ABSTRACT

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As part of the implementation of an Integrated Pest Management program in a public school system, an inventory of woody plants was created for 12 schools and key plants and key pests in the landscape were identified. In addition, the use of alternative tactics was examined for the control of insect and weed problems. The cost and efficacy of hand removal of bagworms (*Thyridopteryx ephemeraeformis)* from Leyland cypress (X *Cupressocyparis leylandii*) was compared to chemical treatment. Both treatments were effective, but handpicking was more costly. The efficacy and costs of the natural product based herbicides glufosinate, pelargonic acid, and acetic acid were compared to glyphosate for weed control in hardscape areas. The natural alternatives were effective, but at a higher cost. An alternative management program that eliminated the use of preemergent herbicides for weed control on athletic fields was also studied. The alternative program did not yield satisfactory results.

THE IMPLEMENTATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM IN A MARYLAND PUBLIC SCHOOL SYSTEM

By

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Dedication

I dedicate this thesis to my family. To my parents, Phil and Lois, who always encourage me and are interested in whatever dream I am pursuing. To my in-laws, Gary and Judy Beck, for patiently listening to countless bug stories during dinner. Finally, to my wonderful wife, Missy, who made it possible to remain sane and fed while completing this thesis. Without all of you, I could not have done it. Thank you.

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Chapter 1

Introduction

Children's exposure to pesticides has been of increasing concern in recent years. In 1987, it was reported that children exposed to pesticides from home and garden use are at higher risk of developing leukemia (Lowengart et al. 1987). Children are more susceptible due to behavioral and physiological factors. Young children spend most of their time indoors crawling or playing on the floor, which increases their chance of exposure to residual pesticides (Schneider and Freeman 2000). Children are also physiologically more susceptible to harmful chemicals than are adults, due to differences in both physical and functional development (National Resource Council 1993). Early damage to young organ systems may be more severe and may inhibit later development. The functionality of organs can also vary between children and adults. For example, the kidneys' ability to remove toxic substances changes with age (National Resource Council 1993). This is important to remember when examining toxicity data collected on adults or other mammals.

These concerns have led to the passage of legislation designed to reduce the exposure of children to pesticides in schools. Thirteen states, including Maryland, have legislation calling for either voluntary or mandatory Integrated Pest Management (IPM) in schools laws. The Maryland regulation (COMAR 15.05.02) mandates that an IPM program be used on school properties. Control measures in these programs are supposed to be primarily nontoxic tactics such as sanitation, structural repair and nonchemical methods. Pesticides are only to be used when these other methods are unreasonable or unsuccessful. The goal of these programs is to reduce the use of pesticides and therefore minimize risk to human health and the environment from pesticides. Activist groups, such as the Maryland Pesticide Network (2004), contend that pesticide free IPM programs are both efficacious and economical.

There is little data available on the costs associated with the use of an IPM program in a public school system. The data that is available focuses on structural and indoor pests such as ants and roaches (Anonymous 2002, Williams et al. 2005). There is clear evidence from these studies that the undertaking of an IPM program for these pests will not only create a safer school, but will also save money in the long term. However, there have been only a few studies published that examine the costs of implementing an IPM program in landscape areas. These have produced conflicting economic results, with some showing an increase and others a decrease in cost (Raupp and Noland 1984, Smith and Raupp 1986, Stewart et al. 2002). These studies were limited in that they focused solely on the control of insect pests on woody ornamental plants. However, in the school landscape there are also hardscape and turf areas to consider. The main pest problems in these areas are weeds. There have not been any studies published on the efficacy and costs associated with changing from a conventionally managed to an IPM program for weeds.

The objective of this study was to examine various aspects of the implementation of a landscape IPM program in a public school system. As part of the design of a monitoring program, I compiled an inventory of woody plants at 12 schools and used this to identify key plants and key pests. I also undertook a study to determine the cost and efficacy of the hand removal of bagworms from Leyland cypress trees. Additionally, I performed two studies on alternative control measures for weeds. The first examined the use of natural product herbicides for the control of weeds in hardscape areas and the second compared two different management approaches on high school athletic fields.

Chapter 2

Establishment of an Inventory of Key Plants and Key Pests in a Maryland Public School System

INTRODUCTION

Studies have been conducted to implement IPM in cities, residential landscapes, parks and institutions, but not for public schools (Olkowski et al. 1978, Hellman et al. 1982, Holmes and Davidson 1984, Raupp and Noland 1984, Smith and Raupp 1986, Coffelt and Schultz 1990). Adoption of IPM programs in public schools has been mandated by many states, including Maryland. One of the important components of an IPM program for landscapes is a plant inventory that identifies key plants. Key plants are those that are in locations that provide a high level of aesthetic or functional value, or those that are most likely to be damaged by pests (Raupp et al. 1992). The number of these in a landscape correlates with the amount of time required to scout a property (Holmes and Davidson 1984, Ball 1987). They are an important consideration when budgeting time and resources to scout and maintain landscape plantings. Managers should avoid pest prone plants when designing a landscape or when replacing dead or damaged material. Selecting pest resistant species and cultivars may decrease amounts of time spent monitoring and reduce the number of treatments. Reducing the need for pesticides is especially important in sensitive landscapes, such as schools, where the use of pesticides is often discouraged or illegal. We also identified key pests of school landscapes. Key pests are those that are most frequently encountered in the landscape (Raupp et al. 1992).

The objectives of this study were to document the diversity of plant materials in public schools and compare this with other inventories. This information was used to identify key plants and pests in the landscapes and to guide design and management decisions made by school planners and managers.

METHODS AND MATERIALS

We based our methodology on earlier studies by Raupp and Noland (1984) and Holmes and Davidson (1984). The program took place in 12 public schools in Howard County, Maryland during the spring and summer of 2003. An initial visit was made to each school and a map was sketched on site. A detailed map was then prepared using computer graphic software (Photoshop, Adobe Systems, San Jose, CA). These maps showed the location and identity of all trees and shrubs on the site. Each plant was assigned a unique number for record keeping. When plants of the same species were growing tightly together, they were designated as a plant unit (Raupp and Noland 1984). A database (Access, Microsoft, Redmond, WA) was used to record each plant and monitoring information throughout the course of the field season. This facilitated compilation of pest problem data for each visit and at the end of the season. Each school was scouted twice during the period from late June to early August. Arthropods were identified in the field. The Plant Diagnostic Laboratory at the University of Maryland diagnosed diseases and physiological problems.

These scouting records allowed us to assess the number of problems associated with each plant. The total number of plant health problems, the occurrence of each arthropod pest, and the incidences of disease were tallied. We used these to define the key plants and key pests in our school landscapes.

Results and Discussion

Identification of Key Plants

We surveyed a total of 1436 plants comprised of 72 species in the 12 school landscapes. The 10 most common trees and shrubs are summarized in Tables 2.1 and 2.2. The ten most common tree species account for 73% of all the trees present in our inventory. Similarly, 92% of all shrubs are represented by only 10 species. These 20 species account for 82% of all the woody plants in our landscapes. A similar pattern was reported for an institutional landscape (Raupp and Noland 1984). In that landscape, a public university, the ten most common tree and shrub species accounted for 80% of the total inventory. The top four trees in that inventory were oak (*Quercus* spp.), pine (*Pinus* spp.), maple (*Acer* spp.) and crabapple (*Malus* spp.) and top four shrubs were Japanese holly (*Ilex crenata*), other hollies (*Ilex* spp.), juniper (*Juniperus* spp.) and yew (*Taxus* spp.). These species are represented on the lists of the most common plants in our school landscapes. This pattern is not limited to institutional landscapes. In Sacramento, CA, eight species comprised 69% of the street trees present (McPherson 1998). Galvin (1999) reported that 89% of street trees in Mount Rainier, MD, were comprised of only 11 species. In a survey of residential landscapes, Raupp and Noland (1984) found that the top ten tree and shrub species comprised 76% of the total plant inventory. Similarly, Holmes and Davidson (1984) reported that the top 20 tree and shrub species comprised 70.5% of the total inventory for residential landscapes. This pattern of limited overall plant diversity and an overabundance of a few species and genera is widespread and a major concern for managers and planners of street trees as well (Nowak 1994, Galvin 1999, Raupp et al. submitted).

The trees and shrubs with the highest percentage of problems among our most common plants are listed in Table 2.3. Numerous problems plagued crabapple, Leyland cypress (X *Cupressocyparis leylandii*), purpleleaf plum (*Prunus cerasifera*), pin oak (*Quercus palustris*), and white pine (*Pinus strobus*) trees. This was also true for shrubs including juniper, winged burning bush (*Euonymus alatus*), Fraser's photinia (*Photinia x fraseri*), pieris (*Pieris japonica*), and yew. These 10 plants accounted for 75% of the total problems but only 39% of the total inventory in our landscapes. Our list of problematic plants differs dramatically from those reported in residential landscapes by Raupp and Noland (1984). Of the most pest prone species that they reported, only crabapple and euonymus are reflected on our lists. This is likely because most of the trees and shrubs they found to be problematic are not common species in the school landscapes that we monitored. Though the plants are different, the pattern of a few plants being afflicted with the most problems is consistent with the findings of others (Holmes and Davidson 1984, Raupp and Noland 1984).

The trees and shrubs with the least likelihood of having problems are listed in Table 2.4. Of our most common trees, red maple (*Acer rubrum*), American holly (*Ilex opaca*), Chinese chestnut (*Castanea mollissima),* eastern redbud (*Cercis canadensis*), and spruce (*Picea* spp.) were virtually problem free in our landscapes. Chinese (*Ilex cornuta*) and Japanese hollies, as well as butterfly bush (*Buddleia* sp.) and leatherleaf viburnum (*Viburnum rhytidophyllum*) were also relatively pest free.

IDENTIFICATION OF KEY PESTS

Arthropods were directly accountable for 57% of the 400 problems reported. Diseased plants represented 11% of our samples. The remaining damage was attributable to cultural problems or physical damage. Six common insects accounted for 95% of the total arthropod pests encountered (Table 2.5). Similarly, Raupp and Noland (1984) reported that ten arthropod pests were responsible for 97% and 83% of the problems in an institutional and residential landscape, respectively. Bagworms (*Thyridopteryx ephemeraeformis*) and Japanese beetles (*Popillia japonica*) were the most common pests observed, accounting for 80% of the arthropod problems. Over 78% of bagworms were found on Leyland cypress and white pines. This is not surprising as both of these plants are excellent hosts for this common pest (Johnson and Lyon 1991). Most of the remaining bagworms were on plants associated with infestations on these hosts. Purpleleaf plum and linden (*Tilia* sp.) accounted for 57% of the host plants for Japanese beetles. Both of these plants have been reported to be preferred hosts for this very damaging beetle (Rowe et al. 2002, Held 2004). Though limited to junipers, juniper tip midge (*Oligotrophus betheli*) was a common pest in our landscapes.

Four of the six most common insects in our inventory are also found on the lists of common pests reported previously in Maryland landscapes (Holmes and Davidson 1984, Raupp and Noland 1984). Mites (Tetranychidae) and lace bugs (Tingidae) were listed as common pests on these inventories. It is likely that spruce spider mites, which are active in the cooler parts of the year, caused some of the damage that we observed on juniper. The lack of suitable host plants for lace bugs, especially azalea (*Rhododendron* spp.), in our landscapes kept them from being a problem. Although our list of key arthropod pests differs somewhat from those previously reported, the pattern of a just a few species being responsible for the majority of the problems remains.

We observed only a few diseases causing damage in our plants. The most common was quince rust (*Gymnosporangium clavipes*). It was found primarily on crabapples and junipers. In addition, many of our juniper problems were diagnosed as Kabatina tip blight (*Kabatina juniperi*). One large planting of Fraser's photinia was infected with entomosporium leaf spot (*Entomosporium maculatum*).

Dieback and yellowing caused by cultural problems and mechanical damage accounted for 25% of the damage recorded. Cultural problems such as compacted soil, improper growing conditions, damage from road salt, and restricted root zones were common. There were also many examples of mechanical damage to plants. This included trampled plants near doorways, broken branches, and lawnmower damage.

CONCLUSION

Our finding that two pests, Japanese beetle and bagworm, accounted for more than 80% of the insect problems is revealing, and different from other reports (Holmes and Davidson 1984, Raupp and Noland 1984). If key pests are taken into account when making plant selections, many pest problems can be avoided. This is especially true with hard to control pests such as the Japanese beetle. For example, Held (2004) found that varieties of crapemyrtle (*Lagerstroemia*) such as 'Acoma' and 'Pocomoke' are resistant to feeding damage from Japanese beetles. It is often not necessary to eliminate plants such as linden from the landscape as numerous resistant varieties are available (Held 2004).

The other key pest, bagworms, are relatively easy to control with well-timed applications of appropriate insecticides or by hand removal (Lemke et al. 2005). Although it may not be practical for a landscape manager to replace susceptible plant material with resistant species or varieties, the identification of key plants and pests in the landscape allows for the prediction of problematic areas to watch. This information is helpful in setting up an efficient and effective monitoring program. Our results indicate that the implementation of IPM in public schools should be relatively straightforward due to the low diversity of plant materials and short list of key pests. The relatively low diversity of plants suggests that when problems do arise, they may be severe (Raupp et al. submitted).

Table 2.1. Ten most common trees in Howard County school landscapes.

Plant	N	% of Total Trees(767)	% of Total Plants(1436)
1. Eastern White Pine	164	21.4	11.4
2. Red Maple	122	15.9	8.5
3. Pin Oak	75	9.8	5.2
4. Purpleleaf Plum	47	6.1	3.3
5. Norway Spruce	30	3.9	2.1
6. Crabapple	25	3.8	1.7
7. Leyland Cypress	25	3.3	1.7
8. American Beech	23	3.0	1.6
9. Spruce	23	3.0	1.6
10. Arborvitae	23	3.0	1.6
Total		73.1	39.1

Table 2.2. Ten most common shrubs in Howard County school landscapes.

Plant	N	% of Total Shrubs(669)	% of Total Plants(1436)
1. Japanese Holly	150	22.4	10.4
2. Japanese Euonymus	141	21.1	9.8
3. Juniper	88	13.2	6.1
4. Yew	53	7.9	3.7
5. Butterfly Bush	41	6.1	2.9
6. Chinese Holly	38	5.7	2.6
7. Winged Burning Bush	34	5.1	2.4
8. Japanese Pieris	25	3.7	1.7
9. Leatherleaf Viburnum	23	3.4	1.6
10. Fraser's Photinia	22	3.1	1.5
Total		91.8	42.8

Table 2.3. Most problem prone of the 15 most common tree and 10 most common shrub species encountered in 12 Maryland schools.

	% of plants with problems[1]
Trees	
Crabapple	121[2]
Leyland Cypress	88
Purpleleaf Plum	62
Pin Oak	47
White Pine	38
Shrubs	
Juniper	84
Winged Burning Bush	74
Fraser's Photinia	33
Pieris	28
Yew	8

[1] Total problems includes arthropod, disease, cultural and mechanical damage.

[2] Values greater than 100% are possible as some plants had multiple pests.

Table 2.4. Least problem prone of the 15 most common trees and 10 most common shrub species encountered in 12 Maryland schools.

	% of plants with problems[1]
Trees	
Red Maple	5
American Holly	0
Chinese Chestnut	0
Eastern Redbud	0
Spruce	0
Shrubs	
Japanese Euonymus	5
Japanese Holly	2
Butterfly Bush	0
Chinese Holly	0
Leatherleaf Viburnum	0

[1] Total problems includes arthropod, disease, cultural and mechanical damage.

Table 2.5. Most common arthropod pests encountered in 12 Maryland schools.

Pest	% of total arthropods (227)
Bagworm	40
Japanese Beetle	40
Juniper Tip Midge	8
Cynipid gall wasp	3
Aphids	2
Pine Needle Scale	2
Total	95.0

Chapter 3

Efficacy and Costs Associated with the Manual Removal of Bagworms, *Thyridopteryx ephemeraeformis*, from Leyland Cypress

INTRODUCTION

The bagworm, *Thyridopteryx ephemeraeformis* (Haworth), is a widespread defoliator of landscape plants. It is listed as one of the top ten pests of urban forests in the northeast and southern United States (Wu et al. 1991). Bagworms feed primarily on the foliage of evergreens, but it will also use deciduous trees as hosts (Felt 1905, Drooz 1985, Johnson and Lyon 1991). Bagworms seriously damage conifers in landscapes thereby reducing their aesthetic value (Raupp et al. 1988). In nurseries even small amounts of bagworm damage has been shown to significantly reduce consumer acceptance of American arborvitae, *Thuja occidentalis* (Sadof and Raupp 1987). For landscape plants Sadof and Raupp (1996) suggest that the public has a similarly low tolerance for disfigurement of woody plants. In their review of nursery and landscape systems defoliation approaching 10% was noticed and elicited a response for corrective actions. Using small evergreens Raupp et al. (1988) determined that as few as nine first instar bagworm larvae could create damage that would prompt most consumers to initiate control.

In the Mid-Atlantic region bagworms overwinter as eggs and emerge in late May through early June. Upon emergence, larvae begin to feed and construct their protective bags from silk and bits of plant material gathered from their host tree. As the season progresses, the larva grows and increases the size of its bag. When it reaches 30-50 mm in length, the larva pupates within the bag. In early fall, the male emerges and seeks out flightless females. After mating, the female lays up to 1000 eggs in her bag (Kaufmann 1968, Johnson and Lyon 1991).

There are numerous insecticides labeled for the control of bagworms. These include synthetic pesticides such as acephate, carbaryl, and permethrin. With increasing adoption of IPM approaches in the urban landscape and nurseries, uses of bio-pesticides as well as biological and mechanical controls have been implemented more frequently. The biorational insecticide spinosad (Conserve, Dow AgroSciences, Indianapolis, IN) and the insect growth regulator tebufenozide (Confirm, Dow AgroSciences, Indianapolis, IN) have been shown to be effective at controlling bagworms (Gill et al. 2002). These products have been shown to have little or no affect on non-target predators and parasitoids (van de Veire et al. 1996, Booth et al. 2003, Schneider et al. 2004). *Bacillus thuringensis* var. Kurstaki and the entomopathogenic nematode *Steinernema carpocapsae* have been used as effective biological control agents when applied to early instar larvae (Bishop et al. 1973, Gill and Raupp 1994).

Many publications recommend the manual removal of bagworms from trees as an alternative to spraying with insecticides (Drooz 1985, Raupp and Davidson 2003). In some environmentally sensitive landscapes, such as schools, it may be preferable or mandated to employ mechanical control in lieu of chemical control. However, there are no published accounts of the efficacy and cost effectiveness of this approach in a managed landscape setting. In this study, we endeavor to determine the efficacy, as well as the costs, of handpicking bagworms from landscape trees.

Materials and Methods

Manual Removal

A planting of Leyland cypress (X *Cupressocyparis leylandii*) heavily infested with bagworm larvae was used for the manual removal study. The site was located at Fulton Elementary School in Howard County, Maryland. Seven trees, approximately 7 m in height were used in this study. Three were assigned to the manual removal treatment and four served as untreated controls. Prior to the removal of bagworms, the surface area of each tree was estimated by assuming it was a right circular cone and computing the area as $S = \pi r \sqrt{r^2 + h^2}$ where S = surface area, r = radius, h = height. Following larval feeding in late August of 2003, bagworm abundance was estimated on each tree. A 0.37 m^2 frame was held at breast height at the cardinal and primary intercardinal points (8 points total per tree) and the number of bags visible within the frame was counted. The following day three workers removed as many bagworms as possible by handpicking them from the designated trees. The amount of time (worker minutes) required to pick bagworms from each tree was recorded. Prior to egg hatch in April of 2004 using the same methods described previously, bagworm densities were again estimated on each tree. The change in bagworm abundance, expressed as a percent change in the density of bagworms, was compared for non-treated and treated (handpicked) trees. Student's t-test was used to test for a difference between the two treatments (Zar 1999). Data was transformed using Zar's modification of the Freedman and Tukey transformation (Zar 1999) to meet the assumptions of the t-test. Untransformed means $\pm$ 1 standard error are presented throughout.

COST ANALYSIS

As this work was part of a study on the implementation of an IPM program in a public school system, labor costs were calculated using the grade and wage scale for the public school system. Costs for the manual removal of bagworms included the labor costs only for the removal of the bagworms. These costs were estimated for one tree and then multiplied by 40 to estimate the costs of treating 40 specimen trees located at the same site. These costs were compared to the costs of treatments with the insecticide tebufenozide (Confirm). Cost of the insecticide treatment was calculated as the sum of the materials and labor. Labor costs included preparation for the treatment, posting, cleanup, and reporting associated with the pesticide application. Pesticide applicators vary in their abilities to complete all steps necessary to conduct pesticide applications. Therefore, we obtained estimates of the amount of time required to treat trees for bagworms by surveying pesticide applicators in charge of pest management at four public institutions, Howard County Public Schools, University of Maryland, United States National Arboretum, and Smithsonian Institution. They were asked to estimate the time required to prepare the chemicals and equipment, spray, post signs, cleanup and complete any necessary paperwork for applications to control bagworms on one and 40, 7 m Leyland cypress trees. The costs of the materials involved in the application were obtained from the Howard County Public School system. Equipment costs, costs of pesticide applicator certification, and other miscellaneous costs were negligible and not included in either of the cost estimates.

Bagworm control costs for one tree and 40 trees using a conventional insecticide or hand removal were compared using a Student's t-test (Zar 1999). Data for 40 trees was log transformed to meet the assumptions of the t-test. Untransformed means $\pm$ 1 standard error are presented.

RESULTS AND DISCUSSION

EFFICACY OF MANUAL REMOVAL

In August of 2003, prior to handpicking, trees in the group slated for manual removal had a bagworm density of 16.9 $\pm$ 2.8 bags/m^2 and control trees had a bagworm density of 56.9 $\pm$ 13.2 bags/m^2. In April of 2004, trees that were handpicked harbored 1.2 $\pm$ 0.3 bags/m^2 and control trees contained 27.6 $\pm$ 8.3 bags/m^2. Manual removal in concert with natural destruction of bagworms provided a 92% $\pm$ 2% reduction bagworm density. Trees that were not subjected to handpicking experienced a 51 $\pm$ 11% decrease in bagworm density between August and April (Table 3.1). The level of decline on handpicked trees was significantly different from that observed on trees where bagworms disappeared by natural causes alone ($P < 0.05$). Manual removal provided a level of control (92%) similar to that reported previously for chemical and biological control agents (Table 3.2). Tebufenozide and spinosad provided 95-100% control of bagworms in a nursery setting (Gill et al. 2003). When applied to early instar larvae, *Bacillus thuringensis* var. Kurstaki provided 77-100% control (Bishop et al. 1973, Gill and Raupp 1994).

In August 2003 when bagworms were removed by hand, care was taken to remove all bagworms. The fact that a residual, low density of bagworms was found the following spring is indicative of two factors operating singly or in concert. First, it is possible that despite our attempts to completely remove bagworms, workers failed to detect all insects on the trees. Second, although hand removal was delayed until bagworm feeding appeared to have ceased, it is possible that late instar larvae colonized the hand picked trees from nearby untreated trees in late August or September after the manipulation had taken place. Late instar bagworms are known to emigrate from poor quality hosts (Cox and Potter 1988). Although none of the non-treated Leyland cypress experienced high levels of defoliation, it is possible that some larvae may have moved from trees with higher bagworm densities to trees with lower ones later in the season.

Population reduction on the control trees was consistent with previous reports of natural populations. Bersiford and Tsao (1975) reported that 43-71% of larvae were killed by natural causes in a Georgia study. Ghent (1999) reported that in a forest setting, 50% of the bagworms were destroyed between autumn and the following spring. Parasitism, particularly by the hymenopteran *Itoplectis conquistor* (Say), was the most commonly reported natural cause of bagworm death (Cronin 1989). Though parasitism can eventually control a bagworm population, bagworms often reach seriously damaging levels before this occurs (Johnson and Lyon 1991). Other predators of bagworms include fungi (Berisford and Tsao 1975), birds (Moore and Hanks 200, Horn and Sheppard 1979, Ghent 1999), and mammals (Ghent 1999).

COST COMPARISONS

As a means of comparison, average hourly wages for laborers and spray technicians were used in the cost calculations. The salaries for these positions are

$16.54/hr and $22.00/hr, respectively. The cost to hand pick bagworms from a tree was calculated using the laborer salary rate. Manual removal of bagworms averaged (± s.e.) 160 (± 12) minutes per tree. The average cost to pick one tree was $44.11 (± $3.18). The estimated time and cost to handpick 40 trees were 6402 (± 462) minutes and $1,764.00 ± ($127.33), respectively.

The cost to spray trees was based on the use of the insect growth regulator tebufenozide (Confirm), mixed with a spreader sticker (Latron B-1956, BFR Products, Five Points, CA), according to manufacturer guidelines. The bulk costs of the chemicals were $45.00/gal and $29.00/gal, respectively. The cost of insecticide and adjuvant to treat a single tree was estimated to be $1.62, and for 40 trees, $12.87.

The salary for a spray technician was used to determine the labor costs for the pesticide preparation, application, posting, cleanup, and paperwork. The time required for 1) setting up and cleaning the spray equipment, 2) posting, and 3) paperwork was similar for one tree, 51.3 (± 5.2) minutes, and 40 trees, 67.5 (± 7.5) minutes. The estimated time required to spray one tree was 20.0 (± 13.4) minutes and 183.8 (± 56.3) minutes for 40 trees. The total labor time for one tree was 71.3 (± 16.6) minutes and for 40 trees it was 251.3 (± 51.0) minutes. The estimated costs to spray one and 40 trees were $27.75 (± $6.10) and $105.00 (± $18.70), respectively.

Total costs to hand remove bagworms from a single tree or from 40 trees differed significantly from the cost to treat them with insecticides (P< 0.01)(Table 3.3). The magnitude of this difference increased dramatically with the number of trees treated. For a single tree the cost of hand removal was only approximately 1.6 times greater than for an insecticide spray. However, for 40 trees the cost of hand removal was about 16.8 times that of an insecticide spray. Spraying one or many trees at the same location required a relatively small increase in time because most of the time is spent preparing for and cleaning up from the application. Whereas, the hand removal of bagworms required a large and unchanging amount time for each tree irrespective of the number of trees treated.

Manual removal proved to be an effective tactic for controlling bagworms. When the infested trees are small enough to safely handpick, this may be a viable solution. The costs of control must be considered as well. If there are a small number of trees, or if they are only lightly infested, there is likely to be little difference in the costs of control between handpicking and insecticide sprays. As the number of trees requiring treatment increases, the costs for handpicking escalate, while the cost of spraying increases only slightly (Table 3.3).

If plant managers desire or are mandated to use alternative tactics to insecticides, such as the manual removal of bagworms, they must be prepared to allocate more money to these efforts. Labor costs will be great because these tactics are labor intensive. It is with these tradeoffs in mind that landscape managers must decide on the management tactics appropriate for their situation.

Table 3.1. Bagworm density in response to manual removal of bagworms from Leyland cypress.

	Bagworm Density (bags/m^2)		
	August 2003	April 2004	Reduction (%)
Manual Removal	16.9 ± 2.8 [1]	1.2 ± 0.3	92.0%
Control	56.9 ± 13.2	27.6 ± 8.3	50.8%

[1] Bagworm densities are means ± SEM.

Table 3.2. Comparison of published efficacies of products labeled for control of bagworm.

Treatment	% Control	Reference
B.t. var. Kurstaki	77-100	(Bishop et al. 1973, Gill and Raupp 1994)
Steinernema carpocapsae	91-100	(Gill and Raupp 1994)
Acephate	86-100	(Doss and Pinkston 1991; 1992a;b; Gill and Raupp 1994)
Carbaryl	70-95	(Neal 1981; Gill and Raupp 14; Gill et al. 2002)
Cyflurthrin	100	(Gill and Raupp 1994)
Permethrin	100	(Neal 1981)
Spinosad	98-100	(Gill et al. 2002)
Tebufenozide	95-100	(Gill et al. 2002)
Trichlorfon	95	(Neal 1981)

Table 3.3. Summary of costs for manual removal and spraying of bagworms on Leyland cypress.

	Cost					
	One Tree			Forty Trees		
	Labor	Material	Total	Labor	Material	Total
Removal	$44.11 ± 3.18	$0.00	$44.11 ± 3.18[1]	$1,764.27 ± 127.32	$0.00	$1,764.27 ± 127.32[1]
Spray	$26.13 ± 6.10	$1.62	$27.75 ± 6.1	$92.13 ± 18.70	$12.87	$105.00 ± 18.70

[1] Total costs differed significantly between manual removal and spaying using a T-Test ($p<0.01$). Data for one tree was not transformed. Data for 40 trees was log transformed prior to the analysis..

Chapter 4

Efficacy and Costs of Alternative Weed Control Tactics on Curbs

INTRODUCTION

The presence of weeds in hardscape areas is a major concern for landscape managers. Weeds become established in organic matter that collects in expansion joints and cracks that form in concrete and paved areas. This is not only aesthetically undesirable, but can also further damage the concrete or asphalt.

There has been little research on the control of weeds in hardscape areas. The use of string trimmers and spot spraying with a broad-spectrum herbicide are common treatments for these problems. The most commonly used non-selective herbicide in the United States is glyphosate, a systemic herbicide that is relatively inexpensive (Kiely et al. 2004). One application usually provides excellent control of both annual and perennial weeds. Glyphosate kills weeds by disrupting the synthesis of aromatic amino acids by inhibiting 5-enolpyruvylshikimate-3-phosphate synthase (Vencill 2002). Due to public concern over the safety of synthetic herbicides, like glyphosate, many landscape managers are under pressure to use natural products perceived to be less toxic (Duke et al. 2002, Young 2004). In some environmentally sensitive landscapes, such as schools, it may be preferable or mandated to employ natural products for pest control. Acetic acid, pelargonic acid, and glufosinate-ammonium (GLA) are commercially available broad spectrum, natural products that are labeled for landscape use. Managers have resisted the use of these products because there is little data on their efficacy and costs in landscape settings (Young 2004).

Acetic acid has been widely recommended for use as an herbicide (Radhakrishnan et al. 2002, Chandran 2003). It is available as concentrated vinegar or in formulated products. When applied directly to weeds, it causes rapid damage to green tissue. Effectiveness depends on the growth stage of the plant and concentration of the acetic acid (Radhakrishnan et al. 2002). When applied to young giant foxtail, a 20% solution provided 100% control. However, when applied to older plants, control dropped to only 55% (Radhakrishnan et al. 2003). Acetic acid often requires repeated applications for complete effectiveness (Burns 2002).

Pelargonic acid is a naturally occurring fatty acid. It is a non-selective, broad-spectrum contact herbicide (Vencill 2002). Similar to acetic acid, it causes rapid damage to actively growing plant tissue by membrane disruption. Though it usually shows good initial knock down, regrowth of the weeds often occurs (Gaussoin and Vaitkus 1998, Kay 1999).

Glufosinate-ammonium is a broad spectrum, foliar applied herbicide. This herbicide was first isolated from the bacterium *Ketasatoporia phosalacinea* (Hoerlein 1994). It is a glutamine synthesis inhibitor, similar in effect to glyphosate (Hoerlein 1994). It has limited translocation in xylem and phloem with only very small amounts of chemical translocated to the roots (Shelp et al. 1992, Pline et al. 1999). As a result, glufosinate is more effective at controlling annuals than perennials (Steckel et al. 1997, Krausz et al. 1999, Pline et al. 1999).

In this study, we measured and compared the efficacy of natural product herbicides and string trimming as well as the conventional herbicide glyphosate. We also estimated the costs of using the alternative herbicides in the place of glyphosate.

METHODS AND MATERIALS

SITE SETUP AND TREATMENTS

This study was conducted at schools in the Howard County Public School System (Maryland, United States). Our sites were two schools in 2003 and four different schools in 2004. Curbs were divided into 25 ft sections and weed growth in the expansion joint between the curb and the sidewalk and in the seam between the curb and asphalt were measured independently. Weed quantity was determined by measuring the total inches of weeds in these areas using a measuring wheel. Weed species present in each section were recorded. Sections of curb were assigned to treatments in a randomized complete block design with six and eleven replicates in 2003 and 2004, respectively. Blocks were assigned based on weed cover prior to treatment. Treatments in 2003 were: an untreated control, glyphosate, a formulated acetic acid product and concentrated vinegar. In 2004, the treatments were: an untreated control, glyphosate, GLA, pelargonic acid, concentrated vinegar and string trimming. Treatments were initiated on 22 July 2003 and 29 June 2004. Herbicides were applied to runoff using a backpack sprayer. String trimming was performed with a handheld, two-cycle model (Stihl, Virginia Beach, VA). Measurements of weed cover were repeated weekly. In 2004, curb sections that exceeded a weed cover threshold of 5% were retreated three weeks after treatment (WAT). String trimming was repeated one and three WAT.

Herbicides were applied according to label rates. Concentrated vinegar and formulated acetic acid (Burnout, St. Gabriel Laboratories, Orange, Va.) were packaged ready to use (RTU). The formulated product and concentrated vinegar have concentrations of 25% (v/v) and 30% (v/v) acetic acid, respectively. Glyphosate (Roundup Pro, Monsanto Company, St. Louis, Mo.) was mixed at 9.72 g·L a.i. The application rate for pelargonic acid (Scythe, Mycogen Corp., San Diego, Calif.) was 35.16 g·L a.i. The GLA (Finale, Bayer Environmental Science, Montvale, N.J.) was mixed at 4.79 g·L a.i. All of the products were mixed with a tracker dye (Lesco Tracker, Lesco Inc., Strongsville, Ohio) at a rate of 3.90 mL·L to insure complete spray coverage. Defoamer (Cleary Chemical, Dayton, N.J.) was added to the glyphosate, pelargonic acid, and GLA at a rate of 3.90 mL·L.

COSTS

The cost of application was determined for each herbicide. Cost of labor and equipment were the same for each product tested so only the cost of the materials was considered. The cost per gallon RTU was determined for each product. If applicable, the cost of tracker and defoamer was added to the cost of the herbicide. We also estimated the cost for the school system to switch from glyphosate to each of the alternative products. As a means to estimate these costs, we calculated the mean gallons of glyphosate sprayed per year for the years 2002 through 2004. This number was multiplied by the cost per gallon RTU of the other chemicals to estimate the cost of using an alternate product for one application.

DATA ANALYSIS

The data were analyzed by repeated-measures analysis of variance using SAS (SAS Institute, Cary, N.C.). Individual treatment means at specific dates were compared by least significant difference (LSD) at a significance level of 0.05.

RESULTS AND DISCUSSION

EFFICACY

Many different weed species were found in our research areas. The most common grassy weeds were smooth crabgrass (*Digitaria ischaemum*), goosegrass (*Eleusine indica*), and large crabgrass (*D. sanguinalis*). White clover (*Trifolium repens*), dandelion (*Taraxacum officinale*), and black medic (*Medicago lupulina*) were the most common broad leaf species.

In 2003, all of the herbicides provided the same level of control. Beginning at one WAT, all products showed a significant level of control compared to untreated areas (Table 4.1). All of the treatments showed a large decrease in weed cover from 2 WAT to 3 WAT. This was most likely due to mortality caused by the hot and dry conditions occurring during this time (Appendix 1).

In 2004, a similar pattern was seen with the herbicides. One week after treatment, all four products showed a significant reduction in weed cover compared to the untreated areas (Table 4.2). Two WAT, the glyphosate, GLA, and concentrated vinegar treated areas had significantly less weed cover (0.6%, 0.1% and 1.5%, respectively) compared to the 10.9% weed cover in the untreated areas. The pelargonic acid treated areas did not differ significantly from the untreated area.

During the third WAT only glyphosate and GLA provided a significant level of control compared to the untreated areas. Areas within pelargonic acid and concentrated vinegar treatments exceeded the weed cover threshold of 5% and were retreated. Following this second application, the weed cover 4 to 6 WAT was not different for any of the products.

The string trimming treatment was not consistently effective throughout the time course of the study (Table 4.3). At 1 WAT, it provided the same level of control as glyphosate. At 2 WAT, weed cover was lower in the string trimming areas, but it was not as low as the glyphosate treated areas. Throughout the remainder of the study, weed cover in the string trimmed areas fluctuated following repeat treatments. String trimming provided only short term control of the weeds and needed to be repeated every two weeks.

COSTS

The estimated costs for the different products were dramatically different. The prices of each product RTU ranged from $1.24 for glyphosate to $35.10 for concentrated vinegar (Table 4.4). When the cost to switch from glyphosate to a natural product is estimated for the entire school system, the differences are even more pronounced. We estimate that it would cost approximately $4520 to switch to GLA and about $188,000 to switch to concentrated vinegar. These estimates assume that only one application of the alternative products was needed. Young (2004) reported that 3 to 5 applications of natural products resulted in control comparable to that of glyphosate. In our study, not all of the areas that were treated with pelargonic acid and concentrated vinegar needed to be retreated. Although the costs of using these natural products will be greater than glyphosate, the differences in efficacy make it difficult to predict how much.

The use of string trimming to control hardscape weeds was not as effective as the use of herbicides. Frequent trimming is required to keep weeds below an acceptable level. Unfortunately, we do not have data on the cost of the string trimming treatments. If effectiveness is considered, herbicides are the better choice. Differences in the number of applications required and the cost of control are important factors to consider when choosing a herbicide. Our data indicate that use of natural products to control weeds will be more expensive than traditional control methods. These findings are relevant and important in situations where control by natural products is mandated, such as school systems and other environmentally sensitive areas. Planners and lawmakers should be prepared to spend more money on weed management or be willing to tolerate more weeds when natural products replace glyphosate.

Table 4.1. Percent weed cover in 7.6m[1] sections of sidewalk following application of herbicides in 2003.

	Weeks After Treatment			
Treatment	0	1	2	3
Control	20.1a[2]	20.3a	21.9a	10.4a
Glyphosate	19.9a	8.3b	7.9b	2.7b
Formulated Acetic Acid	19.5a	6.5b	10.4b	4.9b
Concentrated Vinegar	21.8a	6.0b	10.5b	4.7b

[1] A 7.6 m section of sidewalk contains 15.2 m of area for weed growth: 7.6 m in the expansion joint between the sidewalk and curb and 7.6 m between the curb and the asphalt.

[2] Means within columns followed by different letters are significantly different based on LSD comparison ($P < 0.05$).

Table 4.2. Percent weed cover in 7.6m[1] sections of sidewalk following application of herbicides in 2004.

	Weeks after treatment						
Treatment	0	1	2	3[2]	4	5	6
Control	12.6a[3]	13.7a	10.9a	10.4a	9.6a	8.1a	7.9a
Glyphosate	13.1a	7.2b	0.6c	0.8c	0.9b	0.7b	0.8b
GLA	13.1a	6.5b	0.1c	1.4c	1.2b	1.2b	1.2b
Pelargonic Acid	14.5a	4.9b	6.7ab	6.3b	2.6b	0.7b	0.8b
Concentrated Vinegar	13.4a	2.8b	1.5bc	3.5bc	0.6b	0.5b	0.4b

[1] A 7.6 m section of sidewalk contains 15.2 m of area for weed growth: 7.6 m in the expansion joint between the sidewalk and curb and 7.6 m between the curb and the asphalt.

[2] Some areas within pelargonic acid and concentrated vinegar treatments exceeded a weed cover threshold (5%) and were retreated four WAT. Weed cover ratings starting at 5 WAT represent the response of two applications of pelargonic acid and concentrated vinegar.

[3] Means within columns followed by different letters are significantly different based on LSD comparison ($P < 0.05$).

Table 4.3. Percent weed cover in 7.6m[1] sections of sidewalk treated by string trimming or glyphosate in 2004.

	Weeks after treatment						
Treatment	0	1	2	3	4	5	6
Control	12.6a[2]	13.7a	10.9a	10.4a	9.6a	8.1a	7.9a
Glyphosate	13.1a	7.2b	0.6c	0.8b	0.9b	0.7b	0.8b
String Trim	13.7a	7.0b	5.8b	10.7a	4.8ab	5.6ab	6.6ab

[1] A 7.6 m section of sidewalk contains 15.2 m of area for weed growth: 7.6 m in the expansion joint between the sidewalk and curb and 7.6 m between the curb and the asphalt.

[2] Means within columns followed by different letters are significantly different based on LSD comparison ($P < 0.05$).

Table 4.4. Estimated costs of glyphosate and natural product herbicides reflecting one annual application of each chemical.

	Cost ($) [1]	
Product	per gal.[2]	Total[3]
Glyphosate	1.24	6,880
Glufosinate Ammonium	2.05	11, 400
Pelargonic acid	3.57	19,900
Formulated acetic acid	16.10	89,700
Concentrated vinegar	35.10	196,000

[1] Product costs based on values reported by Howard County, Md. School System.

[2] Cost per gallon is for ready to use including tracker and defoamer as necessary.

[3] Total cost is an estimate of the total annual cost for Howard County and was calculated by multiplying per gallon cost by average annual glyphosate usage by the Howard County, Md. school system for years 2002-04.

Chapter 5

Effects of elimination of preemergent herbicides from a weed management program on high school athletic fields

INTRODUCTION

Athletic fields are often one of the most visible areas of a high school campus. Grounds managers face great pressures to maintain both the fields' aesthetic beauty and a suitable playing surface. An aesthetically appealing field is often seen as a source of pride and as an indicator that the school and community support the teams that use it (Clark 1980). Though many people see athletic fields being maintained to a high standard as only an aesthetic issue, proper management is also necessary for the safety of the athletes. The incidence of injuries has been negatively correlated with field quality (Clark 1980). A 30% reduction in knee and ankle injuries was reported on resurfaced and well-maintained fields (Andreson et al. 1989). Harper (1984) attributes up to 21% of injuries to poor quality fields. This is also a fiscal issue because injuries caused by poor field conditions may result in litigation against school districts, athletic directors, coaches or landscape managers (Mittelstaedt 1990, Davis 1996, Granger 1996).

Hardness and traction are the most important field characteristics in relation to safety. The incidence of impact injuries is related to field surface hardness (Sifers and Beard 1996). Fields with dense turf cover and soil with a high moisture content and low bulk density provide the softest playing surfaces while the hardest surfaces are characterized by low or no turf cover and dry and compacted soil (Rogers et al. 1988, Rogers and Waddington 1990, 1992). Injuries such as knee sprains are often related to how much traction is created at the shoe-surface interface (Orchard et al. 1999). Higher turf quality and high soil moisture levels are correlated with better traction (Rogers et al. 1988, Orchard et al. 1999).

The definition of what constitutes an adequate playing surface varies. For top-level high school athletic fields, Wisconsin and Maryland have established thresholds of 85% and 90% turf cover, respectively (Mertz et al. 2002, Wisconsin Dept. of Agriculture 2002). However, at an 80% groundcover level, only 5% of soccer players thought that the quality of the playing field was poor (Canaway et al. 1990). This translates to a threshold of 10% weed cover for the fields in this study.

Turf with a low weed threshold is usually maintained through the use of sound cultural practices and a herbicide program. Mowing, fertilization and irrigation are the most important cultural practices used to maintain healthy turf. In addition, practices such as aeration, overseeding and dethatching are used throughout the year. Preemergence herbicides are used to prevent weeds from becoming established. The use of lower rates and split applications has allowed managers to more effectively control weeds and apply less active ingredient to the fields (Dernoden 2001). Postemergence herbicides, fungicides, and insecticides are used as necessary to treat problems that occur during the growing season.

There is increasing concern about the exposure of school students to pesticides. This has resulted in the passage of legislation requiring the use of IPM programs on school grounds. Grounds managers report resistance from concerned community groups to the use of preemergence products on high school athletic fields (G. Connor, personal communication, 2002). It is his belief that he will not be able to adequately control weeds without the use of these chemicals.

The objective of this study is to determine the effects of eliminating preemergence herbicides from a turf management program on athletic field turf quality. Instead, only the use of good cultural management practices was used in an attempt to keep weed cover below threshold levels.

METHODS AND MATERIALS

The field plots in this study were high school stadium fields located in Howard County, Maryland, used for football during the fall and soccer in the spring. They are predominantly tall fescue and built on a native soil base. The experiment was conducted on two fields, Atholton High School (AHS) and Hammond High School (HHS), in 2002 and two different fields, Wilde Lake High School (WLHS) and River Hill High School (RHHS), in 2003. The schools were assigned to either a conventional or alternative treatment plan. The conventional fields were AHS and RHHS and the alternative fields were HHS and WLHS. All of the fields received similar cultural management practices each year. Their use was limited to games only. The fields were irrigated 3-5 cm per week 15-20 cm deep and were mowed two to three times per week to 8 cm high. Aeration was performed four times per year with core tines, slicer tines and shatter tines. Topdressing, consisting of 80% silica sand, 10% peat humus and 10% topsoil, was applied annually in 0.64 cm layers. Overseeding was performed immediately after the fall and spring playing seasons (November-December and May) at a rate of 225 $kg \cdot ha^{-1}$. In addition, approximately

45.4 kg of seed was spread in the middle third of the field monthly during the playing season. The fields were dethatched twice a year as part of the overseeding process. The mechanical overseeding equipment pulls up thatch as it aerates and overseeds. The thatch was picked up with pull behind sweepers. Three applications of an 18-18-18 fertilizer with N at 56.3 kg·ha^{-1} per application were applied annually. In addition 24-4-12 with isobutylidine diurea was applied with N at 1181.3 kg·ha^{-1} in the fall and 618.8 kg·ha^{-1} in the spring.

The pesticide treatments applied to each field are summarized in Tables 5.1 and 5.2. In the spring, the conventional fields received a split application of siduron, for pre-emergent control of crabgrass (Vencill 2002). Postemergence herbicides, fungicides and insecticides were applied as needed. The alternative fields received only rescue treatments for insect, weed and disease problems. Applications were performed using a tractor mounted boom sprayer or broadcast spreader, as appropriate.

We measured weed cover throughout the growing season. Percent weed cover was estimated visually at 9-12 random locations along six equally spaced lengthwise transects per field using a 0.37 m^2 grid. Weed cover on each field was estimated by calculating the median of these measurements. Results are presented as median (interquartile range). There was inadequate replication for statistical analysis.

RESULTS AND DISCUSSION

In 2002 there was a trend of higher weed cover on the alternatively managed fields beginning in June (Figure 5.1). Both fields started out with low weed cover in May, 2.5% (0-25%) on the conventional and 0% (0-12%) on the alternative field. As the season progressed, weed cover on the conventional field increased to only 9.5% (5-15%) by July and then decreased. The alternative field increased to 20.5% (15-28.5%) in June and remained at this level for the rest of the season (Table 5.3). The predominant weeds on both fields were annual bluegrass (*Poa annua*), crabgrass (*Digitaria* spp.), goosegrass (*Eleusine indica*) and yellow nutsedge (*Cyperus esculentus*).

In 2003, there was low weed cover on the conventional field and higher weed cover on the alternative field throughout the season (Figure 5.2). On the conventional field, there was 0% (0-4.5%) weed cover at the beginning of the experiment in June and this remained relatively constant throughout the season (Table 5.4). On the alternative fields, there was 10% (3-25%) weed cover by June and it peaked at 12.5% (5-27.5%) in July. At this time, the grounds manager made the decision to apply postemergence treatments for annual grasses and nutsedge as weed cover was getting so high, he was afraid he would not be able to get the field back to playable condition without an expensive renovation (G. Connor, personal communication, 2003). The predominant weeds on the fields were crabgrass, white clover (*Trifolium repens*), annual bluegrass and prostrate knotweed (*Polygonum aviculare*).

Our comparison of a conventional turf care program to an alternative program that lacked preemergence herbicide applications exhibited a similar trend in both years. On the fields that did not receive preemergence herbicides, weed cover increased markedly. During both years, by early summer the fields in the alternative management program had weed cover levels above the threshold set by the state of Maryland. In 2002, the condition of the alternative field was such that an extensive renovation project was necessary to restore it to playable quality (G. Connor, personal communication, 2003).

It is interesting to note that in both years, the need for the application of postemergence herbicides was not eliminated by the use of preemergence herbicides (Tables 5.1 and 5.2). However, the herbicides that were applied in midsummer were for the control of broadleaf species and yellow nutsedge, species not controlled by the preemergence herbicide. On the conventional treatment fields, these applications helped to keep weed cover levels below threshold. However, even with similar rescue treatments on the alternative fields, weeds remained at high levels. The use of fungicides was necessary on both of the conventional, but only one of the alternative fields (HHS). However, the application of insecticides was necessary on both of the alternative, but only one of the conventional fields (RHHS). The lack of replication in this study does not allow us to determine whether the need for different applications was due to treatment differences or to underlying site or seasonal variability. The weather during the two years of this study was very different. During 2002, the region experienced a drought, while 2003 was a wetter than average year (Appendix 1).

Though statistical analysis was not possible in this study, there was a trend that the fields that did not receive preemergence herbicide treatments had higher weed cover throughout the year, exceeding the thresholds established by the state of Maryland for athletic fields. Our results suggest that the use of preemergence herbicides is helpful in maintaining athletic fields at a playable level. Even with their use, further applications of herbicide may be necessary throughout the season to control weed outbreaks.

It is the challenge of the grounds manager to balance the concerns of the community with the need to provide an attractive and safe playing surface on stadium athletic fields. As pressure to eliminate the use of pesticides on school grounds increases, additional alternatives should be explored. This could include switching to a different turf species, such as Bermuda grass (*Cynodon dactylon*), or to an artificial playing surface. It will be important to measure the costs associated with any new management program as well. In order to confidently make recommendations to managers concerning weed management on athletic fields, further studies need to be conducted. These should involve adequate replication and continue for a longer time period so that cultural methods, such as aeration, that may require more than a few months to produce results are able to do so.

Table 5.1. Pesticide applications on high school athletic fields in conventional (Atholton High School) and alternative (Hammond High School) management programs in 2002.

Conventional

Pesticide (Formulation)	Use Type[1]	Rate ($kg{\cdot}ha^{-1}$)	Date
Siduron (50WP)	H	225	23 Mar.
Siduron (50WP)	H	225	12 May
Triadimefon (50DF)	F	1.6	19 June
Flutolanil (70WP)	F	4.5	19 June
Quinclorac (75DF)	H	1.1	3 July
Trifloxystrobin(50GR)	F	0.77	13 July
Trifloxystrobin(50GR)	F	0.77	7 Aug.
Three Way	H	4.6	20 Oct.

Alternative

Pesticide (Formulation)	Use Type	Rate ($kg{\cdot}ha^{-1}$)	Date
Triadimefon (50DF)	F	3	2 July
Flutolanil (70WP) 4.5	F	9	2 July
Trifloxystrobin(50GR)	F	0.77	12 Aug.
Trichlorfon (6.2GR)	I	169	22 Sept.

[1]Use Type: H=herbicide, F=fungicide, I=insecticide

Table 5.2. Pesticide applications on high school athletic fields in conventional (River Hill High School) and alternative (Wilde Lake High School) management programs in 2003.

Conventional

Pesticide (Formulation)	Use Type[1]	Rate ($kg \cdot ha^{-1}$)	Date
Siduron (50WP)	H	225	8 Mar.
Siduron (50WP)	H	225	8 June
Triadimefon (50DF)	F	1.6	24 June
Flutolanil (70WP)	F	4.5	24 June
Quinclorac (75DF)	H	1.1	28 June
Halosulfuron (75DF)	H	0.09	9 July
Fenoxaprop (6.6EC)	H	2.7	17 July
Trifloxystrobin(50GR)	F	0.77	17 July
Imidacloprid (75WP)	I	0.45	2 Aug.
Mancozeb (75DF)	F	3.1	13 Aug

Alternative

Pesticide (Formulation)	Use Type[1]	Rate ($kg \cdot ha^{-1}$)	Date
Fenoxaprop (6.6EC)	H	2.7	30 July
Halosulfuron (75DF)	H	0.09	30 July
Imidacloprid (75WP)	I	0.45	2 Aug.

[1]Use Type: H=herbicide, F=fungicide, I=insecticide

Table 5.3. Percent weed cover on athletic fields subjected to conventional and alternative weed management programs in 2002. Data presented as median (interquartile range).

	% Weed Cover	
Month	Conventional	Alternative
May	2.5 (0-25)	0 (0-12)
June	5 (2-12.5)	20.5 (15-28.5)
July	9.5 (5-15)	20 (7-25)
August	5 (0-10)	20 (10-30)

Table 5.4. Percent weed cover on athletic fields subjected to conventional and alternative weed management programs in 2003. Data presented as median (interquartile range).

	% Weed Cover	
Month	Conventional	Alternative
June	0 (0-4.5)	10 (3-25)
July	0 (0-5)	12.5 (5-27.5)
Aug.	0 (0-0)	7 (0-22.5)
Sept.	0 (0-3)	3.5 (0-10)

Figure 5.1. Percent weed cover on athletic fields subjected to either a conventional or alternative management program in 2002. Box and whisker plot with the horizontal line representing the median, the box representing the interquartile range, and the whiskers extend from the 5th to 95th percentile.

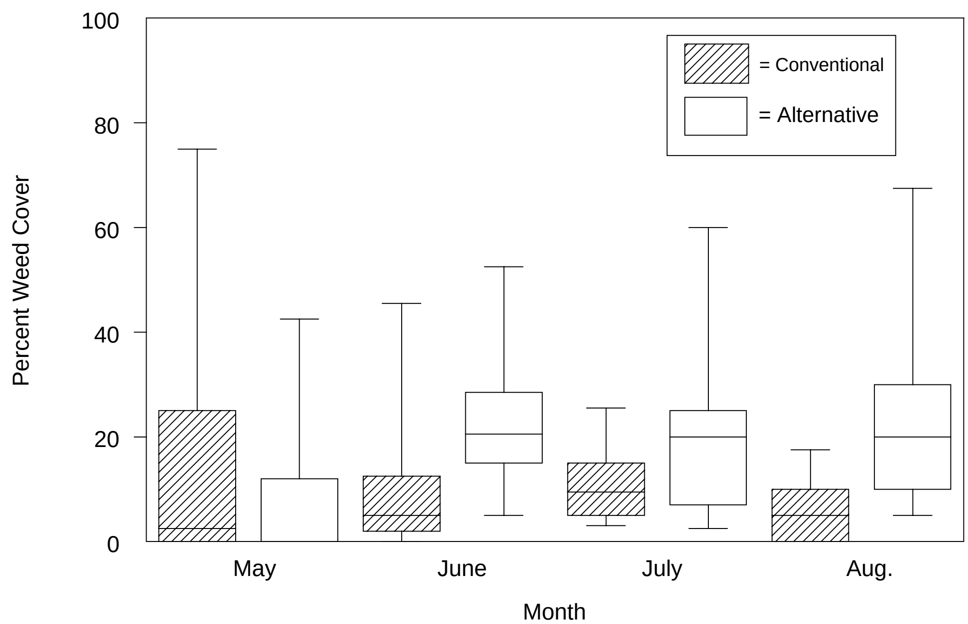
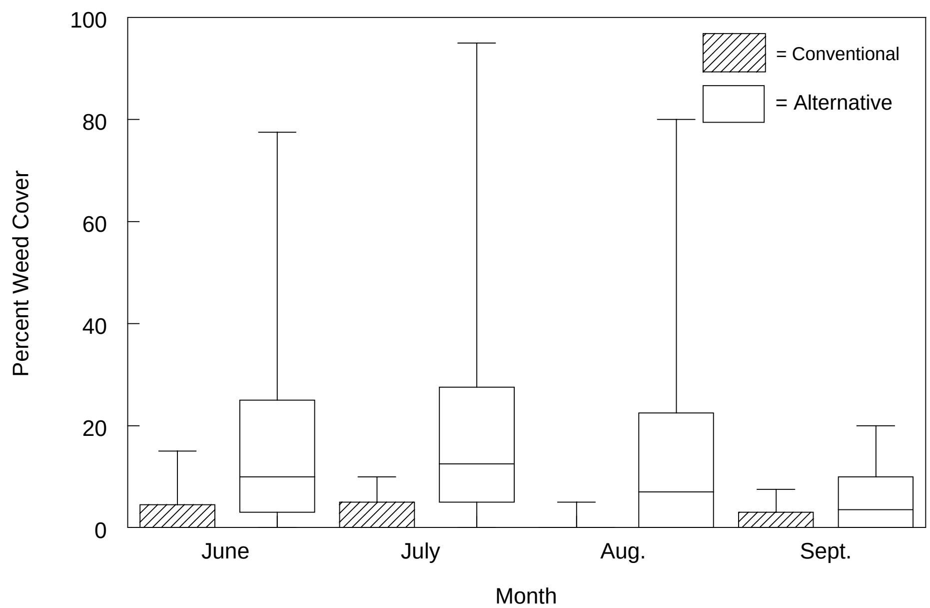


Figure 5.2. Percent weed cover on athletic fields subjected to either a conventional or alternative management program in 2003. Box and whisker plot with the horizontal line representing the median, the box representing the interquartile range, and the whiskers extend from the 5th to 95th percentile.



Appendix 1

Weather Data

2002

Month	Avg temp C	Precip (cm)
Jan.	4	5.56
Feb.	4	0.92
Mar.	7	9.53
Apr.	14	10.35
May	16	7.60
June	23	6.07
July	26	5.75
Aug.	25	8.53
Sept.	21	8.06
Oct.	13	15.28
Nov.	7	9.61
Dec.	1	12.60
Total		99.86

Data based on records from Baltimore Washington International Airport
www.weatherunderground.com

2003

Month	Avg temp C	Precip (cm)
Jan	-2	6.59
Feb.	-1	17.01
Mar.	6	10.61
Apr.	11	6.11
May	15	17.31
June	21	17.68
July	24	14.11
Aug.	24	11.70
Sept.	20	18.95
Oct.	12	14.79
Nov.	10	12.34
Dec.	2	11.95
Total		159.15

Data based on records from Baltimore Washington International Airport
www.weatherunderground.com

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