Reducing the Pollution Potential of Pesticides and Fertilizers in the Environmental Horticulture Industry: I. Greenhouse, Nursery, and Sod Production

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Summary. Pesticides have been the primary method of pest control for years, and growers depend on them to control insect and disease-causing pests effectively and economically. However, opportunities for reducing the potential pollution arising from the use of pesticides and fertilizers in environmental horticulture are excellent. Greenhouse, nursery, and sod producers are using many of the scouting and cultural practices recommended for reducing the outbreak potential and severity of disease and insect problems. Growers are receptive to alternatives to conventional pesticides, and many already use biorational insecticides. Future research should focus on increasing the effectiveness and availability of these alternatives. Optimizing growing conditions, and thereby plant health, reduces the susceptibility of plants to many disease and insect pest problems. Impediments to reducing the use of conventional pesticides and fertilizers in the environmental horticulture industry include 1) lack of easily implemented, reliable, and cost-effective alternative pest control methods; 2) inadequate funding for research to develop alternatives; 3) lack of sufficient educational or resource information for users on the availability of alternatives; 4) insufficient funding for educating users on implementing alternatives; 5) lack of economic or regulatory incentive for growers to implement alternatives; and 6) limited consumer acceptance of aesthetic damage to plants. Research and broadly defined educational efforts will help alleviate these impediments to reducing potential pollution by the environmental horticulture industry.

The environmental horticulture industry is composed of related commodities, including greenhouse, nursery, and turfgrass crops, and the services associated with their use. The primary pesticide-related waste streams in environmental horticulture include used protective clothing, empty pesticide containers, rinsate from containers and equipment, surplus or outdated inventory, pesticide dust or droplets (airborne or on nontarget areas), and excess pesticides applied unnecessarily or mistakenly to targeted areas (Environmental Protection Agency, 1993).

This paper concentrates on reducing the potential for pollution from pesticides and fertilizers applied during greenhouse, nursery, and sod production. We summarize the historical and current use of pesticides and fertilizers in ornamental crop production and detail new developments in pesticides and alternative pest control measures. Finally, in listing some of the impediments to and opportunities for reducing pesticide and fertilizer use, we offer our suggestions for management and educational strategies for reducing the pollution potential of pesticides in environmental horticulture.

The environmental horticulture industry is economically significant and diverse, with rapid and consistent growth (Behe and Beckett, 1993; Hall, 1992; Johnson, 1993). The industry includes production of annuals, perennials, herbs, ornamental and turf grasses, shrubs, trees, field-grown cut flowers, ornamental bulbs and tubers, water-garden plants, tropical plants (including orchids), vines, and even some decorative mosses. Industry wholesale production value increased 622% between 1970 and 1988, an average increase of 34% per year; i.e., the industry is increasing faster than the rate of general economic growth in the United States (Behe and Beckett, 1993). Annual bedding-plant wholesale production grew to over $1.0 billion nationally in 1992; the increase in growth of bedding plants alone has averaged 6% per year since 1974 (Allan et al., 1993; Johnson, 1993). In the United States, 1992 USDA economic survey figures placed the annual value of greenhouse and nursery production at >$9.0 billion (Johnson, 1993). Grower receipts were estimated conservatively to be near $10.4 billion in 1994. This places environmental horticulture as the sixth largest agricultural commodity in total cash receipts (behind beef, dairy, corn, hogs, and soybeans) in the nation (Grooms, 1994). By the year 2000, environmental horticulture is predicted to be ranked third or fourth among the top agricultural commodities in the nation.

Pesticide use in greenhouse, nursery, and sod production

Pesticides have been the primary method of pest control for many years, and growers now depend on them to rid plants of pests. Fumigation with

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compounds like hydrocyanic acid gas, nicotine, and naphthalene was popular in greenhouses in the late 1800s. Some of these compounds cause phytotoxicity to plants and are very toxic to mammals (Richardson and Bulger, 1943; Woods, 1908). In the 1930s, inorganic compounds that acted as stomach poisons, contact insecticides, and pesticides for soil application were used widely to control insects (Cory and Langford, 1933).

In 1942, the chlorinated hydrocarbon DDT was first imported to the United States and became the most important synthetic insecticide. Since the 1940s, growers have relied on inorganic pesticides such as chlordane, dieldrin, and kelthane. The broad-spectrum organophosphates, including parathion introduced in 1946, were used next, and the carbamates group including Sevin and oxamyl followed soon thereafter. The pyrethroids were introduced in the 1970s and are used extensively today.

With respect to fungicides, many salts of heavy metals have fungicidal and bactericidal properties, including mercury, nickel, silver, and zinc compounds, which were used around the turn of the century. By the mid-1930s, fungicides evolved to a second generation based on organic compounds, including the dithiocarbamates (polyram, manzate, dithane, and fermate), followed by the dicarboximides,including captan, which was introduced in 1949 (Bohmont, 1983; Waard et al., 1993). These compounds were surface protectants and were only effective as preventive treatments. The third-generation fungicides also were organic, but they could penetrate plant tissues, become systemic, and thereby control existing infections. These fungicides included 2-aminopyrimidines, benzimidazoles, carboxamides, phenylamides, fosetyl-Al, azoles and related compounds, and morpholines (Waard et al., 1993). Until recently, the most widely used of these materials was benomyl, which was used extensively in ornamentals and turf.

Chemicals have been used to control weeds throughout this century, but the most intensive use has been in the last few decades. Several arsenical compounds have been used for controlling weeds. Lead arsenate often was applied to control crabgrass because it did not cause serious damage to other grasses (Frear, 1948). Other inorganic compounds used to control weeds in the first half of this century were boron compounds, cyanides, thiocyanates, chlorates, copper compounds, ferrous sulfate, sodium chloride, sodium fluoride, and sulfuric acid. Organic herbicides introduced in the 1930s and 1940s included the nitro compounds, oils, and oxy-derivatives of acetic acid. The most noteworthy of the oxy derivatives was 2,4-D, which has been, and still is, widely used to control broadleaf weeds.

Current use of insecticides in greenhouse, nursery, and sod production. A national survey of insecticide use for commercial production of ornamentals and turf was conducted recently, with a primary objective of developing an economic assessment for the insecticides chlorpyrifos and diazinon (Oetting and Allison, 1994). Data from wholesale greenhouse operators, nursery operators, and sod producers were obtained to determine use and efficacy of insecticides in these individual United States industries. Questionnaires were sent to all wholesale grower members of the Society of American Florists and the Professional Plant Growers Association to obtain data for the floriculture industry. Wholesale grower members of the American Association of Nurserymen were used as the sample of nursery operators to study the nursery industry. The members of the American Sod Producers Association were used as the sample of sod producers. The data for this survey were collected in late 1991 and early 1992.

The questionnaires requested insecticide use and efficacy information for these three industries that was to reflect average annual use and efficacies over 3 years (Oetting and Allison, 1994). The use and efficacies were categorized by the pests or pest groups commonly used by the entomologists responsible for pest management recommendations. The selections represent the gamut of pest problems experienced by growers. Data on pest problems, pest control strategies, and nonchemical pest control practices also were obtained. The data, analyzed and tabulated for five distinct regions, were expanded to estimate national values (Oetting and Allison, 1994). Data from the *Floriculture Crops 1990 Summary* (USDA, 1991) were used as the standard to establish total greenhouse production. *The 1987 Census of Agriculture* (U.S. Department of Commerce, 1989) was used as the size statistic for nursery production and for the sod production industry.

The results of this survey indicate that the greatest use of insecticides (expressed in total lbs a.i. applied) in commercial production was in the sod industry. The expanded estimate of annual usage for commercial sod production was >1,357,000 lbs a.i. (615,500 kg a.i.) of insecticide. Isofenphos was the active ingredient used most, and it accounted for 59% of the total insecticide used. Greater than 90% of the isofenphos was used for white grub control, the greatest use occurring in the western and the northeastern United States. Other insecticides commonly used by the sod industry were chlorpyrifos (16% of the total insecticide used) and trichlorfon (13% of thetotal insecticide). White grubs were the most common target pest, as would be expected considering the large amount of isofenphos used, followed by Lepidopterous larvae and billbugs.

The nursery industry was the second greatest consumer of insecticides. More than 1,025,000 lbs a.i. (464,940 kg a.i.) was applied to control insects and related pests on nursery crops. However, this is misleading because 51% of the insecticide use in nursery crops was horticultural oil. Horticultural oil is a biorational insecticide, often considered an alternative to conventional synthetic insecticides. Scales (54%) and mites (34%) were the primary pests treated with horticultural oil. Carbaryl was the conventional insecticide used the most (11.5% of the total insecticide used). However, there were 38 active ingredients reported in use on nursery plants, and eight insecticides had an estimated annual use of >10,000 lbs (4536 kg). Most of the carbaryl use (82%) was divided between treating foliage-feeding worms and foliage-feeding beetles. Mites were treated with the greatest quantity of active ingredients of all the pest categories.

Greenhouse crops were treated with the least total pounds of active ingredients—537,000 lbs (243,583 kg) used annually. Similar to the nursery industry, the biorational insecticides like horticultural oil and insecticidal soap made up a significant portion—34%, of the total insecticide use. A miticide, dienochlor, was the inorganic insecticide used most for a greenhouse pest (11.5% of the total insecticide used), and most of that usage was in the northeastern United States. There were 39 compounds used against greenhouse pests, and 14 of those compounds had annual use of >10,000 lbs (4536 kg). Thrips, aphids, whiteflies, and mites all were treated with different insecticides, and each received similar amounts of active ingredients.

Current use of fertilizers and herbicides in nursery production. Concern for potential regulation of runoff water from greenhouse and nursery operations has prompted considerable research on measuring potential water contamination from fertilizers and herbicides. Although greenhouse operations are concerned about the nutrient and pesticide content of runoff water, there is greater concern in the nursery industry due to the large number of plants grown in pots placed outdoors on areas covered with gravel, plastic, or weed-barrier fabric (bedcovers) (Fig. 1). Problems associated with such areas include nontarget treatments via broadcast application of granular fertilizers and herbicides, application of soluble fertilizers in overhead irrigation, and the loss of granular formulations applied to the potting substrate surfaces by washing or overturning of the pots.

Many nursery firms use controlled-release fertilizers mixed into the potting medium or applied on top of the substrate; others use liquid fertilizers applied through the irrigation system or, most commonly, a combination of both. The fertilizer formulation affects the amount of nitrate-N in the runoff water. Runoff water from production beds in nurseries using controlled-release fertilizers had nitrate-N levels of 0.5 to 33 ppm (average 8 $mg{\cdot}liter^{-1}$) compared to 0.1 to 135 ppm (average 20 $mg{\cdot}liter^{-1}$) for nurseries using a combination of controlled-release and solution fertilizers (Yeager et al., 1993). As a comparison value, the EPA standard for nitrate-N in processed drinking water is 10 ppm.

Many of the currently available controlled-release fertilizers cannot provide season-long nutrition sufficient to maintain plant growth. Therefore, growers frequently apply high amounts of fertilizer in the spring to supply season-long nutrition. Yeager et al. (1993) determined that nitrate levels in runoff were highest in the spring, the first 2 months after topdressing pots with the controlled-release fertilizer, and suggested that the fertilizer be applied at lower rates and more frequently according to plant growth needs. Controlled-release fertilizers with season-long release patterns have been developed recently. These fertilizers appear to have a lower initial release than the traditional controlled-release fertilizers, resulting in less excess nitrate-N immediately after application. Nurserymen are beginning to accept these new products.

Herbicides usually are applied as broadcast sprays or granules, with as much as 80% of the product not reaching the targeted containers but landing on the bedcover instead (Camper et al., 1994). Generally, the herbicides are watered in after application, resulting in potential contamination of the runoff water. Studies with granular herbicides confirmed that the active compounds move from the application site into runoff water and containment ponds (Keese et al., 1994). The greatest concentrations were detected 15 min after runoff began, and residues were detectable in containment ponds until 28 days after herbicide application. Furthermore, the gravel bedcovers retard granule movement, whereas plastic or fabric bedcovers facilitate it (Keese et al., 1994). Bedcovers also had minor effects on herbicide solubility.

Applying herbicides directly to pots as opposed to the broadcast applications would reduce off-site movement of herbicide granules but would increase labor costs (Keese et al., 1994). The development and testing of controlled-release herbicide tablets has been ongoing for more than 20 years, but accurate coverage and timely release of the herbicide in containers have not been optimized to date (Derr, 1994). Controlled-release herbicides would have many of the same advantages and disadvantages as controlled-release fertilizers. Depending on the duration of weed control and the solubility and leachability of the herbicide, using controlled-release herbicides could reduce the number of applications per year, the runoff due to lower nontarget application, and the exposure of applicators, since no mixing or calibration is necessary (Derr, 1994).

Large nursery operations maintain containment ponds to collect runoff water. These ponds collect fertilizers and other contaminants and provide a secured area for their degradation. Camper et al. (1994) measured the containment pond concentrations of three herbicides routinely used in a large container nursery and found that, although the herbicides were detected after application, there was no accumulation of the herbicides in the containment pond water or sediment. As

Fig. 1. *Production of nursery stock outdoors on large areas covered with gravel, plastic, or weed-barrier fabric results in concern about nutrient and pesticide content of runoff water, especially during and after overhead irrigation.*

with insecticides, the trend toward using short-residual herbicides permits the rapid degradation (chemical or microbial) of these chemicals in the environment.

Promising new research in Georgia suggests that a microbial compound currently used in swine manure pits to degrade nitrate-N may be useful in containment ponds or other surface-water collection sites without damaging the pond flora and fauna or nursery crops (J. Ruter, personal communications). The impact of phosphorous movement from nursery operations needs to be evaluated. Phosphorous generally has low solubility in soil solutions and, therefore, has been considered to be less of a problem than nitrogen. However, in container-grown plants, phosphorous readily leaches because the negatively charged phosphate ions are not held by the anion exchange sites on the pine bark-based substrate most commonly used in the nursery industry. Normal phosphorous levels in aquatic systems are very limiting to plant growth. The potential effects of phosphorous pollution may, therefore, be greater than anticipated. Some progressive nurserymen actually are developing constructed wetlands on their properties to provide controlled areas to filter contaminants from water seeping away from the nursery. This land is still available as growing space for wetland species or it may be planted with species that use or accumulate some of the chemicals that must be contained.

Best management practices (BMPs) for nurseries. BMPs are being developed for the nursery industry as a proactive approach to managing operations so that cultural practices have the lowest potential detrimental impact on the environment (American Nurseryman, 1993). This BMP development is a joint effort by the nursery industry, government agencies, and universities and will result in a set of guidelines published as a handbook for growers. The BMPs cover areas such as pest control, chemical applications, water management, fertilization, and worker safety. Yeager et al. (1994) suggested some of the BMPs to be included: collecting runoff water when injecting fertilizer, applying fertilizer only when a plant growth response is expected, eliminating fertilizer broadcasting on spaced containers, eliminating topdressing containers prone to blowing over, watering and fertilizing according to plant needs, grouping plants according to water and fertilizer needs, monitoring quantity of irrigation applied to prevent overwatering, maintaining minimal spacing between containers receiving overhead watering, using low-volume irrigation on large containers, and recycling runoff water. Many of these same recommendations would reduce pollution from herbicide applications as well. The strong industry support for this effort suggests a deep interest in adopting a proactive approach to reducing environmental contamination.

Alternatives to conventional pesticides

New developments in pesticides. Concerns over possible overuse and misuse of pesticides, especially those used for protecting agricultural crops, were expressed in Rachel Carson's *Silent Spring* (1962). This book drew public attention to the impact of hazardous chemicals, especially pesticides, on the environment and led to greater public concern for overuse and misuse of chemicals. Following its publication, studies were initiated to investigate the fate and presence of pesticides in the environment.

The trend in insecticide development is toward selecting compounds that have short residuals and are compatible with nonchemical management alternatives, are less toxic to humans, and are less harmful to the environment. Examples of these compounds are the insect growth regulators (IGRs), toxins from fungi such as avermectin, and bacterial compounds like *Bacillus thuringiensis*. Using soaps and oils to control insects has regained popularity in the ornamentals industry. One of several factors that contribute to this trend is the introduction of new regulations on reentry requirements and worker safety.

Modern pesticides generally do not present the problems of the inorganic and early organic compounds. Because many of the newer compounds are specific to certain insects and do not act as nerve poisons, their acute toxicity, chronic toxicity (especially the potential to cause cancer), or residual environmental contamination is reduced. They biodegrade in the environment much more rapidly, reducing risk of contamination. The chemical industry has moved from a biological discovery approach, based on efficacy, to one that also includes earlier and better knowledge of pesticides' effects on ecosystems and human health (James et al., 1993).

Many of the new insecticides applied to control pests on ornamentals are effective at very low concentrations. The older compounds, such as endosulfan, chlorpyrifos, or diazinon, were used at rates of 0.5 to 1.0 lb a.i. / 100 gal water (0.6 to 1.2 $g \cdot liter^{-1}$), or even higher. Many of the newer chemicals, like bifenthrin and abamectin, are used at rates of 0.1 lb / 100 gal (0.12 $g \cdot liter^{-1}$), or less.

One of the chemical groups categorized as biorational, IGRs (Oetting, 1994), refers to any compound that regulates insect growth by not allowing immature insects to develop into adults. IGRs are usually more selective than traditional nerve poisons, and are effective against a smaller group of insect pests. There are two general groups of IGRs—the compounds that mimic juvenile hormone, and those that inhibit chitin synthesis. More IGRs are used on ornamental crops than on most other crops. The compounds currently registered for use in ornamental production include azadirachtin, cyromazine, diflubenzuron, fenoxycarb, and kinoprene.

Recently, several novel groups of insecticides have entered the market place with new chemistries, such as the avermectins and chloronicotinyls. Soaps and oils have resurfaced; more than half the insecticides used in nursery crop production consisted of horticultural oils, and 34% of the insecticides used in greenhouses consisted of oils and insecticidal soaps (Oetting and Allison, 1994). These compounds are less toxic to humans and more environmentally sound when considering environmental contamination and compatibility with other management tactics.

New herbicide formulations are also being designed for lower application rates, and many of the standard herbicides are being evaluated for weed suppression at lower rates. The application rates of some of the new-chemistry herbicides, like the sulfonylureas, which generally have a low mammalian toxicity rating, are 20 to 300 times lower than those of products like the triazines (Zoschke, 1994). For example, halosulfuron is labelled for use on cool- and warm-season turfgrasses at recommended rates of 0.031 to 0.062 lbs a.i./acre (0.035 to 0.07 $\text{kg}\cdot\text{ha}^{-1}$) compared to up to 2.0 lbs a.i./acre (2.24 $\text{kg}\cdot\text{ha}^{-1}$) of 2,4-D or atrazine. Ongoing research and development in improving formulations, optimizing application timing in conjunction with reduced application rates, developing biological weed control, and emphasizing cultural management to reduce weed problems are means of reducing pollution potential from herbicides in agricultural and nonagricultural systems (Zoschke, 1994).

Fig. 2. *Good sanitation practices and monitoring to determine pest infestations early are low cost, easily adapted methods of reducing the severity of pest problems and the subsequent use of pesticides.*

Current status of IPM in greenhouse, nursery, and sod production. IPM for ornamental production has been discussed for at least 20 years. However, serious attempts to implement IPM have been used only during the last decade. IPM incorporates the use of alternatives with chemical pesticides, thereby reducing the volume of pesticides used and increasing the number of methods available to control pests. IPM does not emphasize eliminating chemical pesticide use.

The current management system in greenhouse, nursery, and sod production depends on conventional chemical insecticides. In a survey of commercial production, all greenhouse and nursery producers used insecticides to manage insects and mites; however, only 69% of sod producers used insecticides (Oetting and Allison, 1994). Most of these greenhouse, nursery, and sod producers indicate that they have adopted some alternative biorational pest management practices. These types of alternative management systems were preventive and curative in nature. Producers frequently identified such practices as surveying or monitoring pest populations as a nonchemical management practice. In reality, these practices are used in chemical and nonchemical management as part of an IPM program. Many growers listed IPM as the alternative to chemical control. Actually, IPM is a management strategy to reduce chemical usage, not a nonchemical practice.

Other surveyed growers listed more specific management practices (Oetting and Allison, 1994). The most frequent responses from greenhouse growers were (by percent of respondents) sanitation methods (25%) [e.g., weed control (16%)], monitoring pests (21%) [e.g., sticky cards (20%), scouting (15%)], cultural practices (11%), and biological control (10%) (Fig. 2, Table 1). The most frequent responses for nursery crops, which were similar to greenhouse responses, were cultural practices (23%) [e.g., crop rotation (8%)], monitoring (17%) [e.g., scouting (15%)], mechanical control (12%) [e.g., manually removing pests (11%)], and sanitation (10%) [e.g., discarding infested plants (7%)]. Sod production responses represented a smaller number of growers. The most frequent responses included cultural practices (64%) [e.g., crop rotation (5%), retilling fields (3%), proper harvest timing (2%), and higher mowing (2%)]. Results of this study indicate that >52% of the sod, nursery, and greenhouse producers used at least one alternative nonchemical pest management practice that either reduced pest populations or pesticide use.

Biological control will be researched extensively in the future. Using natural enemies for pest management will gradually become a part of commercial production. Parasitoids, predators, and microbial insecticides are currently available and are used in some production systems. Heretofore

Table 1. *Summary of pest management strategies implemented in addition to or in place of insecticides. Strategies are expressed in number of respondents using a given strategy and percentage of total responses in a particular strategy within each industry. Due to the use of multiple strategies by a given grower, column totals do not equal 100% (Oetting and Allison, 1994).*

	Greenhouse		Nursery		Sod production	
Strategy	No.	%	No.	%	No.	%
Monitoring[z]	51	21	27	17	0	0
Sanitation[y]	61	25	16	10	2	5
Exclusion[x]	21	9	8	5	0	0
Cultural practices	26	11	38	23	25	64
Biological control	25	10	13	8	3	8
Mechanical control	18	7	19	12	0	0
IPM (not specific)	35	14	35	21	8	21
Soap, oil, plant der.	7	3	8	5	13	34

[z] *Sticky cards, scouting, etc.*
[y] *Removing weeds, discarding leftover plants, etc.*
[x] *Screening, double doors, etc.*

a major problem with the use of natural enemies has been the availability and quality of the living insects. Parasitoids, like *Encarsia formosa,* which is available as a sticky card of parasitized greenhouse whitefly pupae (Fig. 3), and predators are available from several commercial sources in the United States, and the number is increasing. Improved handling procedures during greenhouseinoculation include providing predators like *Neoseiulus cucumeris* in a ready-to-open-and-hang incubator bag complete with grain that supports the grain mites on which the predatory mites feed during incubation (Fig. 4). The limited range of the predators leaving the bag necessitates a high density of inoculum. Microbial pathogens of insects include bacteria, fungi, and viruses. A few of these pathogens, such as *Beauveria bassiana* JW-1, are formulated and available to growers. There are several fungi and viruses currently under study for possible use in greenhouses, and some are registered on other crops. Closely related to microbial insecticides are nematodes formulated for managing insects. For example, the nematode *Steinernema carpocapsae* has been registered for use against fungus gnats in greenhouse production.

The diversity of IPM practices in controlling greenhouse arthropods is addressed by van Lenteren and Woets (1988) and Powell and Lindquist (1992). Much of the IPM in nursery and sod production is directed toward woody ornamentals (Raupp et al., 1992) or turfgrass (Potter and Braman, 1991). The major IPM methods currently being implemented are aimed at reducing potential pest problems and monitoring population levels. Only a limited amount of biological control or other direct pest-population management other than chemical control is being used in ornamental crop production .

Impediments to and opportunities for reducing pesticide use

Potential management solutions. For the past 50 years, pest management has centered around the prophylactic use of pesticides. The increasing cases of pesticide resistance, lack of new chemical registrations, concerns for environmental protection and public safety, and the rising cost of pesticides indicate the need to develop alternative pest management strategies (Cook and Smith, 1988; Heinz, 1990; Lindquist et al., 1979; Zilberman et al., 1991). However, where pesticides have been the predominant pest control method, there are many impediments to reducing their use in greenhouse, nursery, and sod production (Cook and Smith, 1988; Oetting and Allison, 1994; Osborne and Oetting, 1989; Parrella and Jones, 1987; Parrella et al., 1989; Raupp et al., 1989b; van Lanteren and Woets, 1988; Wearing, 1988). For example, in greenhouse, nursery, and sod production, state laws prohibit the interstate transfer of certain pests, such as imported red fire ants, requiring chemical elimination of the pests. In addition, cosmetic standards for ornamental plants dictate that insect pests and diseases be maintained at very low levels or zero (Osborne and Oetting, 1989; Parrella et al., 1989; Parrella and Jones, 1987; Raupp et al., 1989a; van Lenteren and Woets, 1988). These requirements have hindered research to develop sampling and monitoring programs that can be used to detect the presence of pests before they cause economic damage (Oetting and Allison, 1994; Osborne and Oetting, 1989; Parrella and Jones, 1987; Parrella et al., 1989; Wearing, 1988). Consequently, few alternative pest management strategies have been made available that provide adequate protection against pests causing cosmetic damage (Lindquist et al., 1979; Oetting and Allison, 1994; Osborne and Oetting, 1989; Parrella and Jones, 1987). Although alternatives are available for specific pests of defined systems, the lack of an available alternative for controlling all the common pests of the cropping system hampers the technology transfer from research to grower; i.e., due to the missing or unknown components, step-by-step recommendations for implementing alternative control methods are not possible at this time (van Lenteren and Woets, 1988; Osborne and Oetting, 1989; Parrella and Jones, 1987).

Reliable alternative pest control methods are currently unavailable for the ornamental and sod industries. However, the increased use of pest population monitoring and improved cultural practices are important steps toward greater reliance on alternative management strategies (Binns and Nyrop, 1992). Biological control, host plant manipulation, host plant resistance, and other methods will gain greater use and become increasingly important in future management systems. However, insecticides that are compatible with alternative management strategies must remain available. Several sources of information on the inter-

Fig. 3. *A commercial preparation of the parasitoid* Encarsia formosa . *The black dot is a sticky spot containing parasitized greenhouse whitefly pupae from which the mature parasitoid emerges in the greenhouse.*

action of chemicals and biological control agents exist (Hassan, 1985; Hassan and Oomen, 1985). Additionally, many articles on the compatibility of specific natural enemies and environmentally friendly insecticides, horticultural practices, and conventional chemicals exist (e.g., Oetting and Latimer, 1991; Osborne and Petitt, 1985; Rock, 1979).

Research and education strategies. Implementing alternative pest management strategies is a complex process requiring intensive education (Wearing, 1988). Unless alternative pest management programs are simplified and education programs are developed, growers will be reluctant to substitute alternative pest management programs for pesticides (Raupp et al., 1989b; van Lenteren and Woets, 1988). In addition, unless consumers are re-educated to accept products that are less than perfect, it will not be economically feasible for growers to reduce pesticide use greatly (Wearing, 1988).

Limited financial support limits research that could reduce pesticide use in greenhouse, nursery, and sod production (Wearing, 1988). The cost to develop a pesticide into a commercial product can reach $30 million. Only about 1% of this level of funding is allocated by federal, state, and private agencies (Osborne and Oetting, 1989; Parrella and Jones, 1987; van Lenteren and Woets, 1988). In addition, the alternative pest management programs that are available are not as economically advantageous for growers as pesticides (Lindquist et al., 1979; Parrella and Jones, 1987; Wearing, 1988).

In addition to the technical, financial, and educational obstacles, the limited amount of interdisciplinary research among the experts in horticulture, entomology, plant pathology, and agricultural economics has slowed the development of alternative pest management programs that are necessary to reduce pesticide use in the green industry (Parrella and Jones, 1987; Wearing, 1988). New initiatives to address issues facing environmental horticulture in an interdisciplinary manner are underway in groups like The Ornamentals Working Group at The University of Georgia (Latimer, 1995).

Research in the future will focus on developing effective insect resistance-management tactics that can be used to preserve insecticide management systems. The only factors that can be manipulated to reduce selection pressure for resistance are operational factors, such as the insecticides used, area of coverage, timing, rate, and application method (Denholm and Rowland, 1992). Unfortunately, resistance management is complicated, because pesticide use must address other concerns including water pollution and dangers to human health and nontarget species, which can cause the socially optimum level of pesticide use to differ from the private or commercial optimum level (Knight and Norton, 1989).

The search for new pest control management tactics will continue. New chemistry, improved application methods, selective treatment, or other new methods are needed to reduce the environmental effects of pesticides. Alternatives to chemical pesticides are likely to play a more important role, together with increased reliance on biological control (James et al., 1993). However, totally replacing chemicals is not anticipated in the near future.

Summary and conclusions

This paper has summarized the chemical and alternative pest control methods currently in use, and those that have potential for adoption in producing environmental horticulture crops. There are still applied and fundamental problems to be overcome before reliance on chemical pest control in ornamental crop production can be replaced with more environmentally friendly alternatives. Growers are very receptive to proposed changes in pest control, but scientists must recognize the importance of economics in the implementation of any alternative pest control measures. However, the economists also need to place an economic value on worker safety and environmental protection so that these values can be factored into the economic equations. Many of the alternative pest control measures, such as sanitation, are preventative in nature and could be implemented with little effort or cost. However, growers must be educated to that fact. Educating growers on the concept of plant health management would reduce the need for chemical intervention. Optimizing growing conditions and thereby plant growth reduces the susceptibility of plants to many diseases and insects.

Impediments to reducing the pollution potential in environmental horticulture. Impediments to reducing the pollution potential with respect to using conventional pesticides in the environmental horticulture industry include the following:

Fig. 4. *To improve predator survival during greenhouse inoculation,* Neoseiulus cucumeris *is placed in a ready-to-open-and-hang incubator bag that contains grain that supports the grain mites on which the predatory mites feed during incubation.*

1) the limited availability of easily implemented, reliable, and cost-effective alternatives;
2) inadequate funding for research to develop alternatives, particularly for complex, multi-component systems;
3) lack of sufficient educational or resource information for users on potential or available alternatives,
4) lack of funding for educating the users on the implementation of alternatives;
5) lack of economic or regulatory incentive for growers or professionals to implement alternatives; and
6) limited consumer acceptance of aesthetic damage to plants.

Opportunities for reducing the pollution potential in environmental horticulture. Opportunities for reducing the pollution potential of chemicals used in environmental horticulture are excellent. Nursery, greenhouse, and sod producers already are using many of the scouting and cultural practices recommended for reducing the outbreak potential and severity of diseases and insects. They are receptive to alternatives to conventional pesticides and many already use biorational insecticides such as soaps and oils. We must continue to develop alternatives to conventional pesticides and study the complex systems with which we are working.

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