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ORGANICALLY DERIVED WEED CONTROL METHODS

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ABSTRACT

ORGANICALLY DERIVED WEED CONTROL METHODS

By

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The use of pesticides has come under much scrutiny and review in recent years, having a strong impact on turfgrass management, which relies on herbicides to control weeds in established turfgrass. In response to this research in turfgrass management has been exploring the use of organic weed control methods, as an alternative to potentially harmful synthetic herbicides. A variety of research suggest that allelopathic plants may be used as a model for the development of organically derived herbicides. Previous research conducted at Michigan State University (1998) showed that mulched maple (*Acer* species) leaf litter resulted in fewer weeds than control plots or plots treated with oak (*Quercus* species) leaf mulch. In response to these findings a new study was conducted to compare the effects of different mulched maple species on broadleaf weeds in established Kentucky bluegrass (Poa pratensis L.), in a cool season turfgrass zone. The objectives of this study were to a) quantify the effectiveness of maple leaf mulch as an organic broadleaf weed control method, and b) identify which maple species and at what rate (particle size and rate per unit area) provide the most effective control. Experimental design was a RCBD in a 5x2x2+1 factorial, tree leaf species, leaf particle size, leaf application rate, and control, respectively. Leaf species were red maple, *A. rubrum* L.; silver maple, *A. saccharinum* L.; sugar maple, *A. saccharum* M.; sugar maple (high sugar content); and red oak; *Q. rubra* L. Particle sizes were coarse (2.5-6.4 cm^2) and fine (1.3 cm^2), and application rates were low (0.5-kg m^{-2}) and high (1.5-kg m^{-2}). Results suggest that fall tree leaves applied at the high mulch application rate provided the greatest dandelion (*Taraxacum officinale* W.) control, up to 80%. Results obtained after single applications (2004) and two consecutive applications (2005) suggest that sugar maple species provide the greatest dandelion control, up to 81%.

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INTRODUCTION

The use of pesticides has come under much scrutiny and review in recent years (Blais, 2001). The negative attention directed towards the use of pesticides has had a strong impact on turfgrass management, which relies on the use of herbicides to control weeds in established turfgrass stands. The use of pesticides, such as diazinon (organophosphate) and Dursban® (chlorpyrifos), and herbicides, such as clopyralid has been limited and in some cases banned by the Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 2004a and 2004b). Countries, like Denmark for example, have even gone as far as phasing out the use of herbicides on municipal sports areas (Larsen *et al.*, 2004). Turfgrass management research has focused on the development of organic alternatives to existing and potentially environmentally harmful pesticides.

A variety of research has shown that organic or naturally derived alternatives can be used to provide sufficient weed control in a turfgrass setting. Allelopathic chemicals (plant produced metabolites capable of suppressing competing species) that inhibit plant-specific functions, such as respiration and germination, may be used as a model for the development of organically derived herbicides (Duke, 1986; Singh *et al.*, 2003). Allelopathy is the suppression of a plant species by another through the release of toxic substances (allelochemicals) (Weston and Duke, 2003). For example naturally derived corn gluten meal (CGM) has been shown to provide adequate (up to 93.0%) large crabgrass (*Digitaria sanguinalius* L. Scop.) control in established turfgrass (Christians, 1993).

Alleleochemicals are present in a variety of different plant organs including leaves, roots and stems of different plant species. Rizvi *et al.* (1999) notes nearly 80 taxa of tree species display allelopathic effects. In the U.S., black walnut (*Juglans nigra* L.) is an example of a native deciduous tree species that exhibits allelopathic plant suppression. Symptoms exhibited by herbaceous and woody allelopathic susceptible plants of the black walnut tree, include wilting, browning, necrosis and death of nearby plants (Rietveld, 1983; Weston and Duke, 2003). However, allelopathic activity and response appears to be species specific. Suggesting that plant derived allelochemicals can be used in a turfgrass setting to inhibit broadleaf weed activity if in fact inhibitory activity is species specific. For example, mulched maple (*Acer* species) leaf litter resulted in fewer weeds, specifically common dandelion (*Taraxacum officinale* W.), than control plots, while producing no deleterious effects on established turfgrass (Nikolai *et al.*, 1998). Common dandelion can be problematic in a turfgrass setting and therefore would serve as an appropriate model for organic broadleaf weed control exploration in the field of turfgrass management.

LITERATURE REVIEW

Common Dandelion (*Taraxacum officinale* Weber)

Common dandelion (*Taraxacum officinale* W.) is a non-native species to the U.S. that is capable of colonizing a wide variety of habitats. It is considered an invasive weed due to the fact that it has expanded across a geographic area that it previously did not occupy (Vermeij, 1996). Dandelion has a large geographical native range (Eurasia), ability to reproduce asexually, and capability for long distance dispersal. It is also capable of persisting at a low mowing height. All of these are examples of traits that improve this species' invasive ability (Booth *et al.*, 2003). Thus, common dandelion a problematic weed in turfgrass management is frequently observed in home lawns, pastures, and orchards throughout North America (Uva *et al.*, 1997).

Reproduction

This weed is believed to be of Eurasian origin where it reproduced both sexually and asexually (Holm *et al.*, 1997; Royer and Dickinson, 1999). In the U.S. it reproduces primarily asexually, while in the Netherlands and Europe, both sexual and asexual reproducing populations of dandelion are present (Falque *et al.*, 1998; Verduijn *et al.*, 2004). However, in Europe for example, asexual populations are distributed across the continent, while environmental conditions have restricted the distribution of sexuals to southern and central Europe (Verduijn *et al.*, 2004). This supports the idea that harsh environmental conditions favor plants capable of asexual reproduction (Booth, 2003).

In the U.S., dandelion reproduces primarily asexually or apomictically (triploid) allowing them to be capable of producing seed without fertilization (Crocker and Barton, 1953). Apomictic plants produce a reduced amount of pollen, which can result in a hybridized sexual-apomictic cross (Falque *et al.*, 1998). Asexual repriduction allows dandelion to potentially establish an entire population in a new location from one parent plant, improving its chances for colonization (Booth *et al.*, 2003). Dandelions tend to flower from May to June and again in autumn (Uva *et al.*, 1997). Studies estimate that this perennial plant is capable of producing from 3,000 to 21,000 seeds per individual plant depending on the size (Stevens, 1957). Having a number of different biotypes allows dandelion to persist in a wide variety of different habitats and environmental conditions, increasing the weeds invasive potential (Holm *et al.*, 1997). Solbrig and Simpson (1974, 1977) determined that three of four biotypes (isozymally different) were most abundant in specific sites, while the fourth biotype was distributed across the three sites.

Dandelion seeds are viable and non-dormant, capable of immediate germination if favorable conditions are present. Seeds are capable of emerging year-round with major germination flushes during periods of favorable environmental conditions in the spring and fall (Uva *et al.*, 1997). Letchamo and Gosselin (1996) reported that dandelion seed germinates faster and more uniformly at or above a 1.0 cm soil depth, at higher temperatures (25°C in comparison to 10°C), and when continuous light (400-700 nm) was provided. Research also suggests dandelion seeds must be within 2.0 cm of the soil surface to germinate (Royer and Dickinson, 1999). Collectively, these results support the concept that dandelions are capable of germinating when favorable environmental conditions are present primarily from shallow soil depths. Burnside *et al.* (1996) reported that buried (20cm depth) dandelion seeds were viable for up to 9 years. In fact when seeds were stored at –4°C up to 83% viability was retained after 15 years of storage

(Crocker and Barton, 1953). These results suggest that induced dormancy (initiation of dormancy by external forces) is possible when germination conditions are not favourable.

Dispersal

The primary agent of dandelion seed dispersal is wind. Dandelions produce a small seed with a large feathery pappus, which is a modified calyx that facilitates wind dissemination. The pappus expands and forms a parachute like structure allowing for long distance seed distribution (Booth *et al.*, 2003; Small, 1918). Platt (1975) determined that dandelion seeds in tall grass are capable of being broadcast over several hundred meters. Tackenburg *et al.* (2003) determined that updraft simulations caused more than 0.05% of seeds to spread a distance greater than 100 m; a distance usually defined as long distance dispersal (LDD). Other scattering agents have been identified to include animals, humans and water (Clifford, 1956; Egginton and Robbins, 1920; Hodkinson and Thompson, 1997).

Predation

Dandelion seeds and plants are consumed by a variety of predators, including birds and mammals, and are susceptible to a variety of viruses and fungi. The majority of domesticated livestock and a variety of wild animals including bears, gophers, deer, and elk readily consume dandelion, resulting in a minimal effect on forage (Esser, 1993). Dandelion plants and seeds are also susceptible to a variety of viruses and fungi and have been identified as a host to a variety of different viruses, such as beet ring spot, tobacco streak and raspberry dwarf (Royer and Dickinson, 1999). The pathogenic fungi *Sclerotinia sclerotiorum* and *Sclerotinia minor* can be deadly to dandelion plants (Riddle *et al.,* 1991). *S. sclerotiorum* reduced dandelion populations and establishment by up to

81%, and 86%, respectively. This pathogen and others, like *Phoma herbarum* Westendorp have been shown to reduce dandelion populations in controlled environments, but have produced little effect when introduced in the field (Neumann and Boland, 2002).

Competition

Dandelions have begun to be a problematic weed in no-till fields, competing with crops for moisture and nutrients (Royer and Dickinson, 1999). Research has determined that nutrient applications can have an impact on dandelion populations. Increased N fertilization rates typically reduced broadleaf weed populations, like dandelion, by increasing cool-season turfgrass growth (Busey, 2003; Murray *et al.*, 1983). For example, higher dandelion populations were observed in unfertilized turfgrass plots compared to plots fertilized with 300-kg N ha^{-1} yr^{-1}, when herbicides were not applied (Johnson and Bowyer, 1982). Dandelion populations were also less in plots fertilized with 300-kg N ha^{-1} yr^{-1} in comparison to turfgrass treated with 600-kg N ha^{-1} yr^{-1}. Turner *et al.* (1979) observed that increasing rates of P, from 0 to 680 kg of P_2O_5 ha^{-1}, linearly decreased dandelion populations, from 11 to 6-plants m^{-2}, respectively. Increased K and limestone application rates promoted dandelion establishment. Tilman *et al.* (1999) observed that dandelion populations increased 17- to 20-fold as a result of K fertilization increses, suggesting that dandelions are poor competitors for K in a turfgrass setting. Additional dandelion encroachment was greater in Kentucky bluegrass receiving limestone (Turner *et al.,* 1979). Turfgrass with limestone ($CaCO_3$ 58-kg m^{-2}) incorporated into the soil up to a depth of 10 cm prior to seeding had 2.5 times as many dandelions as turfgrass that did not receive liming treatments. Welton and Carroll (1941) observed that dandelions failed on highly acidic (pH 4) soils, suggesting that as acidity increases dandelion vigor decreases.

Cultural Practices

Dandelion is tolerant to a range of cultural practices, such as mowing, but can not tolerate aggressive tillage. Tillage controls dandelions by vegetative destruction of the taproot and burial of seed. Seed burial is an effective form of control because the seeds are not inherently (genetically predetermined) dormant and incapable of emerging from deep soil depths (Royer and Dickinson, 1999). However in the turfgrass management and no-till cropping systems different methods of dandelion control are required.

Dandelion can be controlled with the application of nonselective and broadleaf herbicides. The use of chlorophenoxy herbicides in turfgrass settings is currently one accepted method of chemical control (Riddle *et al.*, 1991). A fall application of chlorophenoxy herbicide at 1.2-L ha^{-1} can be used for sufficient dandelion control. Examples of chlorophenoxy herbicides used in turfgrass management are 2,4-D [(2,4-dichlorophenoxy) acetic acid], and dicamba. Repeated fall and spring applications are often required for long term control due to dandelions dispersal ability. Once weeds are controlled [80% reduction in population (PMRA, 2002)] cultural practices can be used to repress weed growth by improving the competitive ability of the grass. Using cultural practices as a control tool is important because repeated herbicide applications can lead to herbicide resistant dandelion populations (Holm *et al.*, 1997).

Research investigating allelopathic alternatives to existing synthetic herbicides has lead to the identification of some organic compounds that suppress growth of dandelions. For example, corn gluten meal (CGM) applied as a preemergent and preplant-incorporated (mixed into the upper 2.5 cm of the soil) weed control product reduced dandelion survival and shoot length by greater than 50% and root development by 80% (Bingaman and Christians, 1995). Nikolai *et al.* (1998) observed that plots treated with mulched maple leaves had less dandelion flowers and broadleaf weeds in comparison to plots treated with oak and no leaves (9, 83.7 and 85 dandelion flowers per plot, respectively) when nitrogen was not applied. However, the mode of action for dandelion suppression was not determined.

Mulch

Mulch provides a number of beneficial effects when applied to agricultural crops or turfgrass. Sowers and Welterlen (1988) define mulch as a nonliving covering on the soil surface. Mulch can be used to promote turfgrass germination and establishment at the time of seeding (Emmons, 1995; Sorochan and Rogers, 2001), or inhibit weed germination, establishment, and biomass production (Kamara *et al.*, 2000; Singh *et al.*, 2003). When used to promote turfgrass establishment, an effective mulch material stabilizes the soil and provides a favorable environment for seed germination. Mulching materials include a wide range of organic and synthetic products. Organically produced mulch or amendments, however, provide a number of benefits that synthetic mulches do not. These benefits include a biodegradable, naturally derived nutrient source, and the potential allelopathic suppression (release of plant produced toxic chemicals) of weeds (Weston and Duke, 2003).

Applying mulch to the soil surface during turfgrass establishment is a common practice. Mulch prevents soil erosion which reduces seed loss, and creates a controlled microenvironment favorable to seed germination and establishment during periods of adverse growing conditions, by regulating temperature fluctuations and moisture evaporation (Beard, 1973; Turgeon, 2005). Straw is one of the most successful and widely used forms of mulch during turfgrass establishment (Emmons, 1995; Sorochan and Rogers, 2001). Other crop mulches/residues also provide an effective form of erosion control, but have little or no effect on seed germination or seedling development (Turgeon, 2005). Research conducted by Sorochan and Rogers (2001) on seven different types of organic and synthetic mulches determined that straw, pellet mulch and hydro-mulch were the most effective at enhancing turfgrass cover during fall and summer seeding. Results also showed that synthetic products such as crumb rubber could be used to significantly increase turfgrass germination and establishment during fall seeding conditions. However, because synthetic mulch is not biodegradable it may have to be removed after the turfgrass is established, which requires labor and adds cost.

Nutrients

Plant-derived organic mulches can serve as a natural source of plant nutrients, however, these mulches typically contain high carbon (C) to nitrogen (N) ratios (more than 20:1). Residues with a low C:N ratio decompose and release nutrients quickly serving as a good source of nutrients (Tian *et al.*, 1992). High C-containing residues, however, are known to tie up plant available nutrients, particularly N, because microorganisms require N for their metabolic needs limiting its availability during the plant decomposition process (Cooperband, 2002). Corn gluten meal (CGM), which contains approximately 10% N by weight, is an example of a crop residue with a low C:N ratio that can be applied to turfgrass as a natural, slow-release fertilizer (Liu and Christians, 1997). A corn gluten fertilizer (Bradfield's 9-0-0) is currently being developed by Bradfield Industries™ (Springfield, Mo.). In contrast, organic mulch such as municipal yard waste (fall leaves, brush and grass clippings) and crop residues (hay and straw) contain a high C:N ratio (>20:1). In addition to microbial activity, heavy leaf litter applications will also immobilize soil available N (Heckman and Kluchinski, 1996). Soil amended with freshly fallen tree leaves from red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh), sycamore (*Platanus occidentalis* L.), and black walnut (*Juglans nigra* L.) caused rapid immobilization of available soil N (Heckman and Kluchinski, 1995). This rapid immobilization of soil N resulted in severe symptoms of N deficiency and stunted growth in nonnodulating (incapable of symbiotic N_2-fixation) soybeans (*Glycine max* L. Merr.). Interestingly, maple (*Acer* species) leaf mulch significantly increased the total soil C and N by small amounts only at the 0-1.3 cm depth, but had no significant impact on soil C or N at the 1.3-9.0 cm depth (Acosta-Martinez *et al.,* 1999). Also, mulched red oak and Norway maple (*Acer platanoides* L.) leaves had no significant effect on soil pH or soil available P, K, calcium (Ca), and magnesium (Mg) when mulched into established Kentucky bluegrass (*Poa pratensis* L.) (Nektarios *et al.,* 1998). Maple leaves that remain on the soil surface in the fall, which apparently have little or no deleterious effect on soil available nutrients, may however serve as an effective form of broadleaf weed control (Nikolai *et al.*, 1998).

Weed Suppression

Organic mulches/residues appear to inhibit the germination, establishment and growth of a number of different weeds. Factors that may be responsible for this weed suppression including smothering (compromised respiration), covering (reduces available light and moisture), or even allelopathic suppression (Singh *et al.*, 2003). Persistent mulch with a slow rate of decomposition has been used as an alternative long-term method to suppress weed growth by smothering germinating seeds and emerging seedlings (Elmore *et al.*, 1997). A negative correlation was found between decomposition rate and C:N ratio, percent lignin, and polyphenol compound content (Tian *et al.,* 1992) . However, plant by-products with high decomposition rates (low C:N ratio, lignin, and polyphenol content) have been shown to suppress weed growth (Kamara *et al.*, 2000). These plant by-products, which do not appear to suppress weeds by compromising respiration or inhibiting light, inhibited weed growth through another mechanism. Using mulches for weed suppression is of particular interest because of the growing need for environmentally friendly alternatives to pesticides.

Researchers have been developing organic alternatives, such as CGM, to existing pesticides that have a negative environmental impact (Bingaman and Christians, 1995; Liu and Christians, 1997). Corn Gluten Meal, a corn (*Zea mays* L.) grain by-product, inhibits the formation and growth of roots during the germination of several monocotyledon and dicotyledon weed species (Bingaman and Christians, 1995). Christians (1993) determined that corn gluten meal provided up to a 93% reduction of large crabgrass (*Digitaria sanguinalius* L. Scop.) infestations. This protein fraction of corn grain, however, had no effect when applied postemergent to plants with a mature rooting system. Liu and Christians (1997) determined that corn gluten hydrolysate (CGH), hydrolyzed proteins from CGM, naturally act as root-inhibiting compounds. These results suggest that CGM may be allelopathic. Corn gluten meal also contains approximately 10% N by weight, suggesting a benefit as a fertilizer.

Another organic alternative that is being researched by the turf industry is Alldown™ Green Chemistry Herbicides® a nonselective organic herbicide derived from a mixture of citric acid, garlic, and vinegar (Summer Set, 2004). Research conducted at Iowa State University has determined that this product can provide up to 95% control within a 24-hour period (Bingaman *et al.*, 2000).

Allelopathy

Weston and Duke (2003) define allelopathy as the "mechanism of plant interference mediated by the addition of plant-produced secondary products to the rhizosphere". Plant-produced chemicals with allelopathic suppression capabilities are broadly grouped according to the production of secondary metabolites, phenolic and terpenoid (terpene) compounds (Singh *et al.*, 2003). Allelopathic chemicals that inhibit plant-specific functions, such as respiration and germination, may be used as a model for the development of organically derived herbicides (Duke, 1986). Alleleochemicals are present in a variety of different plant structures including leaves, roots and stems. These allelopathic chemicals are released through volatilization, leaching, root exudates, plant death and/or decomposition.

The application of plant by-products (mulch and crop residue) for allelopathic weed suppression has been investigated. Petersen *et al.* (2001) showed that white turnip-rape (*Brassica rapa* L. 'Perko') mulch released the chemical isothiocyanate (ITC) which suppressed germination of several different plant species. Weed suppression occurred in field experiments treated with white turnip-rape mulch, likely the result of high amounts of ITC. It was hypothesized that glucosinolate-derived secondary metabolite was active as both a leachate in the soil profile and as vapors in the soil pores, resulting in the suppression of weed seed germination. Different *Brassica* species such as black mustard (*Brassica nigra* L.) produce the inhibitory ITC compounds as well (Weston and Duke, 2003). Winter rye (*Secale cereale* L.) residues reduced total weed biomass by 63% in comparison to controls treated with poplar (*Populus* species) excelsior (wood shavings) (Barnes and Putnam, 1983). These results support the hypothesis that rye residues are capable of suppressing weeds through allelopathy, rather than physical suppression (smothering or covering). Additionally, rye root leachates reduced lettuce (*Lactuca sativa* L. 'Ithaca') shoot and total biomass by 27 and 25%, respectively, and tomato (*Lycopersicum esculentum* Mill. 'Petoearly') total biomass by 18%, further supporting the idea that rye is capable of allelopathic suppression (Barnes and Putnam, 1983).

There are a number of turfgrass species that produce allelopathic chemicals. Mature leaf and stem tissue extracts of tall fescue (*Festuca arundinacea* Schreb.), Italian ryegrass (*Lolium multiflorum* Lam.) and little barley [*Critesion pusillum* Nutt. A. Love) inhibit seed germination and reduce seedling growth of alfalfa (*Medicago sativa* L.) and Italian ryegrass (Smith and Martin, 1994). Smith and Martin (1994) found that tall fescue stem extracts at a concentration of 2.8 and 2.5-g L^{-1} reduced alfalfa seed germination and seedling growth by 50%, respectively. Furthermore, Italian ryegrass and little barley tissue extract concentrations of 5.0-g L^{-1} reduced alfalfa seed germination and seedling growth by 50%. A tissue extract concentration of >7-g L^{-1} of all three grass species reduced alfalfa seeding length by 100%. Italian ryegrass seed germination and seedling growth was also significantly reduced by tissue extracts from the three grass species, with the exception of Italian ryegrass stem tissue.

A number of different tree species produce allelopathic chemicals. Rizvi *et al.* (1999) notes nearly 80 taxa of tree species display allelopathic effects, with the majority being detrimental to companion crops. Further research on these allelopathic species is needed to determine their possible positive allelopathic effects, like weed suppression (Rizvi *et al.*, 1999). In Southwestern Nigeria, Kamara *et al.* (2000) determined that mulch from quickstick (*Gliricidia sepium* Jacq. Kunth ex Walp.) and Siamese cassia (*Senna siamea* Lam. Irwin and Barneby) significantly reduced weed density and biomass compared to control plots, while lead tree (*Leucaena leucocephala* (Lam.) de Witt) mulch did not suppress weed growth. The decomposition rate of *G. sepium* mulch was faster than *S. siamea* mulch, yet *G. sepium* mulch suppressed weeds as well as *S. siamea* (>80%). This supports the hypothesis that mulch from this tree may control weeds with allelopathic chemicals rather than compromising respiration, inhibiting light or available moisture. Ramamoorthy and Paliwal (1993) found allelochemicals extracted from *G. sepium* contained fifteen different toxic compounds capable of repressing germination and root elongation in sorghum (*Sorghum vulgare* L.). Eucalypt oils from bluegum eucalyptus (*Eucalyptus globulus* Labill.) and lemonscented gum (*Eucalyptus citriodora* Hook.) inhibited the growth (germination, chlorophyll content, and cellular respiration) of the noxious weed congress grass (*Parthenium hysterophorus* L.) (Kohli *et al.*, 1998). *Eucalyptus* species display allelopathic suppression by releasing toxic oils and volatile terpenes into the soil.

In the U.S., black walnut (*Juglans nigra* L.) is one of many deciduous tree species that exhibits allelopathic plant suppression. Black walnut produces an allelochemical known as Juglone (napthoquinone), a highly toxic substance found throughout the tree

(Rietveld, 1983). Shoot elongation and dry weight accumulation of sixteen plant species were reduced by juglone, with several species being affected at concentrations as low as 10^{-6} *M* (Rietveld, 1983). Juglone significantly inhibited plant functions of hydroponically grown corn and soybean (Jose and Gillespie, 1998). Specifically, juglone had the greatest inhibitory effect on the root relative growth rate; concentrations of 10^{-4} *M* reduced growth by 86.5% for corn and 99% for soybean. Two other tree species, maple and oak possess possible allelopathic plant suppression. Decaying leaf matter and leachates from red oak and white oak (*Quercus alba* L.) reduced seed germination and radical growth of Japanese brome (*Bromus japonicus* Thunb.) and Canada wild rye (*Elymus canadensis* L.) (Lodhi, 1976). A number of phytotoxic inhibitors from aqueous extracts of red and white oak have been identified; including scopolin, caffeic acid, ferulic acid, gallic acid, and ellagic acid (Lodhi, 1976).

Maple species are capable of allelopathically repressing a number of plant species. Roots of silver maple (*Acer saccharinum* L.) trees reduced dwarf bamboo (*Sasa pygmaea* Miq.) root weight by 43% and reduced the number of rhizomes by 50%, but had no significant effect on liriope (*Liriope muscari* Dcne. Bailey) and English ivy (*Hedra helix* L.) (Shoup and Whitcomb, 1981). A series of experiments conducted by Tubbs (1973) on sugar maple seedlings in relation to yellow birch (*Betula alleghaniensis* Britton) seedlings determined that sugar maple clearly inhibited yellow birch root growth. Bioassays with root leachates produced by cut roots and intact roots provided evidence that the sugar maple roots produced an inhibitory substance during periods of rapid root growth. In these experiments, nutrients and moisture were not limiting factors, suggesting that physical competition was not responsible for reduced growth in yellow birch seedlings during field experimentation.

SUMMARY

A variety of research conducted in a number of different agriculturally related fields has shown that several allelopathic plants and the application of their byproducts are capable of inhibiting or controlling invasive plants, such as the common dandelion. These organic alternatives have been shown to provide sufficient weed control, without attracting the negative attention that synthetically derived herbicides have recently been receiving. This is critical to turfgrass management, which currently relies heavily on the use of synthetic herbicides for the control of weeds in established turfgrass stands. However, the application of several of these allelopathically derived organic alternatives has not been explored in the field of turfgrass management. Further research is required to determine if these organic alternatives are species specific and applicable in an established turfgrass setting.

EFFECT OF MULCHED MAPLE (*ACER* SPECIES) LEAVES ON COMMON DANDELION (*TARAXACUM OFFICINALE* W.) IN ESTABLISHED KENTUCKY BLUEGRASS (*POA PRATENSIS* L.)

ABSTRACT

Previous research conducted at Michigan State University (1998) showed that maple (*Acer* species) leaf litter, while being mulched into established turfgrass as a disposal method resulted in fewer weeds than control plots or plots treated with oak (*Quercus* species) leaf mulch. This presents the opportunity for a new study to compare the effects of different mulched maple species on broadleaf weeds in a cool season turfgrass zone. The objectives of this study were to a) quantify the effectiveness of maple leaf mulch as an organic broadleaf weed control method, and b) identify which maple species and at what rate (particle size and rate per unit area) provide the most effective control. Research was conducted on established Kentucky bluegrass (*Poa pratensis* L.) on a native Michigan soil (sandy loam). Experimental design was a RCBD in a 5x2x2+1 factorial, tree leaf species, leaf particle size, leaf application rate, and control, respectively. Leaf species were red maple, *Acer rubrum* L.; silver maple, *Acer saccharinum* L.; sugar maple, *Acer saccharum* M.; sugar maple (high sugar content); and red oak; *Quercus rubra* L. Particle sizes were coarse (2.5-6.4 cm^2) and fine (1.3 cm^2), and application rates were low (0.5-kg m^{-2}) and high (1.5-kg m^{-2}). Data collected in 2004 and 2005 included Kentucky bluegrass spring green-up, and clipping yield, surface temperature, soil temperature, soil moisture content, and common dandelion (*Taraxacum officinale* W.) plant counts. Results obtained in 2004 and 2005 suggest after one annual application of fall tree leaves at the high mulch application rate provided the greatest dandelion control, up to 80% (2004) and 70% (2005) in comparison to the control regardless of tree leaf species. Results obtained after single applications (2004) and two consecutive applications (2005) suggest that sugar maple species provide the greatest dandelion control, up to 81% (2004) and 57% (2005) in comparison to the control.

INTRODUCTION

In response to the criticism potentially harmful synthetic herbicides have been receiving research in turfgrass management has been exploring the use of organically derived weed control methods. The organic alternative Corn Gluten Meal for example inhibits the formation and growth of roots of several monocotyledon and broadleaf and dicotyledon weed species, particularly crabgrass (*Digitaria* species) (Bingaman and Christians, 1995). Soybean meal, another organic byproduct, provided up to 55% reduction in common dandelion (*Taraxacum officinale* W.) population in comparison to control plots (Tompkins *et al.*, 2004). Work at Michigan State University (Nikolai *et al.*, 1998) suggested that maple (*Acer* species) leaf litter could be used as mulch with no apparent deleterious effects to established turfgrass. Unrelated to the objectives of the initial research, turfgrass plots that were treated with maple mulch had statistically fewer broadleaf weeds than the oak leaf treated or control plots. Suggesting turfgrass species have little response to mulched maple leaves, while broadleaf weeds have a strong response (reduction in population). Results also suggest that oak leaves have little effect on turfgrass or broadleaf weed species.

These findings present a question for a further study, to compare the effects of different mulched maple (*Acer*) species applied as an organic broadleaf weed control method. To verify the previous observations different *Acer* species leaf mulch will be compared to two "control treatments". One treatment will consist of oak (*Quercus* species) leaf mulch, due to the lack of broadleaf weed control exhibited by the oak in the 1997 experiments. The other control treatment will have no leaves applied (Nikolai *et al.*, 1998). This work presents the opportunity to identify a new method of organic broadleaf weed [specifically dandelion] control. Field experimentation will be conducted at the MSU Hancock Turfgrass Research Center (HTRC), East Lansing, Mich. on established turfgrass plots to examine the allelopathic activity of maple leaf mulch under Michigan environmental conditions. Research will focus on preemergent effects of leaf mulch on dandelion populations, and spring turfgrass characteristics. Research will also explore effects of leaf mulch on environmental conditions (surface temperature, soil temperature, and soil moisture content) to determine if mulch adversely affects conditions during spring dandelion germination.

Specific Objectives

1. Quantify the effectiveness of maple leaf mulch as an organic broadleaf weed control method in a turfgrass setting under Michigan environmental conditions.

2. Identify specific maple species that provide effective broadleaf weed control in this situation.

3. Establish application rate (particle size and rate per unit area) for the most effective broadleaf weed control in this situation.

MATERIALS AND METHODS

A field experiment was initiated August 2003 at the Hancock Turfgrass Research Center (HTRC) (Michigan State University, East Lansing, Mich.) to examine the allelopathic activity of maple leaf mulch under Michigan environmental conditions. Three experimental sites, total surface area of 678 m^2, with established Kentucky bluegrass (*Poa pratensis* var. 'Fylking') (established 1992) on an Aubbeenaubbee-Capac, sandy loam soil (NRCS, 2005), were selected on August 15. Trimec® Classic Broadleaf Herbicide [2,4-Dichlorophenoxyacetic acid (2,4-D), 2-(2-Methyl-4-chlorophenoxy) propionic acid N (Mecoprop), and 3,6-Dichloro-o-anisic acid (dicamba)] (PBI/Gordon Corporation, Kansas City, Mo.) at a rate of 4.1-L ha^{-1} was applied to the experimental sites on 19 August, to eliminate existing broadleaf weeds. This application provided sites free of broadleaf weeds so the preemergent activity of leaf mulch on established turfgrass could be evaluated.

Site Preparation

Established turfgrass sites were preconditioned to increase broadleaf weed infestation by reducing turfgrass cover, using the following cultural practices. First, eliminating standard fertilizer, herbicide applications, and irrigation; and second, plots were scalped (mowing removal of an excessive quantity of green leaves; resulting in brown turfgrass) to 2.5 cm, and verticut (using vertically rotating blades that cut into the face of the turf to reduce thatch and expose bare soil) (Beard, 1973). Additionally, clippings and thatch removal was important to increase dandelion seed to soil contact when the seeds were later sown. Soil samples of the top 10.2 cm were taken to determine the existing nutrient levels of the experimental site (Table 1, 2 and 3) (Michigan State

Table 1: Soil nutrient levels results from initial experimental plot (received mulch applications in 2003) at the HTRC, East Lansing, Mich., 2003.

Soil pH	7.4
Soil Nutrient Levels	
Phosphourus (P)	31.0 ppm
Pottasium (K)	182.0 ppm
Magnesium (Mg)	490.0 ppm
Calcium (Ca)	1932.0 ppm
CEC	14.2 meq/100g
% Exchangable Bases	
K	3.3
Mg	28.7
Ca	68.0

Table 2: Soil nutrient levels results from repeat of initial experimental plot (received mulch applications in 2004) at the HTRC, East Lansing, Mich., 2003.

Soil pH	7.6
Soil Nutrient Levels	
Phosphourus (P)	41.0 ppm
Pottasium (K)	161.0 ppm
Magnesium (Mg)	476.0 ppm
Calcium (Ca)	1822.0 ppm
CEC	13.5 meq/100g
% Exchangable Bases	
K	3.1
Mg	29.4
Ca	67.5

Table 3: Soil nutrient levels results from experimental plot that did not receive mulch applications, HTRC, East Lansing, Mich., 2003.

Soil pH	7.5
Soil Nutrient Levels	
Phosphourus (P)	54.0 ppm
Pottasium (K)	157.0 ppm
Magnesium (Mg)	413.0 ppm
Calcium (Ca)	1781.0 ppm
CEC	12.7 meq/100g
% Exchangable Bases	
K	3.2
Mg	27.0
Ca	69.8

University Soil and Plant Nutrient Laboratory, East Lansing, Mich.). Two weeks after preconditioning, dandelion seed (*Taraxacum officinale* W.) (V & J seed company, Woodstock, Ill., received 11 September 2003) were applied using a drop spreader to the experimental site (11 September) to increase the seed bank (repository of seeds in the soil) of broadleaf weeds. Dandelion seeds were applied at a rate of approximately 2561-seeds m^{-2}, equivalent to 265 grams of dandelion seed per experimental site. The Michigan Department of Agricultural Control Laboratory (East Lansing, Mich.) determined germination rates of 9.3% in 2003 using a 21-day germination test with 20 to 30° C conditions.

Tree Leaf Collection, Preparation, and Application

Deciduous tree leaves were collected at the W.K. Kellogg Forest, Michigan Agricultural Experiment Station (Augusta, Mich.). Collection traps were installed on 25 September 2003 in stands of the following tree species: red maple (*Acer rubrum* L.), silver maple (*Acer saccharinum* L.), sugar maple (*Acer saccharum* Marsh) and sugar maple (high sugar content), and red oak (*Quercus rubra* L.) (Table 4). Sugar maple high sugar content seedlings were transplanted from the Akens Sugar Maple Laboratory (Burlington, Vt.), where they were selected for high sap sugar content using a refractometer, to the W.K. Kellogg Forest in 1977. In 2004, sugar maple high sugar content trees were selectively thinned according to individual sugar percent value and family mean sugar percent (mean sugar value for retained trees is 2.6%). Leaf litter traps (110 m^2) were installed on the forest floor under each stand of trees described above. A total of 550 m^2 of ground was covered. Cloth germination blankets were used to make the litter traps, they were pinned to the base of the trees within the stands and folded

Table 4: Tree plantation list (last updated: 11-20-98), WK Kellogg Forest, Michigan Agricultural Experiment Station (Augusta, Mich.) (information accessible at www.maes.msu.edu/ressta/kelloggforest).

Species	Year Planted	Test type	Acreage	Spacing (ft)	# of Trees	Thinning
Maple, Red	1974	Prov./Prog.	1.3	8 x 8	885	RT
Oak, English, Red, & White	1984	1/2 sib Prog.	3.2	7 x 7	2845	NT
Maple, Silver	1980	Prov.	0.6	8 x 8	408	
Maple, Sugar	1979	1/2 sib Prog.	1.1	8.2 x 8.2	713	ST
Maple, Sugar	1978	1/2 sib Prog.	1.7	9.8 x 9.8	771	ST

Prov. = provenance
Prog. = progeny
Thinning Status
RT = row thinned
ST = selectively tinned
NT = needs thinning

along the edges to create 10 cm sides to prevent the wind from blowing the leaves away. Leaves abscised as a result of environmental conditions and fell into the leaf litter traps. From 17 to 20 October, 45 kg of leaves from each species were collected from the leaf liter traps. A Poulan PRO® #BMV-200 Gas Blower/Vac, (Electrolux Home Products, Nashville, Ark.) was used to collect the leaves from the litter traps, which were then placed in plastic trash bags. The leaves were transported to the HTRC where they were applied as mulch to one of the preconditioned turfgrass sites.

The tree leaves collected for this experiment were mulched and applied to one of the three preconditioned sites at the HTRC to compare their activity on dandelion seedling preemergence. After the leaves were transported to the HTRC on 21 October 2003, the weight of three random samples from each bag was determined. These samples were then dried for 48 hours in a 140° C oven, and weighed again. This was done to determine the moisture content of the leaves within each plastic bag, making it possible for leaf mulch to be applied at identical rates regardless of the moisture content. After determining moisture content half of each (45 kg) sample was ground to a fine particle size by a MacKissic® Mighty Mac™ mulcher (West Power Products, Thorndale, Pa.) with a 1.3 cm^2 metal screen. The remaining 22.5 kg of leaves were mulched to a medium particle size ranging from 2.5 to 6.4 cm^2. It was vacuum mulched by the Poulan PR0® Blower/Vac to create this size. From 23 to 25 October, fine and medium particle size leaves were then applied at two rates; low (0.5-kg m^{-2}) and high (1.5-kg m^{-2}).

Single Application (2003)

Two weeks prior to initial leaf treatment applications (15 October) Trimec® Classic Broadleaf Herbicide was applied at a rate of 4.1-L ha^{-1} because late fall dandelion emergence was observed. On 31 October 2003, four maple species leaf treatments were randomly applied to the initial experimental site (A) along with the oak (non-maple leaf mulch application) at two rates (low and high) and two particle sizes (coarse and fine). A second control plot was left bare to compare the effects of plots treated with mulched leaves to plots without mulched leaves. Individual plot sizes were 2.79 m^2, therefore the low rate (0.5-kg m^{-2}) application weighed 1.4 kg (dry) per plot and the high rate (1.5-kg m^{-2}) weighed 4.19 kg (dry) per plot. On 5 November, all plots were mowed with a rotary push mower to 5.1cm. This was done to ensure that the mulched leaves were incorporated into the turfgrass canopy.

Two Applications (2003 and 2004)

The original experimental site (A) received a second consecutive annual application of mulched leaves in 2004. Dandelion seeds (V & J Seed Company, received 20 October 2004) were applied at a rate of 238 grams per experimental site (2292-seeds m^{-2}) on 28 October. A germination rate of 0.66% was determined by the Michigan Department of Agricultural Control Laboratory, 2004. Freshly fallen tree leaves were collected from 23 to 27 October 2004 then applied at the appropriate rates, adjusted according to moisture content, and particle sizes on 11 November 2004. The leaf applications were then mowed into the turfgrass canopy on 16 November. This plot was not verticut or scalped and did not receive a herbicide treatment allowing for a review of the post emergent effects of the leaf mulch on the existing weed population.

Single Application (2004)

The original study was repeated at a second 226 m^2 experimental site (B). This site received the same preparation treatments as the original experimental site (A) (2003).

On 23 September 2004 irrigation and fertilization were discontinued. The site was verticut and scalped on 10 October. On 21 October, site B was spayed with Trimec® Classic Broadleaf Herbicide (4.1-L ha^{-1}) to remove the existing broadleaf weeds. Dandelion seeds (2292-seeds m^{-2}, 0.66% germination rate) were applied on 28 October to the newly prepared site. The four maple leaf treatments, the oak control (collected 23 to 27 October, from W.K. Kellogg Forest) and the no leaves control treatment were re-randomized then applied at the two rates (0.5-kg m^{-2} and 1.5-kg m^{-2}), adjusted according to moisture content, and two particle sizes (2.5 to 6.4 cm^2 and 1.3 cm^2) on 11 November. The leaf applications were then mowed into the turfgrass canopy on 16 November.

Site Management

Primary cultural practices, mowing, fertilization and irrigation were adjusted throughout the year to promote weed establishment yet prevent total turfgrass desiccation. From 26 April to 06 July 2004 and 2005 the experimental site was managed at a minimal level to promote dandelion emergence. This included no irrigation and no fertilization, which are requirements for maintaining proper turfgrass quality (Turgeon, 2005). Mowing height was maintained at 5.1cm, however the study was scalped on 15 June 2004 and 2005 to 3.8 cm, to further degrade turfgrass quality and promote dandelion growth. From 06 July to 11 November 2004 and 2005, primary cultural practices were adjusted because dandelions were well established and further turf loss needed to be prevented. Irrigation was applied (06 July to 11 November) at 0.25 cm per day by an automatic irrigation system. Country Club™ 21-3-18 (Lebanon Turf products™, Lebanon, Pa.) fertilizer was applied 07 July and 25 August 2004 and 2005 at 25-kg N ha^{-1} $application^{-1}$, and mowing height was maintained at 5.1 cm.

Data Collection

Data was collected from April to September in 2004 and 2005. Data included Kentucky bluegrass visual spring green-up ratings, surface and soil temperature, soil moisture content, Kentucky bluegrass clipping yield, and dandelion population counts.

Three visual Kentucky bluegrass spring green-up ratings were recorded from 03 April to 03 May in 2004 and 20 April to 31 May in 2005. These dates represent roughly a one month period from the time of snow-melt. Visual Kentucky bluegrass spring green-up ratings were based the National Turfgrass Evaluation Program (NTEP) system of rating, a scale of 1 to 9 with 1 equaling straw brown and 9 equaling completely green turfgrass. A rating of 6 or above is considered acceptable.

Surface and soil temperature (4.5 cm depth) data was recorded twice in the spring after snow-melt while mulch stile persisted on the turfgrass surface; specifically on 03 April and 15 April in 2004 and 20 April and 06 May in 2005. Temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.). Soil temperature was measured with a 4.5 cm soil probe, and surface temperature was measured with a thermal couple. Soil moisture content (v/v) was recorded on 15 April 2004 and 06 May 2005 while mulch still persisted with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

Kentucky bluegrass dry clipping yield weights (g m^{-2}) were determined by collecting clippings using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.) set to a mowing height of 3.8 cm then oven dried (140 °C for 48 hrs.). These samples were collected 05 May 2004 and 14 May 2005 in the spring when mulch had degraded to the point where mowing samples could be retrieved without leaf litter and before the first mowing of the season.

Dandelion plant counts were completed by counting the total number of individual dandelion plants per plot (2.8 m^2). Plant counts were done monthly in June, July, August and September of 2004 and 2005.

Statistical Analysis

Data were analyzed as a factorial, randomized complete block design using PROC MIXED procedure in SAS (SAS Institute, 2002). The three studied factors (main effects) included (1) tree leaf species, (2) application rate, and (3) particle size. A comparison control treatment, which did not receive any mulch, was also included in this experiment. Three replications of each treatment combination were also included in each study. Data was analyzed at a 0.05 level of significance. Assumptions of the Analysis Of Variance (AOV) that were checked included normality of the residuals and homogeneity of variances (PROC UNIVARIATE procedure). When residual variances were more than three times different the analysis was adjusted for unequal variances using a REPEATED/GROUP = trt statement (groups data according to treatment). If needed, the treatments with similar variances were grouped and the unequal variances of these groups were accounted for with a REPEATED/GROUP = group statement. The Akaike Information Criterion (AIC) was used in making a final decision on whether to pursue an analysis with unequal variances or a regular analysis with a common variance. The analysis (either unequal variance or common variance) that produced the lowest AIC value (most accurate model) was selected and conclusions about significance of factor effects and mean separations were obtained based on the selected analysis.

RESULTS AND DISCUSSIONS

Single Application

Results collected following one fall application (2003 and 2004) of mulched maple and oak leaves to established Kentucky bluegrass, site A (results obtained in 2004) and B (results obtained in 2005).

Spring Green-up

Significant differences in Kentucky bluegrass spring green-up occurred throughout the month following snowmelt for tree leaf species and mulch application rates after the first year of mulch applications (Table 5 and 7).

Statistically significant differences were observed between tree leaf species on 20 April 2005 (Table 8). The significant differences between species were minimal with red maple producing the greatest green-up rating. All species were significantly greater than the control treatment. Data was significant on this date only making it difficult to identify trends.

Differences occurred between application rates on 03 April, 21 April, and 03 May 2004, and 20 April, and 06 May 2005 (Table 6 and 8). The high rate (1.5-kg m^{-2}) producing the greatest green-up followed by the low rate (0.5-kg m^{-2}) and finally the control treatment in all instances of significance. Results suggest a correlation between Kentucky bluegrass spring green-up and increased mulch rates. These results suggest that the mulched leaves had biodegraded to a point were nutrients would be plant available and acted as an organic nutrient source (Cooperband, 2002; Tian *et al.*, 1992; Heckman and Kluchinski, 1996). Nektarios *et al.*, (1999) observed that plots treated with tree leaves produced a slightly darker green color. They hypothesized that these

Table 5: Analysis of variance (AOV) results for Kentucky bluegrass spring green-up+ after one application of fall tree leaves, single application (site A) 2003, results obtained in 2004, HTRC, East Lansing, Mich.

	Single application 2003		
Contrasts	**03-Apr-04**	**21-Apr-04**	**03-May-04**
Leaf species (L)	ns	ns	ns
Particle size (P)	ns	ns	ns
Application rate (A)	*	*	*
L x P	ns	ns	ns
L x A	ns	ns	ns
P x A	ns	ns	ns
L x P x A	ns	ns	ns

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 6: Effects of leaf species, particle size and application rate on spring green-up+ of Kentucky bluegrass after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, HTRC, East Lansing, Mich.

	Single application 2003		
Leaf species	**03-Apr-04**	**21-Apr-04**	**03-May-04**
control	4.6	6.0	7.1
red maple	6.8	7.6	7.7
red oak	7.2	8.2	8.2
silver maple	6.6	7.5	7.7
sugar maple	7.5	8.2	8.3
sugar maple (hsc)	7.3	8.1	8.3
	ns	ns	ns
Particle size			
control	4.6	6.0	7.1
2.5 to 6.4 cm^2	7.2	8.0	8.2
1.3 cm^2	6.9	7.8	7.9
	ns	ns	ns
Application rate			
control	4.6 a	6.0 a	7.1 a
0.5-kg m^{-2}	6.1 b	7.3 b	7.8 b
1.5-kg m^{-2}	8.2 c	8.5 c	8.3 c

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Table 7: Analysis of variance (AOV) results for Kentucky bluegrass spring green-up[+] after one application of fall tree leaves, single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2004		
Contrasts	**20-Apr-05**	**06-May-05**	**31-May-05**
Leaf species (L)	*	ns	ns
Particle size (P)	ns	ns	ns
Application rate (A)	*	*	ns
L x P	ns	ns	ns
L x A	ns	ns	ns
P x A	ns	ns	ns
L x P x A	ns	ns	ns

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 8: Effects of leaf species, particle size and application rate on spring green-up[+] of Kentucky bluegrass after one fall application of tree leaf mulch, single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2004		
Leaf species	**20-Apr-05**	**06-May-05**	**31-May-05**
control	4.8 a	6.3	7.1
red maple	6.2 b	7.5	7.2
red oak	6.9 c	7.3	7.2
silver maple	6.8 bc	7.5	7.3
sugar maple	6.2 b	7.3	7.3
sugar maple (hsc)	6.8 bc	7.4	7.1
		ns	ns
Particle size			
control	4.8	6.3	7.1
2.5 to 6.4 cm^2	6.6	7.5	7.2
1.3 cm^2	6.5	7.3	7.3
	ns	ns	ns
Application rate			
control	4.8 a	6.3 a	7.1
0.5-kg m^{-2}	5.8 b	7.1 b	7.2
1.5-kg m^{-2}	7.3 c	7.7 c	7.3
			ns

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

differences were the result of dark brown leaves that were incorporated into the lower canopy of the turfgrass stands. Nikolai *et al.* (1998) recorded no differences in turfgrass color as a result of tree leaf applications, but however observed greater turfgrass quality as a result of maple leaf applications. Differences in application rate decreased as time progressed and in single application 2005 on 31 May 2005 they were eventually lost, indicating that as the mulch biodegrades and temperatures increase the green-up advantages provided by the mulch treatments are eventually lost.

Surface Temperature

Surface temperature significant differences were observed for particle size, application rate, and particle size x application rate interactions after the first year of mulch applications (Table 9).

Differences occurred between particle sizes on 03 April, and 15 April 2004 (Table 10). On all dates of significance the fine particle size (1.3cm^2) mulch produced the highest surface temperature followed by the coarse (2.5 to 6.4cm^2) and finally the control even as mean surface temperature increased over time. Suggesting that fine particle size mulch retains or absorbs soil surface heat better than coarse, which in turn had higher temperatures than the control. Vanini (1995) observed similar effects when applying crumb rubber at a fine particle size (2.00/0.84 mm in comparison to 6.00mm), producing a significantly greater surface temperature.

Statistically significant differences were observed between application rates on 03 April 2004, 15 April 2004 and 06 May 2005 (Table 10). The high rate produced the greatest surface temperature followed by the low rate and finally the control treatment in

Table 9: Analysis of variance (AOV) results for surface temperature+ after one application of fall tree leaves, single application (site A) 2003, results obtained 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003		Single application 2004	
Contrasts	**03-Apr-04**	**15-Apr-04**	**20-Apr-05**	**06-May-05**
Leaf species (L)	ns	ns	ns	ns
Particle size (P)	*	*	ns	ns
Application rate (A)	*	*	ns	*
L x P	ns	ns	ns	ns
L x A	ns	ns	ns	ns
P x A	ns	*	ns	ns
L x P x A	ns	ns	ns	ns

+ Surface temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a thermal couple.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level

Table 10: Effects of leaf species, particle size and application rate on surface temperature+ after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003		Single application 2004	
Leaf species	**03-Apr-04**	**15-Apr-04**	**20-Apr-05**	**06-May-05**
control	9.0	19.7	26.9	28.8
red maple	10.0	20.3	26.8	29.4
red oak	9.4	20.3	26.5	29.4
silver maple	10.1	20.8	26.7	29.0
sugar maple	9.8	20.2	27.4	29.8
sugar maple (hsc)	9.3	20.8	26.9	29.6
	ns	ns	ns	ns
Particle size				
control	9.0 a	19.7 a	26.9	28.8
2.5 to 6.4 cm^2	9.5 b	20.1 a	26.4	29.2
1.3 cm^2	10.0 c	21.0 b	27.3	29.7
			ns	ns
Application rate				
control	9.0 a	19.7 a	26.9	28.8 a
0.5-kg m^{-2}	9.3 a	19.7 a	26.9	29.0 a
1.5-kg m^{-2}	10.2 b	21.2 b	26.9	29.9 b
			ns	

+ Surface temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a thermal couple.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

all instances of significant difference. Results suggest that as mulch rate is increased the amount of surface heat retained or absorbed also increased, even as the mean surface temperature increases over time. No significant differences were observed between the control and the low rate on these dates. Vanini (1995) also observed that as topdressing applications of crumb rubber increased surface temperature increased as well.

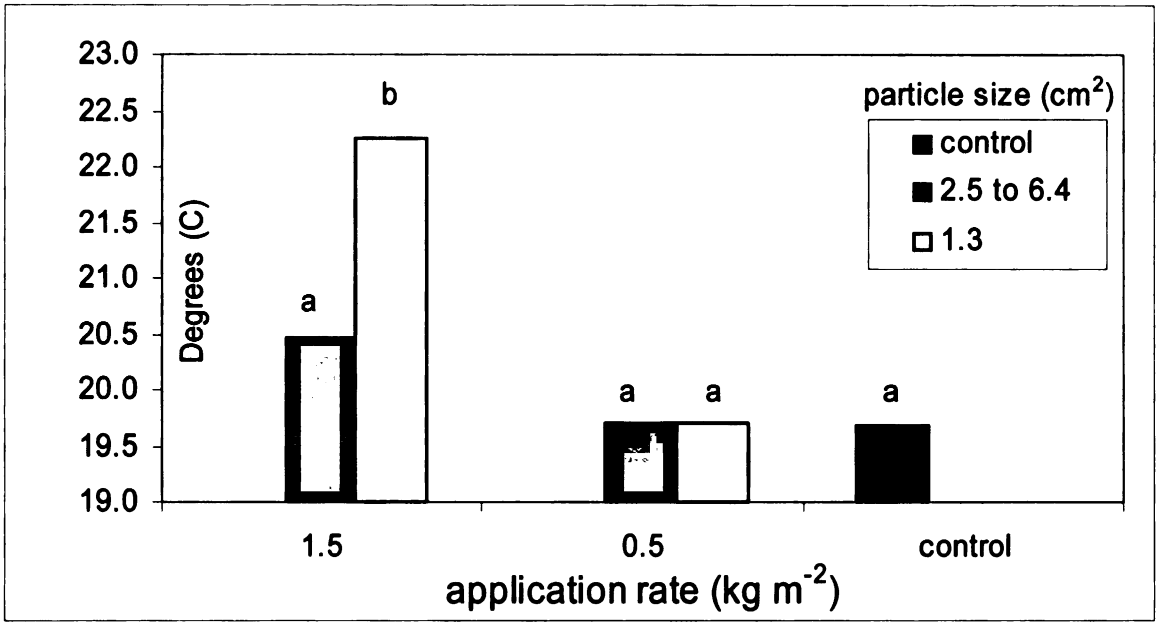
Significant particle sizes x application rate interactions were observed on 15 April 2004 (Figure 1). Interaction results suggest that particle size becomes significant at the high mulch rate, with fine particle size mulch at the high rate producing the highest surface temperature. This was the only date these effects were observed during this study. Results suggest that mulch application rates and particle sizes regardless of species type increase the surface temperate. It is arguable whether these differences are biologically significant on dandelion germination and growth because of the narrow temperature range observed, and the ability of dandelion seeds to germinate and grow at a wide variety of temperature (Holm *et al.*, 1997).

Soil Temperature

Significantly different treatments occurred for application rate and leaf species x particle size interactions after the first year of mulch applications (Table 11).

Differences between application rates occurred on 15 April 2004 and 20 April 2005 (Table 12). In all instances of significant differences the high mulch rate was correlated with the lowest soil temperature followed by the low rate and finally the control, which had the highest soil temperature. Results suggest that increases in mulch application rates slow increases in spring soil temperatures. Vanini (1995) observed, in

Figure 1: Effects of particle size x application rate over time on spring surface temperature following one application of leaf mulch, single application (site A) 2003, results obtained 15 April 2004, HTRC, East Lansing, Mich.



control = no mulch

Lower case letters represent significant differences at a 0.05 probability level.

Surface temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a thermal couple.

Table 11: Analysis of variance (AOV) results for soil temperature+ (4.5 cm depth) after one application of fall tree leaves, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003		Single application 2004	
Contrasts	**03-Apr-04**	**15-Apr-04**	**20-Apr-05**	**06-May-05**
Leaf species (L)	ns	ns	ns	ns
Particle size (P)	ns	ns	ns	ns
Application rate (A)	ns	*	*	ns
L x P	*	*	ns	ns
L x A	ns	ns	ns	ns
P x A	ns	ns	ns	ns
L x P x A	ns	ns	ns	ns

+ Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5cm soil probe.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 12: Effects of leaf species, particle size and application rate on soil temperature+ (4.5 cm depth) after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003		Single application 2004	
Leaf species	**03-Apr-04**	**15-Apr-04**	**20-Apr-05**	**06-May-05**
control	8.3	16.4	19.3	17.4
red maple	8.0	15.8	17.7	17.4
red oak	8.1	15.5	17.7	17.2
silver maple	8.2	15.4	17.8	17.1
sugar maple	7.9	15.5	17.6	17.5
sugar maple (hsc)	7.8	15.4	17.6	17.7
	ns	ns	ns	ns
Particle size				
control	8.3	16.4	19.3	17.4
2.5 to 6.4 cm^2	8.0	15.4	17.7	17.4
1.3 cm^2	8.0	15.7	17.7	17.4
	ns	ns	ns	ns
Application rate				
control	8.3	16.4 a	19.3 a	17.4
0.5-kg m^{-2}	8.0	15.9 a	18.5 b	17.4
1.5-kg m^{-2}	8.1	15.1 b	16.9 c	17.3
	ns			ns

+ Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5cm soil probe.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

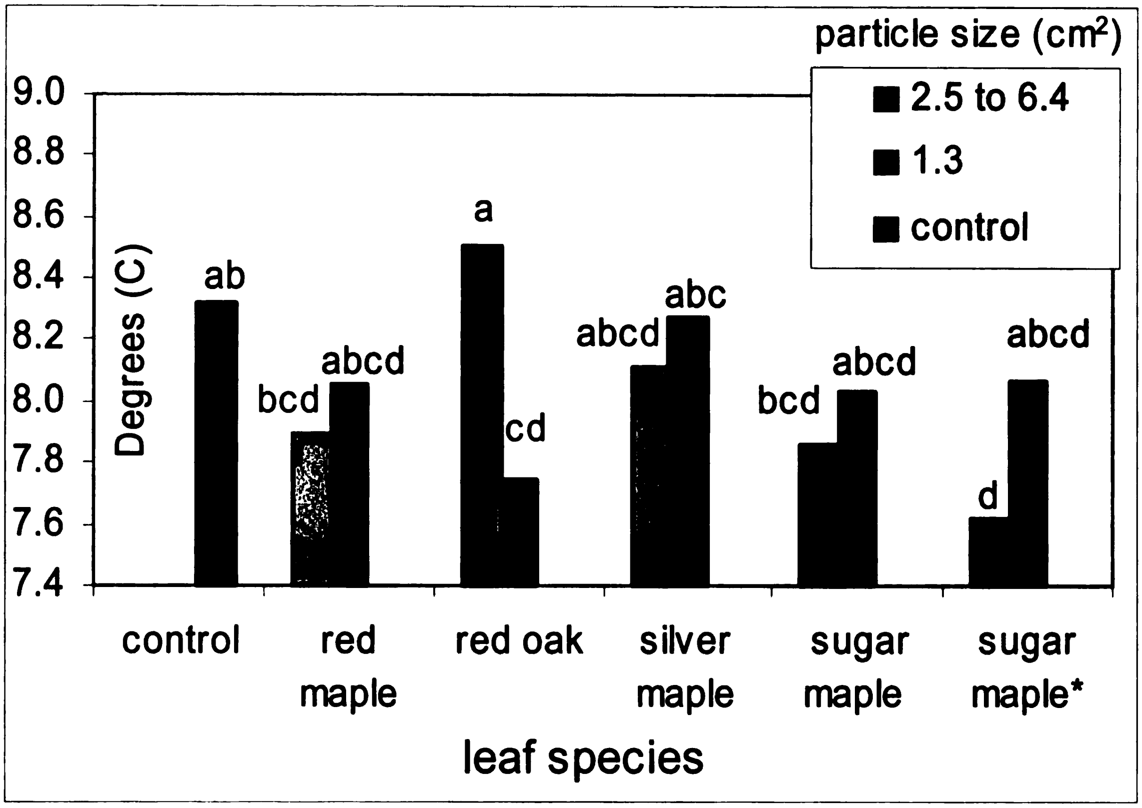
1994 only, that as crumb rubber topdressing application rates increased soil temperatures decreased, similar to results obtained in this experiment.

Differences occurred between species x particle size interactions on 03 April and 15 April 2004 (Figure 2 and 3). Significant interactions suggest that maple species applied at the coarse particle size resulted in lower soil temperatures in comparison to maple species applied at the fine particle size. Red oak applied at the fine particle size resulted in lower soil temperatures in comparison to the red oak applied at the coarse particle size. Results were not confirmed by single application 2005 results. A narrow temperature range makes it difficult to determine if these results are biologically significant on dandelion germination and growth because seeds are capable of germinating and growing at a wide variety of temperatures (Holm *et al.*, 1997). The majority of dandelion seeds that germinate are located on the soil surface and must be within the top 2 cm of the soil, suggesting that surface temperature is more critical when evaluating dandelion germination (Royer and Dickinson, 1999; Letchamo and Gosselin, 1996).

Soil Moisture Content

In regards to soil moisture content differences occurred between leaf species x particle size x application rate interactions on 18 April 2004 (Table 13). Sorochan and Rogers (2001) state that the soil moisture lost from the seedbed varies according to the absorptive capability of the mulch material. These differences were however isolated and trends could not be identified in the disorderly data making the results inconclusive (Figure 4).

Figure 2: Effects of leaf species x particle size on spring soil temperature (4.5 cm depth) following one application of leaf mulch, single application (site A) 2003, results obtained 03 April 2004, HTRC, East Lansing, Mich.



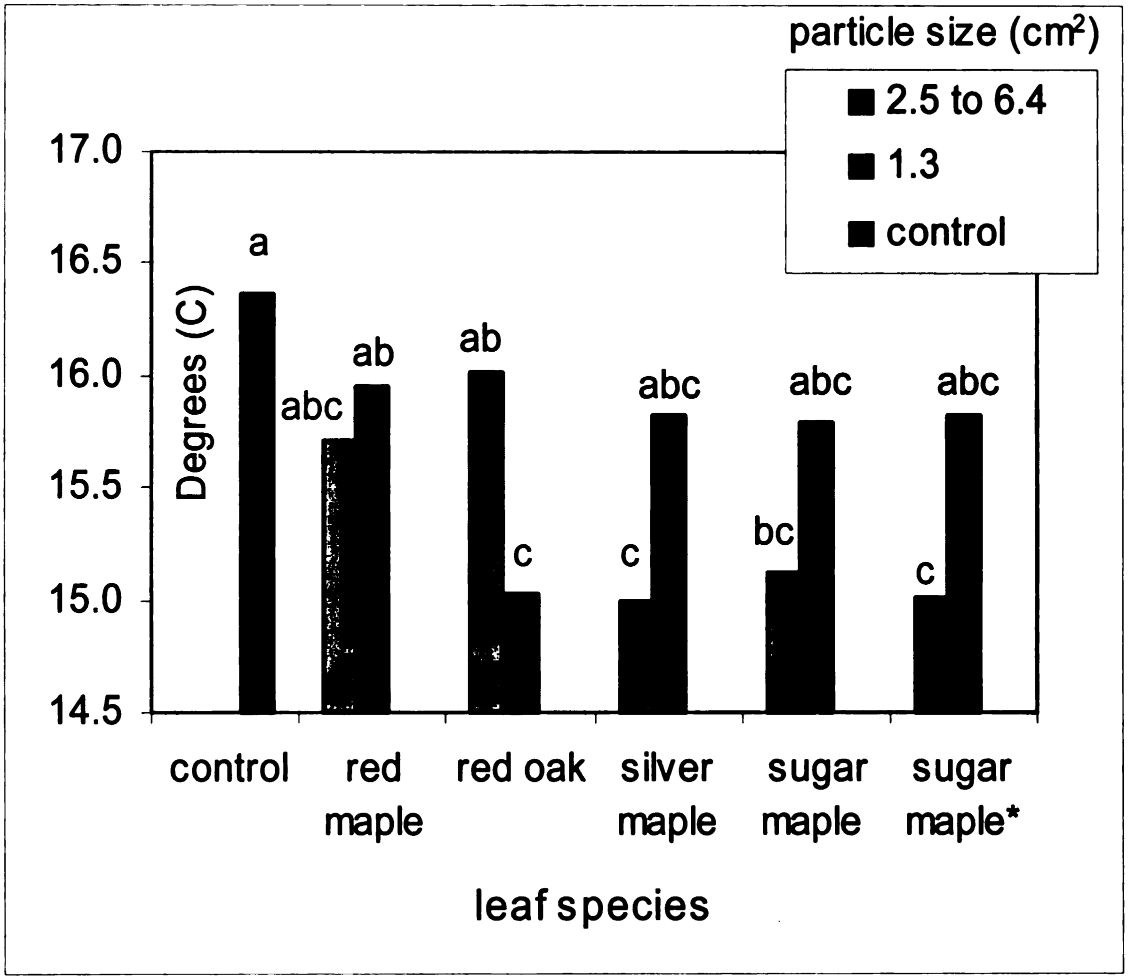
control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5cm soil probe.

Figure 3: Effects of leaf species x particle size on spring soil temperature (4.5 cm depth) following one application of leaf mulch, single application (site A) 2003, results obtained 15 April 2004, HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5 cm soil probe.

Table 13: Analysis of variance (AOV) results for soil moisture content[+] after one application of fall tree leaves, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003	Single application 2004
Contrasts	**18-Apr-04**	**06-May-05**
Leaf species (L)	ns	ns
Particle size (P)	ns	ns
Application rate (A)	ns	ns
L x P	ns	ns
L x A	ns	ns
P x A	ns	ns
L x P x A	*	ns

+ Soil moisture (v/v) content was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 14: Effects of leaf species, particle size and application rate on soil moisture content+ after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003	Single application 2004
Leaf species	**18-Apr-04**	**06-May-05**
control	15.8	9.9
red maple	17.5	10.8
red oak	15.5	10.5
silver maple	15.8	8.9
sugar maple	14.6	10.1
sugar maple (hsc)	17.8	9.3
	ns	ns
Particle size		
control	15.8	9.9
2.5 to 6.4 cm^2	16.3	9.9
1.3 cm^2	16.2	10.0
	ns	ns
Application rate		
control	15.8	9.9
0.5-kg m^{-2}	15.7	9.9
1.5-kg m^{-2}	16.8	10.2
	ns	ns

+ Soil moisture (v/v) content was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

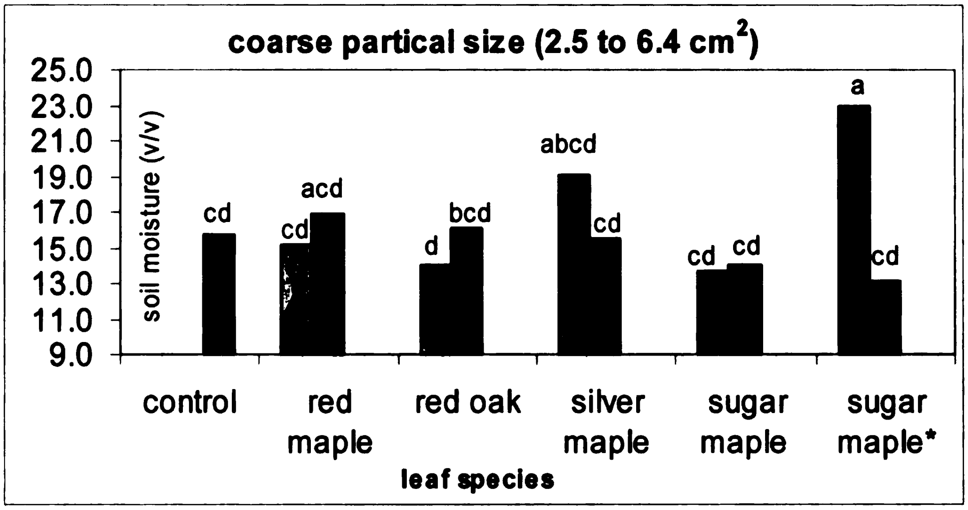
Lower case letters represent significant differences at the 0.05 probability level.

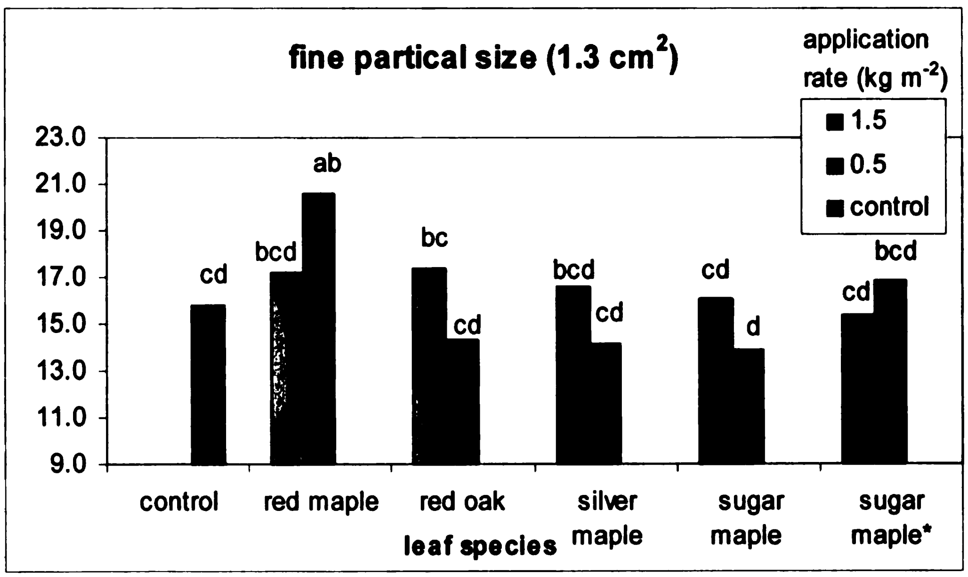
ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Figure 4: Effects of leaf species x particle size x application rate on soil moisture content following one application of leaf mulch, single application (site A) 2003, results obtained 18 April 2004, HTRC, East Lansing, Mich.





control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Soil moisture content (v/v) was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

Clipping Yield

Kentucky bluegrass clipping yields differences occurred between particle size and application rate after the first year of mulch applications (Table 15).

Significant particle size differences were observed on 15 May 2005 (Table 16). The coarse particle size correlated to the greatest clipping yield, followed by the fine and finally the control. Differences between coarse and fine particle sizes were not significant.

Differences between application rates occurred on 05 May 2004 and 14 May 2005 (Table 16). In both instances the high mulch rate correlated with the greatest clipping yields followed by the low rate, which in turn was significantly greater than the control. Suggesting that leaf mulch, regardless of species, may serve as an organic source of nutrients and as the application rate increases the amount of available nutrients increase resulting in increased spring clipping yields (Acosta-Martinez *et al.*, 1999; Heckman and Kluchinski, 1996). Nektarios *et al.* (1999) however, observed no differences in clipping yield as a result of maple or oak leaf applications at a rate of 0.54-kg m^{-2}.

Dandelion Plant Counts

Regarding dandelion weed counts after the first year of mulch, applications differences occurred for leaf species, application rate, leaf species x particle size, leaf species x application rate, and leaf species x particle size x application rate interactions (Table 17 and 19).

Dandelion count differences between species occurred on 07 July, 03 August, and 01 September 2004 and 15 June 2005 (Table 18 and 20). In all instances of significant differences, except June 15, 2005 all leaf species applications resulted in significantly

Table 15: Analysis of variance (AOV) results for Kentucky bluegrass clipping yield+ after one application of fall tree leaves, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003	Single application 2004
Contrasts	**05-May-04**	**14-May-05**
Leaf species (L)	ns	ns
Particle size (P)	ns	*
Application rate (A)	*	*
L x P	ns	ns
L x A	ns	ns
P x A	ns	ns
L x P x A	ns	ns

+ Clipping yield data (g m^{-2}) was collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.).

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 16: Effects of leaf species, particle size and application rate on Kentucky bluegrass clipping yield+ after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, and single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2003	Single application 2004
Leaf species	**05-May-04**	**14-May-05**
control	0.3	0.5
red maple	2.3	2.3
red oak	3.5	2.6
silver maple	2.8	2.0
sugar maple	2.8	3.2
sugar maple*	3.6	2.5
	ns	ns
Particle size		
control	0.3	0.5 a
2.5 to 6.4 cm^2	3.5	2.7 b
1.3 cm^2	2.4	2.5 b
	ns	
Application rate		
control	0.3 a	0.5 a
0.5-kg m^{-2}	1.8 b	1.5 b
1.5-kg m^{-2}	4.1 c	4.0 c

+ Clipping yield (g m^{-2}) data was collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.).

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Table 17: Analysis of variance (AOV) results for dandelion populations[+] after one application of fall tree leaves, single application (site A) 2003, results obtained in 2004, HTRC, East Lansing, Mich.

	Single application 2003			
Contrasts	**09-Jun-04**	**07-Jul-04**	**03-Aug-04**	**01-Sep-04**
Leaf species (L)	ns	*	*	*
Particle size (P)	ns	ns	ns	ns
Application rate (A)	*	*	*	*
L x P	ns	ns	ns	*
L x A	*	*	ns	ns
P x A	ns	ns	ns	ns
L x P x A	ns	ns	*	ns

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 18: Effects of leaf species, particle size and application rate on dandelion populations+ after one fall application of tree leaf mulch, single application (site A) 2003, results obtained in 2004, HTRC, East Lansing, Mich.

	Single application 2003			
Leaf species	**09-Jun-04**	**07-Jul-04**	**03-Aug-04**	**01-Sep-04**
control	8.0	21.4 a	36.8 a	38.3 a
red maple	2.5	7.7 b	18.7 bc	22.1 b
red oak	2.3	7.0 bc	17.6 bc	18.8 bc
silver maple	1.6	9.3 b	20.9 b	21.4 bc
sugar maple	2.6	4.2 c	19.1 bc	22.6 b
sugar maple (hsc)	1.9	8.3 b	15.2 c	17.1 c
	ns			
Particle size				
control	8.0	21.4	36.8	38.3
2.5 to 6.4 cm^2	2.1	7.4	17.8	20.1
1.3 cm^2	2.2	7.9	18.8	20.4
	ns	ns	ns	ns
Application rate				
control	8.0 a	21.4 a	36.8 a	38.3 a
0.5-kg m^{-2}	3.0 b	11.1 b	21.3 b	22.7 b
1.5-kg m^{-2}	1.6 c	6.2 c	15.9 c	16.9 c

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Table 19: Analysis of variance (AOV) results for dandelion populations+ after one application of fall tree leaves, single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2004			
Contrasts	**15-Jun-05**	**05-Jul-05**	**01-Aug-05**	**06-Sep-05**
Leaf species (L)	*	ns	ns	ns
Particle size (P)	ns	ns	ns	ns
Application rate (A)	*	*	*	*
L x P	ns	ns	ns	ns
L x A	ns	ns	ns	ns
P x A	ns	ns	ns	ns
L x P x A	ns	ns	ns	ns

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 20: Effects of leaf species, particle size and application rate on dandelion populations+ after one fall application of tree leaf mulch, single application (site B) 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Single application 2004			
Leaf species	**15-Jun-05**	**05-Jul-05**	**01-Aug-05**	**06-Sep-05**
control	0.9 ab	11.1	27.7	34.2
red maple	0.5 b	4.8	13.8	15.8
red oak	0.4 b	3.7	18.4	20.9
silver maple	1.8 a	5.6	24.1	23.7
sugar maple	0.3 b	5.1	14.2	20.4
sugar maple*	0.8 ab	5.5	18.4	22.8
		ns	ns	ns
Particle size				
control	0.9	11.1	27.7	34.2
2.5 to 6.4 cm^2	0.5	5.6	18.0	23.4
1.3 cm^2	0.9	4.2	17.3	17.9
	ns	ns	ns	ns
Application rate				
control	0.9 ab	11.1 a	27.7 a	34.2 a
0.5-kg m^{-2}	1.5 a	7.9 a	20.4 ab	26.0 b
1.5-kg m^{-2}	0.3 b	3.3 b	15.7 b	18.0 c

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

fewer dandelions in comparison to the control. On two of the four instances of significant differences sugar maple (high sugar content) had the least number of dandelion plants and on only one instance was statistically different from the leading species. On the other two dates of significant differences sugar maple had the least number of dandelions in comparison to the other species. In all instances of significant differences oak had the second least number of dandelion weeds and was not statistically different for the species that provided the best control. In 2004 no statistical differences occurred between red oak, red maple, and silver maple, with silver in two instances providing the least control compared to the other species.

Regarding significant results in 2005, silver maple provided the least weed suppression in comparison to the other species and the control. Results suggest that after one application of leaf mulch sugar maple (high sugar content) provide the greatest dandelion control followed by sugar maple and red oak. Silver maple appeared to have the lowest dandelion suppression capability in comparison to the other species and in one instance was inferior to the control. Nikolai *et al.* (1998) also observed reduced dandelion populations when comparing control plots to plots treated with a mixture of a variety of maple leaves, but however this research did not observe reduced dandelion populations as a result of oak leaf mixture applications. Lodhi (1976) determined that decaying leaf leachates from red oak, the oak species that was selected for this particular research project, reduced seed germination and seedling growth of a variety of herbaceous species. This previous work by Lodhi (1976) and results obtained from this experiment suggest that pure applications of red oak can provide dandelion control competitive with maple leaf applications.

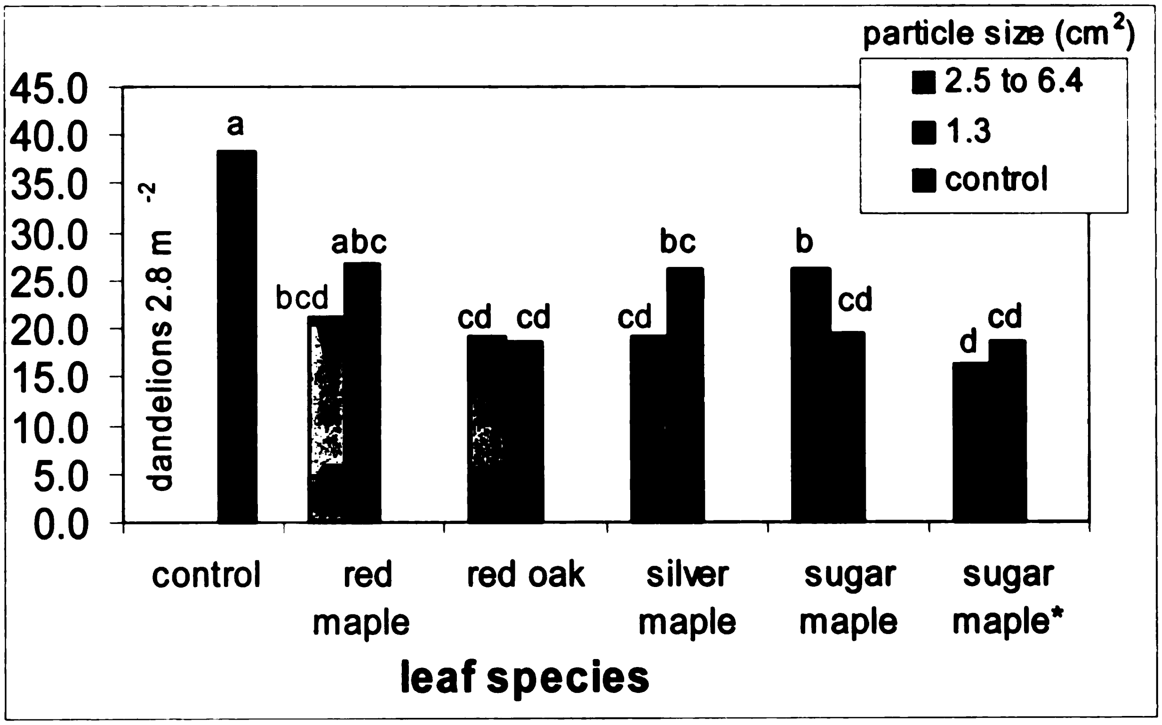
No significant differences in dandelion counts were observed between particle sizes throughout the entirety of the data collection period, suggesting that differences in tree leaf particle sizes had no effect on dandelion populations.

Dandelion population count differences occurred between application rates throughout the entirety of the data collection period in 2004 and 2005 (Table 16 and 18). In all instances, the high mulch application rate had significantly fewer dandelions than the low rate, which in turn had significantly fewer dandelions than the control, suggesting a correlation between increased rates and increased weed control. Results remained statistically different as the mean dandelion population increased over time. Results suggest that increases in mulch rates correlate to increases in dandelion suppression. Tompkins *et al.* (2004) also observed that as organic weed control product rates increased the number of dandelions per m^2 decreased.

Differences occurred between species x particle size on 01 September 2004 (Figure 5) regarding dandelion counts. Results were disorderly and inconclusive because this effect occurred only on this date making it difficult to identify scientific trends.

Significant leaf species x application rate interaction effects on dandelion count differences occurred on 09 June, and 07 July 2004 (Figure 6 and 7). Trends suggest that a relationship exist between species and application rates. Significant rate interactions occurred between leaf species and application rates, with the high application rate having significantly less dandelions than the low rate for red and sugar maple species. Results recorded on 07 July 2004 show that all leaf species applied at the high rate resulted in fewer dandelions than applied at the low rate. Differences between the high and low rate for red oak, sugar maple (high sugar content) and silver maple were not significant.

Figure 5: Effects of leaf species x particle size on dandelion weed count following one application of leaf mulch, single application (site A) 2003, results obtained 01 September 2004, HTRC, East Lansing, Mich.



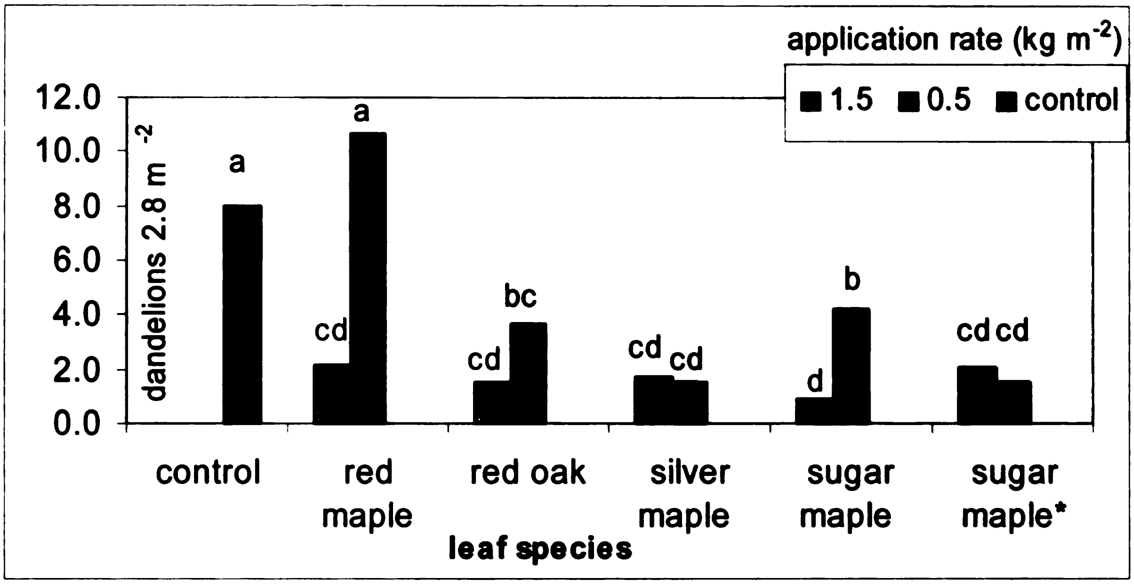
control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

Figure 6: Effects of leaf species x application rate on dandelion weed count following one application of leaf mulch, single application (site A) 2003, results obtained 09 June 2004, HTRC, East Lansing, Mich.



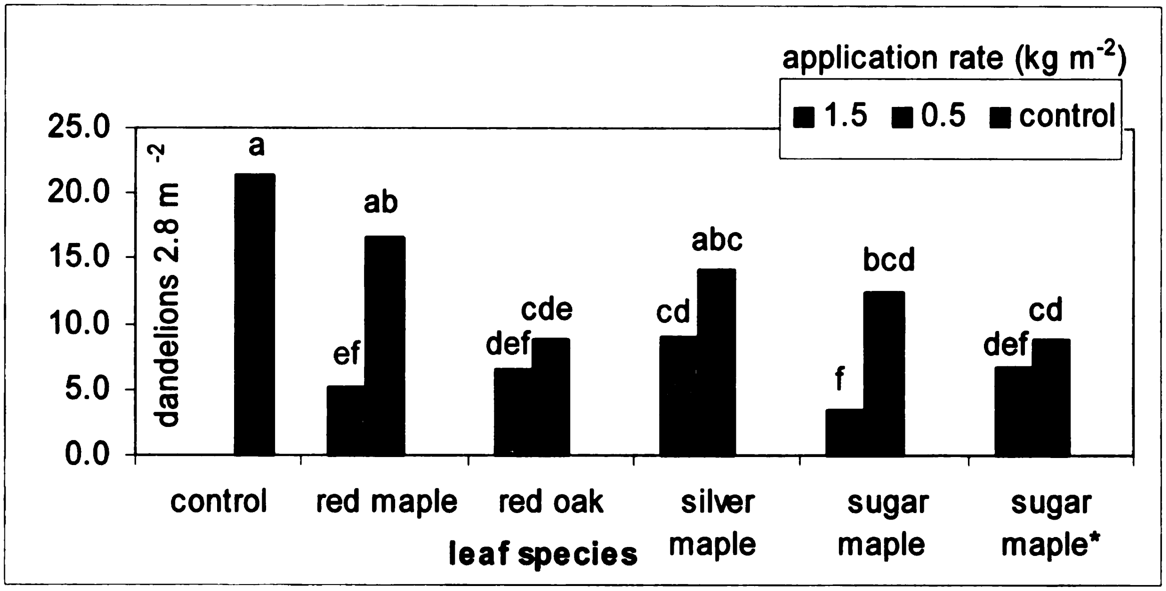
control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

Figure 7: Effects of leaf species x application rate on dandelion weed count following one application of leaf mulch, single application (site A) 2003, results obtained 07 July 2004, HTRC, East Lansing, Mich.



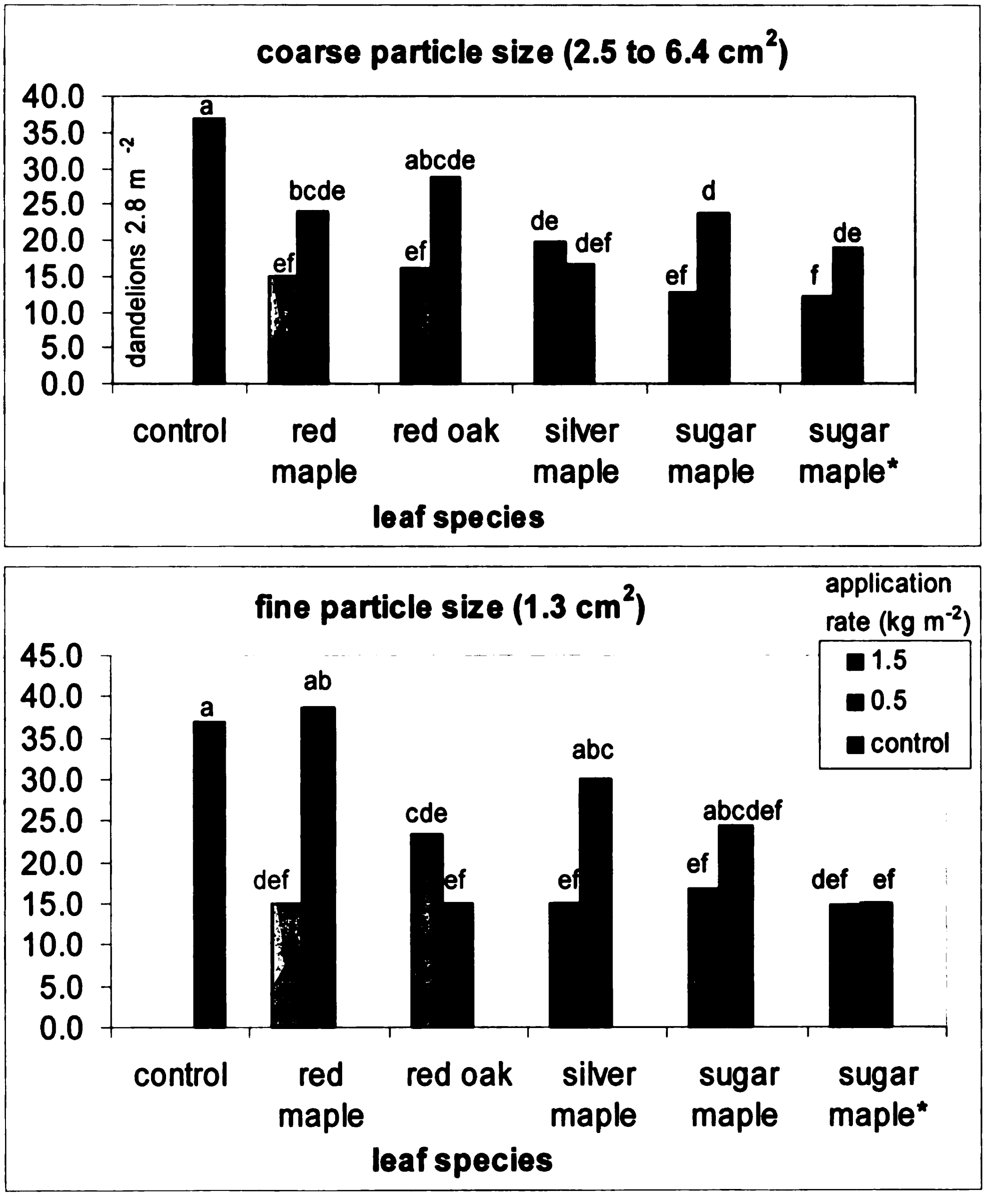
control = no mulch
sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

Significant dandelion count differences occurred between leaf species x particle size x application rate interactions on 03 August 2004 (Figure 8). Results were disorderly and isolated making it inconclusive.

Figure 8: Effects of leaf species x particle size x application rate on dandelion weed count following one application of leaf mulch, single application (site A) 2003, results obtained 03 August 2004, HTRC, East Lansing, Mich.



control = no mulch
sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

Two Applications

Results collected following two consecutive annual fall applications (2003 and 2004) of mulched maple and oak leaves on established Kentucky bluegrass, site A (results obtained in 2005).

Spring Green-up

After the second consecutive year of mulch applications statistically significant Kentucky bluegrass spring green-up differences occurred between tree leaf species, application rates and species x particle sizes interactions (Table 21).

On 20 April 2005 minimal separations between leaf mulch species and the fact that all species were significantly greater than the control suggest that all leaf types increase spring green-up in comparison to the control (Table 22). Results were similar to those observed after on application of leaf mulch on 20 April 2005 (Table 8). Data was only significant on these dates making it difficult to make conclusions regarding the effect of leaf species on spring green-up.

Significant differences between rates were observed on 20 April, and 06 May 2005 (Table 22). The high rate produced the greatest green-up followed by the low rate and finally the control treatment. Results were again very similar to those obtained after single applications of fall tree leaves in 2004 and 2005 (Table 6 and 8), suggesting a correlation between increased application rates and increased spring green-up. Differences decreased over time and on 31 May 2005 after one application and two applications were eventually lost suggesting that effects are lost over time (Table 4 and 18). Results suggest that the mulched leaves may have acted as an organic source of nutrients (Cooperband, 2002; Tian *et al.*, 1992; Heckman and Kluchinski, 1996).

Table 21: Analysis of variance (AOV) results for Kentucky bluegrass spring green-up^{+} after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)		
Contrasts	**20-Apr-05**	**06-May-05**	**31-May-05**
Leaf species (L)	*	ns	ns
Particle size (P)	ns	ns	ns
Application rate (A)	*	*	ns
L x P	*	ns	ns
L x A	ns	ns	ns
P x A	ns	ns	ns
L x P x A	ns	ns	ns

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 22: Effects of leaf species, particle size and application rate on spring green-up[+] of Kentucky bluegrass after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)		
Leaf species	**20-Apr-05**	**06-May-05**	**31-May-05**
control	4.8 a	6.6	7.0
red maple	7.8 c	8.5	7.0
red oak	6.8 b	8.1	7.2
silver maple	7.9 c	8.5	7.3
sugar maple	7.3 bc	8.2	7.1
sugar maple (hsc)	7.4 bc	8.4	7.0
		ns	ns
Particle size			
control	4.8	6.6	7.0
2.5 to 6.4 cm^2	7.4	8.3	7.2
1.3 cm^2	7.5	8.4	7.0
	ns	ns	ns
Application rate			
control	4.8 a	6.6 a	7.0
0.5-kg m^{-2}	6.6 b	8.0 b	7.1
1.5-kg m^{-2}	8.3 c	8.7 c	7.1
			ns

+ Spring green-up was visually estimated on a 1-9 scale, 9 equaling completely green turfgrass and 6 being acceptable.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Leaf species x particle sizes interactions were significant on 20 April 2005 (Figure 9). Interaction results occurred on this date only and are inconclusive due to minimal separations between means.

Surface Temperature

After the second consecutive year of mulch applications statistically significant surface temperature differences between particle size treatments only occurred on 20 April 2005 (Table 23). Fine particle size mulch produced the greatest surface temperature followed by the coarse particle size mulch and finally the control, however differences between coarse and control were not significant (Table 24). Results support earlier data obtained after single leaf applications in 2004 (Table 6), suggesting that fine mulch retains or absorbs surface heat better than coarse mulch and control treatments (Vanini, 1995). It is again arguable whether differences are biologically significant because of the narrow temperature range observed (Holm *et al.*, 1997).

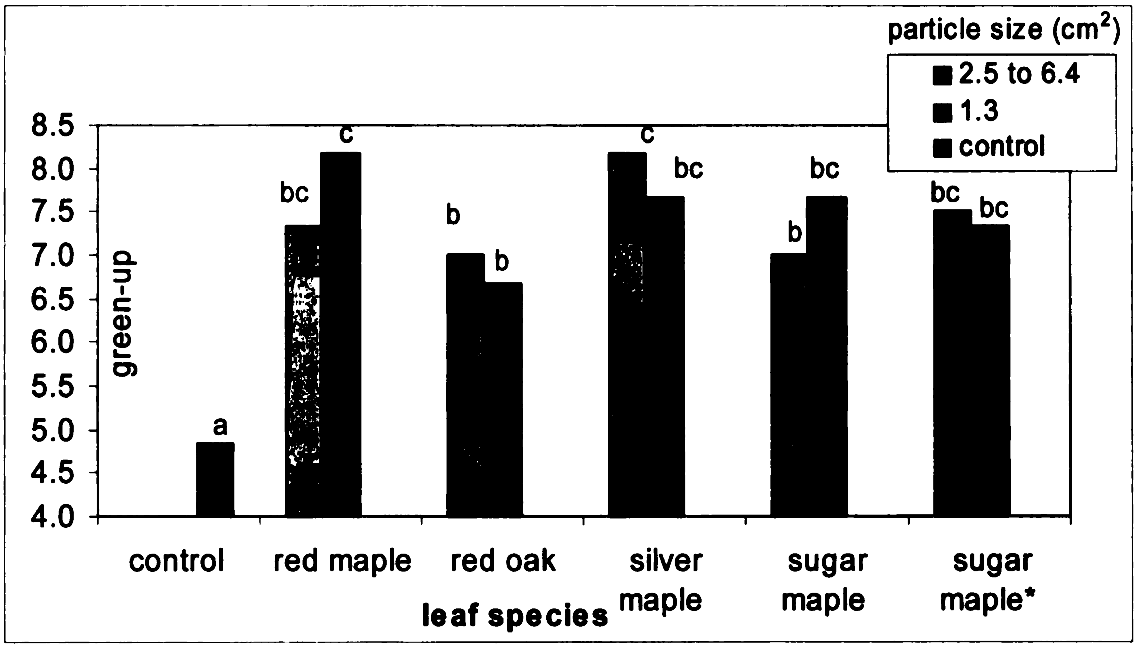
Soil Temperature

After the second consecutive year of mulch applications statistically significant differences were observed between application rates and species x particle size interactions for soil temperature differences on 20 April 2005 (Table 25).

Differences in mulch application rates supported earlier results obtained after single mulch applications in 2004 and 2005 (Table 12), with the high mulch rate correlating to the lowest soil temperature, followed by the low rate, and finally the control (Table 26) (Vanini, 1995).

Species x particle size interactions were inconclusive and did not support earlier results due to the fact that the disorderly mean separations were minimal, and differences

Figure 9: Effects of leaf species x particle size on Kentucky bluegrass spring green-up following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 20 April 2005 HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar content)

Lower case letters represent significant differences at a 0.05 probability level.

Visual green-up ratings scale = 1 to 9 with 1 equaling straw brown and 9 equaling completely green turfgrass.

Table 23: Analysis of variance (AOV) results for surface temperature[+] after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)	
Contrasts	**20-Apr-05**	**06-May-05**
Leaf species (L)	ns	ns
Particle size (P)	*	ns
Application rate (A)	ns	ns
L x P	ns	ns
L x A	ns	ns
P x A	ns	ns
L x P x A	ns	ns

+ Surface temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a thermal couple.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level

Table 24: Effects of leaf species, particle size and application rate on surface temperature[+] after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)	
Leaf species	**20-Apr-05**	**06-May-05**
control	22.0	25.6
red maple	22.2	26.5
red oak	23.4	26.3
silver maple	23.1	26.6
sugar maple	23.0	26.0
sugar maple (hsc)	27.0	25.9
	ns	ns
Particle size		
control	22.0 a	25.6
2.5 to 6.4 cm^2	22.3 a	26.1
1.3 cm^2	25.2 b	26.5
		ns
Application rate		
control	22.0	25.6
0.5-kg m^{-2}	24.7	26.1
1.5-kg m^{-2}	22.8	26.5
	ns	ns

+ Surface temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a thermal couple.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Table 25: Analysis of variance (AOV) results for soil temperature[+] (4.5 cm depth) after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)	
Contrasts	**20-Apr-05**	**06-May-05**
Leaf species (L)	ns	ns
Particle size (P)	ns	ns
Application rate (A)	*	ns
L x P	*	ns
L x A	ns	ns
P x A	ns	ns
L x P x A	ns	ns

+ Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5 cm soil probe.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 26: Effects of leaf species, particle size and application rate on soil temperature[+] (4.5 cm depth) after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)	
Leaf species	**20-Apr-05**	**06-May-05**
control	16.7	19.8
red maple	16.1	19.7
red oak	16.1	20.0
silver maple	15.8	20.4
sugar maple	15.8	20.1
sugar maple (hsc)	15.7	20.2
	ns	ns
Particle size		
control	16.7	19.8
2.5 to 6.4 cm^2	15.8	20.3
1.3 cm^2	15.9	19.7
	ns	ns
Application rate		
control	16.7 a	19.8
0.5-kg m^{-2}	16.2 b	20.0
1.5-kg m^{-2}	15.5 c	20.1
		ns

+ Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5 cm soil probe.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

were isolated (Figure 10). It is again arguable whether differences are biologically significant because of the narrow temperature range observed (Royer and Dickinson, 1999; Letchamo and Gosselin, 1996; Holm 1997).

Soil Moisture Content

Regarding soil moisture content after the second consecutive year of mulch applications differences occurred between leaf species x particle size interactions on 06 May 2005 (Table 27). Results were inconclusive because data was again very disorderly with no apparent relation between leaf species and particle size; it is also noted that this effect occurred only on this date (Figure 11).

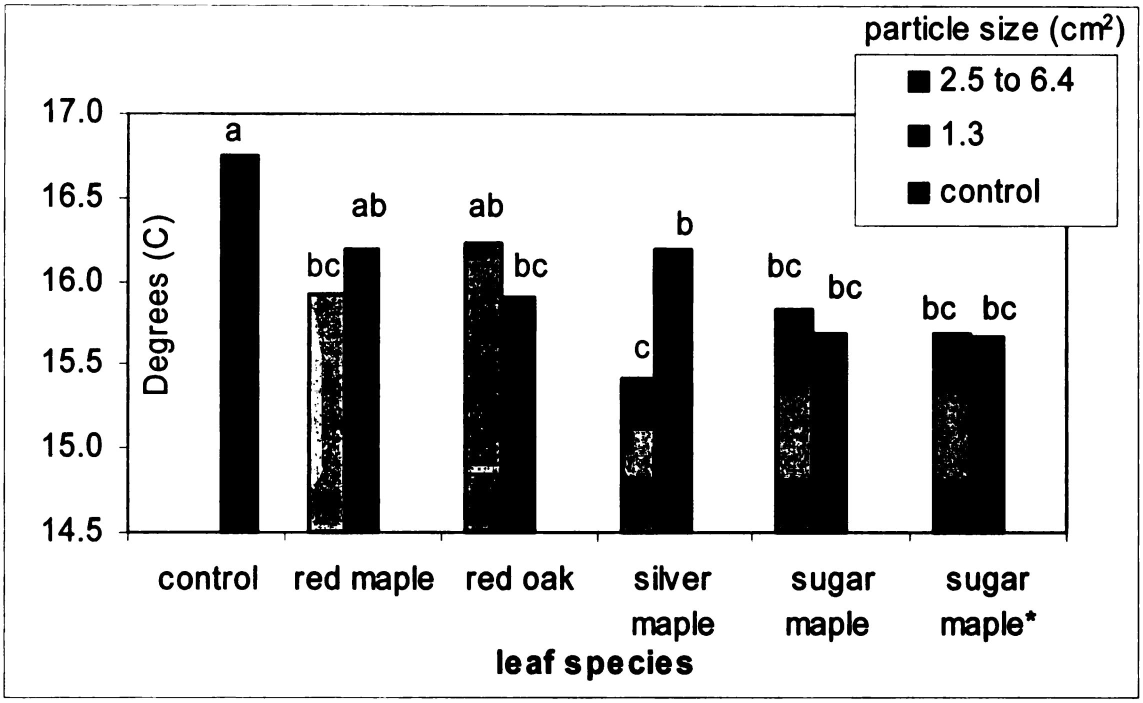
Clipping Yield

After the second year of mulched leaf applications differences between Kentucky bluegrass clipping yields occurred between leaf species, application rate, species x particle size, and species x application rate interactions on 14 May 2005 (Table 29).

Sugar maple leaf applications produced a clipping yield significantly greater than all other species and the control (Table 30). Minimal separations were observed between sugar maple (high sugar content), silver maple, red oak, red maple, and finally the control, which produced the lowest clipping yield.

In regards to application rates results similar to single application 2004 and 2005 (Table 16) occurred (Table 30). High mulch rate correlated to the greatest clipping yield, followed by the low rate and finally the control. The low rate produced a clipping yield that was greater than the control, however these differences were not significant.

Figure 10: Effects of leaf species x particle size on spring soil temperature following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 20 April 2005, HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Soil temperatures (°C) were determined using a SDT141S Digital Thermometer (Brighton Electronics, Inc., Portland, Ore.) and a 4.5 cm soil probe.

Table 27: Analysis of variance (AOV) results for soil moisture content[+] after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)
Contrasts	**06-May-05**
Leaf species (L)	ns
Particle size (P)	ns
Application rate (A)	ns
L x P	*
L x A	ns
P x A	ns
L x P x A	ns

+ Soil moisture (v/v) content was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 28: Effects of leaf species, particle size and application rate on soil moisture content+ after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)
Leaf species	**06-May-05**
control	9.4
red maple	6.3
red oak	7.3
silver maple	6.4
sugar maple	7.5
sugar maple (hsc)	6.9
	ns
Particle size	
control	9.4
2.5 to 6.4 cm^2	7.1
1.3 cm^2	6.6
	ns
Application rate	
control	9.4
0.5-kg m^{-2}	6.6
1.5-kg m^{-2}	7.2
	ns

+ Soil moisture (v/v) content was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

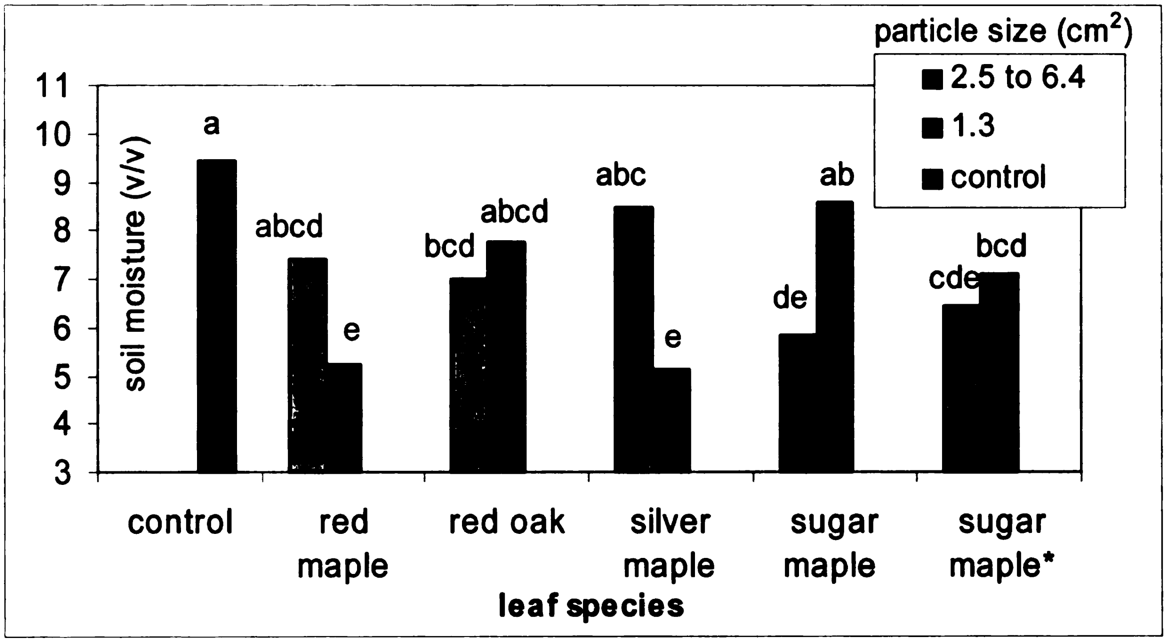
Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Figure 11: Effects of leaf species x particle size on soil moisture content following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 06 May 2005, HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Soil moisture (v/v) content was recorded with a Trime®-FM Mobile moisture meter (MESA Systems Co., Medfield, Mass.).

Table 29: Analysis of variance (AOV) results for Kentucky bluegrass clipping yield[+] after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)
Contrasts	**14-May-05**
Leaf species (L)	*
Particle size (P)	ns
Application rate (A)	*
L x P	*
L x A	*
P x A	ns
L x P x A	ns

+ Clipping yield data (g m^{-2}) was collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.).

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 30: Effects of leaf species, particle size and application rate on Kentucky bluegrass clipping yield+ after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)
Leaf Species	**14-May-05**
control	5.2 a
oak	8.1 abc
red	7.2 ab
silver	9.2 bc
sugar	14.5 d
sugar (hsc)	10.9 c
Particle size	
control	5.2
2.5 to 6.4 cm^2	10.0
1.3 cm^2	10.2
	ns
Application rate	
control	5.2 a
0.5-kg m^{-2}	8.0 a
1.5-kg m^{-2}	12.7 b

+ Clipping yield (g m^{-2}) data was collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.).

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

Differences between leaf species x particle size were disorderly and inconclusive because the effects were isolated making it difficult to identify scientific trends (Figure 12).

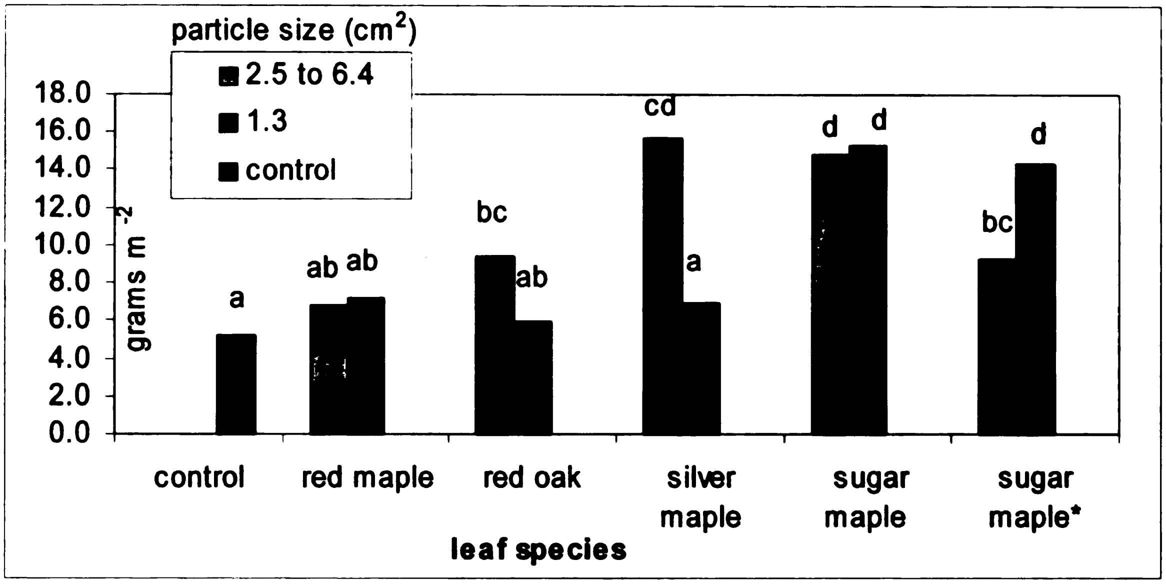
Leaf species x application rate interactions produced significantly different clipping yield result suggesting high application rate become a significant factor in comparison to low rates for red maple, silver maple and sugar maple species after the second mulch application (Figure 13). Differences between red oak applied at the high and low rate were similar to the results described above but not statistically different. Sugar maple (high sugar content) was the only species that produced a greater clipping yield at the low rate, but differences were very minimal and not significant. Results suggest that oak and sugar maple (high sugar content) are not affected by rate as much as other species are in regards to clipping yields. Results suggest that leaf mulch may serve as an organic source of nutrients resulting in increased spring clipping yields in comparison to control treatments (Acosta-Martinez *et al.*, 1999; Heckman and Kluchinski, 1996).

Dandelion Plant Counts

Regarding dandelion weed counts after the second consecutive year of mulch applications, differences occurred for leaf species, application rate, and leaf species x particle size interactions occurred on 15 June, and 05 July 2005 (Table 31).

Dandelion count differences between species after the second consecutive application of mulched leaves occurred on 15 June, and 05 July 2005 (Table 32). In all instances of significant differences, leaf species applications resulted in significantly fewer dandelions in comparison to the control treatment, similar to results obtained after

Figure 12: Effects of leaf species x particle size on Kentucky bluegrass spring clipping yield following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 14 May 2005, HTRC, East Lansing, Mich.



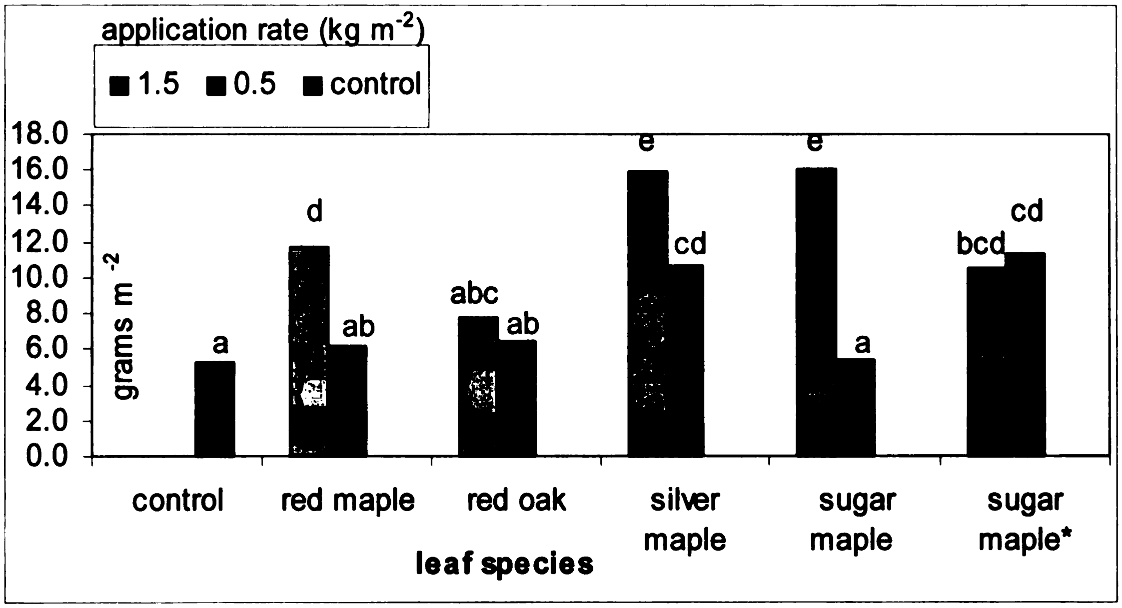
control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Clipping yield (g m^{-2}) were collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.) at 3.81cm then over dried.

Figure 13: Effects of leaf species x application rate on Kentucky bluegrass spring clipping yield following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 14 May 2005, HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Clipping yield (g m^{-2}) were collected using a John Deere® 20 SR7 reel mower (John Deere Co., Moline, Ill.) at 3.81cm then over dried.

Table 31: Analysis of variance (AOV) results for dandelion populations+ after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)			
Contrasts	**15-Jun-05**	**05-Jul-05**	**01-Aug-05**	**06-Sep-05**
Leaf species (L)	*	*	ns	ns
Particle size (P)	ns	ns	ns	ns
Application rate (A)	*	*	ns	ns
L x P	*	*	ns	ns
L x A	ns	ns	ns	ns
P x A	ns	ns	ns	ns
L x P x A	ns	ns	ns	ns

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

* Significant at the 0.05 probability level.

ns Not significant at the 0.05 probability level.

Table 32: Effects of leaf species, particle size and application rate on dandelion populations+ after two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained in 2005, HTRC, East Lansing, Mich.

	Two applications (2003 and 2004)			
Leaf species	**15-Jun-05**	**05-Jul-05**	**01-Aug-05**	**06-Sep-05**
control	40.3 a	56.8 a	217.4	251.7
red maple	24.5 b	41.0 b	178.6	205.6
red oak	19.5 c	31.6 bc	180.4	211.8
silver maple	26.5 b	31.9 bc	144.0	184.9
sugar maple	23.2 bc	30.0 c	154.8	205.7
sugar maple (hsc)	18.4 c	24.3 c	158.5	197.5
			ns	ns
Particle size				
control	40.3	56.8	217.4	251.7
2.5 to 6.4 cm^2	21.3	31.4	175.9	206.3
1.3 cm^2	22.6	32.1	150.5	195.9
	ns	ns	ns	ns
Application rate				
control	40.3 a	56.8 a	217.4	251.7
0.5-kg m^{-2}	24.7 b	35.1 b	172.1	210.1
1.5-kg m^{-2}	19.0 c	28.5 b	154.4	191.3
			ns	ns

+ Dandelion populations (plants per plot - 2.8 m^2) were visually counted.

Lower case letters represent significant differences at the 0.05 probability level.

ns Not significant different at the 0.05 probability level.

control = no mulch

hsc = high sugar content

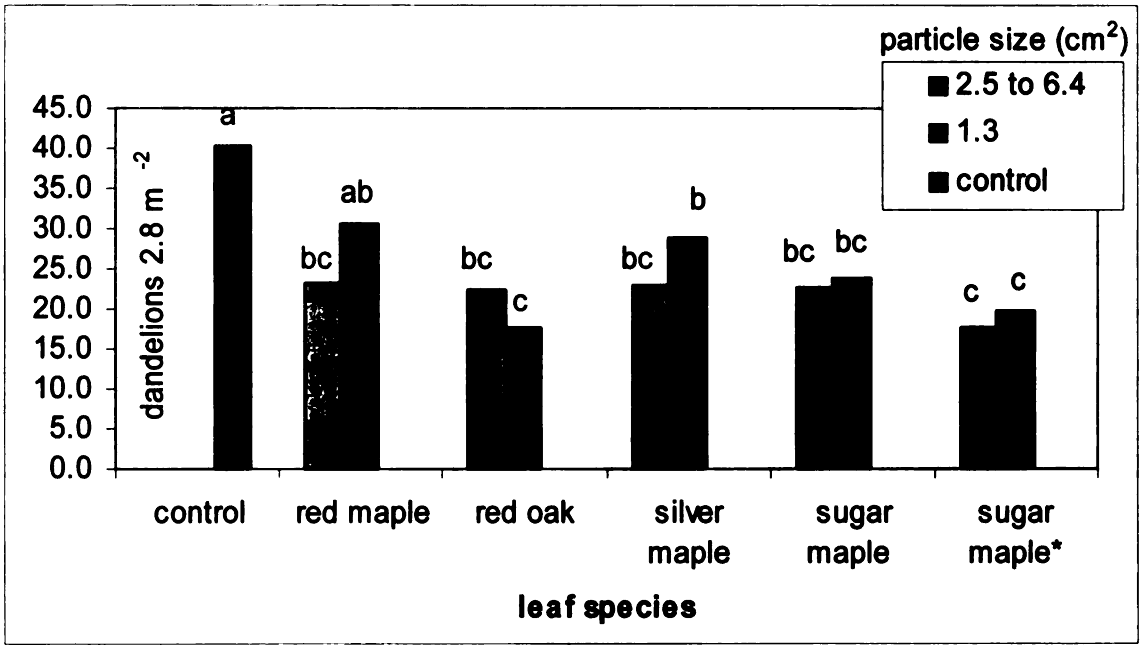
single applications in 2004 (Table 18). In both instances of significant differences sugar maple (high sugar content) had the least number of dandelion plants. On 15 June 2005 oak had the second least number of dandelion weeds and was not statistically different for sugar maple (high sugar content). Sugar maple, on 05 July 2005, had the second least number of dandelion weeds and was not statistically different for sugar maple (high sugar content). No statistical differences occurred between red maple, and silver maple, which provided the least control compared to the other species. Results support earlier data collected in 2004 (Table 18), suggesting that sugar maple (high sugar content) is capable of providing the greatest dandelion control followed by sugar maple and red oak, while red maple and finally silver maple appear to be repeatedly inferior to the other leaf species. Results obtained by Nikolai *et al.* (1998) support the idea that maple leaf species mulch can provide dandelion control in comparison to control treatments, and Lodhi (1976) supports the data suggesting that red oak leaf mulch can provide competitive herbaceous plant germination control.

Application rate differences on dandelion counts occurred on 15 June, and 05 July 2005 after the second year of mulch applications (Table 32). In both instances the high mulch rate had fewer dandelions than the low rate, which in turn had significantly fewer dandelions than the control. Results suggest a correlation between increased rates and increased weed suppression. These results were accompanied by an increasing number of mean dandelions from June to July. Data supports earlier results suggesting that increases in mulch rates correlate to increases in dandelion suppression (Tompkins *et al.*, 2004).

Regarding dandelion population count differences occurred between leaf species x particle size on 15 June, and 05 July 2005 (Figure 14 and 15). Results were disorderly and inconclusive because trends could not be identified when results were compared.

Results obtained after 05 July 2005 were not significantly different. This lose in statistical significance was the results of increasing variability as the average dandelion population continually increased. In these instances residual of variance results were more than three times different. Results were adjusted for unequal variances and then group with treatments of similar variances. Data was however not statistically significant at the 0.05 probability level even when unequal variances were accounted for.

Figure 14: Effects of leaf species x particle size on dandelion weed count following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 15 June 2005, HTRC, East Lansing, Mich.



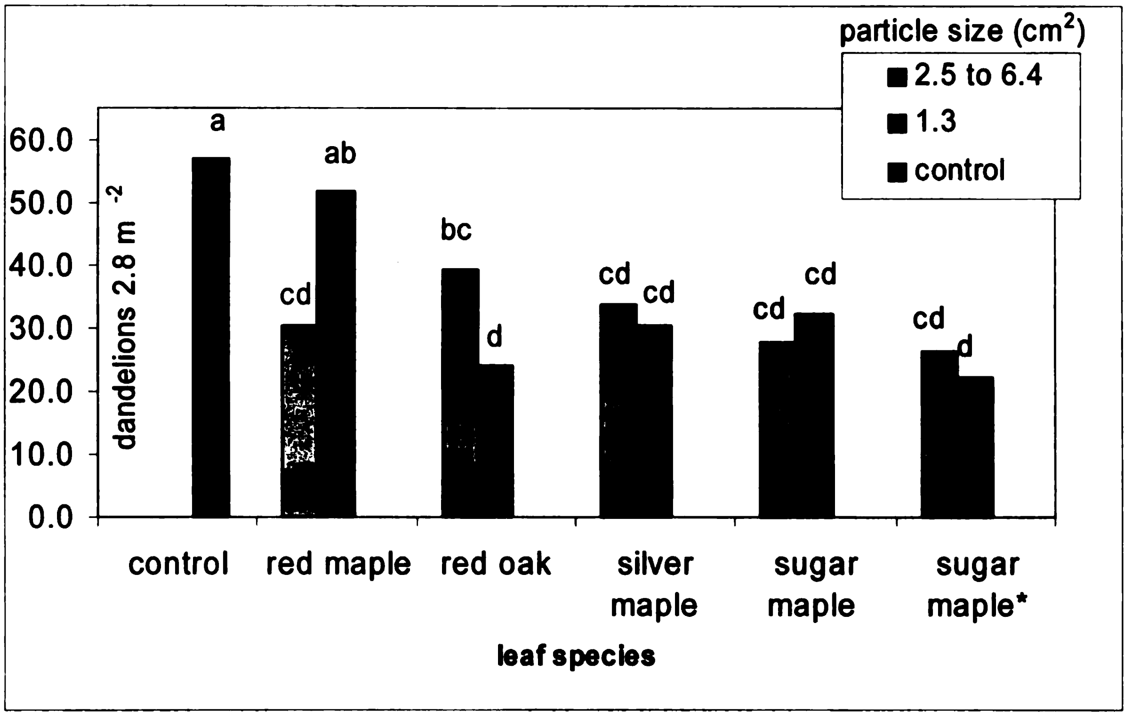
control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

Figure 15: Effects of leaf species x particle size on dandelion weed count following two consecutive applications of fall tree leaf mulch, two applications (site A) 2003 and 2004, results obtained 05 July 2005, HTRC, East Lansing, Mich.



control = no mulch

sugar maple* = sugar maple (high sugar maple)

Lower case letters represent significant differences at a 0.05 probability level.

Dandelion populations (plants per plot - 2.8 m^2) counted visually.

CONCLUSIONS

Annual mulch applications decreased overall dandelion populations in comparison to control treatments. After one annual application of fall tree leaves the high mulch application rate provided the greatest dandelion control, up to 80% (2004) and 70% (2005) in comparison to the control, which can be considered control and suppression respectively by the Pesticide Management Regulatory Agency (PMRA, 2002; Tompkins *et al.*, 2004). After two consecutive annual application (2003 and 2004) of fall tree leaves without herbicide applications the high mulch rate provided up to 53% dandelion control in comparison to the control treatment.

Results obtained after single application 2003 (site A) and two consecutive applications (2003 and 2004) suggest that some maple species provided greater dandelion control in comparison to other species. Single application 2003 and two application (2003 and 2004) results, obtained in 2004 and 2005 respectively, suggest that sugar maple, sugar maple (high sugar content) and red oak leaves provide the greatest dandelion control in comparison to other maple species. These results also suggest that red and silver maple leaf mulch provided the least amount of dandelion control in comparison to the other leaf applications. However single application 2004 (site B) leaf species results (obtained 2005) were not significantly different and therefor do not support differences observed after single application 2003 (site A) results.

Annual mulch applications had a positive effect on Kentucky bluegrass spring green-up and clipping yield. Increased mulch leaf application rates resulted in increased Kentucky bluegrass spring green-up, with the high rate (1.5-kg m^{-2}) producing the highest spring green-up ratings. Differences between leaf species and significant interactions were inconclusive because mean separations were minimal and varied from year to year. A strong correlation was also observed between increasing Kentucky bluegrass clipping yields and increasing mulch application rates. Increased spring green-up and clipping yields suggest that mulch applications functioned as an organic source of nutrients. Increases in spring turfgrass growth may have improved competitive ability of the Kentucky bluegrass and therefor decreased dandelion seed germination during its major flush in the early spring (Turner *et al.*, 1979; Uva *et al.*, 1997). Spring green-up advantages were however lost as atmospheric temperatures increased over time.

Annual mulch application had an effect on surface temperatures, soil temperatures, and soil moisture content but it is arguable whether these results were biologically significant due to the narrow ranges observed. Soil moisture content differences were narrow, and when present were disorderly and isolated making them inconclusive.

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