Review

Reducing the Pollution Potential of Pesticides and Fertilizers in the Environmental Horticulture Industry: II. Lawn Care and Landscape Management

Joyce G. Latimer[1], S. Kristine Braman[2], Reuben B. Beverly[1], Paul A. Thomas[3], Jerry T. Walker[4], Beverly Sparks[5], Ronald D. Oetting[2], John M. Ruter[6], Wojciech Florkowski[7], Denise L. Olson[2], Carol D. Robacker[1], Melvin P. Garber[8], Orville M. Lindstrom[1], and William G. Hudson[9]

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The Ornamentals Working Group, Georgia Experiment Station, The University of Georgia, Griffin, GA 30223.

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[1]*Horticulture.*

[2]*Entomology.*

[3]*Department of Horticulture, The University of Georgia, Athens, GA 30602.*

[4]*Plant pathology.*

[5]*Department of Entomology, The University of Georgia, Athens, GA 30602.*

[6]*Department of Horticulture, Coastal Plain Experiment Station, The University of Georgia, Tifton, GA 31793.*

[7]*Agricultural and applied economics.*

[8]*Department of Horticulture, Rural Development Center, The University of Georgia, Tifton, GA 31793.*

[9]*Department of Entomology, Rural Development Center, The University of Georgia, Tifton, GA 31793.*

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Summary. Optimizing growing conditions and, thereby, plant growth reduces the susceptibility of plants to many disease and insect pest problems. Educating lawn or landscape management professionals and homeowners about plant health management reduces the need for chemical intervention. Pesticides combined with N and P fertilizers contribute to water pollution problems in urban areas; thus, it is important to manage the amount, timing, and placement of chemicals and fertilizers. To educate consumers applying pesticides and fertilizers in residential gardens, we must educate the sales representatives and others who interact most closely with consumers. Evidence suggests that knowledge about the effects of chemicals is limited and that warning labels are not read or are ignored. Integrated pest management (IPM) offers alternatives to conventional chemical treatments, but such methods are not used commonly because of their relatively high cost and their uncertain impact on pests. Pest detection methods and using pest-resistant plants in landscapes are simple and, in many cases, readily available approaches to reducing the dependence on chemical use. Research on effective, low-cost IPM methods is essential if chemical use in landscape management is to decrease. Current impediments to reducing the pollution potential of chemicals used in the landscape include the limited number of easily implemented, reliable, and cost-effective alternative pest control methods; underfunding of research on development of alternative pest control measures; limited knowledge of commercial operators, chemical and nursery sales representatives, landscape architects, and the general public concerning available alternatives; reluctance of the nursery industry to produce, and of the landscape architects to specify the use of, pest-resistant plant materials; lack of economic or regulatory incentive for professionals to implement alternatives; inadequate funding for education on the benefits of decreased chemical use; and the necessity of changing consumer definition of unacceptable plant damage. We need to teach homeowners and professionals how to manage irrigation to optimize plant growth; use sound IPM practices for reducing disease, weed, and insect problems; and minimize pollution hazards from fertilizers and pesticides.

The environmental horticulture industry comprises related commodities including greenhouse, nursery, and turfgrass crops, as well as the services associated with their use. According to estimates from the USEPA, pesticide users in the United States account for one-fourth of the total active ingredients (a.i.) of conventional pesticides used in the world—about 1.1 billion pounds a.i. (499 million kg) (Aspelin, 1994). Herbicides are used in the greatest amounts in the United States—620 million pounds a.i. (281 million kg)—followed by insecticides at 247 million pounds a.i. (112 million kg), and fungicides at 131 million pounds a.i. (59.4 million kg) (Fig. 1a). Seventy-five percent of the total amount of pesticides used in the United States is used in traditional agriculture (Fig. 1b). Eighteen percent of the pesticides in the United States is sold to industrial, commercial, and government entities (including commercial ornamental crop producers and professional pest control operators), and 7% is sold to home and garden consumers. Only about 25% of the total amount of pesticides sold in the United States is used for nonagricultural purposes. However, most nonagricultural applications are in urban areas, thus increasing their perceived impact. The agriculturally accepted concept of a risk to benefit ratio is considered by many to be unacceptable for pesticide use in urban areas. Since the benefits of high-quality ornamental plantings are difficult to quantify, any risks associated with pesticides in landscapes or lawns may be deemed unacceptable (Adamczyk, 1993).

This paper emphasizes methods to reduce potential pollution from pesticides and fertilizers applied during lawn care and landscape management. The first part summarizes the scope and economic impact of this segment of the environmental horticulture industry. The next part describes the status of pesticide and fertilizer use by consumers, the potential for pollution from fertilizers, and the historical use of chemical pesticides in the management of lawns and landscapes. Current status of alternative pest control measures and the impediments to reducing pesticide use in landscapes are detailed. We conclude with a summary of the impediments to reducing potential pollution from pesticides and fertilizers in urban landscapes and a summary of management and educational strategies for reducing pollution in environmental horticulture.

Scope and economic impact of the lawn care and landscape management industry

Ornamental horticulture interacts with almost every homeowner and consumer in the United States. More than 80% of the 93.3 million households in the United States participates in gardening activities (Behe and Beckett, 1993). Consumer interest in gardening, landscaping, and hobby-greenhouse activities is increasing. In 1993, per capita spending by consumers on plant materials averaged $150 (Johnson, 1993). Also, in 1993, lawn care continued to rank as the lawn and garden activity with the highest level of United States household participation and total spending, with an estimated 52 million households spending a total of $6.4 billion for lawn-care-related products and equipment (National Gardening Association, 1994).

The public's increased horticultural activity has resulted in more pesticide use. Nationwide, 27 million households reported using pesticides at least once during 1989 to control pests of their lawns, trees, and gardens (Raupp et al., 1992). From 1989 to 1993, the total number of households practicing insect control ranged from a low of 23 million households in 1993 to a high of 37 million in 1990 (National Gardening Association, 1994). A recent survey of Albuquerque, N.M., residents revealed that 90% of residents had someone in the home who applied insecticides in their own landscapes, spending an average of $36.10 per year per household on pesticides (Ward et al., 1993).

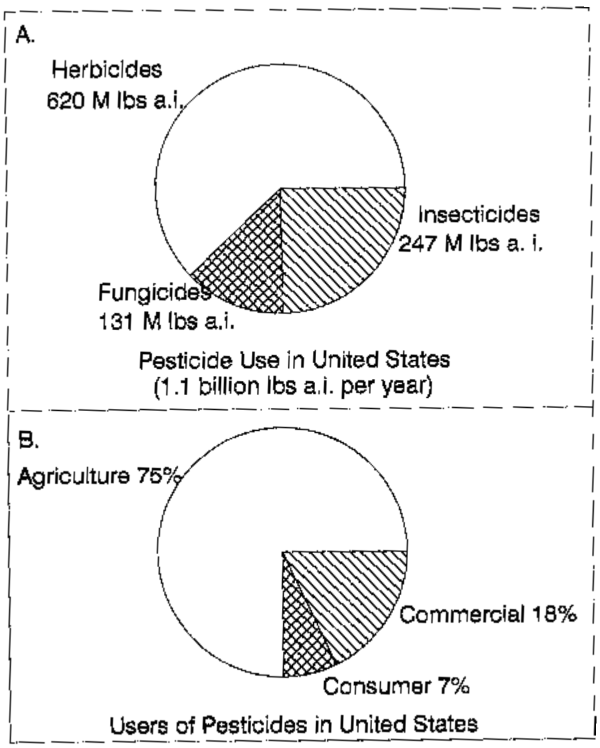

Fig. 1. *(A) Distribution of types of pesticides used in the United States. (B) Distribution of major pesticide users in the United States; commercial includes industrial and government entities, environmental horticulture operations, and professional pest control operators (based on data of Aspelin, 1994).*

In addition to pest control by homeowners, a large management industry maintains plants in the landscape. In 1993, lawn care and landscape services were purchased by 11.1 million United States households (16%) (National Gardening Association, 1994), resulting in about $12.5 billion spent on these services (Seed World, 1993). The number of homeowners using professional landscape services increased 29% between 1992 and 1993 and was expected to increase another 6% in 1994 (Seed World, 1993). Jobs and income generated by the landscape management and lawn-care industry represent a growing contribution to local economies. According to Hubbard et al. (1989, 1990), the number of full- and part-time employees in landscape firms operating in the metro-Atlanta area in 1987 exceeded 5300, with an annual payroll of almost $42 million; metro-Atlanta lawn-care firms employed more than 5600 employees with an annual payroll of over $53 million.

Status of pesticide and fertilizer use in urban landscapes

Managed landscapes are characterized by tremendous diversity of plant material and associated potential pests compared to traditional agricultural monoculture situations. This degree of complexity confounds attempts to develop and implement integrated pest management (IPM) strategies.

Many insects, weeds, and diseases commonly occur in lawns and ornamental landscapes. Details of the biology, occurrence, and management of the most injurious turfgrass insects are reviewed by Tashiro (1987). Johnston and Lyon (1988) provide a detailed review of the insect pests found on landscape ornamentals.

Pesticide and fertilizer use by consumers. Sixty-nine million of the 94 million households use at least one pesticide per year (Aspelin, 1994). Insecticides, primarily for structural and nuisance pests, account for the most active ingredient used in the home and garden market, followed by herbicides, fungicides (not including disinfectants), and others (rodenticides, fumigants, and molluscicides).

Using results from the 1990 National Home and Garden Pesticide Use Survey (NHGPUS), Whitmore et al. (1993) estimated that 90% of single-family residences had at least one pesticide in storage in 1990 and 22% had more than five products in storage. Households treat for microorganisms (mildew, mold, bacteria, and virus, 47%), ants (36%), mosquitoes (28%), cockroaches (24%), and fleas (24%). Only 14% of households treat for insect pests in lawns, ornamentals, or garden. Weeds also were treated by about 14% of households.

The 1993–94 National Gardening Survey (NGS) reported that 54% of all United States households, or 52 million households, participated in do-it-yourself lawn care in 1993, spending an average of $130 per household (National Gardening Association, 1994). Twenty-four percent of households landscaped in 1993, spending an average of $250 per household. In addition, 28% and 21% of households participated in shrub and tree care, respectively. Fifty-six percent of United States households purchased outdoor fertilizers, insect controls, or chemicals. The most common do-it-yourself products purchased for lawn and garden activities included weed and feed fertilizer (28% of households), ready-to-use insect control spray (22%), dry or granular chemical fertilizer (17%), liquid or water-soluble fertilizer (15%), and ready-to-use or concentrated herbicide (13%). Natural or less-toxic insect control products were purchased by only 6% of the households. Natural fertilizers also were purchased by some households; blended all-natural or organic fertilizers were purchased by 8%; blood meal, bone meal, and rock powders by 6%; and manure by 11% of households.

Almost 15% of households with a private lawn in the 1990 NHGPUS had pesticides applied by someone other than a member of the household, generally by a commercial lawn care company (Whitmore et al., 1993). The 1993–94 NGS reported that 16% of households purchased the services of lawn care or landscaping professionals, 12% of the households purchased lawn care service, and 6% purchased landscape management services (National Gardening Association, 1994). Surveys of specific areas, such as San Diego County, Calif., found that 10% of households had someone outside the home applying their pesticides (Pittenger and Lazaneo, 1989). Preliminary survey results of Albuquerque residents indicated that 8% of the residents have professional applicators apply pesticides to control landscape pests (Ward et al., 1993).

Sixteen of the states surveyed in the 1990 NHGPUS require direct notification or posting of pesticides used by commercial lawn care and landscape management companies (Whitmore et al., 1992). Fifty-seven percent of households using the services of lawn care companies in these states reported that they were informed of the chemicals used and advised of safety precautions. However, only 35% of those using landscape service companies were informed of the chemicals used. In states where notification is not required by law, only 38% of households using lawn care services were informed of the chemicals used. EPA currently is circulating draft guidelines for national posting requirements for commercial pesticide applicators, which also may include a call for voluntary posting by homeowners applying pesticides to their own landscapes (Nursery Manager, 1994). Connecticut already requires homeowners and professional applicators to post chemicals used, but enforcement is limited by resources (Adamczyk, 1993).

Consumer education regarding the safe and proper use of pesticides and fertilizers is necessary to reduce the potential for pollution. A recent analysis of American gardeners by level of activity, participation, and sophistication revealed that 61% could be considered dabblers—those who are beginners, have minimal training or experience, and spend 2 h per week or less at gardening (B. Behe, personal communication, 1993). Nineteen percent are decorators—those who own their own home, spend 5 h per week in gardening activities, and are functional gardeners. Eighteen percent of the gardeners are cultivators—those with 17+ years experience and spend 10 h per week in gardening activities. Finally, only 3% are masters—those with 20+ years experience, who spend an average of 26 h per week gardening, and have an average of seven people soliciting their advice on gardening. These survey results indicate that most garden-product consumers have the least amount of experience in appropriate horticultural practices and safe use of pesticides. Relatively few are in a position to educate fellow gardeners. Less than 50% of the homeowners reads the pesticide label, and many ignore common safety procedures, particularly with regard to pesticide storage (McEwen and Madder, 1986; Whitmore et al., 1993). Six percent of all households in the NHGPUS had pesticides in storage because they did not know how to dispose of them properly (Whitmore et al., 1993).

A 1981 survey of Virginia homeowners' preferences in lawn care revealed that 63% rated their lawns as average, but 70% was not satisfied with the current condition of the lawn (Robinson, 1985). Most (95%) of the homeowners thought that well-kept lawn and shrubs increased the dollar value of their homes, and 75% of the homeowners was willing to pay up to $100 per year for lawn care. The survey further revealed that most homeowners did not know what primary pests were present in their lawns or what control methods were recommended for pests. Eighty-five percent said that insect pests were not causing damage to their lawns, and a similar percentage did not apply insecticides to their lawns yearly. Asked to identify their lawn problems, 43% cited poor soil conditions (fertility, pH), 30% cited water availability, and 3% cited insect and disease pests. The survey author suggested that Virginia residents may be amenable to implementing an IPM program because they are not predisposed to depend on pesticides for insect control, and cultural and nonchemical remedies are more appropriate for the problems they identified.

Results of a homeowner survey in Albuquerque indicated that 17% of the homeowners received their pest control information from nursery sales people, 14% from friends and relatives, 13% from university, extension, or Master Gardener sources, 13% from the pesticide labels, 12% from books, 10% from newspapers and magazines, 8% from pest control or landscape professionals, 6% from television or radio, and 5% from garden clubs (Ward et al., 1993). However, the homeowners were not confident in the information they received from sales representatives. Highest confidence ratings were given for information from university or Master Gardener sources or the pesticide labels.

A Univ. of California (UC) study found that 22% of the people surveyed received their pest control information from nurseries, because they were convenient and easy to use, whereas only 2% received information from UC Extension Service (Pittenger and Lazaneo, 1989). The UC and New Mexico sources indicated that educational activities should be focused on professionals in sales, so they may extend that information to the general public.

Potential for pollution from fertilizers in urban landscapes. Several authors have discussed research on the potential for nonpoint source pollution by nutrients applied to landscapes, particularly turf areas (Gold et al., 1990; Gold and Groffman, 1993; Gross et al., 1990; Harrison, 1992; Morton et al., 1988; Petrovic, 1990).

A nutrient applied to a landscape becomes a pollutant when it moves from the root zone, generally, the top 20 cm (8 inches) of soil, into a water body. Nutrients reach surface waters either in solution or in suspension attached to soil particles in runoff water. To reach groundwater, nutrients must leach in percolating water draining below the root zone. Soil P is relatively insoluble, so its potential for nonpoint source pollution generally depends on physical movement to surface waters in association with eroded soil particles; such erosion usually is limited from well-maintained landscapes (Gross et al., 1990; Harrison, 1992; Harrison et al., 1993). Although P runoff amounts from turf areas may be higher than amounts reported in the literature due to excessive soil compaction in high-traffic areas, which reduces water infiltration (Harrison et al., 1993), the probability that P applied to landscapes will pollute surface waters seems small for most situations.

In contrast to P, the solubility, mobility, and potential loss of N from the landscape depends on many complex transformations (Petrovic, 1990). Nitrogen can be applied to the landscape in various chemical forms such as urea, ammoniacal, and nitrate forms; in organic forms such as peat, lawn waste, and sludge; or as combinations of these forms. In addition, most of the N resident in the soil profile is in organic form in living or dead plant, animal, and microbial biomass. To become available for plant use , this organic N must be mineralized to inorganic forms. Urea is rapidly hydrolyzed to the ammoniacal form after application. Ammoniacal N, either applied directly or formed from urea, is subject to volatilization loss as gaseous ammonia. Alternatively, ammoniacal N, which is relatively soluble, can move through the soil profile in solution or be assimilated by plant roots or microbes. Being positively charged, ammoniacal N also is adsorbed by soil particles by cation exchange.

In well-aerated soil under favorable temperatures, ammoniacal N is converted rapidly by soil bacteria to the nitrate form by nitrification. Nitrate thus formed, or applied directly as fertilizer, is negatively charged and not retained by cation exchange. Nitrate is also quite soluble and moves readily in the soil solution. When excess water moves through the soil profile, nitrate can be leached readily from the root zone, thus becoming a potential pollutant. Alternatively, in warm, poorly aerated soil, which occurs after heavy irrigation or rainfall, soil bacteria can use nitrate in the place of oxygen in their respiration processes, resulting in volatile losses of nitrous oxides due to denitrification. Finally, free nitrate, as with ammonium, can be taken up by plant roots or be assimilated by soil microbes and thus immobilized or rendered unavailable for plant use until the death and decomposition of the microbial biomass.

Relatively little N leaches from well-managed turf areas, and nitrate-N concentrations reported in leachates are well below the 10 mg·liter^{-1} standard for drinking water established by EPA (Gold et al., 1990; Gold and Groffman, 1993; Gross et al., 1990; Morton et al., 1988). However, these studies must be examined critically: the authors applied N as urea to established turf but did not determine losses due to ammonia volatilization. The low amounts of N leached in these studies may have been due to N volatilization losses. In other studies reviewed by Petrovic (1990), more N leached below the root zone when turf was fertilized with the nitrate form than when urea was applied. Thus, the potential for N to leach from landscapes is greater than might be inferred from some studies, if soluble N forms are applied. Although using urea fertilizer limits the likelihood of leaching, if the amount of ammonia volatilization is excessive, urea application would not be appropriate in terms of economics or resource management. Rather, the key will be to enhance efficient plant use of appropriate forms of N fertilizer.

Landscapes are typically perennial and densely populated with various plant species that tend to reduce pollution potential. Grasses, as well as herbaceous and woody perennials, develop extensive root systems over time, thus ensuring rapid recovery and assimilation of available N. Furthermore, the plant litter that accumulates in perennial landscapes (leaf litter and thatch) provides a relatively stable source of N, which can be recycled slowly through the system. Likewise, the stable soil–plant systems allow development of large microbial populations, further ensuring efficient scavenging of N not quickly taken up by higher plants. As long as the soil is well aerated and the landscape species are healthy and appropriately irrigated and fertilized, N leaching should be minimized.

A notable exception to this optimistic view is soil of perennial systems, in which stable large pores, as from root channels and worm or insect tunnels, can develop. These biopores provide channels for rapid movement of excess water through the soil profile and out of the root zone, possibly resulting in some localized loss of N from the soil–plant system. This effect has been noted in agricultural systems under conditions of reduced tillage (McCracken et al., 1995), although reduced tillage did not increase nitrate leaching consistently.

In summary, the overall nature of the landscape system should mitigate against nonpoint source pollution by applied N and other fertilizers. Keeping available N in the root zone requires proper management of fertilizer form, amount, timing, and placement, as well as good irrigation management. The potential nonpoint source pollution from landscape fertilization depends on the movement of water through the soil profile at times when the soil solution contains soluble N. Thus, soil water relations may have as much to do with potential fertilizer pollution as nutrient management itself. Indeed, Morton et al. (1988) showed that overwatering fertilized lawns increased N loss, but well-managed irrigation, even with high N application, did not result in higher N loss than from nonfertilized controls. Appropriate irrigation management in landscapes is important for providing proper nutrients for vigorous plant growth and in preventing nonpoint source pollution. Improving irrigation efficiency requires knowledge of the moisture retention of the root medium to apply water to maintain, but not exceed, that retention capacity. Since relatively few residential landscapes are provided with installed irrigation, education on water application methods and soil water management is a critical need. Water management as a pollution prevention strategy would require substantial education of landscape managers and homeowners, but would serve the dual purpose of conserving water by preventing its wasteful application and protecting water quality by reducing runoff and leaching of plant nutrients.

Historical aspects of landscape pest management. Insect pests have been managed primarily by conventional chemical insecticides. Use of a pesticide is often the only practical means of preventing unacceptable damage to turf or amenity plants from heavy or unexpected pest infestations. Efficacy of commercially available and experimental compounds is being evaluated constantly (e.g., Mizell and Schiffauer, 1987; Niemczyk, 1987).

Historically, the gypsy moth eradication campaign in Massachusetts between 1891 and 1900 is reported as the first major attempt to manage a landscape pest (Raupp et al., 1992). This campaign led to the development of lead arsenate as an insecticide, the use of which continued for another 50 years. Spraying with other inorganic and botanical insecticides was common until the development of synthetic organic insecticides after World War II. The highly effective cyclodiene insecticides (chlordane, dieldrin, aldrin, and heptachlor) were used very effectively to control insect pests in the landscape during the 1950s and 1960s (Potter and Braman, 1991). However, the advantage of long residual effectiveness of these chemicals was outweighed by increased insect resistance (Reinert, 1982; Tashiro, 1982) and environmental concerns, which resulted in cancellation of cyclodiene registrations. Organophosphates (e.g., chlorpyrifos, diazinon, trichlorfon, isazophos, and ethoprop) and carbamates (bendiocarb and carbaryl) gained more widespread use during the 1970s and 1980s. Synthetic pyrethroids such as fluvalinate and cyfluthrin have been labelled more recently for use in the landscape.

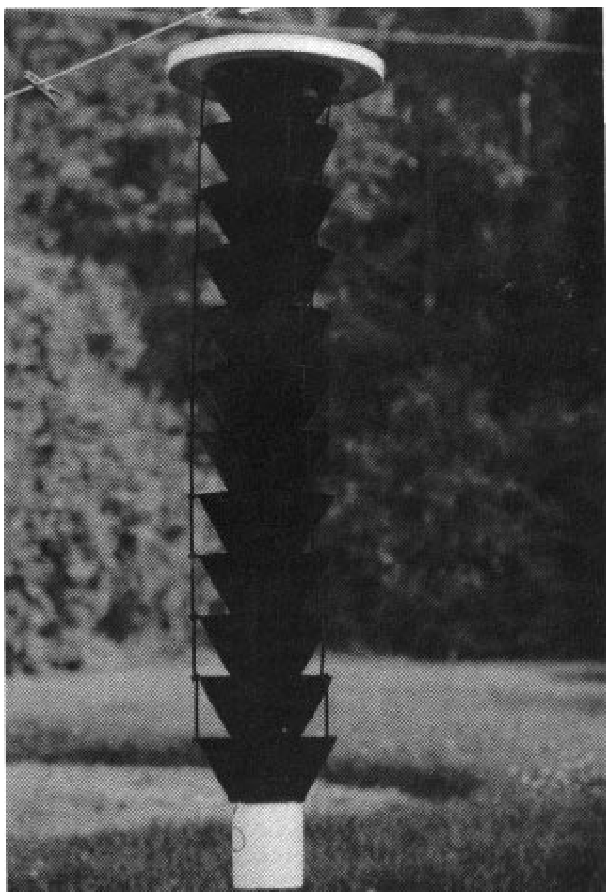

Fig. 2. *A Lindgren funnel—a pheromone trap used to monitor or collect bark beetles—aids in determining when, or if, chemical intervention is necessary. (Photo courtesy of Whitney Cranshaw and Tom Eckburg.)*

Heavy reliance on insecticides in agricultural systems has resulted in several pests' developing resistance to these chemicals. Although the magnitude of resistance problems in the landscape is not known, a recent review suggests that at least 36 insect and mite pests of landscape plants are resistant to at least one kind of insecticide (Raupp et al., 1992).

Recent surveys have determined amounts of pesticide used in production of sod, greenhouse, and nursery plants (Oetting and Allison, 1994). However, few studies have examined pesticide use patterns in the landscape. Neely et al. (1984) provided questionnaires on fungicide and insecticide usage to 529 commercial and 40 municipal arborists in Illinois during 1982; 156 arborists responded. The respondents purchased a combined volume of 41,768 kg (9200 pounds) of fungicide and 1,021,500 kg (225,000 pounds) of insecticide in 1982. Benomyl, maneb, and zineb were the most frequently used fungicides, whereas carbaryl, dimethoate, malathion, and dormant oil were the most frequently used insecticides. Scab and rust were the primary diseases. Scales, aphids, and bagworms were the most prevalent insect pests. Most of the tree species common in residential areas were sprayed for one or more pest problems.

Several studies document a reduction in pesticide use following implementation of IPM in landscapes. Holmes and Davidson (1984) reported a 94% reduction in volume of pesticide used when 11,000 plants on 26 client properties in Maryland were transferred from the previous three cover sprays per year to a system of biweekly plant monitoring with spot-spraying as necessary. Results of other studies found a reduction in pesticide use often exceeding 70% of pre-IPM levels (Coffelt and Schultz, 1990; Funk, 1988; Sherald and DiSalvo, 1987; Smith and Raupp, 1986).

Status of alternatives to conventional pesticides in urban landscapes

The development of IPM for the landscape for the most part has paralleled that for agriculture, but it is characterized by some noteworthy special challenges. As outlined by Potter (1993) for turfgrass IPM, the acceptance and implementation of IPM for the landscape is more difficult than for agricultural crops because of the 1) perennial nature of the system, 2) greater heterogeneity of plants and uses and the diversity of clientele, 3) high aesthetic standards, 4) lack of sampling methodology and decision-making guidelines, and 5) lack of reliable, cost-effective alternatives to pesticides. Despite these limitations to adoption of IPM strategies, considerable progress has been made in developing alternative strategies to traditional chemical control efforts.

Pest detection. In existing landscape IPM programs, monitoring provides information on the temporal and spatial abundance of pests and natural enemies to indicate the most effective timing and placement of control tactics. Monitoring techniques used in IPM programs include visual inspection of plant material. Indicators of insect abundance such as frass also have been used to monitor for insects. Pheromones have been identified and used for traps to detect and survey gypsy moths (Reardon et al., 1987), clearwing borers (Neal and Eichlen, 1983), tip moths (Gargiullo et al., 1983), Japanese beetles (Tumlinson et al., 1977), and certain lawn moths (Clark and Haynes, 1990) (Fig. 2). Forecasting models based on heat-unit accumulations have been developed for a number of turf and ornamental pests including masked chafers (Potter, 1981), azalea lace bug (Braman et al., 1992), elm leaf beetle (Driestadt and Dahlsten, 1990), bronze birch borer (Akers and Nielsen, 1984), flatheaded appletree borer (Potter et al., 1988), bagworm (Neal et al., 1987), obscure scale (Potter et al., 1989), and others. Unfortunately, the value of these sampling tactics is limited, because few population thresholds are defined for the vulnerable or damage-inducing stages of important pests.

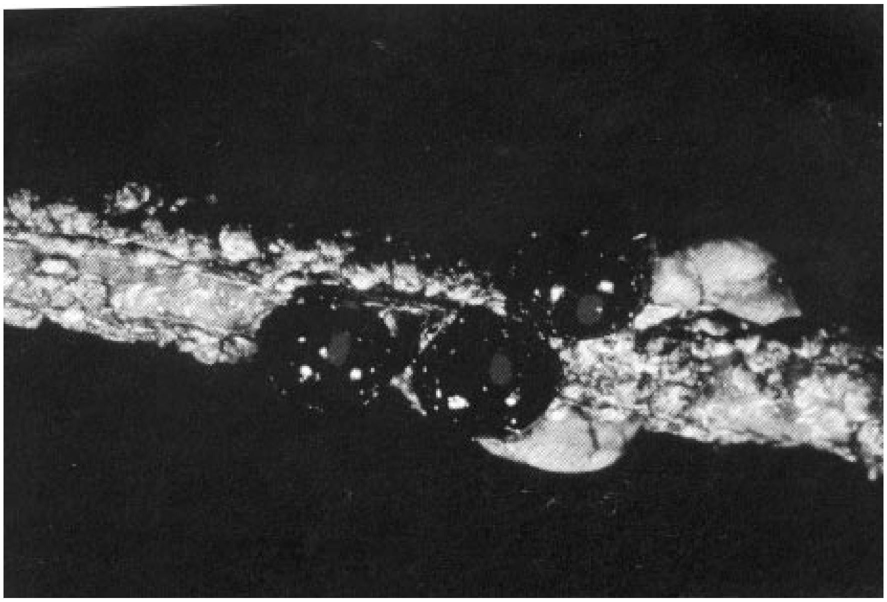

Fig. 3. Chilocorus kuwanae, *(a) adult and (b) larva, is a predator that effectively reduces populations of the euonymous scale. (Photo courtesy of USDA.)*

Studies of ornamental plants have revealed a general pattern that the public perceives, and finds unacceptable, damage or defoliation that exceeds 10% (Raupp et al., 1989a). Coffelt and Schultz (1990) determined that defoliation by orangestriped oak worms that exceeded 10% was not acceptable to most homeowners. Vigor of the trees as measured by starch reserves was not affected, however, until defoliation levels approached 25%. By delaying intervention until an aesthetic threshold of 25% was reached, significant reductions in pesticide use and real cost savings were achieved.

Cultural tactics. Cultural practices, such as fertilization, irrigation, mowing, and topdressing, may affect pest abundance or the expression of injury or disease. Little research has addressed the response of insect pests to the many cultural factors that could be modified to reduce infestation. To reduce herbicide use for weed control in turfgrasses, research in cultural methods that decrease weed populations will be increasingly important.

Improper placement of ornamental plants in landscapes can profoundly affect their susceptibility to pests and plant establishment success. Understory species such as dogwoods and azaleas, for example, are vastly more prone to infestation and damage by dogwood borer and azalea lace bug, respectively, when grown in full sun than shade (Potter and Timmons, 1983a; Raupp, 1984; Trumbule and Denno, 1995). Drought renders many plants susceptible to attack by mites and borers, to certain disease-causing fungi, and to white grubs in turf (Mattson and Haack, 1987; Potter and Gordon, 1984).

Mechanical methods are useful in managing several landscape pests. Sticky traps, banding, and pruning can remove pests from trees or shrubs. Care to prevent wounding landscape trees substantially reduces problems with borers and plant pathogens (Potter and Timmons, 1983b).

Host-plant resistance. An increased number of turfgrass cultivars and ornamental plants with improved disease resistance are currently available. Endophyte-enhanced cool-season turfgrass cultivars offer some protection from insect pests as well (e.g., Siegel et al., 1989). A large range in susceptibility among plant species and cultivars to insects and disease-causing pests has been documented for euonymus to euonymus scale, crape myrtle to crape myrtle aphid and powdery mildew, azaleas to azalea lace bug, junipers to bagworm, ornamental trees to Japanese beetle, cotoneaster and pyracantha to hawthorn lace bug and fireblight, and many other ornamental plant–pest combinations (Raupp et al., 1992; Smith-Fiola, 1995). Greater collaboration among plant pathologists, entomologists, and plant breeders offers the potential for landscape pest management based on plant resistance and reduced pesticide use, without sacrificing plant quality. Reluctance of the nursery industry to increase production of pest-resistant plant materials and the failure of landscape architects to recommend their use are cited as primary obstacles to more widespread adoption of resistant plants for the landscape (Raupp et al., 1992). Landscape architects influence the choice of landscape materials (Garber, 1993) and are an appropriate target audience for educational efforts concerning the use of pest-resistant plants.

Biological control. Biological control of urban pest problems has a broad appeal to management professionals and their clients because of the apparent ecological and environmental safeness of such an approach. Classical biological control, conservation efforts, and augmentation have been attempted in landscape settings with varying degrees of success. Dreistadt et al. (1994) list 19 woody landscape pests that are reported to be substantially controlled by natural enemies introduced for classical biological control in California. Raupp et al. (1992) discuss control successes for insect pests that attack landscape plants in various locations around the world. They report that, in many cases, beneficial insects were imported to control pests in agricultural settings and subsequently made the transition to controlling pests in urban environments. Most of the successes involved hymenopteran parasitoids controlling scale insect pests. However, predatory insects also have been effective. For example, the imported coccinellid *Chilocorus kuwanae* has become established (Fig. 3) and has reduced populations of the scale *Unaspis euonymi* effectively (Drea and Carlson, 1987).

Managed landscapes contain a rich diversity of beneficial arthropods, as evidenced by the fauna reported in maintained turfgrasses (Cockfield and Potter, 1984; Braman and Pendley, 1993a, 1993b). A 3-year study in Maryland revealed the presence of 28 species of predaceous coccinellid beetles in nurseries (Staines et al., 1990). The need for conservation of existing natural enemies has been demonstrated by outbreaks of nontarget pests after applying pesticides. Scale insects, one of the most problematic woody plant pests, often have large parasitoid complexes. The influence of these natural enemies may not be realized fully, however, because their activity tends to peak during the period of greatest scale crawler activity. This developmental period is the time most often recommended for insecticide control to target the crawlers, because this stage is the most vulnerable developmental stage of scale insect pests. Research aimed at determining compatibility of various management strategies is needed.

Insecticides. Microbial, botanically derived, and other products reported to be environmentally benign that have been successfully used in landscape pest management include dormant and summer oils, azadirachtin (neem oil), insecticidal soaps, *Bacillus thuringiensis* (Bt), and entomogenous nematodes. Neely and Smith (1991) reported that almost 50% of arborists surveyed used summer oil sprays, soaps, and Bt. Highly refined summer oils that are now available are very effective for many ornamental plant pests and are safe for plants when applied as directed. Miller (1989) reviewed the use of insecticidal soaps and oils on amenity plants. These materials are particularly effective against soft-bodied, sucking pests including aphids, adelgids, and scale crawlers. Improved formulations of azadirachtin with very low mammalian toxicity have received expanded registrations and are now available for use on turf and ornamentals. Synthetic insect growth regulators with novel chemistry are currently in development. They show excellent activity against soil-dwelling and foliar-feeding pests in turfgrass.

Two strains of the Bt pathogen have registration for use against more than 20 species of defoliating caterpillars that may affect ornamentals (Raupp et al., 1992). Conventional Bt formulations also are labelled for turf caterpillars, but they are not used widely in the industry because their performance is often erratic (Potter, 1993). New strains of Bt have been discovered that have activity against mites, flies, and beetles, offering great potential for use in landscape pest management.

Nematodes (round worms) offer advantages in pest control that include their lack of mammalian toxicity, compatibility with conventional spray equipment, effectiveness on a broad array of pests, relatively quick kill, and potential for commercial production (Potter, 1993). Nematodes have been used successfully to control clearwing moth larvae in several tree species (Potter and Timmons, 1983a, 1983b), black vine weevil larvae in potted nursery stock (Stimmann et al., 1985), and the turfgrass pests white grubs, cutworms, sod webworms, billbugs, and mole crickets (Potter and Braman, 1991). *Steinernema carpocapsae*, the component of most currently marketed nematode formulations, has low mobility and poor host-finding capability in soil. Other nematode species currently are being researched, and improvements in cultural and storage techniques will lead to enhanced effectiveness and greater use in future IPM programs.

Relatively few insecticides and acaricides are registered for use on ornamentals (Mizell et al., 1991) and turf. Those that are still available should be managed carefully to maintain their effectiveness and to protect workers and the environment. The current trend in application of chemical pesticides in landscape management is to-ward those materials that have very low use rates and low mammalian toxicity compared to traditional products. Advances in application technology, such as subsurface application of insecticides for turf, allow for placement of insecticides in the root zone where insects are feeding, reduce surface exposure, and in some cases allow lower use rates.

In summary, significant progress has been made in developing components of and, to a lesser extent, in implementing IPM for turfgrass and landscape plants. The advances in research on nematodes, environmentally benign insecticides, microbial insecticides, systemic fungicides, and host-plant resistance provide an encouraging framework for developing sound management strategies. Somewhat less progress has been made in using predators and parasitoids as control tactics; developing simple, cost-effective and noninvasive sampling tactics; and industry education. However, Raupp et al. (1992) emphasize that, during the past 2 decades, at least 11 IPM programs have been implemented for woody plants in nurseries or urban settings. The authors note that these programs were sponsored largely by universities, although several cooperative efforts among universities, municipalities, institutions, state and federal agencies, and private enterprise were noted. Nine of the studies reported a reduction in pesticide use associated with the implementation of IPM. In some cases costs declined, but in others costs increased. Adoption of IPM strategies has emerged primarily in tree-care firms in the northeastern United States and in California. Surveys indicate that those who receive formal IPM training are more likely to adopt IPM practices (Raupp et al., 1989b).

Impediments to reduced pesticide use in landscapes

While prospects for the implementation of IPM on a broad scale are good, limitations must be addressed. Concerns over potential risks to human health and the environment have led to public demand for critical reassessment of current management tactics, but have in no way lessened the demand that translates into high aesthetic standards for urban landscapes and recreational turf. Research and educational efforts that assess and change the public's tolerance of nondamaging levels of pests and willingness to pay for alternative methods of pest control are needed. Generally, landscape management and lawn care firms, competing among themselves and pressured by customer demands, apply pesticides following a prescribed regimen, only occasionally using methods that minimize the use of chemicals. Customers purchasing management services have limited understanding of scouting-based diagnosis and its relationship to the judicious use of pesticides. Combined educational efforts by industry and university professionals will be required to modify public expectation about what constitutes responsible service as well as quality landscapes.

Additional constraints include the lack of knowledge concerning the biology and ecology of many prominent pest species and their associated beneficials as well as the impact of weather on specific diseases of ornamentals. More than half (57% to 70%) of the respondents to a metro-Atlanta survey identified the following factors as limiting the implementation of IPM in lawn care and landscape management: information about pest biology is lacking; alternatives to traditional chemicals are undetermined, costly, or ineffective; and IPM practices are too time-consuming or are not well received by clients (S.K. Braman, personal communication). One commonly identified impediment, from this limited list, was a lack of available information about pest biology.

The complex interactions that exist in diverse landscapes currently are poorly understood. Difficulty in predicting the occurrence and severity of pest outbreaks limits proactive management tactics. The current lack of reliable and cost-effective alternatives constrain managers to use effective, inexpensive, and more-reliable management choices, which are usually conventional insecticides.

Conclusions

This paper has summarized the chemical and alternative control methods currently available, as well as those that have potential for adoption for insect and disease control in the lawn-care and landscape management industry. Technical and fundamental problems must be overcome before the industry's reliance on chemical pest control can be replaced with more environmentally friendly alternatives.

The limited experience of homeowners in pesticide use provides a great opportunity to educate these people on alternative insect and disease control measures. Educating professional lawn or landscape management operators and homeowners on the concept of plant health management would reduce the need for chemical intervention.

Developing regional manuals for plant health management and holding workshops in nurseries, greenhouses, and other large sales outlets for plant and pesticide products, such as Home Depot or Wal-Mart, would target the consumers needing the information. A large percentage of the lawn and landscape management operators in the Atlanta survey and homeowners in the New Mexico and California surveys indicated that they obtained their pest control information from sales representatives. Sales representatives are a potential audience for educational efforts aimed at promoting environmentally friendly application of pesticides. Information on structural and nuisance pests should be included, since these are the pests most commonly treated by consumers.

Impediments to reducing potential pollution in environmental horticulture. Impediments to reducing the potential for environmental pollution with respect to the use of conventional pesticides in the ornamental horticulture industry include the following:

1) Inadequate pest sampling methods; sampling approaches developed for use in agronomic systems are not directly applicable to managed landscape settings because of the aesthetic nature of the managed resource, its diversity and heterogeneity, and because existing sampling methods are cumbersome, destructive, and time-consuming.
2) The reluctance of the nursery industry to produce, and of the landscape architects to recommend, pest-resistant plant materials, which reduces the availability and widespread adoption of these materials in the landscape.
3) The nonavailability of easily implemented, reliable and cost-effective pest management alternatives and insufficient research

to develop alternatives, particularly for the complex, multi-component, urban landscape.

4) The limited amount of educational or resource information on potential pest management alternatives available for users and the limited funding opportunities available for research and education efforts to implement alternatives.
5) The absence of an economic or regulatory incentive for professionals or homeowners to implement alternatives to conventional pesticides which limits the urgency in development or implementation of alternative measures.
6) Consumers' intolerance of low levels of aesthetic damage and of a professionals' failure to treat perceived problems; consumer education by industry and university professionals will be required to modify public expectation about what constitutes responsible service as well as quality landscapes.
7) The lack of effective and accurate public education programs for safe and efficient use of chemicals in and around the home.

Opportunities for reducing the pollution potential in environmental horticulture. Although research is still necessary to continue to develop alternatives to conventional pesticides, assess their feasibility, and study the complex landscape systems, our primary opportunities for reducing the pollution potential of chemicals used in lawn care and landscape management are in the education of management professionals and homeowners. We must increase the use and acceptance of scouting or other methodology, with treatment for pests of lawns and ornamentals only as necessary. Management professionals, nursery sales representatives, and homeowners must be educated on the value of soil testing and the proper use and application of fertilizers. Research is still needed to determine the most appropriate form of N for various soil profiles and landscape uses to enhance N use and avoid leaching and runoff. We need to educate homeowners and professionals on irrigation management, reduction of disease and insect problems, and prevention of pollution by fertilizers and pesticides.

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