botrytis, powdery mildews, downy mildews, *Alterneria* spp., Fire blight, *Xanthomonas* spp.	Foliar Spray	AgraQuest Davis, CA Ph: (530) 750-0150 Fax: (530) 750-0153 www.agraquest.com

[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of the products or vendors that may also be suitable.

biological control agents does require special knowledge and a different mind set toward plant production.

Biological control is the suppression of disease through the manipulation or use of one or more organisms other than humans. The basic tenant of biological control is that a balance between the host plant and potential pathogens must be maintained such that the growth of the pathogen is not favored. This balance is dependent on the establishment and maintenance of a stable microbial community. One means of developing a beneficial microbial community is through the introduction of biological control agents. Currently, there are only two commercial products that are EPA-registered to control *Botrytis* on ornamental and nursery crops (Table 5). However, there are a few other products near registration (Table 6) and many more being developed.

Biological controls can control *Botrytis* by secreting antimicrobial compounds that inhibit or kill *Botrytis* mycelia or spores, competing for nutrients to prevent germination or growth, induce plant resistance, or directly parasitize and feed on *Botrytis* mycelia or sclerotia. Therefore, most biological control agents should be applied as protectants before symptom development. Resistance development to most biological control agents is generally not a concern, since most operate by multiple mechanisms. However, resistance might develop to biological control agents that mainly operate by production of antibiotics.

THE FUTURE

The control of plant diseases is entering a new era. We are no longer looking at each production problem as an isolated entity but are realizing that every management decision influences whether disease will develop and impacts which control measures should be implemented. We have begun to look beyond the short-term gains of the amount of marketable-product produced, to long-term sustainability and profitability. In essence, growers are becoming ecosystem managers. When using this approach, we must remain aware of the most basic concept of ecology. A stable ecosystem is a diverse ecosystem, where diversity implies that all components are interacting. Thus, when making disease management decisions, we must think in terms of integrating multiple measures to create a stable control system. This integration will include the implementation of appropriate cultural practices along with judicious use of chemical and biological controls. The effective management of *Botrytis* diseases requires such an approach.

FURTHER READING

Hausbeck, M.K. and **G.W. Moorman.** 1996. Managing *Botrytis* in greenhouse-grown flower crops. Plant Disease 80:1212-1219.

Jarvis, W.R. 1992. Managing diseases in greenhouse crops. APS Press, St. Paul, MN

Mahaffee, W.F. Biological Control. (in press) In: R. Jones. and D.M. Benson. (eds.), Diseases of woody ornamentals in nurseries. APS Press, St. Paul.