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Current and Future Research Directions of Ornamental Pathology

The ornamental horticulture industry in the United States comprises diverse plant groups, including bedding plants, bulb crops, floriculture crops (cut flowers and pot plants), foliage plants, bare root and container nursery crops, and plants in the landscape (Fig. 1). Each of these is viewed as an individual market segment. Accurate information on the value of the ornamental industry is difficult to obtain. According to USDA crop report data, the estimated value of the ornamental industry in 1986 was $3.94 billion (Table 1). Others have estimated that the value of the floricultural industry alone is in excess of $3 billion (10,17).

This paper has its origin in a discussion session sponsored by the Diseases of Ornamental Plants and Turfgrass Committee held at the 1986 APS annual meeting. The purpose was to identify new production trends, the most important diseases, and areas of research important for the future of each segment of the ornamentals industry. The information presented at the discussion session and in this paper represents the authors' summary and analysis of information obtained through contacts and discussions with their colleagues across the United States in 1986.

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Bedding Plants

The production of bedding plants is a thriving component of the ornamental industry, with 3.5 billion plants produced annually in the United States. This crop comprises a wide variety of seed-propagated species, including annual and perennial flowers, vegetables, and herbs, as well as geraniums and other plants grown from cuttings. The five best-selling plants during 1985 were impatiens (*Impatiens wallerana* Hook. f.), petunias (*Petunia* × *hybrida* Hort. Vilm.-Andr.), marigolds (*Tagetes patula* L. + *T. erecta* L.), tomatoes (*Lycopersicon esculentum* Mill.), and geraniums (*Pelargonium* × *hortorum* L. H. Bailey) (19).

Bedding plants have traditionally been direct-seeded into trays or flats, then transplanted later into packs for sale. A high level of new technology has been introduced to the industry. Over 40% of bedding plants are now produced as "plugs," in a highly efficient, mechanized system (2). Plug flats have up to 648 tiny

Fig. 1. The ornamental horticulture industry comprises diverse plant groups. The ultimate use of many of these plants is in the landscape.

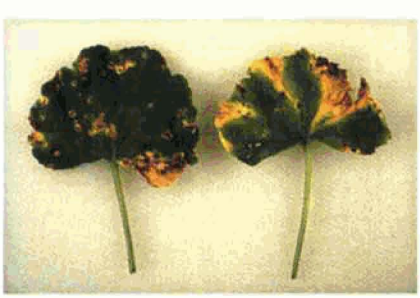

Fig. 2. Quality control problems associated with the delivery of blight-free cuttings to greenhouse growers has resulted in increased concern about bacterial blight of geranium.

cells, each containing as little as 1 cm^3 of growing mix. Seed propagation specialists produce seedlings in these plugs and sell them to other growers for transplanting and finishing. Plug production may involve the use of seeding machines, conveyor belts, automatic flat fillers, automatic watering systems, and transplanting machines. However, while bedding plant production systems are becoming increasingly modernized, it appears that many "old-fashioned" diseases still plague the growers. Profitable plug production requires a high degree of crop uniformity and crop quality; even a low percentage of disease is unacceptable.

The major disease problems affecting bedding plants are damping-off caused by *Rhizoctonia solani* Kühn and *Pythium* spp. and Botrytis blight caused by *Botrytis cinerea* Pers. ex Fr. Each of these organisms affects a wide range of plant species.

To eliminate the threat of damping-off, integrated control or management systems need to be developed or better adapted. The plug production system is very new; not only do we not have the cultural factors, such as mix, fertilizer, and irrigation, worked out, we do not have knowledge of the proper fungicide rates for the low soil volumes in plug tray compartments. Improved delivery methods for fungicides should be developed, perhaps focusing on development of formulations comprising tiny particles that will distribute evenly in plug trays. The potential role for use of bioantagonists such as *Gliocladium* and *Trichoderma* spp. in the growing mix or as a seed treatment is very promising (14).

Bacterial blight of geranium (Fig. 2), caused by *Xanthomonas campestris* pv. *pelargonii* (Brown) Dye, is a serious problem needing research leading to effective control. Because of its high potential for spread and damage, there is a zero tolerance for this disease in stock production programs. Many of the stock production systems, as they are being practiced today, are not delivering blight-free cuttings to the greenhouse growers. Research is needed to develop cultural, biological, or chemical controls, or combinations of these, that could help eliminate this disease problem from geranium production.

Seed pathology is another area of bedding plant culture needing research. Many common pathogens, such as *X. campestris* pathovars on tomato and zinnia (*Zinnia elegans* Jacq.), are seed-transmitted. Research within the seed industry should be focused on mechanisms or systems to effectively eliminate

Table 1. Wholesale value of ornamental crops and major production areas in the United States in 1986

Crop segment	Value (million $)	Major production areas
Bedding plants[a]	547.1	Michigan California Ohio Florida Pennsylvania
Bulb crops[b–d]	57.8	Florida Washington Oregon California
Floriculture crops[a]		
Cut flowers	359.1	California Florida Colorado
Pot plants	386.3	California Pennsylvania Ohio
Foliage plants[a]	515.4	Florida California Texas Hawaii
Nursery crops[e]	2,080.0	California Michigan Ohio Texas Pennsylvania

[a] Floriculture crops, 1986 summary, USDA.
[b] Floriculture Agriculture in the 80's. 1983. Ornamental Horticulture Floriculture Committee Report, University of Florida, Gainesville.
[c] Trippi, J. 1986. Melridge Inc. flowers into rapid expansion. The Oregonian, 22 June 1986.
[d] Washington State Bulb Commission.
[e] Research summary, Scope IV of the Nursery Industry. 1982. Horticultural Research Institute, Inc., Washington, DC. 19 pp.; USDA, 1985.

Fig. 3. Viruses are being controlled in commercial production by the use of tissue culture and clean stock programs. (A) Flowers on a healthy lily plant and (B) flowers on a plant infected with lily symptomless virus and tulip breaking virus. (Courtesy R. S. Byther)

pathogens from seed sources. Biological or chemical treatments, combined with effective cultural management systems, should be developed for both seed and seed crops.

Additional needs and concerns of horticulturists and pathologists include: 1) improving the understanding of the host range and vectoring of tomato spotted wilt virus by the western flower thrips, now widely distributed and resisting control efforts in greenhouses throughout the United States; 2) fine-tuning the environmental management schemes for control of Botrytis blight; 3) defining the role of fungus gnats in the spread and development of bedding plant diseases; and 4) determining whether bedding plants treated chemically to suppress disease will later develop symptoms in the landscape.

Bulb Crops

Bulb and corm production in the United States is centered in Florida, Washington, Oregon, and California. The largest single producer of flower bulbs in the world is located in western Washington State. Crops include *Gladiolus, Caladium, Narcissus, Iris*, lilies (*Lilium* spp.), and tulips (*Tulipa* spp.).

Patterns of bulb sales for production of cut flowers, pot plants, and garden uses have changed rapidly during the last 5 years. Export demand for U.S. bulbs has decreased while domestic cut flower consumption has increased. Domestic forcing under glass has become increasingly important, and a major portion of the foundation stock produced by Washington growers is now used for the domestic cut flower market.

The lily crop in the United States comprises Easter lily (*L. longiflorum* Thunb.) and Asiatic hybrid lilies. In the mid 1960s, lily bulbs from Asiatic hybrid lilies, hybridized and grown in Oregon, became the source of foundation stock for development of a major cut flower export industry from the Netherlands to other areas of Europe and the United States. In 1985, U.S. importation of Asiatic hybrid lilies had increased to 32 million stems.

Many of the disease problems affecting bulb crops have not been completely controlled. As the nature of the culture and markets change, however, the relative importance of the disease problems also may change. For example, while soilborne fungi, including *Fusarium, Pythium, Rhizoctonia, Sclerotinia*, and *Phytophthora*, remain important problems in field culture of lilies, new tissue culture technology and propagation may significantly change the relative importance of these pathogens. The Easter lily may now be produced from a leaf explant to a flower in 1 year, without a dormant bulb stage, in a protected environment on a raised bench (18).

Development of virus-free Easter lilies, Asiatic hybrid lilies, bulbous iris, gladiolus, and caladium, with subsequent increases in bulb production and improved flower quality, has also been accomplished in tissue culture (Fig. 3). The most important disease of caladium is caused by dasheen mosaic virus (DMV). R. D. Hartman and F. W. Zettler at the University of Florida, Gainesville, have produced plants free from DMV and have shown that if the clean stock is isolated, DMV infection can be controlled (21,22). Although significant accomplishments have been made on the development of clean stock in tissue culture, additional research is required to determine how to reduce levels of reinfection by viruses, particularly aphid-transmitted viruses, when infection pressure from adjacent growing areas cannot be avoided. Some use has been made of protective oil sprays in the field to reduce the rate of infection. With some bulb crops, however, research is needed to determine periods of transmission to minimize the number of applications of protective oils, which can be phytotoxic. In the future, field exposure of virus-free plants may be minimized by growing stocks in protected structures during the buildup phase.

Other areas of research on bulbs, and application of the results, will be influenced by economic and market factors. For example, the use of the product as either a dry bulb or a cut flower in a foreign or domestic market will largely determine priorities for disease control. Some areas where greater research effort will be needed in the future include:

1. *Virus identification.* Limited information is available on the identity, impact, spread, and importance of the viruses in domestic and imported bulbs.

2. *Economic impact.* The economic impact of control strategies is not well understood. Although information is available on control of fungus and nematode diseases, many growers do not follow the control recommendations. For example, the effectiveness of fungicide dips for control of basal rot drops off significantly if stocks are not dipped within 48 hours after digging. Although most growers use fungicides for basal rot, the bulbs are usually not treated at the proper time.

3. *Pesticide use concerns.* Fungicide resistance in the field and greenhouse as well as potential groundwater contamination are major concerns. The use of pesticides may be restricted further because of problems associated with crop rotation.

4. *Genetic manipulation.* Identification, selection, and development of disease-resistant cultivars could significantly reduce the impact of several major diseases of bulb crops.

Floriculture Crops

Cut flowers. The major cut flower crops in the United States today are carnation (*Dianthus caryophyllus* L.), chrysanthemum (*Chrysanthemum* × *morifolium* Ramat.), and rose (*Rosa* spp). Other important minor crops are *Eustoma grandiflorum* (Raf.) Shinn., Peruvian lily (*Alstroemeria* spp.), statice (*Limonium* spp.), *Gerbera jamesonii* H. Bolus ex Hook. f.), snapdragon (*Antirrhinum majus* L.), and *Freesia* spp. There has been recent interest in exploiting cuts in *Liatris* spp., *Anemone* spp., and sweet William (*Dianthus barbatus* L.).

The most important production diseases are those induced by the vascular wilt pathogens, such as *Fusarium oxysporum* f. sp. *dianthii* (Prill. & Del.) Snyd. & Hans. and *Phialophora cinerescens* (Wr.) Van Beyma of carnation (3,6). The initial worldwide spread of these diseases was due to contamination associated with vegetative propagation material (6). Ground beds predominate in many cut flower production farms. Once introduced, vascular wilt pathogens are difficult to eradicate even when the beds are steamed and/or fumigated. Pathogen-free propagation programs are routinely employed, especially for carnations and chrysanthemums (Fig. 4), so problems usually occur from reinfestation at the production level. A solution may be through breeding new cultivars with tolerance or resistance (3). Unfortunately, currently available resistant cultivars seldom approach the quality and yield of the more traditional clones. Even so, an integrated approach that includes the use of biocontrol agents may have potential and is a fascinating area for basic and applied research.

Some well-known diseases continue to be of importance, in spite of recent introductions of fungicides effective for control. For example, powdery mildew of rose continues to be a troublesome and costly disease, and Botrytis blight of statice is so destructive that it is often a limiting factor in cut flower production (11). Botrytis blight is a threat to all phases of postharvest handling, shipping, and storage on any cut flower.

Virus diseases may occur sporadically but usually are reduced or eliminated by replanting with healthy propagative material (e.g., 16). Problems arise, however, in meeting the health-certificate requirements of foreign nations when propagative material is to be transferred. Traditional diagnostic procedures related to bioassay, serology, and electron microscopy (e.g., 8) may not be sufficient to completely meet certificate approval and are costly. Research is needed to help develop accurate, rapid, and cost-effective detection methods.

Foliar diseases may be difficult to control in covered structures even if effective fungicides are available.

Greenhouse environments can be extremely conducive to diseases such as rose powdery mildew and Botrytis blight. Research is needed to identify and quantify environmental components and to determine how they can be manipulated to control specific foliar diseases. Some growers have been reluctant to manage environment in this era of high energy costs. However, a recent cost analysis suggests that management of excessive humidity can be achieved for $0.059/m^2 of greenhouse space based on need for 150 days per year (4). More research into integrated disease control, combined with cost-benefit analysis, could have a significant beneficial effect on greenhouse culture.

In cases such as advanced carnation culture, research has resulted in healthy, commercially grown crops. Floriculture disease research can contribute to making U.S. products more competitive with imported products. To meet such competition, domestic growers must produce both high yield and high quality per unit of area. Research on floriculture has long since established maximum yield parameters based on environmental control and cultural procedures. Even so, there is evidence that the maximum genetic potential for growth has not yet been achieved—and this is where the plant pathologists can contribute. For example, apparently healthy plants may be reduced in growth by so-called minor root pathogens (e.g., some *Pythium* spp.) that decrease water and nutrient uptake. By controlling these pathogens, increased vigor and growth of carnations have been achieved so that increases from 20 to 60 flowers/m^2/year have been achieved from soil applications of ethazol or metalaxyl after steaming (7). This treatment cost approximately $0.86/m^2 but resulted in an increased income of $3.20–$9.60/m^2 annually in commercial greenhouses. Attainable yield may have been reached, but is it absolute? Some rhizosphere-competent biocontrol agents are potentially capable of producing growth-stimulating factors where they can be absorbed by the root tips (20). Such a response could make biocontrol agents in the floriculture industry even more cost-effective than conventional fungicidal protectants.

Pot plants. Numerous plant species are offered by the floriculture pot plant industry in the United States. The four major crops are poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch), chrysanthemum, geranium, and Easter lily. There are many "minor" ones, e.g., *Fuchsia*, cineraria (*Senecio* × *hybridus* (Willd.) Regel), gloxinia (*Sinningia speciosa* (Lodd.) Hiern), *Cyclamen* L., African violet (*Saintpaulia* H. Wendl.), and New Guinea impatiens. This industry is changing, and consideration of the research needs of the future for pot plants requires an understanding of the direction of these changes. Key trends (15)—recognizing that they are trends and that circumstances may change or reverse them—include:

1. The nature of the industry is international. Unrooted vegetative cuttings for pot plant production are now imported in significant numbers, and known systemic bacterial, fungal, and viral pathogens are imported with them.

2. Production of floriculture crops in the future will be market-directed, rather than production-directed. That is, products will move at all levels in the marketplace on the basis of diversity and quality as perceived by increasingly sophisticated consumers. Production efficiencies will be geared primarily to quality and secondarily to quantity.

3. Consumer demand for floricultural products in the United States is diversifying and growing. It will continue to grow in the coming decade but, given current trends, a major portion of this increased demand may be met by imports.

4. Information pertaining to the production of floriculture products, particularly flowering pot plants, will be more important to profits than the product itself. Consider the culture-indexed, virus-indexed, horticulturally select vegetative cutting now widely available in the marketplace. The cutting itself has value, but profits earned from it will depend on the information that will maximize its growth potential and its quality "on the shelf."

5. To remain competitive, production of floriculture crops has become "high tech," and future success in the world market will depend on "fast," highly mechanized, and computerized growing systems, supplied with "pathogen-free" plants suited to such systems.

6. Differences in production techniques and production operations for pot plants grown from seed, tissue culture, and vegetative cuttings will decrease. The industry will deal in terms of "propagation units" or "propagules," all of which must be indexed to be free from plant pathogens. Propagules will tend to equalize in terms of cost and value irrespective of whether they are derived from seed, tissue culture, or vegetative cuttings.

7. Finally, the industry will continue to segment into producers of "young plants" (specialist propagators), "prefinished plants," and "finished, flowering pot plants" (Fig. 5). Producers of young and prefinished plants will continue to grow in size and decrease in number. Finishers will be size-independent and will vary from small producers serving local markets to large producers specializing in regional, national, and perhaps international markets.

The overall approach to the control of diseases of flowering pot plants must continue to be based on a pathogen-free production concept (5) because the production system being put into place in response to market-directed criteria will not tolerate the introduction of plant pathogens. A high priority should be placed on production of propagating materials free from root, basal stem, and systemic pathogens. Continued research should emphasize: 1) the etiology of new and introduced diseases, 2) indexing techniques and technology to significantly improve the probability of pathogen detection, and 3) multiplication systems designed to increase indexed propagules while minimizing both horticultural variation and the probability of pathogen introduction. Priorities should be given to diseases caused by viruses, viroids, mycoplasmalike organisms, and rickettsia-like bacteria.

The use of pathogen-free growing materials (soil mixes, pots, containers, benches, etc.) will continue to be important in the management of these diseases. Steam treatment of all growing materials remains the best procedure for the pathogen-free production of pot plants. Further attention should be directed to development of these nonchemical techniques and technologies, to make them better suited to "state-of-the-art" production systems.

Sanitation will continue to be emphasized. Research on techniques and biocides that will reduce the probability of the introduction of root, basal stem, and/or vascular wilt pathogens into pathogen-free production systems is also needed. Priority should be given to water quality (specifically related to pathogen contamination), nonspecific erwinias and pseudomonads, specific soil biocides that can be applied through automated irrigation systems without hazard to the environment and without inducing pathogen resistance, and the development of broad-spectrum disinfestants that are active in the presence of organic matter but nontoxic to humans or plants.

The new, highly capitalized, sophisticated facilities now being utilized for flowering pot plant production have also opened new opportunities for the control of leaf, stem, and flower diseases. These facilities include mechanized, computer-regulated growing systems; low-cost heating systems that include overhead radiant heating as well as on-bench and under-bench heating; glazing materials that provide for the differential transmission of radiant energy; computer-regulated fogging, misting, and irrigation systems; computer software for the prediction of epidemic outbreak of leaf, stem, and flower diseases and for the modification of the environment to reduce the epidemic potential; and the potential for the mechanized and computerized application of biocides. High priority, thus, should be given to innovative studies on the epidemiology and control of the leaf, stem, and flower diseases of pot plants (particularly Botrytis blight, powdery mildew, and bacterial leaf spots) that will utilize these technological advances.

Finally, even though the number of pot plant species and cultivars commercially produced in the United States is large, and although the number of diseases of these is also large, the development of resistant species and cultivars using genetic engineering techniques certainly merits high priority for research.

Foliage Plants

Approximately 500 species of plants are being grown and sold as foliage plants or as cut foliage, with new species or cultivars constantly being introduced into the trade. The more important species belong to 13 plant families (9), but for practical reasons our survey was limited to six families: Araceae, Palmae, Araliaceae, Agavaceae, Moraceae, and Polypodiaceae. Numerous popular and therefore economically important species are included in the first three families.

Etiology of foliage plant diseases generally seems to be understood, but there are problems of unknown or complex etiology that critically need resolution. The most common disease problems are soilborne diseases of Araceae, Palmae, and Polypodiaceae and aerial diseases of Palmae and Agavaceae. The soilborne pathogens include, in descending order of importance, *Pythium* spp., *Rhizoctonia* spp., *Phytophthora* spp., and *Fusarium* spp. Important causes of aboveground diseases include *Xanthomonas* spp., *Colletotrichum* spp., and *Erwinia* spp.

An important research need appears to be improved diagnostic methods for common pathogens. Field diagnosis is not sufficient to identify the nature or cause of diseases, and classic isolations or simple laboratory tests are effective but slow. Thus, new information for detection techniques or procedures may not be critical but does warrant some long-term, in-depth study, particularly for diagnosing soilborne diseases of ferns and aerial diseases of palms. Also, while the epidemiology or mode of spread of many important diseases is generally understood or surmised, there is need for epidemiological research into soilborne diseases of Araceae and ferns and for aerial diseases of Agavaceae, Palmae, and Araliaceae.

Chemical usage accounts for approximately 90% of the control practices, with the balance consisting of cultural or biological control methods. These estimates apply to both soilborne and aerial diseases. There is a critical need for new disease control information, particularly for aerial diseases of palm, and for improved control practices for other plant groups. Also, there is a need for research to aid registration of chemicals effective against soilborne diseases of aroids and aerial diseases of aralioids. Although newly introduced cultural practices, such as tissue culture, have provided significant disease control in some cases, they have also introduced new problems or increased severity of other problems in other instances.

Compared with the production of flowering ornamentals, the science of producing foliage ornamentals is in a very early developmental stage, and efforts to obtain information about specific host-pathogen interactions are complicated and diluted by the great diversity of foliage plants (Fig. 6). Because of the lack of specific information on the control of foliage plant diseases, recommendations are often based on principles and general information derived from studies of diseases of other crop plants. Thus, in foliage pathology, there is a need for research on a broad front, requiring advances in etiology, detection methods, epidemiology, and control procedures in order to provide firm rationale for economic control of significant diseases.

Container-grown Woody Plants

Nurseries in the United States are very diversified. On the basis of production systems, they may be classified as either field production or container production. This section focuses on container-grown woody ornamentals (Fig. 7). This segment of the industry has evolved rapidly since the early 1950s into a highly scientific and successful method of nursery production. Species of rhododendron and azalea (*Rhododendron*) and of juniper (*Juniperus*) are among the most popular container-grown crops.

Whereas certain foliar diseases, such as fire blight, Entomosporium leaf spot, and Rhizoctonia web blight, are serious problems on some crops, root diseases are clearly recognized as the most important problems across this segment of the ornamental industry. *R. solani* and *Pythium* spp. tend to be limited to newly rooted cuttings and liner-size plants, while *Phytophthora* spp. (Fig. 8) are serious pathogens at all stages of production. A number of research questions relating to root diseases are important to the future of container-grown nursery crops. For example, research over the past 10–15 years has shown that brief exposure of plants to conditions of drought, flooding, temperature extreme, nutrient deficiency, salinity, or air pollution can predispose them to various diseases. The roots of container-grown plants are especially subject to these stresses because the small soil volumes provide very little buffering and the containers usually are fully exposed to climatic factors. Whereas we know environmental extremes influence host susceptibility, we have not fully identified critical thresholds or how threshold values for one stress may be modified by the concomitant effect of

Fig. 4. Chrysanthemum is one of the major cut flower crops, and clean stock programs are essential for production of a healthy crop.

Fig. 5. The industry trend for floriculture crops continues to segment into specialized propagators. These poinsettias are in a standard shipping box sent to a finisher.

Fig. 6. Over 500 species of plants are being grown and sold as foliage plants. This diversity greatly complicates the study of foliage plant diseases.

others. Additional detailed information is needed in this area to better enable informed plant management in the nursery.

We also do not have sufficient information regarding effects of the environment on pathogen activity and the epidemiology of diseases in container systems. Information of this type is available for some fungi in agricultural soils, but it may not be relevant to the container environment, where the physical and chemical properties of the media are quite different and where features such as water status and aeration can change relatively quickly. Such information will become increasingly important over the next decade as nurserymen proceed with efforts to automate their production systems. Work is being done to develop computerized systems for nursery operations that would control irrigation (taking crop and climatic data into account), fertilization (timing and amount), plant spacing, etc. The specific conditions that nurserymen will strive to achieve or maintain will be based largely on developing crop growth models. While environmental conditions also influence pathogen activity in containers, we presently do not have enough information to incorporate even the most common of diseases into a crop model.

Another area where changes are occurring that could dramatically affect nurserymen over the next decade is that of disease diagnosis. As new diagnostic aids, such as monoclonal antibodies, are developed and come into wide use, they could place powerful tools in the hands of growers, enabling accurate disease diagnosis and ensuring appropriate use of fungicides, including both selection of specific material(s) and timing of applications. Although offering some new opportunities to growers, these new methods for rapid, sensitive detection of pathogens also could cause problems for the nursery industry. Monoclonal antibodies could enable large-scale screening of nursery shipments by state regulatory agencies or the purchasers of plants. The detection of pathogens, even on nonhosts, could result in price downgrading, return of the infested material to the nursery or origin, or quarantine problems. If the tests are highly sensitive, nurseryman and consumers will call on researchers to provide information they are not currently prepared to provide. Issues such as propagule viability, the significance of latent infections, population dynamics, and disease-significant thresholds, as well as the mediating effects of plant species, potting media, and suppressive fungicides, will all become increasingly important to the sale and shipment of nursery plants. Many of these questions are difficult to answer using conventional methods of detection. Monoclonal antibodies or cDNA probes could provide researchers with the tools needed to address such questions.

Another research area needing expanded effort is that of nonchemical disease control. Currently, nursery growers rely heavily on pesticides for disease control, but pathogen tolerance to chemicals is a continual problem. In addition, the cost of generating efficacy and phytotoxicity data for the large numbers of plant species under cultivation can discourage chemical companies from expanding the labels on new materials to include nursery crops.

Most of the effort toward nonchemical controls for nursery crops has centered around suppressive container media made from compost of hardwood bark, fir bark, or municipal sewage sludge (12). Although there has been some notable success, the results in some areas have been erratic. There are many variables in the composting process, with the final product being strongly influenced by the nature of the raw product used in the compost, the composting process itself, and the maturity of the compost. Because nursery production involves a high degree of plant handling, such nonchemical approaches to control can be commercially practical. Thus, research in this area could significantly contribute to disease control.

Another approach to nonchemical control that has been underexplored with nursery crops is identification of disease-resistant cultivars. Often, susceptible cultivars have strong name recognition with consumers, and nurserymen feel obliged to grow them in response to market demand. Susceptible plants can be an important source of inoculum in nurseries, however, and their elimination from the production system could substantially improve sanitation. The development of realistic, reliable methods for assessing host resistance stands as an important research need. Screening methods may need to employ various stress treatments to ensure the stability of resistance and should take into account the fact that plant materials are often shipped to widely different climatic regions.

Landscape Plants

People are motivated to purchase landscape plants for two reasons: the

Fig. 8. Phytophthora root rot on container-grown plants such as (A) azalea and rhododendron and (B) juniper can cause serious losses during production and in the landscape. (Fig. B courtesy R. K. Jones)

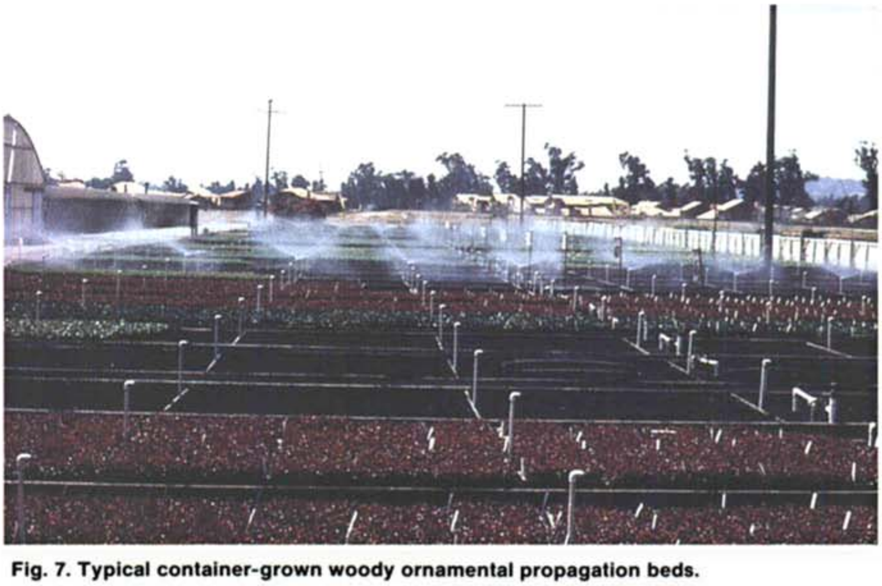

Fig. 7. Typical container-grown woody ornamental propagation beds.

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Dr. Aragaki is a plant pathologist at the University of Hawaii, Honolulu. His research and teaching activities involve the etiology and control of fungal diseases on *Dendrobium*, *Anthurium*, and poinsettia.

Dr. Baker received his Ph.D. at the University of California, Berkeley, in 1954. Since then, he has taught and done research at Colorado State University, Fort Collins, except for appointments as visiting professor at the University of California (Berkeley) during 1963–1964 and as a National Science Foundation senior postdoctoral fellow at Cambridge University, England, during 1968–1969. His original research responsibility in Colorado was to develop control measures for diseases of ornamentals; this resulted in establishment of large pathogen-free operations for propagating carnations in the state. His other research interests involve the modeling of phenomena associated with the ecology of soilborne pathogens and mechanisms and enhancement strategies related to biological control. Space biology is an occasional hobby, and his research group has flown two biosatellite experiments involving crown gall in Russian spacecrafts.

Ms. Daughtrey is an extension associate with the Cornell University Department of Plant Pathology. She received her B.S. degree from the College of William and Mary and an M.S. degree from the University of Massachusetts. Her extension and research activities focus on disease identification and control in the commercial production of ornamental greenhouse and nursery crops.

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Dr. MacDonald is an associate professor of plant pathology at the University of California, Davis, where he also holds a courtesy appointment to the Department of Environmental Horticulture. He completed his graduate studies at the University of California, Davis, earning his Ph.D. in 1977. His research has emphasized Phytophthora root rots of container-grown plants and the role of environmental stress in disease severity.

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personal satisfaction derived from an attractive landscape planting (Fig. 1) and the practical inducement of increased property value (1). Shade trees such as maples (*Acer* spp.), oak (*Quercus* spp.), ash (*Fraxinus* spp.), dogwood (*Cornus* spp.), flowering crab (*Malus* spp.), sycamore (*Platanus* spp.), *Prunus* spp., and elm (*Ulmus* spp.) are clearly the most important plant group nationally. Next come evergreens (pines (*Pinus* spp.), junipers, spruce (*Picea* spp.), fir (*Abies* spp.), and *Magnolia*); shrubs (azalea/rhododendron, holly (*Ilex* spp.), *Photinia*, lilac (*Syringa* spp.), *Camellia*, and *Cotoneaster*); and flowering plants (roses, marigolds, geraniums, and *Aster*). Interiorscapes and vine/ground covers (*Vinca*, ivy (*Hedera* spp.), *Ajuga*, *Liriope*, and *Pachysandra*) receive less interest. This trend appears to be influenced regionally, however, as shrubs rank well above other plant groups in southern states. Table 2 indicates the most important disorders and diseases identified for each plant group.

Table 2. Top-ranking disorders in the landscape for five ornamental plant groups

Plant group	Disorder	Percentage of respondents[a]
Deciduous trees	Declines and diebacks, cause unknown	25
	Anthracnose	15
Evergreens	Foliage and bud blights	40
	Declines and diebacks	18
Shrubs	Fungal foliage and flower diseases	31
	Fungal root diseases	16
Flowering plants	Fungal foliage and flower diseases	26
	Bacterial diseases	19
Interiorscapes	Environmental	48
	Miscellaneous	32

[a] Percentages based on responses from 60 plant pathologists working on landscape and interiorscape diseases and disorders in the United States.

Methods to improve the accuracy and speed of field and laboratory diagnosis are badly needed and may be the best application of biotechnology to landscape plants. We must also be able to interpret the significance of microorganisms associated with plants, however.

Research into the discovery and deployment of resistant cultivars deserves increased attention. Genetic engineering approaches may help, but teamwork among appropriate disciplines must be encouraged to hasten the potential of useful discovery. It should be cautioned, however, that the great diversity among landscape plants, the time required to develop a horticulturally useful end product, and the constant turnover in consumer interests will make control of landscape plant diseases through genetic means more difficult than with most other crops, thus giving nearly equal emphasis to cultural and other control approaches.

In terms of cultural control, there is a need to better identify and promote plant/site selections, especially for plants that require relatively low maintenance. Also, the availability of pathogen-free plant material is generally regarded as a critical factor in disease control, although it may be of limited importance in some situations because of the perennial nature of most crops, the indigenous character of pathogens, and the resulting potential for reinfestation. There are many important examples, however, such as interstate movement of interiorscape plants and Phytophthora root and crown infections, where improved plant health is still an important need.

There is need for new chemicals to aid disease control. For example, systemic fungicides that move basipetally and control pathogens such as root basidiomycetes, as well as other problems presently untouchable, would be of enormous benefit. Research to minimize the potential for pathogen resistance and to develop application techniques that reduce plant injuries is important. Public concerns about the use of pesticides in an urban environment should be addressed, partly through research leading to IPM approaches that could better pinpoint needs and target applications. Equally important is more information regarding possible deleterious effects of pesticides, so their role in a control program can be determined more confidently. There is a great need for research on the etiology, monitoring, or modeling of diseases, including definition of susceptible growth stages, and the influence of fertility and environmental factors, particularly stresses, that can affect host-pathogen interactions. Finally, there is an important need for research leading to expanded biological control opportunities and expanded evaluation of resistant varieties.

Conclusions and Directions

It is clear that the ornamentals industry is large and complex and that each segment of the industry has many important and unresolved problems. Although some of the problems are unique to certain segments of the industry or to regions of the country, there are some unifying themes. For example, over the next decade, the ornamental horticulture industry will continue to undergo many changes in production and shipping procedures. The major changes include mechanization and automation systems for improved crop management and the use of biotechnology in plant production (Fig. 9). These advances are now requiring large financial investments but are intended ultimately to reduce production costs and maximize profits. Many of the changes could significantly affect the epidemiology or severity of diseases. Plant pathologists will need to work closely with horticulturists to try to assure that new management practices will have beneficial, or at worst neutral, effects on disease. Integrated crop pest management systems can then be more easily developed and tailored for the specific market segments and for production regions, where appropriate.

Another trend is that newly developed technology, production processes, products, and information will become increasingly proprietary. The owners of these will carry their ownership rights as far in the industry hierarchical scale as possible (grower, broker, wholesaler, retailer) in order to enjoy the greatest advantage possible for the "value added," and this will change the traditional production marketing relationship significantly. Therefore, ornamental plant pathologists will need to be continually abreast of the state of the art and seek innovative networking systems. This will help ensure that future research is directly related to industry needs.

We also feel there is a need for improved information flow among researchers, extension personnel, and grower trade associations. While there clearly are important gaps in our knowledge, many problems cited by growers have already been researched and effective control measures published. The results, however, are not always published or even summarized in publications read by growers. Further, new growers continually enter the ornamental horticulture business, and many of the publications that aided their predecessors are no longer available. We should consider revising or reprinting the best of these earlier publications and developing others that are needed. We must take advantage not only of traditional publication avenues but also of trade journals that welcome articles on plant disease research. We must also be willing to speak at national and regional meetings of grower/trade associations.

Fig. 9. Mechanized systems for improved crop management in greenhouses will be a major thrust during the next decade. (A) Modern facilities include (B) automated potting and loading equipment, (C) conveyor systems, (D and E) movable benches, and (F) computer-controlled environmental conditions. (Figs. B, C, D, and F courtesy V & V Noordland, Inc.)

Certainly, from a grower's perspective, knowledge of research results and what those results mean in terms of management alternatives are critical needs. We must not lose sight of this.

Finally, we would like to point out that the high value of most ornamental crops, as well as their documented economic and aesthetic contribution to a large sector of the population, fully warrants support for research. It appears that in the future, however, traditional public-supported research and information programs in the United States will continue to decline and that these responsibilities will be increasingly transferred to the private sector. Although there are many state and national organizations that encompass various segments of the industry and support research activities, the support is limited and often dependent on grower donations. A major challenge to the industry will be to develop a system for funding that recognizes the high cost of research and to realize the need for an increasing role in its support. Success in generating competitive levels of research funding for ornamental pathology will contribute greatly to keeping the U.S. ornamental horticulture industry thriving in the face of extreme foreign competition in our markets. Perhaps we can draw from the current programs at the USDA Florist and Nursery Crops Laboratory as a model for success. This is an example of a joint government- and industry-funded research group (13) conducting basic research on identified industry problems, including pest management as well as crop introduction and production. More programs of this type are needed.

Acknowledgments

We wish to thank our colleagues who participated in the respective surveys and Diane Ritthaler, at Washington State University, for typing this manuscript.

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