Alternative Mulch Species, With and Without Dimethenamid-P, for Weed Control in Nursery Container Production.

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Abstract

Weed control has been a persistent problem in the nursery industry. These antagonistic weeds incur many challenges and cost to control them as well as reducing the container plants marketability (Neal, 1999; Simpson et al, 2002). The necessity to control weeds in container plant production has propelled two nursery management practices, hand pulling and herbicide applications. There are numerous problems associated with current weed control practices including increasing labor cost, herbicide resistant weeds, misapplications, injury to non-target plants, and environmental concerns. Mulches may have potential to be valuable assets in the struggle to reduce labor costs, effectively control weeds, and reduce the negative environmental impacts of current practices. Pine bark mini-nuggets, as with other tree-derived mulches, create an environment that is not conducive to weed seed germination due to low fertility, large particle size, and hydrophobic properties (Richardson et al., 2008). In other studies, combinations of herbicides and mulches were deemed most effective. In addition to tree-derived mulch materials such as pine bark, pine straw and hardwood chips, other readily available tree-derived mulch species such as Chinese privet (*Ligustrum sinense*), sweetgum (*Liquidambar styraciflua*), and eastern red cedar (*Juniperus virginiana*) could be used as mulch in container production in lieu of commercialized pine bark mini-nuggets. The objective of this study was to evaluate four readily available mulch species at multiple depths for long term weed control and phytotoxicity in container grown nursery plants. Mulch treatments were evaluated with and without dimethenamid-p herbicide (Tower®). All aforementioned mulches were tested at depths of 2.5, 5.1, or 10.2 cm (0, 1, 2, and 4 in), with and without dimethenamid-p herbicide, to determine if

there were any differences among treatments through the duration of a growing season on weed counts and fresh weight of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*), and spotted spurge (*Euphorbia maculata*). At the first 30 day evaluation, there were no differences in treatments other than containers without mulch. Dimethenamid-p was shown to have better weed control without the addition of mulch than containers not treated with herbicide but did not increase efficacy when compared at 2.5, 5.1, or 10.2 cm (1, 2, or 4 in) of mulch. By the initiation of the second evaluation period (~45 days after treatment), dimethenamid-p had lost considerable weed control efficacy and mulch depth main effect remained significant through the third evaluation period (~160 days after treatment). Quadratic or linear trends over mulch depth indicated that weed control increased with mulch depth on all weed species across all evaluations. There were no consistent differences observed between mulch species. Mulch and herbicide effects on the growth of wax-leaf ligustrum (*Ligustrum japonicum*) and snowball viburnum (*Viburnum macrocephalum*) were evaluated separately. No phytotoxicity injury was observed at any date in the study. Plant size index indicated that dimethenamid-p treatments reduced the growth of both species by an average of 5 cm (1 in); mulch species or depth did not. Data showed that mulches prepared from any of these readily available tree species could be viable weed control options.

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CHAPTER I

Introduction and Literature Review

The economic prosperity and technological advancement generated post WWII drastically changed the emerging industry of container grown plants. A rapidly developing housing market with an equally rapidly developing need for desirable landscape plants caused growers to shift from field grown production methods to container grown. These containers allowed plants to be shipped further due to lighter growing mediums (substrates) and increased the longevity of ornamental plants (Knox and Chappell 2014). Ideal growing conditions created in nursery container production caused certain measures of weed control and prevention to become important issues in the rapidly expanding nursery industry.

Weeds have been defined as a plant that happens to germinate in a location that is undesirable. A weed to a container nursery grower can be much more than a wanton plant. Like a true antagonist, weeds actively oppose the aspirations of container nursery producers, to efficiently and consistently produce quality ornamental plants. Neal (1999) defines a weed as an adversary not only to the desired plant, but also to the grower. Weeds are plants that compete with a crop for essential components to a crops' growth and development (i.e. light, water, space, and nutrients) (Neal 1999), components critical in container production due to the limited amount of space within a container. Not only do weeds pose a threat to the health and growth of desired plants, but weeds also muddle best management procedures (BMP's) while reducing container plant marketability (Neal 1999; Simpson et al. 2002). These antagonistic plants incur many challenges and costs to control them as well as reducing the container plants marketability

(Neal 1999; Simpson et al. 2002). For these reasons, weed control practices are a primary concern in nursery container production.

Impact of weeds and common control practices

Weeds cause major problems in container crop production by reducing the crop value through competitive effects (Berchielli-Robertson et al. 1990) and reducing marketability due to demands for weed-free plants (Neal 1999; Simpson et al. 2002). Numerous researchers have reported that only one weed in a small container (trade gal or 1 gal) could affect growth of a container plant (Berchielli-Robertson et al. 1990; Fretz 1972; Walker and Williams 1989) but this is highly variable depending on both the crop and weed species. Fretz (1972) reported one red-rooted pigweed plant (*Amaranthus retroflexus*) reduced growth of a trade gallon container-grown *Ilex crenata* 'Convexa' by 47%. One crabgrass (*Digitaria sanguinalis*) diminished the growth of *I. crenata* 'Convexa' up to 60% when compared to the weed free control. One eclipta (*Eclipta prostrata*) diminished the shoot dry weight of 'Fashion' azalea by 50% (Berchielli-Robetson et al. 1990). With the extent of crop loss or reduction due to weeds plainly observed and researched, it is easy to see why nurseries sometimes spend as much as $4000 per acre to manually pull weeds (Mathers 2003). This seems like an egregious amount of money; however, marketability for container crops can be directly associated with the demand for weed-free plants (Simpson et al. 2002).

The necessity to control weeds in container plant production has propelled two nursery management practices, hand pulling and herbicide applications. Hand weeding is an increasingly expensive option due to increasing labor cost (Gilliam et al. 1990) and further complicated by immigration regulations. Some nurseries have entire crews devoted to hand pulling weeds in containers year around. Through communications with nurseries like Monrovia, among others, Mathers (2003) estimated that nurseries spend $500 to $4000 per acre for manual weed removal. This price varies depending on the weed pressure and species. For some nurseries, the expense of hand pulling weeds is just a part of doing business in container plant production. However, any methods to reduce cost of weed control could have a dramatic impact to the industry.

Nursery growers typically apply preemergence herbicides 3 to 5 times annually to reduce the need for hand weeding. Preemergence herbicides in a granular formulation are commonly broadcast applied using a cyclone or “belly-grinder” spreader, despite more recent research revealing the ineffectiveness of some granular formulations when compared to liquid formulations (Wehtje et al. 2015). There are numerous problems associated with current application methods of preemergence herbicides including resistant weeds, improper handling of materials and application procedures, injury to non-target plants, and environmental concerns.

Emergence of herbicide resistant biotypes has become a considerable threat to agronomic and horticultural weed control methods. A biotype is a population of a species that possesses genetic characteristics different from the entire population. The emergence of resistant biotypes can either be spontaneous or promoted by mutagenesis (Heap et al. 2004). Herbicides possess the capability of producing biotypes by selectively limiting the population to those specimens resistant or tolerant of the herbicide’s mode of action, allowing the resistant biotypes to reproduce and establish a more resistant population (Mallory-Smith et al. 1999). Mutagenesis may also occur as a result of contact with the herbicide, subsequent mutations may occur, providing resistance to that chemical pathway (Hager et al. 1998). Research has shown that alternating herbicide mode of actions and limiting herbicide applications can effectively reduce the potential for herbicide resistant biotypes (Holt and LeBaron 1990; Prather et al. 2000;

Retzinger and Mallory-Smith 1997). Although resistant biotypes in nursery container plant production occur less often than other facets of agriculture, it is vital for nursery growers to understand the potential side-effects of herbicide use and take measures to prevent them (Hager et al. 1998).

Many different circumstances may result in out of control weed populations despite the use of multiple herbicide applications. Very often, these problems occur due to improper herbicide applications resulting in poor control, non-target injury, and failure to comply with herbicide labels. Unfortunately for many of these situations, effective weed control could have been achieved with compliance to the herbicide's label. Timing is critical when using a "blind" method of weed control; such is the case when using preemergence herbicides (Altland 2002; Case et al. 2003). If weeds have already germinated, even though very small in size, it may be too late to achieve control with an application of many preemergence herbicides (Altland 2002). Preexisting weeds may also be the result of improper calibration. Whether the herbicide is applied as a liquid or granular formulations, proper calibration is needed to insure uniformity, prevent plant injury, and control weeds. Calibrating granular herbicide applications, the most common formulation applied in container production, is relatively easy but achieving uniformity is not (Gilliam et al. 1992). When testing the effects of granular and liquid applications of flumioxazin, Wehtje et al. (2015) showed that if an area the size of a dime were to remain herbicide prill free, a weed could stand a 50% chance of survival. Although herbicides have played a critical role in the development and growth of the container plant industry, herbicide applications are not without fault or problems. Besides calibration struggles, the potential to lose control, or injure plants, applicators must also be aware of environmentally impactful procedures to reduce non-target loss (Altland 2002; Gilliam et al. 1992).

Herbicide problems associated with non-target herbicide loss are largely attributed to improper application procedures (Case and Mathers 2006). Non-target loss is further convoluted with increased container spacing at the time of application. Porter and Parish (1993) reported 12% and 23% non-target loss on trade gallon containers when configured in a hexagonal pot to pot configuration and square pot to pot configuration, respectively. Gilliam et al. (1990) reported similar results with non-target losses ranging from 51% to 80% when granular herbicides were applied to trade gallons spaced 18 to 30 cm (7 to 12 in) on center. Research has shown herbicide fate and displacement is directly correlated depending on whether individual prills land in, or outside of, the container.

Though results may vary depending on herbicide characteristics, research has shown preemergence applied herbicides typically remain in the top 2 cm (1.25 in) of container substrate and do not leach through drain holes to any significant degree (Horowitz and Elmore, 1991; Wehtje et al. 1993; Wehtje et al. 1994). The lack of mobility is attributed to high organic matter compositions of many container substrates (Horowitz and Elmore 1991; Wehtje et al. 1994). Aside from herbicide fate in containers, any potential detriment from herbicide use in container production is due to non-target loss, the herbicide that doesn't land in the targeted container (Keese et al. 1994; Riley 2003; Riley et al. 1994; Wehtje et al. 1993; Wehtje et al. 1994). Non-target loss resulted in herbicide spikes in recaptured irrigation runoff immediately following a herbicide application (Keese et al. 1994; Riley 2003; Riley et al. 1994). The concentration of herbicide residue spikes in recapture ponds was attributed to the amount of chemical applied as well as the type of groundcover (plastic, fabric, or gravel) and was up to 15% of the amount of herbicide applied (Riley 2003). Although herbicide concentrations have not been shown to accumulate in recapture ponds or cause damage if reused as irrigation water, the potential for problems to arise in the form of environmental restrictions remain.

The increasing demand for instant landscapes and large container plant production has led many growers to begin producing more crops in 26.5 L (7 gal) containers and larger. Weed control practices in large container production must be altered from that used in smaller container production. Increased herbicide non-target loss between the large spacing required for large container production renders popular herbicide application practices inefficient and raises environmental concerns.

Alternative means of weed control

Mulches have proven to be an effective non-chemical alternative for weed control in large containers. Mulches can be defined as any physical material or materials applied to the surface of the soil or substrate (Chalker-Scott 2007). This definition could include many things from turfgrass to parking lots. Perhaps a better horticultural definition of mulches was presented by Lal (2002), who included that mulches must have the ability to create favorable environments for plant growth. Mulches have been shown to improve soil moisture, reduce erosion and compaction in soils, maintain optimal soil temperatures, increase soil nutrition, reduce pesticide contamination, improve plant establishment and growth, and reduce disease and weed pressure (Chalker-Scott 2007). Mulches offer potential to reduce manual labor cost, effectively control weeds, and reduce potential environmental impacts relative to current practices.

Several criteria must be met in order for a mulch to be considered effective. Effective mulches must be readily available, inexpensive, and acceptable to consumers (Richardson et al. 2008). Waste products, organic and inorganic, were a focus for many years in mulch research.

Products that would normally be sent to a landfill such as newspaper or tires have been evaluated as mulches (Pellet and Heleba 1995). Smith et al. (1997) reported that newspaper pellets at 5.1 cm (2 in) depth controlled spurge (*Euphorbia* maculate) in the landscape for at least 60 days. However, waste paper has been shown to reduce available nitrogen when applied as a mulch in container production (Glenn et al. 2000). Contrarily, some reports indicate that the zone of nitrogen unavailability may exist only in/around the soil/mulch interface in that other studies have shown mulching increases fertility and allows fertilizers to readily pass through (Broschat 2007; Chalker-Scott 2007; Greenly and Rakow 1995; Pickering and Shephard 2000). Ground tires were used in a separate study to provide good initial control, but weeds gradually began to penetrate the barrier after 2 months (Calkins et al. 1996). For the most part, waste product mulches are minimally effective due to limited availability and consumer acceptability.

Another inhibiting factor for some growers concerning container mulches is the cost of mulches relative to herbicides. As reported by Amoroso et al. (2007), herbicides are the cheapest way to control weeds in 3-L containers ($0.05/pot per application). The initial cost is the lowest available option but this cost does not take into account many of the nonconstructive side effects of herbicide use including injury to non-target plants, environmental damage, inefficient applications, and non-target loss. Without taking into account any of these cost inflating side effects, a typical nursery would spend $0.15-$0.25 annually per 3-L (trade gal.) container on a preemergence herbicide program. Cost for manual removal of weeds per container ranges between $0.15/pot and $0.53/pot per growing season (Amoroso et al. 2007). Many factors can affect the year to year expense of controlling weeds such as rainfall, irrigation practices, weed species, and weed pressure. Aside from anomalies, the standard weed control practices most commonly used, a mixture of herbicide application and hand-pulling, can accumulate extensive costs for a nursery grower. Any reduction in weed control cost would have a major impact on the success of the nursery industry.

Fabric discs of various materials have been evaluated for weed control in container production, but with limited success due to voids around the container-fabric interface or being blown away by winds (Appleton and Derr 1990). Overall cost per 18 cm diameter (7 in) mulching disc (including installation) is approximately $0.27/pot for both AW-Disk® and TWM disk. Though initial cost is high, the investment can be distributed over the course of two years due to the capability of reuse (Amoroso et al. 2007). The current decrease in herbicide use could result in a rise in non-chemical alternatives used for weed control and, as a consequence, a reduction of the fabric disk production cost (Amoroso et al. 2010). However, with increased demand for these engineered and manufactured methods, economics teaches that cost, in some cases, will increase. Mulches that are already in abundant quantities, sustainable, and efficient in weed control, such as tree derived mulches, could yield reduced costs to control weeds in containers.

Tree-derived mulches such as chipped cedar, pine bark mini-nuggets, and douglas fir have widespread availability, reasonable consistency, and are generally accepted by consumers (Llewellyn et al. 2003). Tree derived mulches have been studied as far back as the early 20th century when turf was shown to negatively affect the growth of young trees (Duke of Bedford and Pickering 1919). From this foundational study, mulches have been shown to offer a wide variety of beneficial characteristics in both the landscape and container setting. Although all of the beneficial characteristics do not correlate directly from a landscape setting to container production environments, some benefits do still apply.

Tree derived mulches are very appealing to container growers for attributes observed in landscape trials like water retention, temperature control, weed control, and reducing pesticide use. Water is a valuable commodity critical to a plants growth and development in both the landscape and nursery environments. Tree derived mulches have demonstrated water conservative properties when applied at varying depths in landscape trials due to increasing percolation and decreasing evaporation (Chalker-Scott 2007; Ferrini et al. 2008; Greenly and Rakow 1995; Maggard et al. 2012; Pickering et al. 1998; Singer and Martin 2008). However, the ability of mulches to conserve water in a container are more opaque with some studies revealing container water loss was primarily attributed to transpiration, and mulches had no effect on container water content (Altland and Lanthier 2007; Amoroso et al. 2010; Medina et al. 2005). Similar differences in attributes of mulches between landscape and containers are recorded in mulches' ability to moderate soil temperatures. Mulching in landscape and field production settings had lower daily maximum temperatures and higher daily minimum temperatures (Greenly and Rakow 1995; Pickering et al. 1998; Montague and Kjelgren 2004; Chalker-Scott 2007; Singer and Martin 2008; Maggard et al. 2012). However, high temperature levels recorded in containers are primarily attributed to color of the container and mulch treatments were unable to ameliorate this effect (Amoroso et al. 2010).

While mulching may have other beneficial effects to both the landscape and container plant industries, one of the most profound and well documented effects is tree-derived mulches ability to suppress weed growth. Pine bark mini-nuggets, as with other tree-derived mulches, create an environment that is not conducive to weed seed germination due to low fertility, large particle size, and hydrophobic properties (Richardson et al. 2008). Weed control efficacy reports in landscape trials vary in their results. Skroch et al. (1992) reported that five commonly used tree-derived mulches (pine bark, hardwood bark, cedar chips, and two pine needle species) reduced total weed counts by only 50% when applied at 9 cm (3.5 in). However, though a 50% reduction can be deemed unacceptable in commercial standards, it is important to note that the majority of the weeds present were tough perennial weeds, bermudagrass and yellow nut sedge. In other landscape studies conducted on tree-derived mulches, weed control was deemed acceptable and significantly different when compared to non-treated control (Billeaud and Zajicek 1989; Broschat 2007; Greenly and Rakow 1995).

Tree-derived mulches have also been effective weed suppressors in nursery production, providing good, long term control of weed species (Richardson et al. 2008; Wilen et al. 1999). In other container plant studies, combinations of herbicides and mulches were deemed most effective. Case and Mathers (2003) reported good long-term container plant weed control mulched with douglas fir and pine bark nuggets in combinations with either acetochlor applied at 2.8 kg a.i./ha (2.5 lbs a.i./A), flumioxazin at 2.2 kg a.i./ha (2.0 lbs a.i./A), or oryzalin at 2.2 kg a.i./ha. Neither oryzalin nor flumioxazin provided long term control when applied alone, and pine bark nuggets and douglas fir provided only moderate long-term control. However, mulch applications were applied at a depth of one mulch particle layer, not allow any overlapping of particles. Mulches, when applied for weed control, are most effective when applied at greater depths, 5.1-7.6 cm (2-3 in) and greater (Greenly and Rakow 1995; Richardson et al. 2008). Increasing mulch depths may lead to decreasing plant growth due to decreased levels of gas exchange or moisture against the plant stem, though this is also disputed (Billeaud and Zajicek 1989; Greenly and Rakow 1995, Richardson et al. 2008). Besides more popular tree-derived mulch types such as pine bark, pine straw and hardwood chips, other readily available tree-derived mulch species such as Chinese privet (*Ligustrum sinense*), sweetgum (*Liquidambar* *styraciflua*), and eastern red cedar (*Juniperus virginiana*) could be used as mulch in container production in lieu of commercialized pine bark mini-nuggets. Research with these available tree species could expand alternatives to current standards of weed control.

The objective of this study is to evaluate four readily available mulch species at multiple depths for long term weed control and phytotoxicity in container grown nursery plants. The four species to be evaluated are Eastern red cedar, ground whole loblolly pine (*Pinus taeda*), Chinese privet, and sweetgum. Mulch treatments will be evaluated with and without dimethenamid-p herbicide (Tower®), a commonly used herbicide labeled for container plant production. These data could provide growers with needed information in the event of increased EPA regulations and restrictions concerning herbicide runoff. Regardless of looming regulations, tree-derived mulches such as these could provide nursery growers a viable option to decrease spending from hand removal and herbicide control of weeds.

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CHAPTER II

Mulch Type and Depth Influences Weed Control on Three Major Weed Species in Nursery Container Production

Abstract

The necessity to control weeds in container production has pushed two control practices, preemergence herbicide application and hand pulling. There are numerous problems associated with these methods such as injury to non-target plants, inefficient best management practices, and environmental concerns. Nonchemical weed control methods could reduce herbicide-based environmental concerns. Readily available tree-mulch species, Eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), Chinese privet (*Ligustrum sinense*), and sweetgum (*Liquidambar styraciflua*) were harvested, chipped and evaluated at multiple depths with and without dimethenamid-p (Tower®). Pine bark mini-nuggets were also evaluated. Data from this study reveals that any of these potential mulch species applied at a depth of at least 5.1 cm (2 in) will provide long-term control of spotted spurge, phyllanthus, and eclipta.

Introduction

A weed to a container nursery grower can be much more than an outcast plant. Like a true antagonist, weeds actively oppose the aspirations of container nursery producers, to consistently grow and produce quality ornamentals efficiently. Weeds are plants that compete with a crop for essential components to a crops' growth and development (i.e. light, water, space, or nutrients) (Neal 1999), components critical in container production due to the limited amount of space within a container. Numerous researchers have reported that only one weed in a small container (trade gal. or 1-gal) could affect the growth of a container crop (Berchielli-Robertson et al. 1990; Fretz 1972; Walker and Williams 1989) but this is highly variable depending on both the crop and weed species. Fretz (1972) reported that one red-rooted pigweed plant (*Amaranthus retroflexus*) resulted in 47% reductions in growth of a trade-gallon container-grown *Ilex crenata* 'Convexa' and one-trade-gallon container-grown *I. crenata* 'Convexa' and one crabgrass (*Digitaria sanguinalis*) reduced the growth of *I. crenata* 'Convexa' up to 60% when compared to the weed free control. One eclipta plant (*Eclipta prostrata*) reduced the shoot dry weight of *Rhododendron* 'Fashion' (Berchielli-Robertson et al. 1990). Not only do weeds pose a threat to the health and growth of desired plants, but weeds also muddle best management procedures (BMP's) while reducing container plant marketability (Neal 1999; Simpson et al. 2002). These antagonistic plants incur many challenges and cost to control them as well as reducing the container plants marketability (Neal 1999; Simpson et al. 2002). For these reasons, weed control practices are a primary concern in nursery container production.

The necessity to control weeds in container plant production has motivated two nursery management practices, hand pulling and herbicide applications. Hand weeding is an increasingly expensive option due to increasing labor cost (Gilliam et al. 1990). Through communications with nurseries like Monrovia, among others, Mathers (2003) reported that nurseries spend an estimated $500 to $4000 per acre for manual weed removal. This price varies depending on the weed pressure and species attempted to control. To reduce the need for hand weeding, nursery growers typically apply preemergent herbicides 3 to 5 times annually. Preemergent herbicides are commonly broadcast in a granular form using a cyclone or "belly-grinder" spreader, despite more recent research revealing the ineffectiveness of some granular applications when compared to liquid formulations and applications (Wehtje et al. 2015). There are numerous problems associated with current application methods of preemergent herbicides including resistant weeds, improper handling of materials and application procedures, injury to non-target plants, and environmental concerns.

Mulches have proven to be an effective, non-chemical alternative for weed control. Tree derived mulches such as chipped cedar, pine bark mini-nuggets, and douglas fir have widespread availability, reasonable consistency, and are generally accepted by consumers (Llewellyn et al. 2003). Landscape studies conducted on tree-derived mulches, weed control was deemed acceptable and significantly different when compared to non-treated control plots (Billeaud and Zajicek 1989; Broschat 2007; Greenly and Rakow 1995). Tree-derived mulches have also been effective weed suppressors in nursery production, providing good, long term control of detrimental weed species (Richardson et al. 2008; Wilen et al. 1999). In other container plant studies, combinations of herbicides and mulches were deemed most effective. Case and Mathers (2003) reported good long-term container plant weed control mulched with douglas fir and pine bark nuggets in combinations with either acetochlor applied at 2.8 kg a.i./ha (2.5 lbs a.i./A), flumioxazin at 2.2 kg a.i./ha (2.0 lbs a.i./A), or oryzalin at 2.2 kg a.i./ha (2.0 lbs a.i./A). Neither oryzalin nor flumioxazin provided long term control when applied alone. Likewise, pine bark nuggets and douglas fir mulches provided some control but did not meet commercial standards. However, mulch applications were applied at a depth of one mulch particle layer, not allowing the particles to overlap. Mulches, when applied for weed control, are most effective when applied at greater depths, 5.1-7.6 cm (2-3 in) and greater (Greenly and Rakow 1995; Richardson et al. 2008).

Other readily available tree-derived mulch species such as Chinese privet, sweetgum, and eastern red cedar could be used as mulch in container production in lieu of commercialized pine bark mini-nuggets. The objective of this study was to evaluate four readily-available tree species as mulch applications at multiple depths for long term weed control. The four species tested were Eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), Chinese privet (*Ligustrum sinense*), and sweetgum (*Liquidambar styraciflua*). Mulch treatments were evaluated with and without dimethenamid-p herbicide (Tower®).

Materials and Methods

This study was conducted at the Paterson greenhouse complex at Auburn University in Auburn, AL. The experiment was initiated 19 April 2014 and repeated again on 17 March 2015 when Eastern red cedar, loblolly pine, Chinese privet, and sweetgum trees, 10 to 20 cm (4 to 8 in.) in diameter measured at 30.5 cm (12 in) from the soil, were harvested. Only the trunk portions of these trees were used to provide mulch. Harvested trees were chipped with a chipper (Vermeer BC1400 XL, Vermeer Manufacturing Company, Pella, Iowa) one week after harvesting. Along with these four mulches, pine bark mini-nuggets were included (Pine Bark Mini-Nuggets Landscape, Garick, LLC. Cleveland, Ohio) to provide a commercially comparative mulch treatment. Each mulch species was sieved through a series of wire screens [5.1, 2.5, 1.3, and 0.6 cm (2, 1, 0.5, 0.25 in) screens] to determine particle size distribution ratios between mulches (Fig. 2.1).

Treatments consisted of a factorial arrangement of five mulches (eastern red cedar, loblolly pine, Chinese privet, sweetgum, and pine-bark minnuggets), three mulch depths [2.5, 5.1, and 10.2 cm (1, 2, and 4 in)], and two herbicidal treatments [No herbicide and dimethenamid-p (Tower®)]. Two additional treatments were a nontreated control (no mulch with no herbicide) and a no mulch with herbicide for a total of 32 treatments. Three weed species, long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*), and spotted spurge (*Euphorbia maculata*), were tested, each receiving all 32 treatments. Each treatment was replicated five times for a total of 60 pots per weeds species (note: there are three mulch depth treatments within each mulched container). The study was arranged in a complete random design within each weed species.

On 26 May 2014 and on 13 April 2015, 95 L (25 gal) containers were filled 12.7 cm (5 in) from the top with a 6:1 pine bark:sand (v/v) substrate amended per cubic yard with 2.3 kg (5 lbs) dolomitic lime, 6.4 kg (14 lbs) of Polyon® 18-6-12 (Pursell Technologies, Sylacauga, Alabama) and 0.7 kg (1.5 lbs) Micromax® (Scotts Co., Maryville, Ohio). Containers were placed on the nursery pad and irrigated twice daily for 3 days with 2.5 cm (1 in) of water to allow for settling and accurate adjustment of substrate depth. Tower® was then applied at 2.1 L-product/ha (30 fl oz/A) to the herbicide designated pots as a liquid application [280 L/ha (30 gal/A)] with a CO_2 pressure backpack sprayer. The space at the top of the containers was to allow space for dividers. These dividers consisted of corrugated polypropylene sheets held in place by a dowel to divide the containers into thirds. Each third of the pot was seeded with 10 seeds of long-stalked phyllanthus, eclipta, or spotted spurge applied to the surface of the media on 31 May 2014 and 16 April 2015. The three partitions of each pot were designated one of the three mulch depths so that each pot contained 2.5, 5.1, and 10.2 cm (1, 2, and 4 in) of mulch. Mulch was spread immediately after seeding.

Each year, three evaluation periods were conducted to record treatment efficacy and longevity of weed control over the course of a growing season. Each evaluation period allowed weeds to grow for approximately 30 days after seeding. At this time, weeds, if any, were counted, clipped at the mulch or substrate surface, and fresh weights were taken. One week after weed harvest, the containers were sprayed with paraquat dichloride (Gramoxone® Inteon by Syngenta) to kill any remaining weeds. One week after paraquat was applied, containers were reseeded on top of the mulch or substrate surface with 10 seeds of the designated weed species, initiating the next evaluation period. This process was repeated once more to initiate the final evaluation period.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). Each weed species and experimental rounds were analyzed as separate experiments, and the experimental design was a split plot with mulch type and herbicide application in the main plot and mulch depth in the sub-plot. Where residual plots and a significant COVTEST statement with the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity for weed fresh weight. Weed counts were analyzed using the Poisson distribution. Single degree of freedom orthogonal contrasts were used to test linear and quadratic trends over mulch depth. Differences between herbicide treatments were determined using the Shaffer Simulated method. All reported means are least squares means. All significances were at $\alpha = 0.05$.

Results and Discussion

Data for the first evaluation period in 2014 was taken 30 June 2014. Herbicide by mulch depth interaction influenced weed counts and fresh weights of each weed species in the first experimental run (Table 2.1). Least square means comparison within each weed species showed differences in containers treated with or without dimethenamid-p with no mulch. Non-mulched containers of long-stalked phyllanthus had higher weed counts in non-herbicide treated containers than containers that receive herbicide, 4 and 2 respectively. Long-stalked phyllanthus fresh weights were also higher in non-herbicide treated containers than those that received herbicide, 9.28 g and 0.04 g respectively. Similar results were recorded in eclipta and spotted spurge. At 2.5 cm (1 in) of mulch, spotted spurge had fewer weeds in containers with herbicide than in containers without herbicide. No other differences in mulch depth and herbicide treatments were observed. Negative quadratic trends in weed counts and fresh weights were shown with increasing mulch depth for all weed species in containers without herbicide. Spotted spurge fresh weights had means of 27.02 g in containers without mulch, 2.26 g at 2.5 cm (1 in), and 0 g in both 5.1 and 10.2 cm (2 and 4 in) depths. Results from the first evaluation period in 2014 and 2015 (Table 2.2) showed similar results.

In the first evaluation period of 2014 and 2015, mulch species was observed to be insignificant. However, dimethenamid-p and mulch treatments were shown to provide good weed control over a span of 30 days. All treatments showed complete control of eclipta in the first experimental runs of 2014 and 2015, something not observed in any other experimental run. These results coincide with the results from Duryea et al. (1999) who concluded the effects of mulches for weed control were greatest when the mulch is fresh and contained hydroxylated aromatic compounds believed to inhibit seed germination. Weed seed placement below mulch treatments for the first run could have also attributed to the effectiveness of mulches. It is also important to note that herbicide did not change the efficacy of mulches to control weeds other than spotted spurge weed counts in 2014 at a mulch depth of 2.5 cm (1 in).

The second evaluation period (seed placed on top of the mulch/substrate surface) did not yield results consistent with the first run or between years. In 2014, evaluation period 2 had significant interactions between herbicide and mulch depth (Table 2.3). Unlike the first period, containers treated with herbicide and without mulch had higher weed counts than containers with no herbicide and no mulch across all weed species. For example, eclipta had a mean of 3 weeds in containers treated with herbicide and no mulch and 1 in non-mulched, no herbicide containers.

Long-stalked phyllanthus also had greater fresh weights in containers treated with herbicide and no mulch, 2.66 g, than those without herbicide and mulch, 0.62 g. Eclipta and spotted spurge fresh weights were affected by mulch depth only. Spotted spurge had decreasing fresh weights with increasing mulch depth, 3.87 g in containers without mulch, 0.24 g at 2.5 cm (1 in), and 0 g in both 5.1 and 10.2 cm (2 and 4 in) depths. Significant linear or quadratic trends were recorded across mulch depths, regardless of herbicide application or weed species. Weed counts and fresh weights decreased with increasing mulch depth.

In 2015, evaluation period 2 showed significant herbicide by mulch depth interactions which indicated that dimethenamid-p was still active (Table 2.4). Long-stalked phyllanthus, eclipta, and spotted spurge fresh weights as well as spotted spurge weed counts had higher numbers in containers without mulch or herbicide than those containers with herbicide and no mulch. Long-stalked phyllanthus, eclipta, and spotted spurge growth in herbicide treated containers without mulch were reduced by 93, 78, and 65%, respectively, when compared to containers without herbicide or mulch. Long-stalked phyllanthus and eclipta weed counts were affected by mulch depth only. With the exception of long-stalked phyllanthus containers treated with herbicide, significant linear or quadratic trends were recorded across mulch depths, regardless of herbicide application or weed species. Weed counts and fresh weights decreased with increasing mulch depth. Weed counts of eclipta and spotted spurge were also affected by mulch species (Table 2.5). Pine bark mini-nuggets controlled spotted spurge and eclipta better than eastern red cedar, loblolly pine, Chinese privet, or sweetgum at 2.5 and 5.1 cm (2 and 4 in). No other differences between mulch species and depth were observed.

The second evaluation period revealed widely different results between 2014 and 2015. In 2014, dimethenamid-p treatments had seemingly lost all efficacy. When compared to the non-herbicide treated containers, weed counts and fresh weights were actually higher. Germination test were conducted in paper towels on all weed species prior to the initiation of the study to insure approximate 90% germination rates were met. These test indicated that all weed species had a germination rate over the target 90%. However, results throughout the study revealed inconsistent germination rates in the pine bark/ sand substrates. A random event of inconsistent germination could have caused herbicide treated containers to show greater weed counts and fresh weights than non-herbicide treated containers. Dimethenamid-p has a short half-life of approximately 21 days (Senseman 2007). Microbial activity coupled with the herbicide's high adsorption to the high levels of organic matter found in soilless growing media presumably rendered the herbicide ineffective by the second evaluation period of the experiment (~45 days after treatment). However, in 2015, dimethenamid-p had not lost efficacy and reduced the growth of all weed species and weed counts of spotted spurge. Cooler weather decreases microbial activity and can increase the longevity of a herbicide's half-life. It is possible that the earlier, cooler start in 2015 (16 April as opposed to 31 May) allowed the herbicide's efficacy to be extended up to or beyond 45 days.

Differences between mulch species were only observed in 2015 in evaluation period 2 when analyzing eclipta and spotted spurge weed counts at 2.5 and 5.2 cm (1 and 2 in) depth. A weather recording station on Auburn University's campus recorded rainfall for each evaluation period. In 2014, evaluation period 1, 2, and 3 received 8.56, 7.75, and 5.84 cm (3.37, 3.05, and 2.30 in) of rain, respectively. In 2015, evaluation period 1, 2, and 3 received 5.66, 14.53, and 4.06 cm (2.23, 5.72, 1.60 in) and of rain, respectively. Throughout the 30 day period during the second evaluation period in 2015, 13 days were overcast. It is our hypothesis that the amount of rain received during this evaluation period attributed the difference recorded in mulch species.

Pine bark mini-nugget's larger particle size distribution and hydrophobic properties lent it an advantage during this wet period to best maintain its weed control efficacy.

The third evaluation period in 2014 and 2015 revealed mulch depth was the only main effect on weed counts and fresh weights of all weed species (Tables 2.6 and 2.7). Significant quadratic trends were recorded across mulch depths. In all weed species, weed counts and fresh weights decreased with increasing mulch depth. In containers without mulch, eclipta fresh weights averaged 12.51 g in the final evaluation period of 2014. Mulch depths of 2.5, 5.1, and 10.2 cm (1, 2, and 4 in) reduced eclipta fresh weight by 98, 99.5, and 100%, respectively. Spotted spurge fresh weight was reduced 90, 99.5, and 100% by 2.5, 5.1, and 10.2 cm (1, 2, and 4 in) of mulch, respectively, when compared to containers without mulch in 2015.

These results demonstrate that tree-derived mulches are an effective, non-chemical alternative method of weed control. These data indicate that a depth of 5.1 cm (2 in) with any of these readily available, tree-derived mulches will provide enduring weed control of detrimental weed species in container plant production. However, further research must be conducted to analyze specific decomposition rates as noticeable decomposition differences were observed between mulch species. This information would be vital in determining application procedures in larger container production where plants are grown up to 18 months or longer. Additionally, cost analysis research must be conducted to help enforce implementation of these mulches from an economic perspective. Currently, the cost for pine bark mini-nuggets is ~$37 per cubic meter. At this price, it would cost $0.22 (not including labor) to apply 5.1 cm (2 in) of mulch in a 26 L (7 gal) container. This price may be relatively comparable to the cost Amoroso et al. (2007) reported to apply preemergence herbicides to a 1 L (trade gallon) container ($0.05/application applied 3-5 times per year). If this process can be made economical, the use of mulches in container plant production can alleviate many of the problems associated with common weed control methods such as injury to non-target plants, inefficient BMPs, and environmental concerns.

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Figures and Tables:

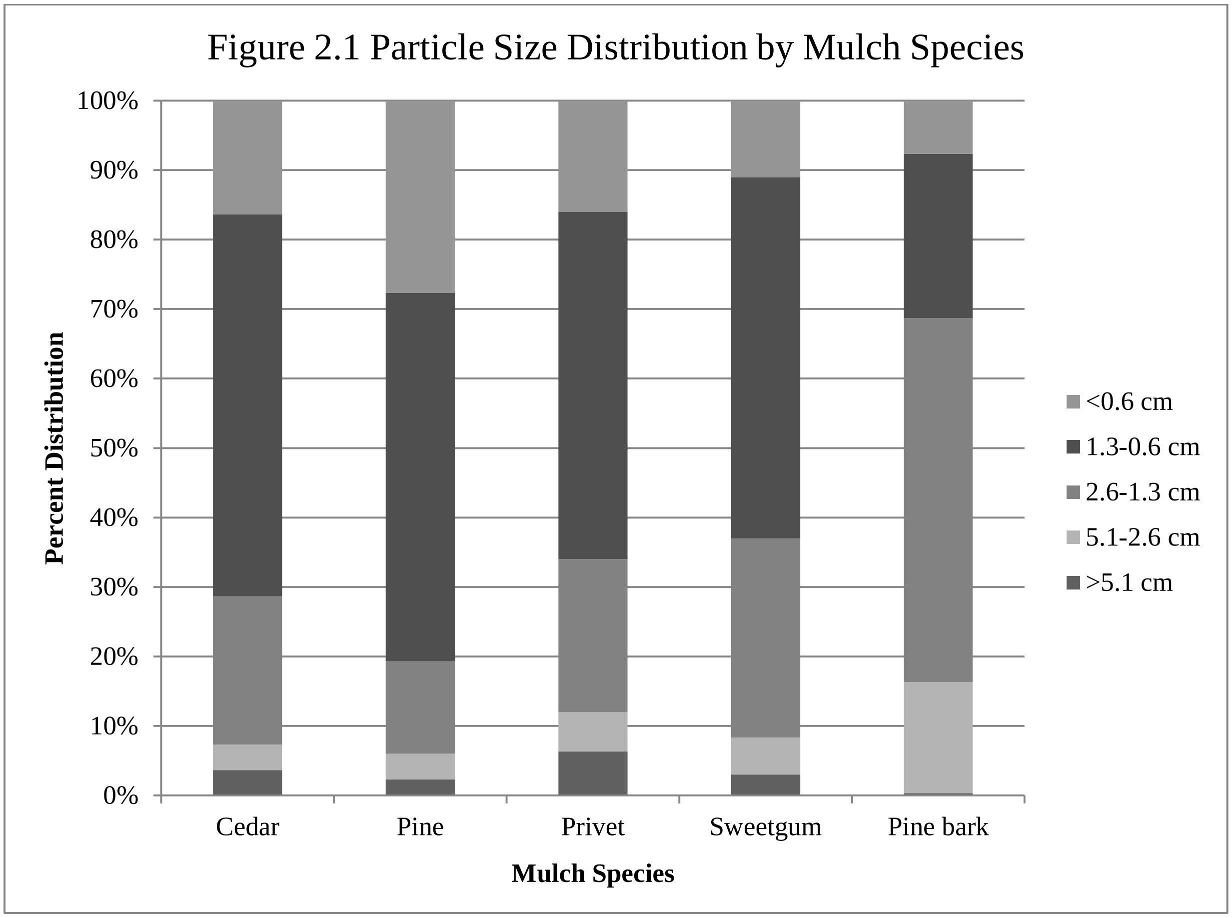

Table 2.1. First evaluation period in 2014. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

Weed species	Herbicide[y]	Mulch depth (cm) 0	2.5	5.1	10.2	Significance[x]
		Weed count (no./pot)				
Long-stalked phyllanthus	no	4a[w]	1	0	0	Q***
	yes	2b	1	0	0	Q***
Eclipta	no	4a	0	0	0	Q***
	yes	0b	0	0	0	NS
Spotted spurge	no	6a	1a	0	0	Q***
	yes	0b	0b	0	0	NS
		Fresh weight (g/pot)				
Long-stalked phyllanthus	no	9.28a	1.68	0.09	0.00	Q***
	yes	0.04b	0.02	0.00	0.00	NS
Eclipta	no	34.46a	0.00	0.00	0.00	Q***
	yes	0.00b	0.00	0.00	0.00	NS
Spotted spurge	no	27.02a	2.26	0.00	0.00	Q***
	yes	0.00b	0.00	0.00	0.00	NS

[z]Treated on 31 May 2014. Data recorded 30 June 2014, 30 days after treatment. Each weed species was analyzed separately. Significant herbicide by mulch depth interactions were detected for all species and both responses at $\alpha = 0.05$.

[y]Dimethenamid-p (Tower®) was broadcast applied prior to seed (10 seed/rep) and mulch applications at 2.1 L-product/ha or 1.57 kg a.i./ha (30 fl.oz.-product/A or 1.40 lbs a.i./A).

[x]Nonsignificant (NS) or quadratic (Q) responses at $\alpha = 0.001$ (***) for mulch depth.

[w]Least square means comparisons between no herbicide and herbicide at each mulch depth (in columns) using Bonferroni's Test at $\alpha = 0.05$.

Table 2.2. First evaluation period in 2015. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

Weed species	Herbicide[y]	Mulch depth (cm) 0	2.5	5.1	10.2	Significance[x]
		Weed count (no./pot)				
Long-stalked phyllanthus	no	5a[w]	0	0	0	Q***
	yes	1b	0	0	0	Q*
Eclipta	no	6a	0	0	0	Q***
	yes	0b	0	0	0	NS
Spotted spurge	no	7a	0	0	0	Q***
	yes	0b	0	0	0	NS
		Fresh weight (g/pot)				
Long-stalked phyllanthus	no	0.72a	0.01	0.09	0.00	Q***
	yes	0.02b	0.00	0.00	0.00	Q*
Eclipta	no	3.82a	0.00	0.00	0.00	Q***
	yes	0.00b	0.00	0.00	0.00	NS
Spotted spurge	no	4.52a	0.02	0.00	0.00	Q***
	yes	0.00b	0.00	0.00	0.00	NS

[z]Treated on 16 April 2015. Data recorded 19 May 2015, 33 days after treatment. Each weed species was analyzed separately. Significant herbicide by mulch depth interactions were detected for all species and both responses at α=0.05.

[y]Dimethenamid-p (Tower®) was broadcast applied prior to seed (10 seed/rep) and mulch applications at 2.1 L-product/ha or 1.57 kg a.i./ha (30 fl.oz.-product/A or 1.40 lb a.i./A).

[x]Nonsignificant (NS) or quadratic (Q) response at α = 0.05 (*) or 0.001 (***) for mulch depth.

[w]Least square means comparisons between no herbicide and herbicide at each mulch depth (in columns) using Bonferroni's Test at α=0.05.

Table 2.3. Second evaluation period in 2014. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

Weed species	Herbicide[y]	Mulch depth (cm) 0	2.5	5.1	10.2	Significance[x]
		Weed count (no./pot)				
Long-stalked phyllanthus	no	2b[w]	2	1	0	L***
	yes	3a	1	1	0	Q***
Eclipta	no	1a	0	0	0	Q***
	yes	3b	0	0	0	Q***
Spotted spurge	no	4b	1	0	0	Q***
	yes	5a	1	1	0	Q***
		Fresh weight (g/pot)				
Long-stalked phyllanthus	no	0.62b	0.88	0.08	0.00	L***
	yes	2.66a	0.50	0.30	0.00	Q***
Eclipta	n/a[v]	1.19	0.20	0.09	0.00	Q***
Spotted spurge	n/a	3.87	0.24	0.00	0.00	Q***

[z]Treated on 31 May 2014. Data recorded 19 August 2014, 80 days after treatment. Each weed species was analyzed separately. Significant herbicide by mulch depth interactions were detected for all species for weed counts and long-stalked phyllanthus for fresh weights at $\alpha = 0.05$.

[y]Dimethenamid-p (Tower®) was broadcast applied prior to seed (10 seed/rep) and mulch applications at 2.1 L-product/ha or 1.57 kg a.i./ha (30 fl.oz.-product/A or 1.40 lb a.i./A).

[x]Linear (L) or quadratic (Q) response at $\alpha = 0.001$ (***) for mulch depth.

[w]Least square means comparisons between no herbicide and herbicide at each mulch depth (in columns) using Bonferroni's Test at $\alpha = 0.05$.

[v]Only the mulch depth main effect was significant at $\alpha = 0.05$.

Table 2.4. Second evaluation period in 2015. Effect of herbicide and mulch depth on weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

		Mulch depth (cm)				
Weed species	**Herbicide[y]**	**0**	**2.5**	**5.1**	**10.2**	**Significance[x]**
		Weed count (no./pot)				
Long-stalked phyllanthus	n/a[w]	2[v]	1	1	0	Q*
Eclipta	n/a	4	2	1	1	Q***
Spotted spurge	no	8a	3	2	0	Q***
	yes	6b	3	2	0	Q***
		Fresh weight (g/pot)				
Long-stalked phyllanthus	no	9.66a	2.90	3.15	0.00	Q*
	yes	0.64b	1.00	0.01	0.00	NS
Eclipta	no	63.14a	21.91	18.74	8.50	L**
	yes	13.99b	13.56	4.56	0.47	Q***
Spotted spurge	no	99.02a	15.35	5.47	0.37	Q***
	yes	35.16b	10.98	3.23	0.22	Q**

[z]Treated on 16 April 2015. Data recorded 30 June 2015, 75 days after treatment. Each weed species was analyzed separately. Significant herbicide by mulch depth interactions were detected for all species for fresh weights and spotted spurge for weed counts at $\alpha = 0.05$.

[y]Dimethenamid-p (Tower®) was broadcast applied prior to seed (10 seed/rep) and mulch applications at 2.1 L-product/ha or 1.57 kg a.i./ha (30 fl.oz.-product/A or 1.40 lb a.i./A).

[x]Nonsignificant (NS), linear (L), or quadratic (Q) response at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***) for mulch depth.

[w]Only the mulch depth main effect was significant at $\alpha = 0.05$.

[v]Least square means comparisons between no herbicide and herbicide at each mulch depth (in columns) using Bonferroni's Test at $\alpha = 0.05$.

Table 2.5. Second evaluation period in 2015. Mulch species and depth influence weed counts of spotted spurge (*Euphorbia maculata*).[z]

	Mulch depth (cm)				
Mulch species	**0**	**2.5**	**5.1**	**10.2**	**Significance[y]**
Eastern red cedar	7ns[x]	3a	2a	0ns	Q***
Loblolly pine	7	3a	3a	1	Q***
Chinese privet	7	3a	2a	1	Q***
Sweetgum	7	4a	2a	0	Q***
Pine bark mini-nuggets	7	1b	0b	0	Q***

[z]Treated on 16 April 2015. Data recorded 30 June 2015, 75 days after treatment. Significant mulch species by mulch depth interaction were detected at $\alpha = 0.05$.

[y]Quadratic (Q) response at $\alpha = 0.001$ (***) for mulch depth.

[x]Least square means comparisons among mulch species at each mulch depth (in columns) using Bonferroni's Test at $\alpha = 0.05$.

Table 2.6. Third evaluation period in 2014. Mulch depth affects weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

	Mulch depth (cm)				
Weed species	**0**	**2.5**	**5.1**	**10.2**	**Significance[x]**
	Weed count (no./pot)				
Long-stalked phyllanthus	2	1	0	0	Q***
Eclipta	3	0	0	0	Q***
Spotted spurge	5	2	1	1	Q***
	Fresh weight (g/pot)				
Long-stalked phyllanthus	3.13	0.33	0.06	0.00	Q***
Eclipta	12.51	0.29	0.06	0.00	Q***
Spotted spurge	12.86	4.46	1.00	0.03	Q***

[z]Treated on 31 May 2014. Data recorded 10 October 2014, 132 days after treatment. Each weed species was analyzed separately. Only mulch depth was significant for both responses at $\alpha = 0.05$.

[x]Quadratic (Q) response at $\alpha = 0.001$ (***) for mulch depth.

Table 2.7. Third evaluation period in 2015. Mulch depth affects weed counts and fresh weights of long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*) and spotted spurge (*Euphorbia maculata*).[z]

	Mulch depth (cm)				
Weed species	**0**	**2.5**	**5.1**	**10.2**	**Significance[x]**
	Weed count (no./pot)				
Long-stalked phyllanthus	4[v]	1	0	0	Q***
Eclipta	4	0	0	0	Q***
Spotted spurge	6	2	0	0	Q***
	Fresh weight (g/pot)				
Long-stalked phyllanthus	5.77	0.27	0.05	0.00	Q**
Eclipta	6.42	0.28	0.01	0.00	Q***
Spotted spurge	4.63	0.48	0.02	0.00	Q***

[z]Treated on 16 April 2015. Data recorded 1 October 2015, 168 days after treatment. Each weed species was analyzed separately. Only mulch depth was significant for both responses at $\alpha = 0.05$.

[x]Quadratic (Q) response at $\alpha = 0.01$ (**) or 0.001 (***) for mulch depth.

CHAPTER III

Effects of Woody Mulches and Dimethenamid-p on Container Grown *Ligustrum japonicum* and *Viburnum macrocephalum*.

Abstract

Current weed control practices in nursery container plant production consist primarily of hand weeding and series of preemergence herbicide applications. Non-chemical weed control methods, such as mulches, could diminish non-target herbicide loss, reduce potential environmental concerns, and decrease the expense of weed control. Before implementation, alternative methods of weed control must be evaluated for effects on the growth of common container species. Readily available tree species, Eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), Chinese privet (*Ligustrum sinense*), and sweetgum (*Liquidambar styraciflua*), were evaluated at multiple depths with and without a herbicide treatment of dimethenamid-p (Tower®). Herbicide treatments resulted in less growth of both wax-leaf ligustrum (*Ligustrum japonicum*) and snowball viburnum (*Viburnum macrocephalum*) up to 7%. Mulch species and depth had no effect on plant growth. Results indicate that these readily available mulch species can be applied at depths up to 10.2 cm (4 in) for weed control in container plant production.

Introduction

Weeds have been noted to cause major problems in container plant production by reducing the crop value through competitive effects (Berchielli-Robertson et al. 1990) and reducing marketability due to demands for weed free plants (Simpson et al. 2002). Their effects on container grown ornamentals are amplified due to limited space and resources restricted by the container. Many researchers have recorded the devastating effects of just one weed on a container grown ornamental (Berchielli-Robertson et al. 1990; Fretz 1972; Walker and Williams 1989). Although the competitive effect of a weed is highly variable depending on the species of both the ornamental plant and weed, reductions in growth and shoot weight of the container grown ornamental have been reported at 47% and greater (Berchielli-Robertson et al. 1990; Fretz 1972; Walker and Williams 1989). The necessity to control weeds in container production has pushed growers to utilize a combination of two weed control methods, manual removal and preemergence herbicides.

Weed control practices may differ depending on the container size and the species grown. Increased container spacing for larger container production may render common weed control practices inefficient and be a potential cause for environmental concern. With cost ranging from $0.15/pot to $0.53/pot, the cost of manual weed removal can accumulate quickly and future projections may indicate labor cost will only increase (Amoroso et al. 2007). Since manual removal is costly, many growers rely on multiple applications of preemergence herbicides to help control weeds. The use of these herbicides, though impactful in the growth and success of the nursery industry, can contribute to some environmental concerns, specifically from non-target loss. This problem is further compounded by increased container spacing at the time of application. Porter and Parish (1993) showed 12% and 23% non-target loss on trade gallon containers when configured in a hexagonal pot to pot configuration and square pot to pot configuration, respectively. Gilliam et al. (1990) reported similar results in that non-target losses ranging from 51% to 80% when herbicides were applied to trade gal containers spaced 18 to 30 cm (7 to 12 in) on center. In many applications, the fate of herbicide granules subjected to non-target loss results in significant herbicide spikes in recapture ponds shortly after herbicide applications (Keese et al. 1994; Riley et al. 1994, Riley 2003). In one study, the herbicide residue spike found in a recapture pond was attributed to an estimated 15% of the total amount of herbicide applied (Riley 2003). Although herbicide concentrations have yet to cause damage if reused as irrigation water, the potential for this environmental concern to issue change is impending.

Mulches have proven to be an effective non-chemical alternative for weed control in both the landscape and the nursery container industry. Tree derived mulches such as chipped cedar, pine bark mini-nuggets, and douglas fir have widespread availability, reasonable consistency, and are acceptable by consumers (Llewellyn et al. 2003). Mulches have been shown through research to be able to improve soil moisture, reduce erosion and compaction in soils, maintain optimal soil temperatures, increase soil nutrition, reduce pesticide contamination, improve plant establishment and growth, and reduce disease and weed pressure (Chalker-Scott 2007). Mulches offer the potential to be valuable assets to nursery container growers in the struggle to reduce manual labor cost, effectively control weeds, and reduce potential environmental impacts of current practices.

In landscape studies conducted on tree-derived mulches, weed control was deemed acceptable and significantly different when compared to non-treated control plots (Billeaud and Zajicek, 1989; Greenly and Rakow, 1995, Broschat, 2007). Tree-derived mulches have also been shown to be effective weed suppressors in nursery container production, providing good, long term control of detrimental weed species (Richardson et al, 2008; Wilen et al., 1999). In other container studies, combinations of herbicides and mulches were deemed most effective. Case and Mathers (2003) reported good long-term container weed control mulched with douglas fir and pine bark nuggets in combinations with either acetochlor applied at 2.8 kg a.i./ha (2.5 lbs a.i./A), flumioxazin at 2.2 kg a.i./ha (2.0 lbs a.i./A), or oryzalin at 2.2 kg a.i./ha (2.0 lbs a.i./A). Neither oryzalin nor flumioxazin provided long-term control when applied alone, and pine bark nuggets and douglas fir provided only light long-term control.

Research has shown that mulching, in both the landscape and container production, provides improved weed control with increasing depths of mulch (Richardson et al., 2008; Greenly and Rakow, 1995). However, Billeaud and Zajicek (1989) reported decreased plant growth of *Ligustrum japonicum* with increasing mulch depths in their landscape trial. Richardson et al. (2008) reported no effect in growth of various ornamental species with increasing mulch depth [up to 7.62 cm (3 in)] in a container trial.

Objective of this study was to evaluate four readily-available mulch species at multiple depths, with and without herbicide applications, to determine any potential phytotoxic effects on *Ligustrum japonicum* (wax-leaf ligustrum) and *Viburnum macrocephalum* (snowball viburnum) in container production. Four mulch species tested were Eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), Chinese privet (*Legustrum sinense*), and sweetgum (*Liquidambar styraciflua*). Mulch treatments were evaluated with and without dimethenamid-p herbicide (Tower®).

Materials and Methods

This study was conducted at the Paterson greenhouse complex at Auburn University in Auburn, AL. The experiment was initiated 19 April 2014, and repeated again beginning on 17 March 2015. Eastern red cedar, loblolly pine, Chinese privet, and sweet gum trees were harvest 10 to 20 cm (4 to 8 in) in diameter measured at 30.5 cm (12 in) from the soil. Only the trunk portions of these trees were used to provide mulch. Harvested trees were chipped with a chipper (Vermeer BC1400 XL, Vermeer Manufacturing Company, Pella, Iowa) one week after harvest.

Chipped mulches were left on nursery pads for approximately one month. Along with these 4 mulches, pine bark mini-nuggets were included (Pine Bark Mini-Nuggets Landscape, Garick, LLC. Cleveland, OH) to provide a commercially comparative mulch treatment. Each mulch species was sieved through a series of wire screens [5.1, 2.5, 1.3, and 0.6 cm (2, 1, 0.5, 0.25 in) screens] to determine particle size distribution ratios between mulches (Fig. 3.1).

Snowball viburnum (*Viburnum macrocephalum*) and wax leaf Ligustrum (*Ligustrum japonicum*) were potted up from 3.8 L (1 gal) containers to 26.5 L (7 gal) containers on 31 May 2014 and 14 April 2015 to determine if the mulch species or depth caused phytotoxic injury to either species. The 3.8 L container plants were transplanted in 26.5 L containers filled with substrate, leaving 10.2 cm (4 in) from the top of the containers. Substrate used was 6:1 (v:v) pine bark:sand amended per cubic yard with 2.3 kg (5 lbs) dolomitic lime, 6.4 kg (14 lbs) of Polyon 18-6-12 (Pursell Technologies, Sylacauga, AL) and 0.7 kg (1.5 lbs) MicroMax (Scotts Co., Maryville, OH). All plants were placed on the nursery pad and irrigated twice daily with 2.5 cm (1 in) of water. Tower® was then applied as a directed spray to the substrate surface at 2.1 L-product/ha (30 fl oz/A) to the herbicide designated containers as a liquid application [280 L/ha (30 gal/A)] with a CO_2 pressure backpack sprayer on 2 June 2014 and 16 April 2015. Containers were then mulched with the designated mulch treatments on the same day.

Treatments consisted of the aforementioned 5 mulches (Eastern red cedar, Loblolly pine, Chinese privet, sweetgum, and pine bark min-nuggets), 2 mulch depths [5.1 and 10.2 cm (2 and 4 in)], 2 levels of dimethenamid-p (Tower®) (No herbicide and herbicide), for each of the two ornamental species. In total, there were 22 treatments (including control and herbicide with no mulch). Each treatment was replicated 5 times for a total of 110 specimens per ornamental species. The study was arranged in a complete random design within each ornamental species and arranged in a factorial arrangement.

Phytotoxicity ratings were taken by two researchers and their ratings averaged. The rating scale was numbered 0 to 10 with 0 being no observed injury and 10 being an observed dead plant. Ratings were taken at 30, 60, 90, and 120 days after treatment (DAT). At 120 DAT, plant size indices (height x width x perpendicular width) were also recorded. Data was subjected to analysis of variance which reflected the factorial treatment arrangement (SAS 9.3, SAS Institute, Cary, N.C.).

Results and Discussion

Analysis of variance showed differences in plant growth in both ornamental species. This difference was not recorded in mulch type or depth, but in the herbicide treatment (Table 3.1). Wax-leaf ligustrum and snowball viburnum had less growth over 120 DAT when Tower® was applied as a directed spray than plants with no herbicide treatment. Though small in its effect, Tower® herbicide affected the growth indices (GI) in ligustrum by an average of 4 cm (1.5 in) and viburnum by an average of 5 cm in 2014. In 2015, ligustrum and viburnum treated with herbicide had a smaller GI by an average of 10 cm (4 in) and 6 cm (2.4 in), respectively. Despite being significantly different, the 5% difference in growth was not impactful of the plants marketability.

Tower® (dimethenamid-p) is a chloroacetamide herbicide belonging to the herbicide mode of action Group 15/Group 3. These modes of actions target active growing points such as meristematic sites, inhibiting cell division by disabling the cell’s ability to produce long chain fatty acids critical for cell division. However, *Ligustrum japonicum* and *Viburnum macrocephalum* are labeled for use with either over the top or direct spray applications. This leaves no explanation for the loss of growth recorded in both 2014 and 2015 other than Tower® may show no indications of injury but may inhibit growth in a manner that did not affect the plants marketability, as observed in this study.

As reported in a previous study showing mulch treatments were non-injurious to ornamentals in container production (Richardson et al. 2008), no phytotoxic injury was observed on either wax-leaf ligustrum or snowball viburnum through 120 DAT. These results come contrary to the results found in Billeaud and Zajicek's (1989) study which reported decreased plant growth of *Ligustrum japonicum* with increasing mulch depths in their landscape trial. This difference may be attributed to the greater pore space and gas exchange capability of container substrates compared to those of field soil. Oxygen levels in the soil decreases at increasing soil depths. The addition of deep mulch layers may also affect oxygen concentrations in the root zone (Billeaud and Zajicek 1989). However, one study observing the effects of mulch depth on oxygen concentrations showed no effect in soil oxygen levels at varying mulch depths (Greenly and Rakow 1995).

Similar to the results observed in other landscape and container studies, the results from this study indicate that mulches of varying species can be applied for weed control in container production of two common ornamental species. Specifications for large container production should be considered when deciding on which method of weed control should be used. Large spacing required for larger plants will render popular methods of weed control to be costly, inefficient, and potentially environmentally hazardous. Mulches can be an inexpensive, long lasting method of weed control that is easily applied and could be mechanized to increase ease of application and decrease cost.

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Figures and Tables:

Figure 3.1 Particle Size Distribution by Mulch Species

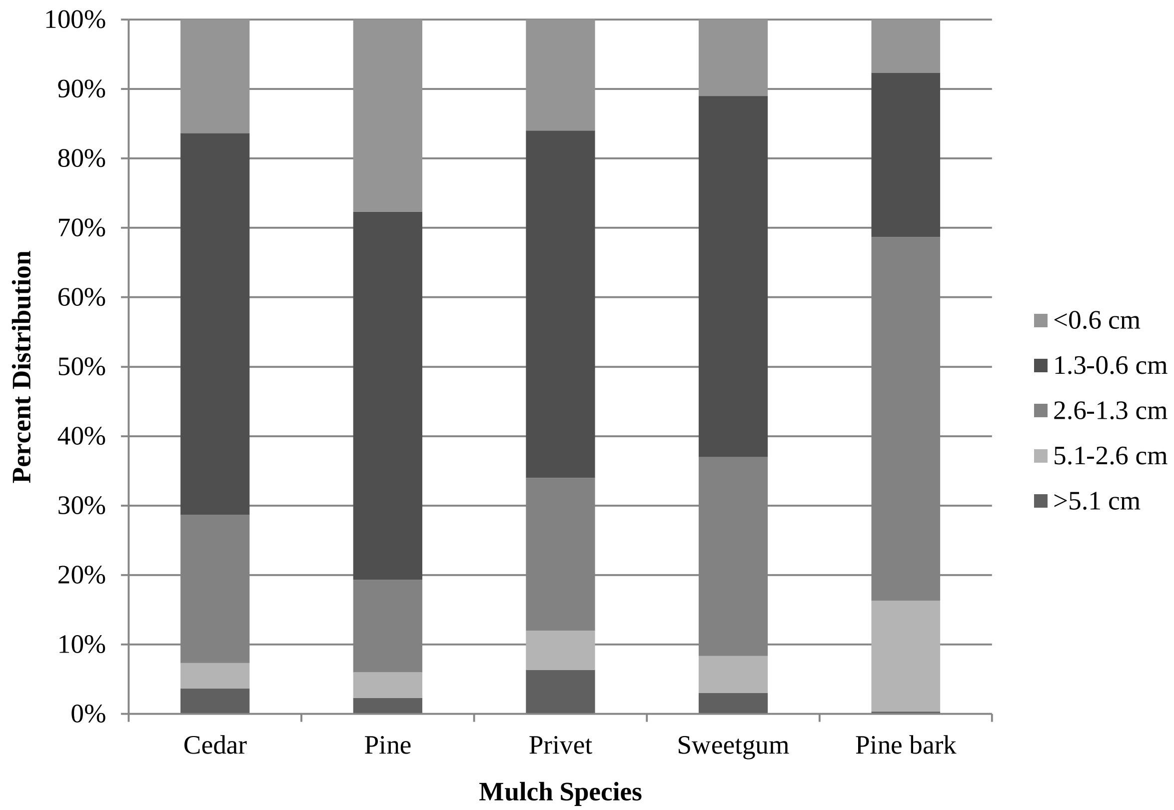

Table 3.1. Effect of mulch species, depth, and herbicide on size index of Wax-leaf ligustrum (*Ligustrum japonicum*) and Snowball viburnum (*Viburnum macrocephalum*).

		Wax-leaf Ligustrum		Snowball Viburnum	
		Size Index (cm^3)[z]		Size Index (cm^3)	
2014	**With Tower**[y]	112	b[x]	82	b
	Without Tower	116	a	87	a
	P-value	0.04		0.02	
	Percent Difference	3%[w]		6%	
2015	**With Tower**	141	b	132	b
	Without Tower	151	a	138	a
	P-value	0.0004		0.007	
	Percent Difference	7%		4%	
		P-value			
2014	**Mulch Species**	0.31	NS[v]	0.22	NS
	Mulch Depth	0.42	NS	0.68	NS
2015	**Mulch Species**	0.46	NS	0.07	NS
	Mulch Depth	0.52	NS	0.85	NS

[z]Size Index = plant height + width + perpendicular width / 3.

[y]Active ingredient: dimethenamid-p. Tower® applied as a directed spray to substrate surface prior to mulch applications at 2.1 L-product/ha or 1.57 kg a.i./ha (30 fl oz-product/A or 1.40 lb a.i./A).

[x]Means within column and year followed by the same letter are not significantly different based on analysis of variance at $\alpha = 0.05$ (n=55).

[w]Percent Difference = ((SI With Tower / SI Without Tower) x 100) – 100.

[v]NS= nonsignificant.

CHAPTER IV

Final Discussion

Weed control is an issue of upmost importance in container plant production. Despite current research improving herbicide application methods and formulations, modern techniques used for weed control can be costly, inefficient, and environmentally hazardous. Mulches offer potential to be valuable assets to nursery growers in the struggle to reduce manual labor cost, effectively control weeds, and reduce potential environmental impacts of current practices. The sustainable solution to many of these dilemmas was evaluated to further advance the understanding and application procedures for mulching in container plant production.

Weed control efficacy of readily available tree mulch species [Eastern red cedar (*Juniperus virginiana*), ground whole loblolly pine (*Pinus taeda*), Chinese privet (*Ligustrum sinense*), and sweetgum (*Liquidambar styraciflua*)] were assessed at multiple depths with and without the use of a preemergence herbicide (dimethenamid-p) on three weed species [long-stalked phyllanthus (*Phyllanthus tenellus*), eclipta (*Eclipta prostrata*), and spotted spurge (*Euphorbia maculata*)]. In the first evaluation period of 2014 and 2015, mulch species was observed to be insignificant. However, dimethenamid-p and mulch treatments were shown to provide good weed control over a span of 30 days. Weed seed placement below mulch treatments for the first run could have also attributed to the effectiveness of mulches, but, additionally, the effects of mulches for weed control are greatest when the mulch is fresh and may contain hydroxylated aromatic compounds believed to inhibit seed germination. It is also important to note that herbicide did not change the efficacy of mulches to control weeds other than spotted spurge weed counts in 2014 at a mulch depth of 2.5 cm (1 in).

The second evaluation period revealed widely different results between 2014 and 2015. In 2014, dimethenamid-p treatments had seemingly lost all efficacy. When compared to the non-herbicide treated containers, weed counts and fresh weights were actually higher. Germination tests were conducted in paper towels on all weed species prior to the initiation of the study to insure approximate 90% weed germination rates occurred. However, results throughout the study revealed inconsistent germination rates in the pine bark/sand substrates. A random event of inconsistent germination could have caused herbicide treated containers to show greater weed counts and fresh weights than non-herbicide treated containers. Dimethenamid-p has a short half-life of approximately 21 days. Microbial activity coupled with the herbicide's high adsorption to the high levels of organic matter found in soilless growing media presumably rendered the herbicide ineffective by the second run of the experiment (~45 days after treatment). However, in 2015, dimethenamid-p had not lost efficacy and reduced the growth of all weed species and weed counts of spotted spurge. Cooler weather decreases microbial activity and can increase the longevity of a herbicide's half-life. It is possible that the earlier, cooler start in 2015 (16 April as opposed to 31 May) allowed the herbicide's efficacy to be extended up to or beyond 45 days.

The third evaluation period in 2014 and 2015 revealed mulch depth was the only main effect on weed counts and fresh weights of all weed species (Tables 2.6 and 2.7). Significant quadratic trends were recorded across mulch depths. In all weed species, weed counts and fresh weights decreased with increasing mulch depth. In containers without mulch, eclipta fresh weights averaged 12.51 g in the final evaluation period of 2014. Mulch depths of 2.5, 5.1, and 10.2 cm (1, 2, and 4 in) reduced eclipta fresh weight by 98, 99.5, and 100%, respectively.

Spotted spurge fresh weight was reduced 90, 99.5, and 100% by 2.5, 5.1, and 10.2 cm of mulch, respectively, when compared to containers without mulch in 2015.

Mulches effect on the growth of *Ligustrum japonicum* and *Viburnum macrocephalum* in this study were similar to the results observed in other landscape and container studies. Results from this study indicate that mulches of varying species and depths [up to 10.2 cm (4 in)] can be safely applied for weed control in container production of two commonly grown ornamental species. Specifications for large container production should be considered when deciding on which method of weed control should be used. Large spacing required for larger plants will render popular methods of weed control to be costly, inefficient, and potentially environmentally hazardous.

These results demonstrate that tree-derived mulches are an effective, non-chemical alternative method of weed control. These data indicate that a depth of 5.1 cm (2 in) with any of these readily available, tree-derived mulches will provide enduring weed control of detrimental weed species in container plant production. However, further research must be conducted to analyze specific decomposition rates as noticeable decomposition differences were observed between mulch species. This information would be vital in determining application procedures in larger container production where plants are grown up to 18 months or longer. Additionally, cost analysis research must be conducted to help enforce implementation of these mulches from an economic perspective. If this process can be made economical, the use of mulches in container plant production can alleviate many of the problems associated with common weed control methods such as injury to non-target plants, inefficient BMPs, and environmental concerns.