COMPARING ATTRIBUTES OF EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA* L.) MULCH TO OTHER COMMONLY USED WOOD MULCHES

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ADAM MAGGARD

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University of Florida

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Thesis Approved:

Rodney E. Will

Thesis Adviser

Thomas C. Hennessey

Janet C. Cole

Dr. Mark E. Payton

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Throughout the southern Great Plains, eastern redcedar *(Juniperus virginiana* L.*)* flourished along ridgetops, canyons and river bottoms that did not regularly burn. In recent years, fire suppression and poor land management practices have allowed eastern redcedar to rapidly increase, invading many native grasslands and prairie ecosystems, altering ecosystem functions and the landscape (Briggs et al. 2002, Ganguli et al. 2008). The encroachment of eastern redcedar affects cattle operations, wildlife habitat, water yield, nutrient cycling, and carbon sequestration (Engle et al. 1996). The cost of doing nothing will ultimately lead to environmental and human health risks, such as severe wildfire, that pose destruction of ecosystems and threaten human health and safety (Drake and Todd 2002). With the demand for bagged landscaping mulch expected to increase (Taylor 2007), an expansion in the redcedar mulch market has potential economic benefits to the southern Great Plains and will help restore native prairie ecosystems.

Anecdotal evidence suggests that redcedar mulch is superior to more common wood mulch alternatives such as pine bark, hardwood, and cypress (*Taxodium distichum*) because of oils contained in redcedar that may discourage termite activity and possibly inhibit weed germination and growth, as well as physical characteristics that may lead to increased resistance to offsite movement. In contrast, some people perceive that redcedar mulch reduces soil moisture or negatively affects plants, perhaps confusing the effects of live trees with that of mulch. Our long-term goal is to increase the harvest and use of redcedar in the southern Great Plains. Landowners currently dealing with invasion of redcedar, pay up to several hundred dollars per acre for removal (Drake and Todd 2002). The high cost of removal prevents many landowners from eliminating the trees, leading to a greater problem. Expansion of the redcedar mulch market will reduce redcedar on the landscape, benefit producers, increase tax receipts, and benefit landowners by reducing the cost of removal and restoring the land values.

In the United States, the market for landscape mulch is increasing. The demand for varied looking landscapes that include mulch is increasing as is the demand for use of green residuals (Satkofsky 2001). At the same time, concerns about future availability of bark for mulch are rising because of its popularity for alternative uses such as fuel and energy along with decreased timber production which is the source of bark residuals (Lu et al. 2006). In 2006 it was predicted that the demand for bagged mulch could potentially increase by 5.5% per year and approximately double annual sales from around 550 million dollars to 915 million dollars within a decade (Taylor 2007). Another concern is harvesting trees of intact, functioning ecosystems for use as mulch. Cypress wetlands form the basis of an important ecosystem that naturally filters pollutants and excess nutrients important for maintaining water quality, providing critical habitat to many wildlife species and freshwater fisheries, and providing storm surge protection along some coastal areas. Currently there is controversy that intact ecosystems are being destroyed by clearcutting for production of cypress mulch (The Save Our Cypress Coalition)**.** With increasing concern regarding availability or source of currently popular wood mulches, increasing demand of the mulch market, and economic and ecological problems caused by redcedar encroachment in the southern Great Plains, there is certainly room for expansion of the redcedar mulch market and for redcedar mulch to become a popular "environmentally friendly" alternative in the mulch industry.

Organic mulches such as wood chips and shredded bark are commonly used in landscaping and horticultural applications. Mulches are generally beneficial for plant growth because they reduce competition from weeds, increase soil moisture by reducing evaporation, and moderate soil temperature (e.g., Cook et al. 2006, Johansson et al. 2006, Iles and Dosmann 1999). In some cases, mulches also alter soil chemistry and nutrient availability (e.g., Billeaud and Zajicek 1989, Pickering and Shepard 2000). Mulches also can affect soil insect populations and depending on mulch type and species of insects, mulch may increase or decrease populations (Jordan and Jones 2007, Sun 2007). Less information exists regarding mulch treatments that may contain chemicals or oils that affect plant growth and weed germination, physical attributes that may affect weed seed establishment, and consumer preference of different mulches. Studies have been conducted on termite interaction with mulch in lab settings (Duryea et al. 1999, Long et al. 2001, Sun 2007), but none have been conducted in a natural field setting.

The specific objective of this research was to provide information regarding attributes of redcedar mulch compared to other commonly used wood mulches. To accomplish this objective, redcedar mulch was compared to other mulches by measuring soil moisture content, soil nutrients, growth and survival of planted trees, annuals and perennials, weed suppression and growth, rate of mulch decomposition, rating of mulch appearance (survey data), and termite activity. In addition, we conducted a shadehouse study to determine the effects of mulch treatment and mulch leachate on germination of common weed species.

The first year of the study comprised nine locations that included three each of tilled full-sun (tilled), non-tilled full-sun (full-sun), and non-tilled shaded sites (shaded) that represented potential locations where mulch might be used in a landscape setting. At each site, redcedar, pine bark nuggets, pine, cypress and hardwood mulch as well as a non-mulched control where weeds were killed using herbicides and a non-mulched control without weed control (63 plots total) were tested. The second year of the study, conducted in a full-sun environment only, included the addition of red-dyed mulch and eucalyptus mulch treatments, termite study, weed seed germination study, mulch leachate study, and a mulch appearance survey.

CHAPTER II

REVIEW OF LITERATURE

Eastern Redcedar (*Juniperus virginiana* L.)

Eastern redcedar is a juniper that is native to North America. It ranges from southeastern Canada to northern Florida and west to Great Plains states (Lawson 1985). It is a small to medium sized tree that rarely reaches 18.3 m in height. Like many species it prefers deep moist sites, but rarely becomes dominant on such sites due to competition from other species. Eastern redcedar is commonly used for windbreaks, snow fences, shelterbelts, Christmas trees, and erosion control. The heartwood of the eastern redcedar is commonly used in making closets, dressers, and also fencepost because of its aromatic and decay resistant properties. Oil is also distilled from the wood and leaves and is used in making perfumes and medicines.

Eastern redcedar has the ability to grow on a variety of soil types and under extreme environmental conditions. It can be found on sites ranging from rocky hillsides to bottomlands near or around moist riverbeds and swamps. Its hardiness provides increased opportunities for regeneration and establishment. Besides its ability to grow on a variety of site conditions, eastern redcedar does not have any serious pests (Gilman and

Watson 1993). It is a pioneer invader that is one of the first to inhabit pastures and disturbed sites.

In Oklahoma, eastern redcedar flourished along ridgetops, canyons and river bottoms that did not regularly burn. In recent years, fire suppression and poor land management practices have allowed eastern redcedar to rapidly increase, invading many native grasslands and prairie ecosystems, altering the native landscape (Briggs et al. 2002, Ganguli et al. 2008). In the past, conservation and planting programs encouraged the use of potentially invasive species for wildlife benefit. Eastern redcedar was intentionally planted outside its native habitat (Ganguli et al. 2008) and as shelterbelts (Lawson 1985).

Eastern redcedar encroachment into grassland ecosystems is linked to fire suppression and increased human population (Briggs et al. 2002). The use of fire around developed areas has been greatly reduced or eliminated.

In Oklahoma, over 3.2 million hectares of grasslands contain more than 617 eastern redcedar trees per hectare with an estimated additional 121,405 hectares being invaded annually (Drake and Todd 2002). The encroachment of eastern redcedar drastically alters the ecosystem. Cattle operations, water yield, nutrient cycling, and carbon sequestration are affected by the encroachment. In addition, redcedar increases the risk of severe wildfires due to increased fuel loads and volatility.

Several techniques can be used to remove eastern redcedar. Prescribed burning is effective for controlling small eastern redcedars, but once the trees reach approximately 3 m tall they are no longer susceptible to prescribed fire (Ortmann et al. 2007). Once they become too large for prescribed fire, or when they are located in places where application of prescribed fire is not an option, mechanical removal is necessary and can be accomplished using a variety of equipment. Cutting below the lowest live branch is effective because redcedar will not resprout (Hartzler 2006). Mechanical removal is expensive, costing up to several hundred dollars per acre. Chemical removal is used in controlling eastern redcedar trees through broadcast applications and spot treatments. Trees taller than 0.61 m are controlled more effectively using spot treatment (Grazon P&D, Surmount, Tordon 22K, Velpar) (Hartzler 2006). Chemical removal is not the most popular method because of limitations and regulations on many chemicals and because the dead trees remain on the site.

Market for Redcedar Mulch

In the United States, the market for landscape mulch continually increases. Currently the demand for varied appearing landscapes is increasing along with the demand for use of green residuals (Satkofsky 2001). At the same time, concerns about availability of bark for mulch in the future is rising because of the popularity of alternative uses such as fuel, energy, and decreased timber production (Lu et al. 2006). In 2006 it was predicted that the demand for bagged mulch could increase by 5.5% per year and approximately double annual sales from around 550 million dollars to 915 million dollars within a decade (Taylor 2007).

Coastal cypress forests are being threatened by development and over harvesting. There are concerns that cypress mulch that was once a by-product from harvesting is now being harvested primarily for mulch (The Save Our Cypress Coalition). With the increasing concern regarding the use of cypress mulch, the increasing demand of the landscaping and mulch market, and the economic and ecological problems caused by redcedar in Oklahoma, redcedar mulch seems to be a reasonable mulch alternative. Unlike cypress, harvesting redcedar and using it as mulch would be environmentally friendly and would aid in restoring ecosystems and wildlife habitat that are currently being disrupted and destroyed.

Organic Mulch

Mulch can be defined as any material placed on the surface of soil for protection of soil properties and erosion (Harris 1992). Commonly used organic mulches include wood chips, shredded bark, pine straw, wheat straw, and compost. Mulches are widely used in landscaping and horticultural applications. Improved soil properties, weed suppression, plant growth and survival, and its ability to add aesthetic value are common objectives for applying mulch (Rose and Smith 2009).

Effects of Mulch on Soil

Soil moisture can be expressed as either volumetric water content which is the volume of water per unit volume of soil or gravimetric water content which is the mass of water per unit mass of dry soil (Schaetzl and Anderson 2005) and is an important factor in plant growth. Water is removed from the soil through two major processes, transpiration and evaporation. Transpiration removes more water from the soil than evaporation (Kramer 1944).

Mulch can conserve soil moisture by reducing evaporation and reducing weeds that compete for water use (Harris 1992). Water loss is considerably decreased when soil is covered with a dry loose mulch (Kramer 1944), primarily due to reduced evaporation (e.g., Cook et al. 2006, Johansson et al. 2006, Iles and Dosmann 1999). Mulches reduce runoff allowing more water to soak into the soil (Harris 1992) by absorbing the impact of rain drops and allowing increased infiltration rate (Greenly and Rakow 1995). A study showing the effects of soil moisture on wheat yield monitored the effects of three treatments (no mulch- control, catch crop and mulch) and found that soil water storage under mulch was considerably higher than under the non-mulch-control and produced the highest wheat yield (Zhang et al. 2008). A study measuring the effects of mulch on tree root environment found that moisture content within the mulch and in the soil below was higher than in other treatments of grass and bare soil (Watson 1988).

Soil temperature is determined by the amount of heat exchanged between the soil and the soil surface. It has an effect on many soil characteristics, especially water movement (Schaetzl and Anderson 2005). Mulch moderates soil temperature. Non-mulched soils have been reported to be 10^{o}C warmer than mulched soils (Greenly and Rakow 1995). Mulch acts as insulation for the soil. In cooler months it prevents heat loss and in the warmer months it decreases the maximum soil temperature (Zhang et al. 2008). A study conducted by Sarkar and Singh (2006), reported that soil under straw mulch had a greater soil temperature in the morning and lower soil temperature in the afternoon compared to non-mulch treatments.

Mulch color also plays a role in moderating soil temperatures. Dark colored mulches absorb heat from sunlight. Using dark colored mulches in cooler months would keep the soil warmer. Light colored mulches reflect sunlight. In warmer months light colored mulches can keep soil temperature cooler (Harris 1992). A study conducted in the warmer months of August and September, showed that soil temperature under organic mulches like wheat straw which is light in color was lower than under darker mulches or no mulch (control) (Cook et al. 2006).

Mulch effect on soil pH is inconsistent. Mulch can increase, decrease, or have no effect on soil pH. A study reported that the pH of soil under a mulched treatment was significantly lower at 5.8 then the non-mulched treatment at 6.7 (Himelick and Watson 1990). Other studies showed similar results that support mulch decreased soil pH (Billeaud and Zajicek 1989, Duryea et al. 1999). In contrast, a study conducted by Iles and Dosmann (1999) reported that the pH in mulched plots increased and the pH in non-mulched plots decreased. Other studies have found that soil pH was unaffected by the mulched or non-mulched treatments (Broschat 1997, Tukey and Schoff 1963). The effect of mulch on soil pH is inconsistent and could be a result of differences in the inherent pH of the soil and the pH of the mulch used in the treatments. Soils with a higher pH were decreased by mulch treatments (Billeaud and Zajicek 1989); whereas, pH of soils with a lower pH was increased by mulch treatments (Pickering and Shepard 1990). Higher pH in the mulched treatments could have been from basic cations (NH_4^+) entering the soil while mulches decomposed (Tisdale et al. 1993).

Mulches also can affect nutrient availability, either directly or indirectly. Mulch can directly alter nutrients from leaching and decomposition. Indirectly, mulches provide a favorable environment for microorganisms to increase nutrient availability from the mineral soil (Harris 1992). Microorganisms have also been reported to absorb small amounts of nutrients from decomposing mulches. For instance, when of pine bark, hardwood, cypress, or pine bark nugget mulches were applied without plastic weed barrier soil nitrogen decreased due to small amounts of nitrogen from the decomposing mulches being absorbed by soil microorganisms (Billeaud and Zajicek 1989). The size to which mulch is shredded can affect nitrogen dynamics. Coarse chipped wood bark resulted in no significant difference in mineral nitrogen levels compared to the non-mulched control, but fine-ground wood mulch increased mineral nitrogen in relation to the control (Pickering and Shepherd 2000). Initial nutrient concentrations in different mulches appear to influence differences in available nitrogen. Pickering and Shepherd (2000) discussed that mulches with a low carbon to nitrogen ratio (horse manure and garden compost) increase soil nitrogen, and mulches with high carbon to nitrogen ratios (coarse wood chips and bark) do not alter soil nitrogen.

Magnesium (Mg), potassium (K), and phosphorous (P) soil concentrations also have been studied with the use of mulch. Both pine bark and eucalyptus mulch increased concentration of (Mg) in the soil and cypress mulch increased (K) concentrations greater than non-mulched plots (Broschat 1997). Available (P) was greater in mulched plots versus non-mulched plots (Tukey and Schoff 1963). Another study showed no differences in nutrient availability with mulch applications (Ashworth and Harrison 1983). Foshee III et al. (1999) found no differences in nutrient availability except soil K increased under grass clippings.

Effects of Mulch on Weed Suppression

Mulch can control competition by suppressing weeds. Weeds can reduce the aesthetic quality of the landscape and compete with other plants for water, nutrients, and light. Reduced competition by weeds allows greater availability of water and nutrients for landscape plants (Harris 1992). One study tested 16 mulch treatments including a non-mulched bare soil plot and showed that weed numbers were always greater in the bare soil plots (Stinson et al. 1990). Similar results have occurred in other studies in which all mulched treatments were superior in reducing weed growth and dry weight compared to non-mulched treatments (Abouziena et al. 2008, Broschat 1997). The ability of mulch to effectively reduce competition may depend on particle size of the mulch. For instance, Billeaud and Zajicek (1989) noted that weed numbers were reduced in mulched treatments compared to the non-mulched treatment, but the coarser mulch (pine bark nuggets) reduced weed population more than other mulch treatments. The depth at which the mulch is applied also affects weed growth and weed species. One study measured weed growth and species diversity with different mulch depths (0-7.5 cm, 7.5-15 cm, and 15-25 cm) and showed that weed growth and species diversity were both increasingly reduced with mulch depth, with the most significant effect occurring between the 0-7.5cm depths (Greenly and Rakow 1995). Other than the ability of mulch to physically control weed growth, mulch may contain allelopathic substances that affect seed germination. Water extracts from several commonly used mulches inhibited growth of lettuce seeds (Duryea et al 1999 a).

Effects of Mulch on Plant Growth

Plant growth can be increased by benefits that mulch can provide to soil and weed suppression. Plant growth response to mulch can be variable and often depends on the type of mulch being used. Wheat straw mulch produced the highest wheat crop yield compared to non-mulched wheat and a legume crop largely because soil water storage was increased by the mulch (Zhang et al. 2008). Other studies have shown similar results.

Wheat straw mulch significantly increased grain yield of barley compared to not mulching, although tillage in a split plot with two tillage depths and three mulch treatments at150 mm and 90 mm depth may have influenced the results (Sarkar and Singh 2006), and Chakraborty et al. (2008) found that under low water conditions, rice husk mulch resulted in higher yields than transparent or black polyethylene mulched plots. Growth of mustard crops increased with application of horse manure, garden compost, cocoa shells, and finely ground bark; whereas, black polyethylene, wood chips and coarse bark did not affect growth (Pickering and Shepard 2000). Organic mulches appear to have significant effects on increased plant growth compared to inorganic mulches like black polyethylene, but physical characteristics of mulch, such as size might also be factors along with the type of mulch.

Tree and seedling growth can also be increased by benefits mulch can provide. Mulch can affect the growth of plants. Factors such as mulch depth, treatment types (turf, bare soil, tilled), soil type, mulch treatment, and plant species influence plant growth. Mulch applied at different depths around pine and oak trees resulted in increased diameter growth compared to non-mulched trees. Depth of the mulch treatments was important in shoot growth, where mulch depth of 7.5 cm increased shoot growth more than depths of 0, 15, or 25 cm (Greenly and Rakow 1995). Growth and health of Green Mountain sugar maples *(Acer saccharum* Marsh. ‘Green Mountain’) increased and tree stress decreased with mulch application compared to turf grass or no mulch. The crowns of the trees in the mulched treatments were almost double the size of the trees in the non-mulched turf grass treatments (Green and Watson 1989). Similar results occurred with desert willow (*Chilopsis linearis* Cav.) such that seedling growth increased with mulch compared to turf grass treatments but not compared to bare soil treatments (Kraus 1998).

Root systems of white oaks (*Quercus alba* L.) increased fine root development with wood chip mulch compared to non-mulched treatments. Mulched treatments also contained over twice the percentage of mycorrhizal roots as non-mulched plots likely resulting in better utilization of soil resources by the oak root systems (Himelick and Watson 1990). Similar results occurred when tree root densities increased in all mulched treatments of partially composted wood chips or leaves compared to bare soil treatment or grass treatment (Watson 1988).

Effects of Mulch on Insect Repellency

With increased use of mulches in landscapes, the association between mulch and insects is gaining interest. Recently, studies have tested the effect of mulches on harboring or repelling insects. One study compared insect abundance and species composition in mulched treatments to bare soil treatments and found that insects significantly increased in population in the mulched plots and not the bare soil treatments. However, insect numbers varied by mulch treatment with hardwood mulch containing the highest insect populations while species composition was not affected (Jordan and Jones 2007). Redcedar mulch, in particular, had repelled red imported fire ants (*Solenopsis invicta* Buren) over commonly used mulches of pine bark, cypress, and hardwood (Anderson et al. 2002, Thorvilson and Rudd 2001). Similar studies strongly suggest that redcedar mulch repels insects. Meissner and Silverman (2001) showed that when Argentine ants (*Linepithema humile* Mayr) were allowed to colonizing in redcedar mulch or other mulches (cypress, pine straw, pine bark, and hardwood), the ants did not colonize in the redcedar mulch. When redcedar mulch was the only mulch offered the ants still did not colonize in it. The same study concluded that redcedar mulch was highly toxic to the ants, resulting in very high mortality rates. Redcedar mulch placed around the base of trees contained fewer ant nests than other mulches suggesting that redcedar mulch can be used to reduce ant nests thus reducing ant activity (Meissner and Silverman 2003).

Several studies have tested the effect of mulches on harboring or repelling insects in crops. Johnson et al. (2004) tested the effect of straw mulch on insects in potato crops and found that potato leafhopper (*Empoasca fabae* Harris) populations were lower in straw mulch treatments before cultivation then in straw mulch and control treatments after cultivation, in which both cultivated treatments contained more weed growth. Similar studies have shown that mulch color can affect insects on crops. Polyethylene mulch painted with an aluminum color repelled more aphids, thrips, and whiteflies than any other color (Csizinszky et al. 1995). Aluminum-colored polyethylene also repelled aphids but attracted tomato pinworms (*Kieferia lycopersicella* Walshingham) and tomato fruitworms (*Heliothis zea* Boddie), suggesting that some insects are repelled and others are attracted to reflective colors (Schalk and Robbins 1987).

Several studies have shown that mulch treatment plays an important role in termite activity. A study comparing melaleuca (*Melaleuca quinquenervia* Cav.), cypress, eucalyptus, pine sapwood, pine bark, pine straw, and Gainesville Regional Utilities (GRU) mulch containing a combination of prunings were all consumed by subterranean termites (*Reticulitermes virginicus* Banks) except the melaleuca mulch. This resistance could be due to the chemical composition of the melaleuca (Duryea et al. 1999).

Subterranean termite feeding activity under organic and inorganic mulches using cardboard monitors was higher in inorganic mulch but mulch cover type did not affect the number of cardboard monitors found by termites (Long et al. 2001). Redcedar and melaleuca mulches could not successfully initiate new colonies of Formosan termites (*Coptotermes formosanes* Shiraki). Unlike in the other mulches such as eucalyptus, pine straw, pine bark, and hardwood (Sun 2007). Although organic tree based mulches provide a unique opportunity for termites to feed because of the enhanced food quality due to mulch degradation from weathering and microorganisms (Sun 2007). Factors such as chemical composition in some mulches and the type of termites present seem to influence mulch effect. Other factors such as insect type and mulch color seem to determine how effectively the mulch repels insects.

Decomposition of Mulch

Reasons for studying the decomposition rate of organic mulches include but are not limited to the decline in aesthetic value and economic value as mulch decomposes, and effect on soil and plant properties. As organic mulches decompose, nutrients are generally added to the soil, but the rate at which mulches decompose may affect soil fertility. Rapidly decomposing mulches such as straw and sawdust may cause a nitrogen deficiency in the soil (Harris 1992). Rapidly decomposing mulch increases the rate that nutrients enter the soil, but a high rate of decomposition may be too fast for plant uptake, thus not being able to meet their needs (Kettler 1997). The chemical composition of mulch may influence decomposition rate. Polar C fraction (sugars, starches, tannins) and acid insoluble fraction (lignin) are correlated with decomposition rates. Polar C fraction increases with decay and acid insoluble fraction decreases with decay thus decomposition rates are largely determined by initial chemistry of the mulch (Valenzuela-Solano and Crohn 2006). The rate at which mulches decompose also has been linked to the moisture content and temperature. During the dry season, fresh organic leaf material and rice straw were used as mulch and placed in eight moisture regimes. Mulches continuously kept wet and at a low moisture regime were found to have decreased decomposition rates (Seneviratne et al. 1998).

Few studies have tested the decomposition rate of different organic mulches. A study conducted by Duryea et al. (1999a) tested the decomposition rates of six common landscape mulches ranking them from fastest to slowest (GRU- a mulch comprised of prunings and clippings from a utility company, eucalyptus, pine straw, cypress, melaleuca, and pine bark), with the GRU and eucalyptus mulch decomposing at rates of 32% and 21% after one year compared to the other mulches that ranged from 3% to 7%. The GRU and eucalyptus mulches also had the highest year-round respiration rate which is likely caused by the high decomposition rates. The GRU mulch also had the highest total nutrient content which has been found to correlate with decomposition rates (Duryea et al. 1999a). Another study compared the decomposition rates of hardwood wood and bark particles to softwood wood and bark particles and showed that the hardwood of all species tested decomposed faster than any species of softwood tested (Allison and Murphy 1962).

Offsite movement of mulch due to wind or water has not been extensively studied, but it has been commonly noted that wood and bark mulch can be displaced by strong winds. Shredded mulch is more resistant to wind movement and should be used in areas with frequent and strong winds (Whiting et al. 2009). Wood and bark mulch have also been reported to float in areas of with excessive rainfall and runoff (Whiting et al. 2009). It appears that mulch decomposition is the primary reason for needing to replenish mulch to a site, with the exception of sites that have frequent heavy rainfall and high winds, or a major storm event which would be hard to account for in choosing a type of mulch.

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CHAPTER III

METHODOLOGY

Study Sites

The research sites included multiple plots located on both Oklahoma State University’s Natural Resource Ecology and Management (NREM) arboretum (N 36^{o}07’ 18.30”, W 97^{o}06’ 16.89”) and the adjacent Oklahoma State University botanical gardens (N 36^{o}07’ 12.00”, W 97^{o}06’ 07.86”) one mile west of campus in Stillwater, OK. Soils consisted of very deep, well drained fine-silty loam in the Norge series (USDA-NRCS 2010). These soils are moderately slow permeable, thermic udic paleustolls and are located on upland locations that are on nearly level to sloping broad flats and upper side slopes of upland terraces. The 30-year average annual precipitation for Stillwater, OK is 93 cm. The average precipitation over the two years of the study was 104 cm in 2009 and 90 cm 2010 (Oklahoma Agweather 2011 (a)). The average temperatures for Stillwater, OK during the 2009 and 2010 growing seasons (April-September) were 22.9^{o}C and 24.6^{o}C, respectively. The 2009 growing season had a temperature range from a minimum of -5^{o}C to a maximum of 42.7^{o}C, and the 2010 growing season had a temperature range from a minimum of 2.2^{o}C to a maximum of 42.2^{o}C (Oklahoma Agweather (b)).

Treatments

In March 2009, nine locations that included three each of tilled full-sun (tilled), non-tilled full-sun (full-sun), and non-tilled shaded sites (shaded) were located (2009 plantings). Plots were tilled to a depth of 7.6 cm using a rotary tiller (CountyLine by King Kutter, model TG-48-YK, Winfield, AL) 121 cm in width, pulled behind a tractor (John Deere, model 5400, Moline, IL) before the mulch treatments were applied. Existing vegetation at all sites was cut at ground level before mulch application. At each site, seven circular 1.5 m diameter plots (1.77 m^2) were established and randomly assigned one of the following mulches; redcedar (Eastern Redcedar Mulch, LLC., Stillwater, OK), pine bark nugget, pine, cypress, hardwood (Green Country Soil, Inc., Miami, OK), a non-mulched control where weeds were killed using herbicide, or a non-mulched control without weed control (63 plots total).

On 17 April 2009 within each 1.5 m diameter plot, two trees were planted, one 11.4 liter containerized Shumard oak (*Quercus shumardii* Buckl.) and one 11.4 liter containerized redbud (*Cercis canadensis* L.) (Cedar Valley Nurseries, Ada, OK). Shumard oak and redbud were chosen because they are commonly used in landscape and mulched settings across the southern Great Plains. On 20 April 2009, 176 liters of mulch was added to each of the plots to a depth of about 7 -10 cm. In addition to the trees, four individuals of six species of annuals were planted (Spring Creek Nursery, Tulsa, OK) in each mulch plot after the last frost on 21 April 2009. Annuals were chosen based on how common they are in a landscape setting and general popularity. Each plot within the shade environments contained of one set of four begonia shade and one set of four impatiens, two thirds of the plots within the full-sun environments contained one set of four begonia sun and one set of four lantana, and one third of the plots contained one set of four coleus and one set of four salvia, for the tilled environment, two thirds of the plots contained one set of four coleus and one set of four salvia and one third of the plots contained one set of four begonia sun and one set of four lantana (test including annuals, n=3).

Based on the results from the 2009 plantings, five new replications were established on 2 March 2010 (2010 plantings). Each replication contained nine circular 1.5 m diameter plots (1.77 m^2) that were randomly assigned one of each of the mulches used in the 2009 plantings, along with two new mulch treatments for the 2010 planting; red-dyed mulch (Green Country Soil, Inc., Miami, OK) and eucalyptus mulch (AAction Mulch, Inc., Fort Myers, FL) (45 plots total). Four of the five new replications (36 plots) were located and established on the NREM arboretum and the fifth replication (9 plots) was located and established on the Oklahoma State University botanical gardens. All replications for the 2010 plantings were established in an open, non-tilled (full-sun) environment type. On 12 March 2010, 176 liters of mulch was applied at a depth of 7 to 10 cm to each of the plots randomly selected within each replication. Similar to the 2009 planting, one Shumard oak and one redbud was planted within each mulch plot. In addition to the trees, four individuals each of four species of perennials (4 per plot, 180 total, 45 of each species) were planted on 22 April 2009 after the last frost. The perennials (Guthrie Greenhouses, Guthrie, OK) planted were Arizona sun *(Gaillardia aristata* Pursh*)*, mountain mist *(Dianthus gratianopolitanus* Vill.*)*, autumn joy *(Sedum telephium* L.*)*, and blackeyed Susan *(Rudbeckia hirta* L.*)*.

After planting, the plots were undisturbed. The 2009 plantings that included the annuals were watered every three days during periods without rain. The 2010 planting that included the perennials were watered every two days for the first several weeks and then only during extended periods without rain (approximately 10 to 14 days). Roundup® (2% glyphosate, Monsanto Company, St. Louis, MO) was used to kill weeds within the non-mulched herbicide plots.

Measurements and Experimental Design

For the 2009 plantings, measurements were conducted durring the 2009 and 2010 growing seasons. Soil measurements included volumetric soil moisture content, soil temperature, soil pH, and soil nutrients. Volumetric soil moisture content was measured every seven to ten days throughout the 2009 and 2010 growing seasons at a soil depth between 0 and 15 cm by time domain reflectometry using the Mini-Trase TDR system (Soilmoisture Equipment Corp., Santa Barbara, CA). Soil temperature was measured hourly between 21 July 2009 and 29 July 2009 at a soil depth of 7.6 cm using WatchDog® model 425 and model 450 sensors (Spectrum Technologies, Inc., East Plainfield, IL). Soil was collected from each plot between 0 and 7.6 cm using a 1.9 cm diameter soil probe on 15 April 2009 before the application of mulch, on 17 December 2009 at the end of the first year, and on 17 November 2010 at the end of the second year. Four samples per plot were combined into one composite sample. All soil pH and nutrient samples were analyzed by the Oklahoma State University Soil, Water and Forage Analytical Lab. Soil pH was analyzed on a Mettler, Seven Multi meter with a Thermo Orion, Ross Sure-flow electrode. Soil nitrate was analyzed on a Lachat, QuickChem 8500, flow injection analyzer (Hach Company, Loveland, CO), using the cadmium reduction method. Phosphorus (P) and potassium (K) were analyzed on a Spectro Arcos ICP (inductively couple plasma) (AMETEK, Inc., Berwyn, PA).

Tree height growth was measured from the soil to top of the Shumard oaks and from the soil to tallest point on the redbud trees when first planted and then again at the end of the first and second growing seasons. Tree diameter was measured approximately 2 mm above ground level to the nearest millimeter when first planted, then at the end of the first and second growing seasons. Annual plant development was determined by harvesting the plants on 21 August 2009 and drying to a constant biomass at 65^{o}C, and then weighing. Weeds were harvested at mulch level on 25 August 2009 using cutting shears and clippers, dried to a constant biomass of 65^{o}C, and then weighed. After determining weed biomass, plots were kept weed-free for the remainder of the growing season using directed sprays of glyphosate.

Mulch decomposition rates were determined by measuring weight loss of mulch subsamples. Mesh bags (3 mm^2 mesh opening) for each of the mulched plots (45) were filled with a known weight of oven-dried mulch and then the bags were placed in the plots so that bags were above the soil, but below the surface of the mulch. Mesh bags were collected at the end of the second growing season (2009 planting) and dried to a constant biomass of 65^{o}C and weighed. Percent loss from two bags per plot was averaged.

The experimental design for the 2009 plantings consisted of a split-plot with environment type (n=3) as the whole plot factor and mulch treatment (n=9) as the sub-plot factor. For volumetric soil moisture content, a repeated measure analysis was conducted for 17 sampling dates for the first growing season and 18 sampling dates for the second growing season. Because of significant interactions between date and mulch treatment, soil moisture was further analyzed for each date separately.

For the 2010 plantings, unless otherwise noted, measurements were conducted using similar techniques as described for the 2009 plantings. Soil temperature was not measured for the 2010 plantings. Soil samples were collected on 2 March 2010 before mulch application and on 17 November 2010 at the end of the first year. Redbud trees were measured the same way for initial measurements, but height growth at the end of the 2010 growing season was measured as new terminal growth due to the trees bending from the wind. Perennial growth was determined by measuring canopy spread in a north/south and east/west direction and then calculating area using the formula for an ellipse (πab), a = distance from center to vertex and b = distance from center to co-vertex. Relative height growth (RHG) and relative area growth (RAG) were calculated to determine perennial growth while compensating for differences in plant sizes at planting. Relative height growth and RAG were based on when the perennial species reached its greatest size throughout the growing season, determined by periodic measurements. Relative height growth was calculated by subtracting initial height measurements from the height measurement taken on the next measurement date and dividing that by the original height of the plant (height-original height/original height). Relative area growth was calculated by subtracting original area measurements from the area measurement taken from the next measurement date and dividing that by the original area of the plant (area-original area/original area). Perennial plants were measured three times during the growing season, on 29 April 2010, 20 July 2010, and 17 September 2010. Relative height growth and RAG data for all perennials were calculated using the measurement taken between the initial measurement on 29 April 2010 and its greatest size, measured on 17 September 2010. Weed growth was measured by harvesting on 22 July 2010. To determine mulch decomposition, one mesh bag was collected from each plot for analysis after the 2010 growing season.

The experimental design for the 2010 plantings was a randomized complete block (n=5) for soil measurements and plant measurements. Mulch decomposition measurements were also a randomized complete block design, but had (n=4), because no mulch decomposition bags were placed in the block on the botanical gardens because the plots were also used for educational display. For volumetric soil moisture content, a repeated measure analysis was conducted for 21 sampling dates during the growing season. Because of significant interactions between date and mulch treatment, soil moisture was further analyzed for each date separately.

In addition to the field study, several controlled experiments were conducted during 2010. These included, a weed seed germination study using mulch, a weed seed germination study using mulch leachate, a mulch appearance survey, and a termite study. Methodology for each study is described below.

Weed Seed Germination Study

The study was conducted in a shadehouse at the Oklahoma State University botanical gardens. The shadehouse was used to moderate temperatures during summer with high temperatures often exceeding 35^{o}C.

Forty pots (13 l) with drainage holes were arranged in five rows of eight pots. The eight pots within each row included the seven mulch treatments used in the 2010 planting plus a non-mulched control. Pots were randomly assigned places within each row.

Approximate numbers of seeds used were determined by counting totals of three 0.62 cm^3 samples of each seed species. Means for seed counts were crabgrass (*Digitaria sanguinalis* L.) 452.3 ± SE 5.9, Johnsongrass (*Sorghum halepense* L.) 127.3 ± SE 2.9, lambsquarter (*Chenopodium album* L.) 774.7 ± SE 24.4, redroot pigweed (*Amaranthus retroflexus* L.) 1080 ± SE 41.4 and ragweed (*Ambrosia artemisiifolia* L.) 113 ± SE 2.3. Ten yellow nutsedge (*Cyperus esculentus L.)* tubers were used per pot due to their large size. Seeds were pre-soaked in tap water the night before planting (approximately 15 hours) to remove any chemical germination inhibitors and to speed up the germination process. Potting soil (Earthgro® all natural, Hyponex Corporation, Marysville, OH) was used in the study because it lacked fertilizer and to avoid using soil contaminated with outside seeds. Ingredients in the potting soil included one or more of the following: hypnum peat, forest products (compost), sand, perlite, and pine bark. Potting soil was placed to a depth of 10 cm in each pot. Twelve wooden dividers were placed in the soil; six were used to designate areas for seed species in the pots and six were used as labels for each seed species planted in the pots.   Within pots, seeds were placed within an area consisting of a wedge equal to 1/6th of the pot. Each pot had a surface area of 250 cm^2 at the top of the pot.

Seeds were then placed on the soil surface in each of the pots. Once the seeds were transferred to the pots, they were covered with about 1.5 cm of potting soil. About 3.8 cm of mulch was placed over the potting soil with one mulch treatment per pot. Pots were placed in the shadehouse and watered by an automated sprinkler system once per day for 40 minutes. The study was conducted from 26 May through 21 June 2010 and repeated from 31 August through 20 September 2010.

Seed germination was monitored every three days for a total of 26 days for the first repetition and 20 days for the second repetition. Seeds were considered germinated and counted when emerged through the mulch. Each germinated seed was counted and the entire seedling was removed. After germination, totals were calculated. Yellow nutsedge and ragweed were eliminated from the analysis due to insufficient germination across all treatment types. The experimental design was a split-plot with mulch treatment (n=10) as the whole plot factor and weed species (n=80) as the sub-plot factor.

Leachate Germination Study

The study was conducted in the same location as the weed seed germination study and with a similar design. However, instead of testing the combined chemical and physical effects of mulch, the chemical effects of mulch leachate were tested. Leachate was extracted from each mulch by placing 5.14 liter of each of the different mulches in different 22-liter buckets and filled with water to approximately ¾ full. The buckets were then left to soak for two days. New leachate was made every two days for the duration of the study and the leachate was used to irrigate the seeds.

Similar numbers of seeds were used as described above for the weed seed germination study. Seeds were pre-soaked in the appropriate leachate the night before planting (approximately 15 hours). After soaking, pots were planted as described above with the exception that no mulch was placed on top. Seeds were watered every day with approximately .4 liters of their appropriate mulch leachate. Control pots were watered with tap water.

Two repetitions, each consisting of five replicates were conducted. The first repetition took place from 19 August 2010 through 25 August 2010 and the second repetition took place from 24 September 2010 through 30 September 2010. Seed germination was monitored every six days. The two studies lasted until no more seed germination occurred for several days.

As with the mulch germination study, germination totals were insufficient for yellow nutsedge and ragweed across all treatments. The experimental design was a split-plot with mulch treatment (n=10) as the whole plot factor and weed species (n=80) as the sub-plot factor. Data were analyzed using ANOVA.

Mulch Appearance Survey

The mulch appearance survey was conducted at the 2010 planting at the botanical gardens at Oklahoma State University (one full replication). The botanical gardens have frequent visitors, along with special events (Garden Fest, Horticulture Field Days, etc…) resulting in an ideal location for the survey. Data were collected three times between 3 June 2010 and 14 July 2010. The plots were numbered 1 to 9 and no information was provided prior to people taking the survey (n=93 surveys completed). Surveys consisted of a series of questions asking opinions regarding appearance and preference for the various mulch treatments.

Termite Study

The study took place in research plots used for the 2009 and 2010 plantings (108 plots). On 13 July 2010 four 6.4 x 5.1 x 10.2 cm blocks of untreated pine lumber were placed in each plot. Untreated pine lumber was chosen because it is a preferred food source for termites. Blocks were placed within each plot based on north, south, east, and west coordinates. Blocks placed in mulched plots were buried so a layer of mulch was below the block and layer of mulch above each block (approximately 1cm), forcing termites to travel through the mulch to get to the blocks. Blocks placed in non-mulched control plots were staked with a nail to prevent movement and disturbance from weather. After staking, the blocks were covered with a thin layer of soil (Approximately .5 cm).

Termite activity was monitored by checking blocks 30, 90, and 150 days after placement until winter and then every 90 days beginning on 21 March 2011. Block checks consisted of observing termite activity (termites or damage present). Each block was briefly removed from the plot with minimal disturbance and examined. Data recorded for each block consisted of marking whether the block was hit or not hit, active or not active (termite presence). Blocks hit are referred to as (activity), regardless of whether blocks were active or not active.

CHAPTER IV

RESULTS

Soil Moisture

2009 Plantings

Mulch increased volumetric soil water content (VWC) during drier periods, but little difference existed among mulched treatments. Date interacted with mulch treatment ($p<0.0001$) during year 1 of the 2009 plantings. Therefore VWC was analyzed for each date separately. Before mulch application, soil VWC was similar among treatments (first two measurement dates, Figure 1A). As the soil dried, differences in VWC developed between mulched and non-mulched treatments. Between 13 May 2009 (5th measurement date) and 5 June 2009 (8th measurement date), VWC of the control no herbicide (CNH) treatment was lower than that of the control with herbicide (CWH) treatment which was lower than in the mulched treatments (mulch effects $p<0.05$). Soil moisture among the various mulched treatments was similar except that the pine mulched treatments had greater VWC than the other mulched treatments from 8 July 2009 (12th measurement date) to 9 September 2009 (15th measurement date). Towards the end of the growing season and after large rainfall events, VWC in all treatments increased and were similar (9 September 2009 and beyond).

During drier periods, the tilled treatments had greater VWC than the full-sun or shaded treatments by several percent (date x env; p=0.003). While VWC in mulched treatments varied among environment type (env x mulch treatment; p<0.0001), differences were primarily in the amount of how much lower the VWC of non-mulched treatments in the different environment types were compared to mulched treatments.

During the second growing season of the 2009 plantings, date interacted with mulch treatment (p<0.0001) for VWC. Soil moisture was similar among treatments at the beginning of the second growing season (12 March 2010; first measurement date, Figure 1B). As the soil dried, differences developed between the mulched and non-mulched treatments. Between 8 April 2010 (2nd measurement date) and 5 May 2010 (5th measurement date), VWC of both the CWH and CNH treatments were lower than in the mulched treatments (mulch effects; p<0.05). No differences occurred among mulched treatments during the second growing season. Following significant rainfall events, generally no significant differences existed among the treatments. Near the end of the growing season as the soil dried, VWC of all treatments decreased and were similar (11 September 2010 and beyond). For most of year two, the tilled treatments had greater VWC than the full-sun or shaded treatments (env; p<0.0001, date x env; p<0.0001). While VWC in mulch treatments varied among environments (env x mulch treatment; p<0.0001), as in 2009, the main difference was how much lower the non-mulched treatments were compared to the mulched treatments.

2010 Plantings

Similar to the 2009 plantings, mulch conserved soil moisture during drier periods and little difference occurred among mulched treatments (date x mulch treatment; $p<0.0001$). Soil moisture was similar among treatments of 2010 plantings at the beginning of the growing season (first two measurement dates, Figure 2). As the soil dried, differences developed between the mulched and non-mulched treatments. Volumetric water content of the CWH and CNH treatments were lower than those of mulched treatments throughout much of the growing season. During much of the first half of the growing season, VWC of the CNH treatment was lower than VWC of all other treatments (from 5 May 2010 to 11 May 2010 and again from 30 May 2010 to 1 July 2010) (mulch effects; $p<0.05$). Eucalyptus mulch resulted in a lower VWC than hardwood mulch from 24 June 2010 (10th measurement date Figure 2) to 11 July 2010 (12th measurement date).

Soil Temperature

Mulch moderated soil temperature, decreasing daily maximum and increasing daily minimum temperatures. Air temperature during the eight day measurement period between 21 July 2009 and 29 July 2009 ranged from 14°C to 39°C and averaged 25°C. Maximum soil temperatures during the period and average daily maximum soil temperatures of the mulched treatments and the CNH treatment were lower than CWH treatment ($p=0.001$) (Fig. 3). Control with herbicide treatment had maximum temperatures 4 to 6°C warmer than all other treatments. No significant differences occurred in maximum temperature among the mulched treatments. Minimum temperature and average daily minimum temperature of the mulched treatments were warmer than both non-mulched treatments ($p=0.0002$). Mulched treatments had minimum temperatures 2 to 3°C warmer than the non-mulched treatments. No differences existed in minimum temperature among the various mulched treatments. Average temperature did not differ among mulched treatments. However, the average temperature was warmer in CWH, redcedar and hardwood treatments than in the CNH treatment (treatment effect; $p=0.02$). As expected, the temperature was lower in the shade than in full-sun or tilled environments by an average of 3°C ($p<0.0001$).

Soil Nutrients

2009 Plantings

During the first growing season, soil pH was affected by both mulch treatment ($p=0.02$) and environment type ($p<0.02$). Soil pH increased in the hardwood mulched treatment but decreased in the other treatments (Fig. 4A). Thus the change in pH was greater with hardwood mulch than with any other treatment except CWH. The tilled environment with a mean increase of 0.18 was greater than the full-sun and shaded environments with mean pH changes of -0.05 and -0.12, respectively. Likewise, change in soil pH over the two years of the study depended on mulch treatment ($p=0.006$) and environment type ($p<0.04$). Although soil pH decreased between the first and second growing season for all treatments, hardwood mulch and CWH increased soil pH when considered over the entire two-year period of the study. The tilled environment had a mean change (0.03) significantly greater than the shaded and full-sun environments with mean changes -0.26 and -0.28, respectively, over the two years of the study.

Treatments did not affect change in soil nitrate or P concentration during the first growing season ($p=0.52$, $p=0.78$), respectively or during the two-year study duration, ($p=0.26$, $p=0.85$), respectively (Fig. 4B and 5A, respectively).

During the first growing season, soil K concentration was affected by mulch type ($p<0.0001$). Hardwood mulch increased soil K while soil K decreased in all other treatments (Fig. 5B). This resulted in a greater increase in soil K with hardwood mulch than in all other treatments. During the two year duration of the study, the change in hardwood mulch was greater than that of all other treatments ($p<0.0001$). The change in soil K concentration for the CWH and redcedar mulch was greater than with pine and pine nugget mulches over the two years of the study. Even though soil K decreased between the first and second growing seasons for all treatments, the change for hardwood mulch was positive when considered over the entire two-year period of the study.

2010 Plantings

Mulch treatment did not affect change in pH ($p=0.18$) (Fig. 6A), soil nitrate concentration ($p=0.07$) (Fig. 6B), soil P concentration ($p=0.11$) (Fig. 7A), or soil K concentration during the 2010 growing season ($p=0.09$) (Fig. 7B).

Weed Growth

Mulch reduced weed growth during the first growing season of the 2009 planting ($p=0.003$) and no significant difference in weed growth occurred among the mulches (Fig. 8). The CWH plots contained weeds due to aggressive invasion and growth in the otherwise vegetation free plots during the two weeks after herbicide application. Similarly, weed growth during the first growing season of the 2010 planting was suppressed by mulch ($p<0.0001$) with the CNH plots having greater weed growth than all other treatments (Fig. 9). As expected, the CWH treatment had the least weed growth of all treatments.

Plant Growth

Growth of Annuals

Mulch increased growth of lantana (p=0.0004) (Fig. 11B) and coleus compared to non-mulched treatments and hardwood mulch resulted in less growth of coleus compared to other mulches (Fig 12A). Mulch did not affect growth of the other four annual species (begonia shade p=0.21 (Fig 10A), begonia sun p=0.25 (Fig. 11A), impatiens p=0.36 (Fig 10B), salvia p=0.43 (Fig. 12B); although, mulch application tended to increase biomass growth. Although salvia growth was not affected by mulch, survival was generally lower than that of the other annual species with both control treatments (33% for CWH, 25% for CNH) compared to pine nugget (92%), cypress (100%), redcedar (100%), and pine (100%) mulched treatments (p=0.04). Hardwood mulch had 58% mortality, but this did not differ from other treatments. Survival of the other five species was not affected by mulch application, but survival was high at 100% for begonia shade and coleus, 99% for impatiens, 96% for lantana, and 90% for begonia sun.

Growth of Perennials

Mulch did not affect growth of perennials. All *Rudbeckia hirta* plants died prior to growth measurements. Relative area growth (RAG) (p=0.14) and relative height growth (RHG) (p=0.16) of *Gaillardia aristata*, did not differ among treatments (Fig. 13A). Three *Gaillardia aristata* perennials did not survive in the CNH treatment and one did not survive the cypress mulched treatment but no mortality occurred in other treatments. The RAG (p=0.99) and RHG (p=0.89) of *Dianthus gratianopolitanus*, were not affected by mulch treatments. Though growth was not affected, none of the *Dianthus gratianopolitanus*, planted in the CNH treatment survived (Fig. 13B), while one died in the hardwood mulched treatment, one died in the CWH treatment. No mortality occurred in any other treatments. Treatment did not affect RAG (p=0.82) or RHG (p=0.86) of *Sedum spectabile* (Fig. 13C).

Redbud Height and Diameter Growth-2009 Plantings

Mulch increased height growth of redbuds for the 2009 growing season (p=0.05), but did not affect growth for the 2010 growing season (p=0.96) (Fig. 14). Thus mulch increased redbud height after two years compared to non-mulched treatments (p=0.03). In 2009, redbuds in hardwood and redcedar mulched treatments had greater growth than those in the CWH treatment. Total height growth for redbuds of the 2009 plantings during the two growing seasons was greater in the hardwood and redcedar mulched treatments than for both non-mulched treatments. Environment affected redbud height growth during the 2010 growing season (p=0.01), but no environment by mulch interaction existed for redbud height growth in 2010 (p=0.51). Redbud height increase in tilled treatments (0.57 m) was less than in full-sun (0.87 m) but greater than in shade (0.27 m).

Mulch increased diameter growth of redbuds in 2009 (p=0.05), but diameter growth was not affected in 2010 (p=0.31) (Fig. 15). In 2009, redbuds receiving pine mulch had greater growth than those in non-mulched treatments. Environment affected redbud diameter growth in 2010 (p=0.04). No environment by mulch interaction occurred for redbud diameter growth in 2010 (p=0.72). Redbud diameter increase in tilled treatments (6.6 mm) was less than in full-sun (11.0 mm) but greater than in shade (3.5 mm).

Shumard Height and Diameter Growth-2009 Plantings

Mulch did not affect height growth of Shumard oaks in 2009 (p=0.76), but resulted in increased growth in 2010 (p=0.01). For the 2010 growing season, Shumard oaks in pine and pine bark nugget mulched treatments had greater growth than those in any other treatment (Fig. 16). No differences in height growth of Shumard oaks occurred during the duration of the two growing seasons (p=0.25).

Similarly to redbuds, mulch resulted in increased diameter growth of Shumard oaks in 2009 (p=0.02), but not 2010 (p=0.69). For the 2009 growing season, Shumard oaks receiving cypress, pine, pine bark nugget, and redcedar mulch had greater growth than those in CNH treatments (Fig. 17). Shumard oaks receiving pine mulch had greater diameter growth for the duration of the two growing seasons than those receiving hardwood mulch or those in non-mulched treatments (p=0.05).

Redbud Height and Diameter Growth-2010 Plantings

Mulch treatment did not affect terminal growth of redbuds (p=0.87) (Fig. 18A). Similar to the 2009 plantings, mulch resulted in increased diameter growth of redbuds (p=0.01). Redbud trees in the mulched treatments and CWH treatment had greater growth than those in the CNH treatment (Fig. 18B).

Shumard oak Height and Diameter Growth-2010 Plantings

Mulch treatment did not affect height growth of Shumard oaks (p=0.50) (Fig. 19A). They also did not affect diameter growth of Shumard oaks (p=0.31) (Fig. 19B).

Mulch Decomposition

For the 2009 planting, hardwood mulch decomposed faster than all other mulched treatments (mulch effect, p=0.004). Cypress mulch decomposed faster than redcedar and pine bark nugget mulch (Fig. 20). Similar results occurred in the 2010 planting. Redcedar and eucalyptus mulch decomposed the slowest and were slower than pine, red-dyed, and pine bark nugget mulch (mulch effect, p=0.03) (Fig. 21).

Mulch Appearance Survey

Mulch Appearance Ranking

When asked to rate each mulch type on a scale of 1-4, with 1 being most attractive and 4 being least attractive, mulched treatments were favored in appearance over non-mulched treatments (p<0.0001). Redcedar mulch was ranked the best overall and had a higher rating than red-dyed and hardwood mulches (Fig. 22). Red-dyed mulch ranked lower than redcedar, cypress, pine, pine bark nugget, and eucalyptus mulches. Master gardeners ranked red-dyed mulch lower than all other mulches (p<0.0001). Avid gardeners also ranked red-dyed mulch lower than redcedar, cypress, hardwood, pine, and eucalyptus mulch (p<0.0001). Occasional gardeners ranked red-dyed mulch as the best overall and greater than pine, eucalyptus, and hardwood mulch (p<0.0001).

Percent Use

When asked to list all the mulch types they would consider using, redcedar mulch ranked the highest among mulches and highest overall at 61.9 %, followed by cypress and eucalyptus mulches at 59.1% and 53.5%, respectively (Fig. 23). Red-dyed mulch ranked lowest among mulches at 33.8 % (Fig. 23). Non-mulched treatments ranked the lowest with 5.6 % of participants indicating they would use the CNH and 1.4 % of participants indicating they would use the CWH (Fig. 23).

Most Attractive

When asked to list which mulch type they found most attractive, mulched treatments were favored over non-mulched treatments. The mulched treatments chosen as the most attractive were redcedar, cypress, and red-dyed mulch (Fig. 24). Redcedar ranked the highest with 13 of 63 participants choosing it as their favorite closely followed by cypress and red-dyed mulch at 12 participants each. Hardwood mulch was chosen as the least favorite of the mulches with only 3 of 63 participants choosing it as the most attractive.

Weed Seed Germination Study

Mulch interacted with weed species ($p<0.0001$). Germination of all four weed species was greatest in the non-mulched control application compared to all mulch treatments. Of the mulch treatments, germination of three of the species tested was greater with eucalyptus than with other mulches.

Crabgrass, Johnsongrass, lambsquarter, and redroot pigweed germination was greater ($p<0.0001$) in the non-mulched control treatment than with any mulch. No significant differences in crabgrass germination existed among mulched treatments (Fig. 25A). Among the mulched treatments eucalyptus mulch had greater Johnsongrass, lambsquarter, and redroot pigweed seed germination than any other mulched treatments (Fig. 25B-D). Greater lambsquarter germination seed germination occurred with pine bark nugget mulch than with pine mulch (Fig. 25C).

Leachate Germination Study

Leachate treatment interacted with weed species (p<0.0001). Crabgrass germination was lower (p=0.006) in redcedar and red-dyed mulch leachate treatments than in the control, eucalyptus, pine, and pine bark nugget leachate treatments (Fig. 26A). Johnsongrass germination was similar (p=0.07) in all leachate treatments, although the eucalyptus leachate treatment showed greater germinants than the rest of leachate treatments (Fig. 26B). Lambsquarter germination was lower (p=0.0001) in red-dyed mulch leachate treatment than with all other leachate treatments (Fig. 26C). The redcedar leachate treatment had less germination than the control treatment (Fig. 26C). Pigweed germination was greater (p=0.0002) in the control treatment and eucalyptus leachate treatment than in the redcedar and red-dyed mulch leachate treatments. Pigweed germination was lower in the red-dyed mulch leachate treatment which was lower than all other leachate treatments except the redcedar leachate treatment (Fig. 26D).

Termite Study

For the 2009 plantings, 27 of 63 plots contained *Reticulitermes flavipes* (Kollar) termite activity. As of 4 July 2011, the hardwood mulched treatment had the highest observed termite activity with 6 of 9 hardwood mulched plots containing termite activity, which was twice as many as redcedar and pine bark nugget mulched plots (Fig. 27). The CNH treatment contained the least termite activity with only two plots infested. For the 2010 plantings, termite activity was lower, with only 5 of 45 plots containing activity, three red-dyed mulched plots, one hardwood mulched plot and one cypress mulched plot.

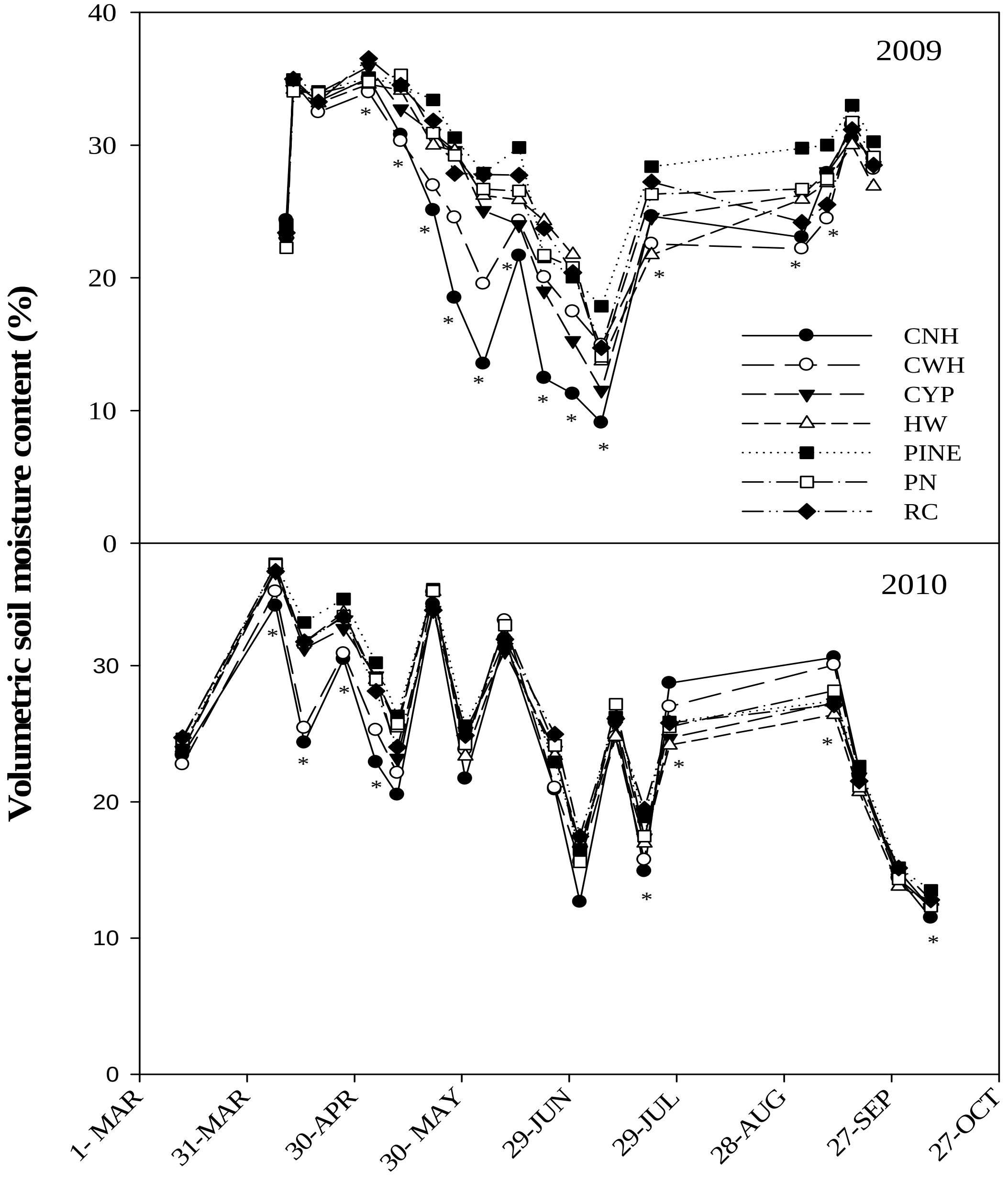

Fig. 1: Volumetric soil moisture content (%) for year 1, 2009 planting (A) and volumetric soil moisture content (%) for year 2, 2009 planting (B) measured between 0-15cm. An asterisk (*) below the data represents dates when mulch effect is significant (p<0.05). CNH = control no herbicide, CWH = control with herbicide CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine nugget mulch, RC = redcedar mulch. (n=9).

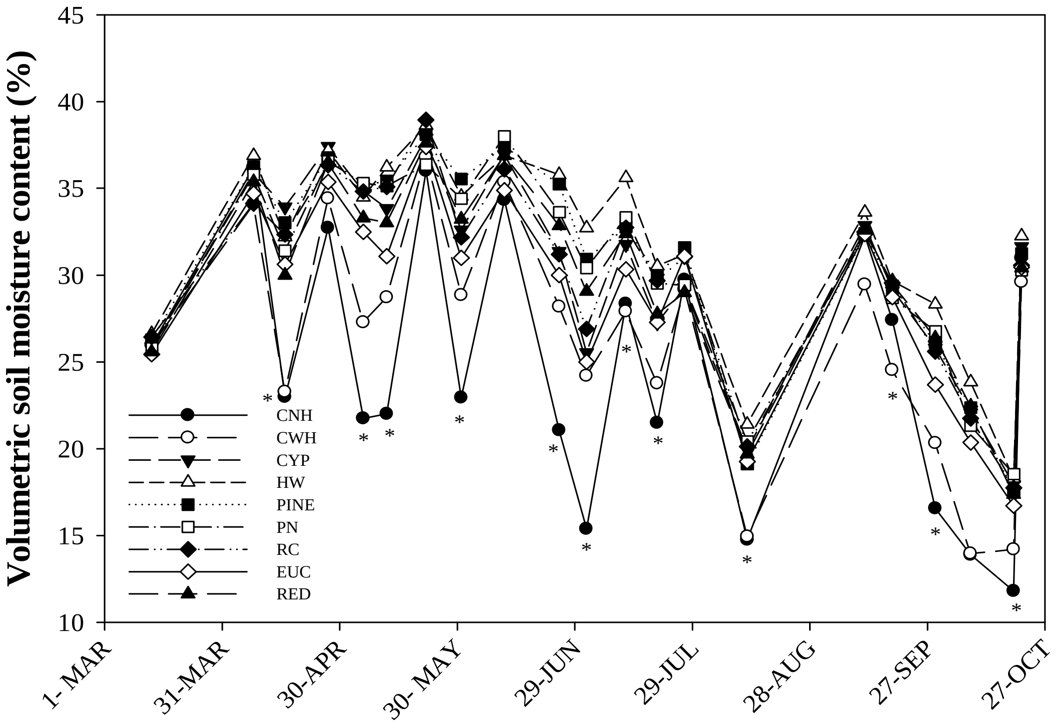

Fig. 2: Volumetric soil moisture content (%), for 2010 planting measured between 0-15cm. An asterisk (*) below the data represents dates when mulch effect is significant ($p<0.05$). CNH = control no herbicide, CWH = control with herbicide CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine nugget mulch, RC = redcedar mulch, EUC = eucalyptus mulch, RED = red-dyed mulch (n=5).

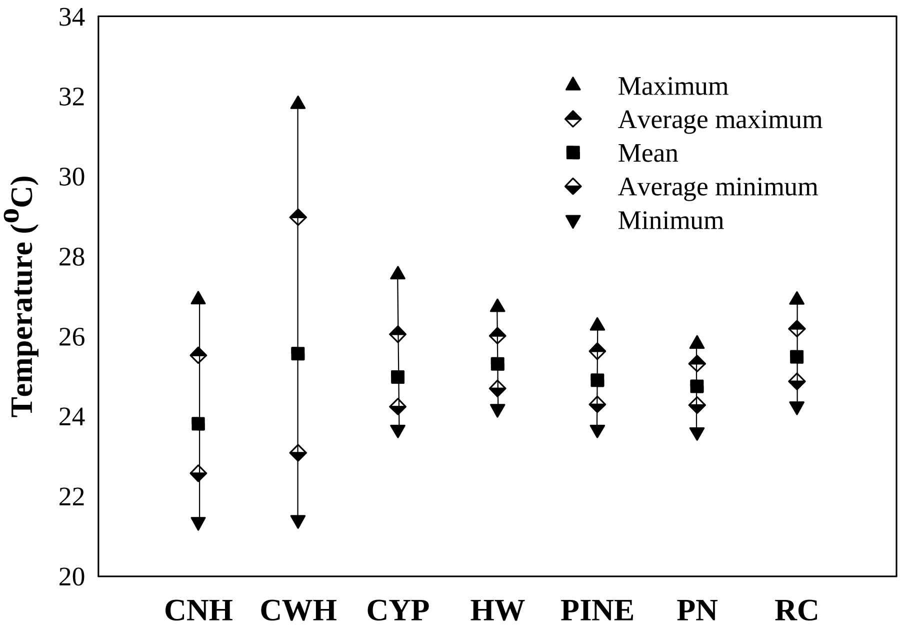

Fig. 3: Soil temperature measured for one week (21-29 July 2009). Mean is average of hourly measurement during this period. Average maximum and average minimum are the average daily extremes. Maximum and minimum are the extreme high and low temperature. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

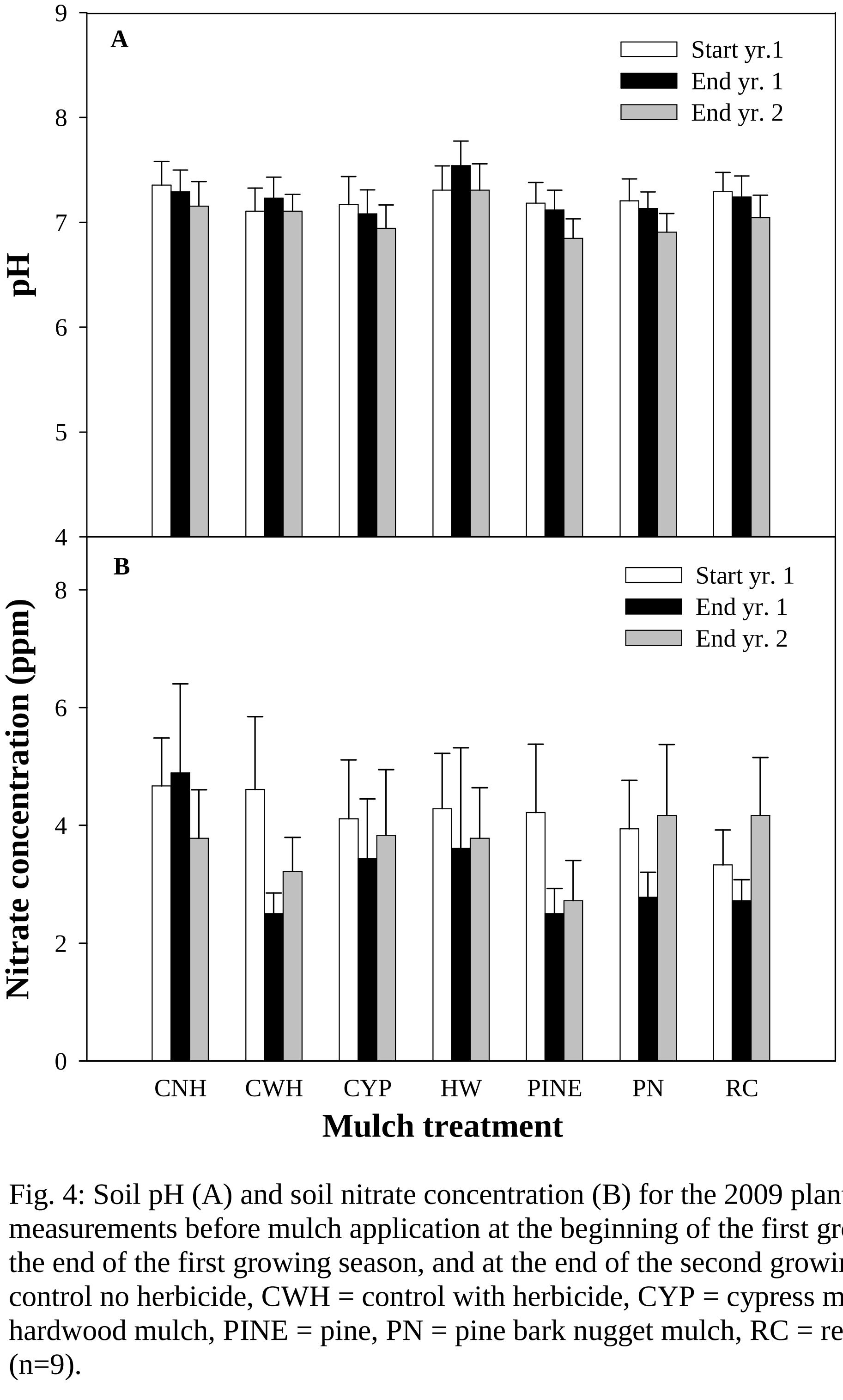

Fig. 4: Soil pH (A) and soil nitrate concentration (B) for the 2009 plantings. Soil measurements before mulch application at the beginning of the first growing season, at the end of the first growing season, and at the end of the second growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

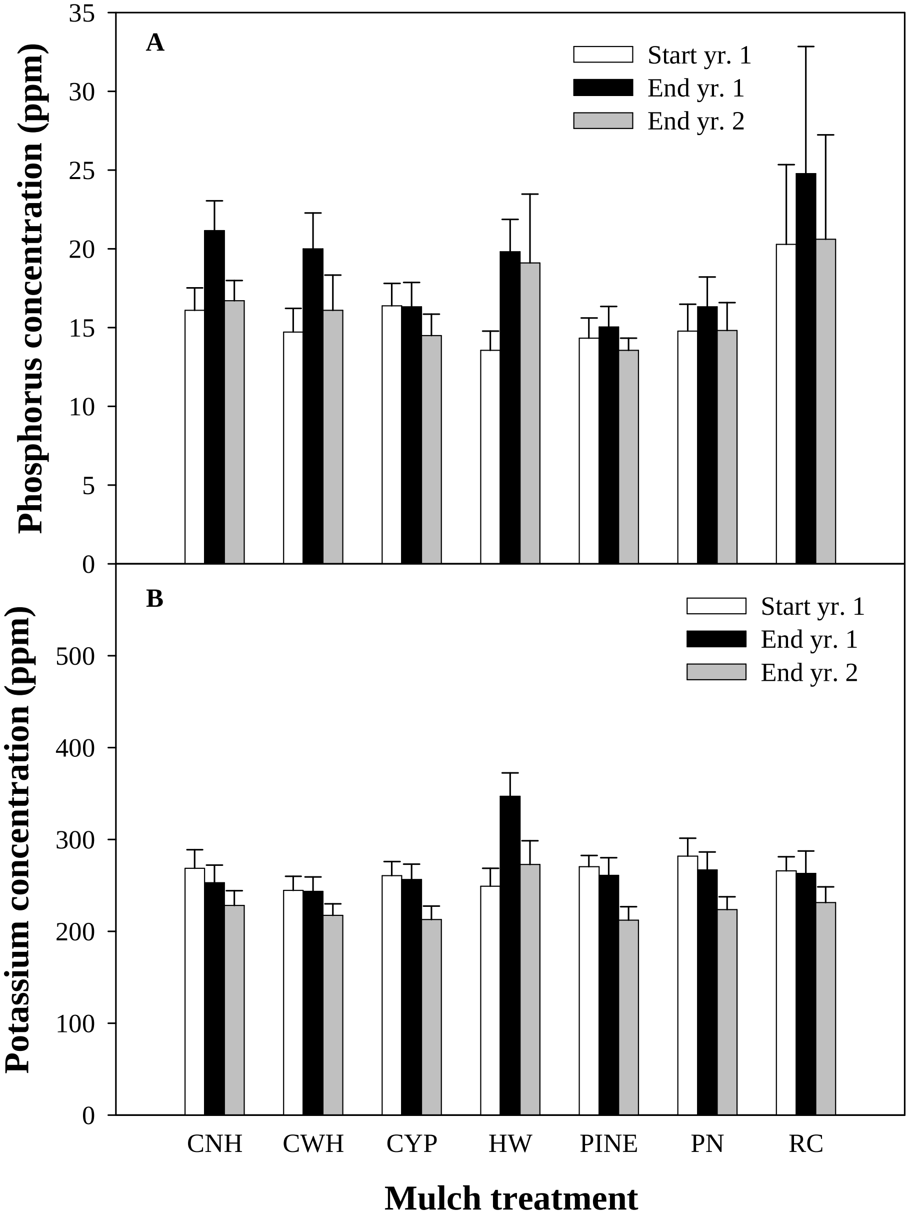

Fig. 5: Soil phosphorus concentration (A) and soil potassium concentration (B) for the 2009 plantings. Soil measurements before mulch application at the beginning of the first growing season, at the end of the first growing season, and at the end of the second growing season. End of year 1 and year 2 measurements included mulch application. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

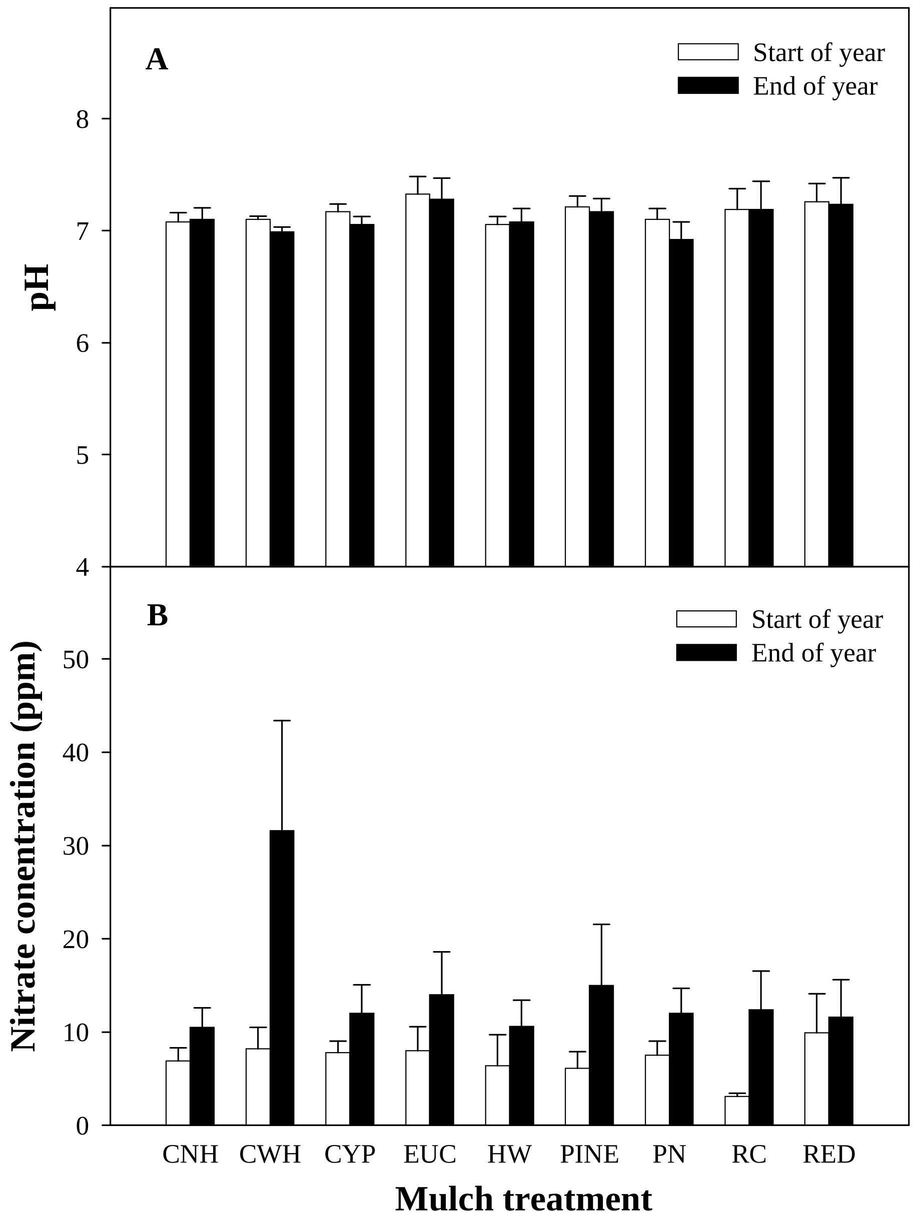

Fig. 6: Soil pH (A) and soil nitate concentration (B) for the 2010 plantings. Soil measurements at the beginning of the growing season before mulch application and at the end of the growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=5).

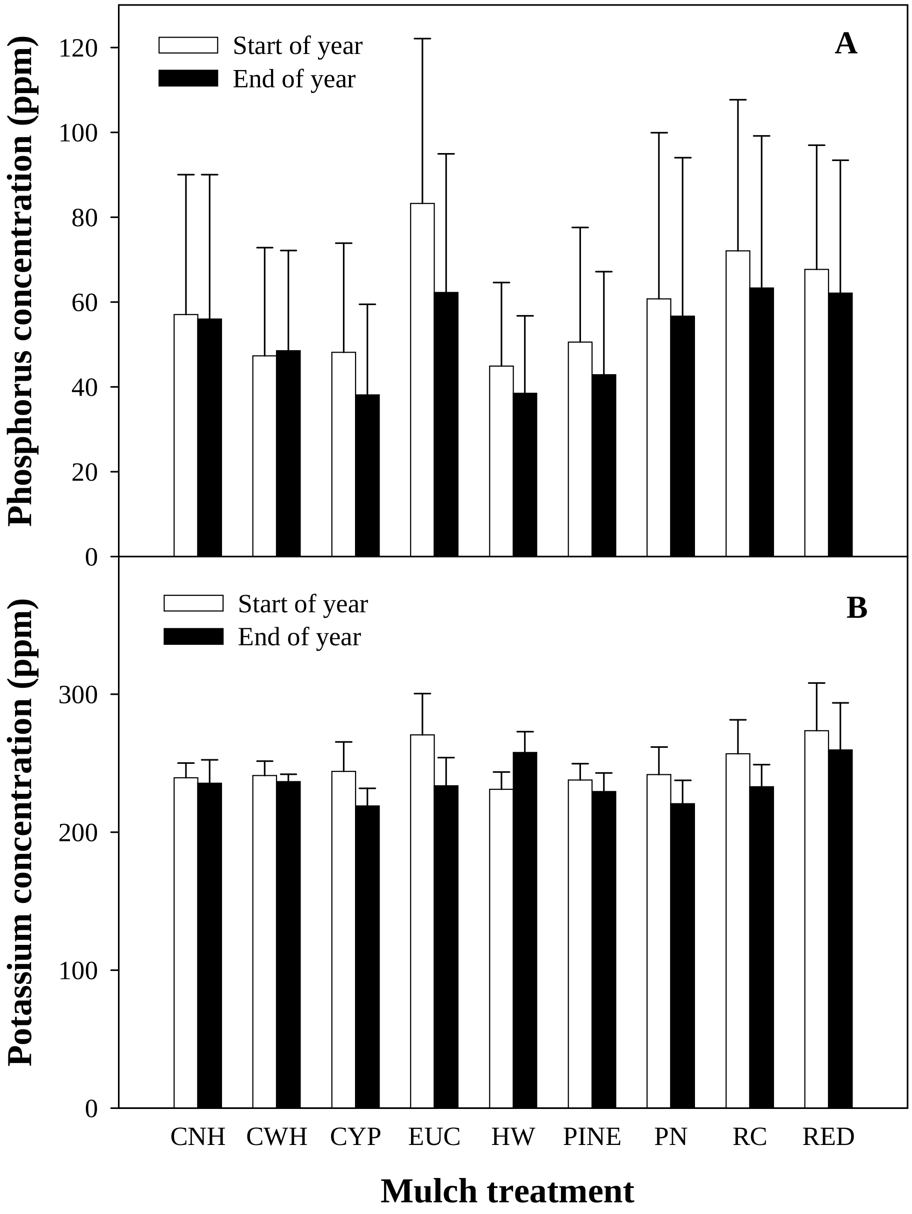

Fig. 7: Soil phosphorus concentration (A) and soil potassium concentration (B) for the 2010 plantings. Soil measurements at the beginning of the growing season before mulch application and at the end of the growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=5)

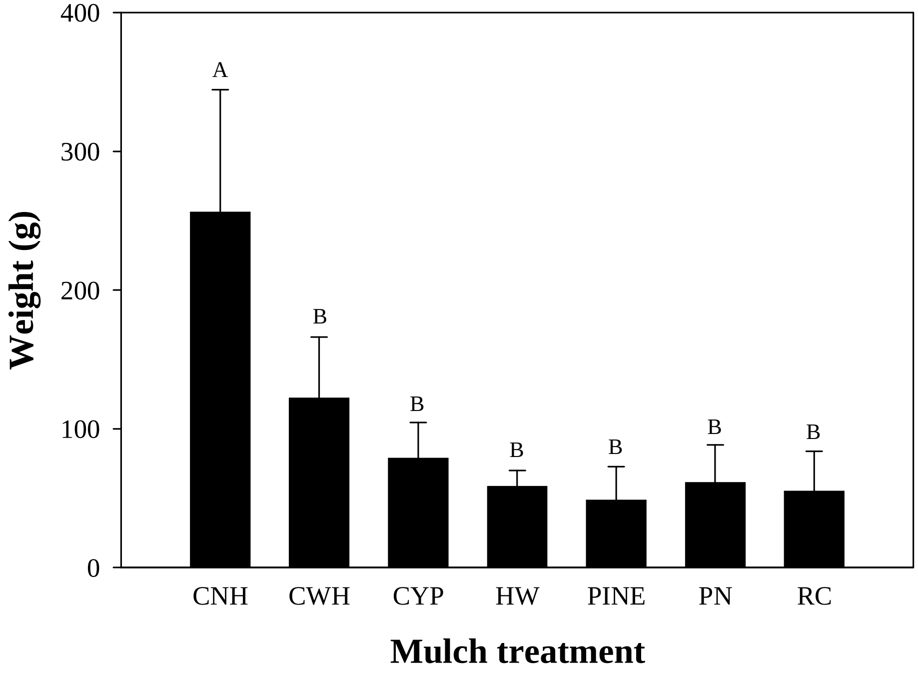

Fig. 8: Weed growth for 2009 planting. Means with the same letter are not significantly different (Duncan’s *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

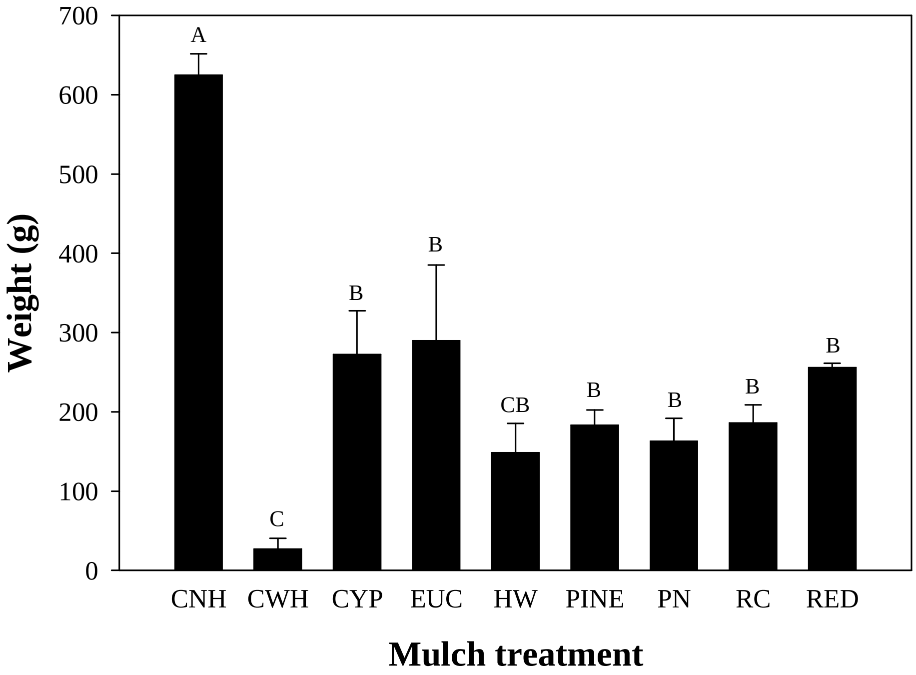

Fig. 9: Weed growth for the 2010 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=4).

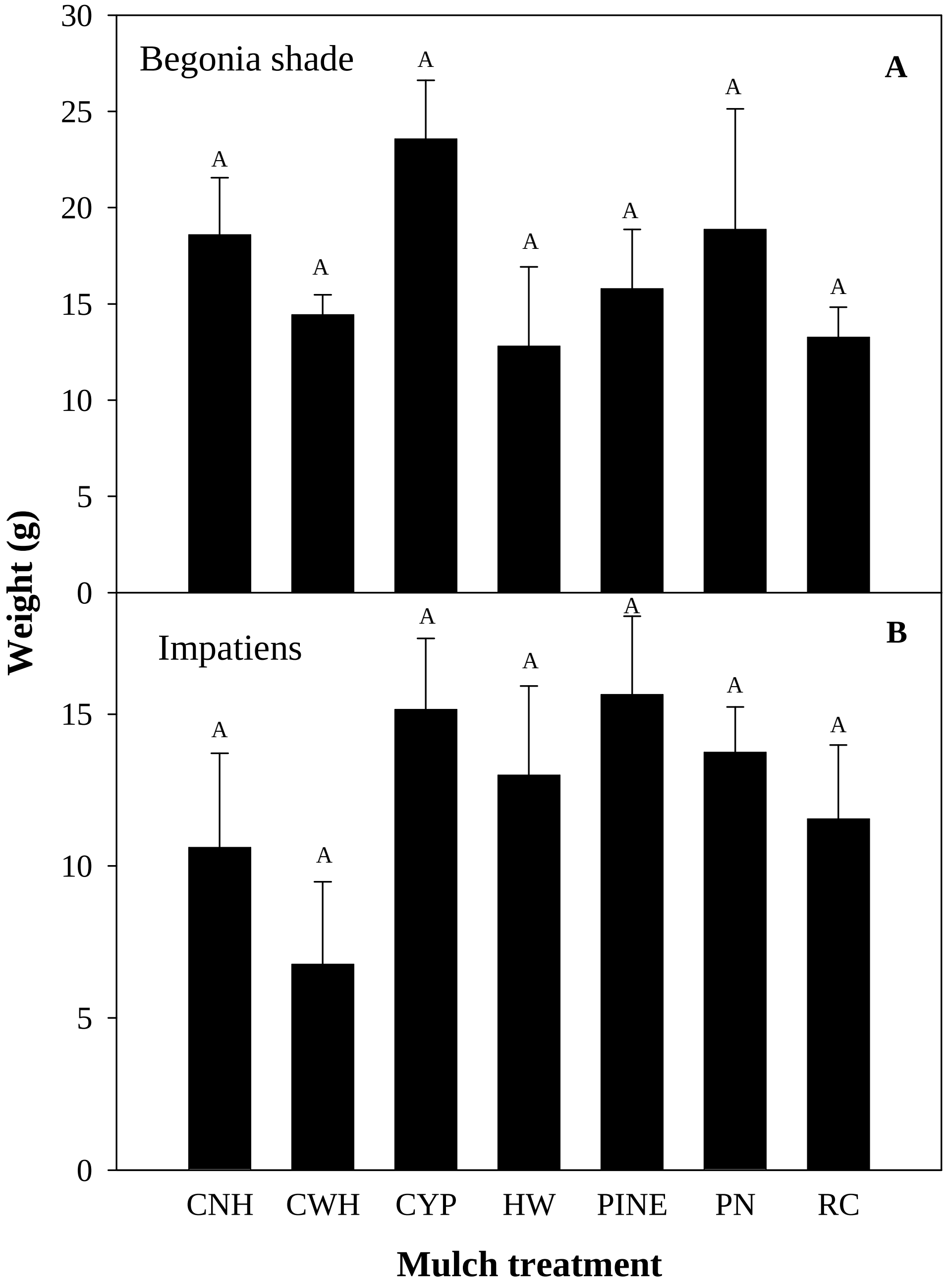

Fig. 10: Begonia shade growth (A) and impatiens growth (B) (2009). Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=3).

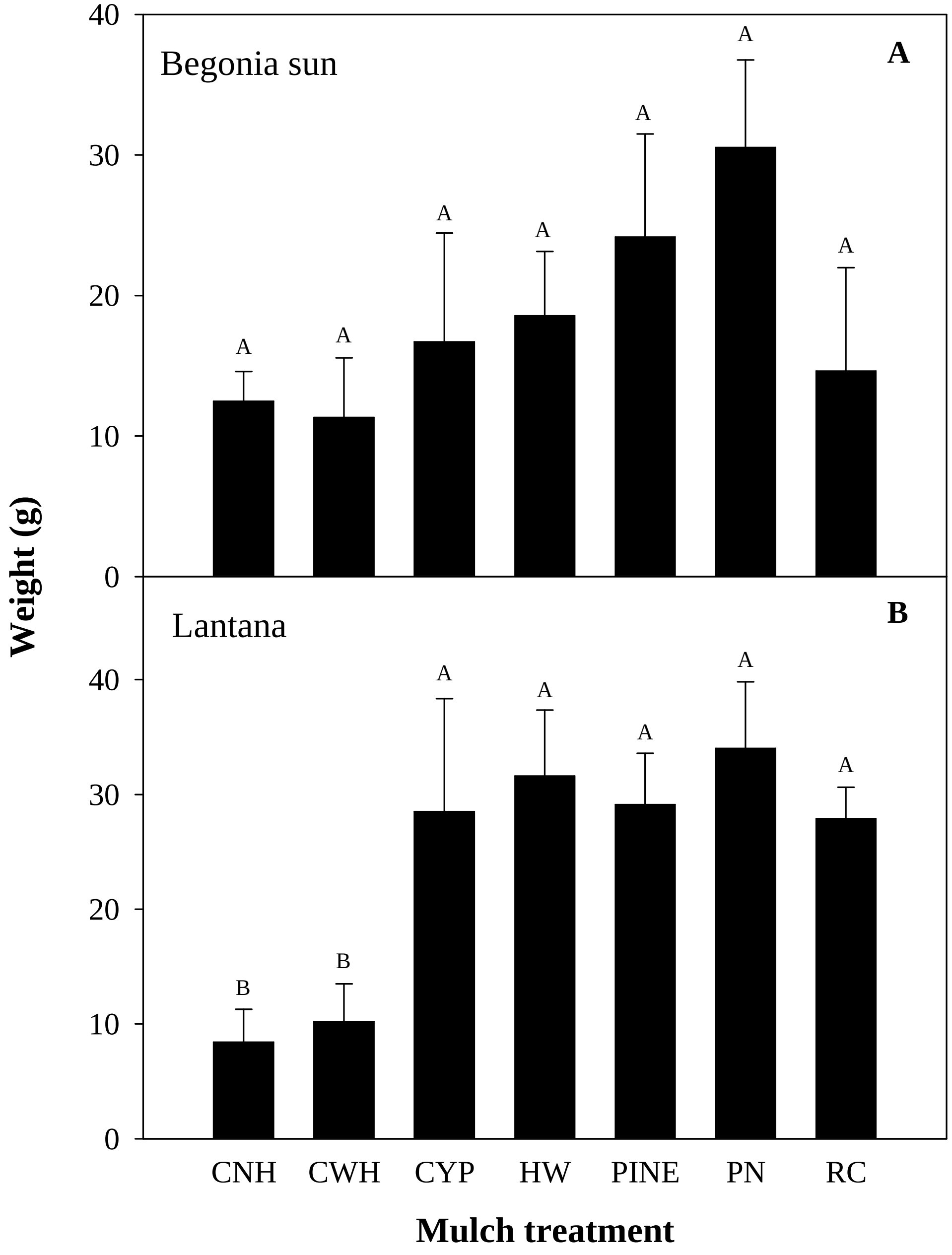

Fig. 11: Begonia sun growth (A) and lantana growth (B) (2009). Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=3).

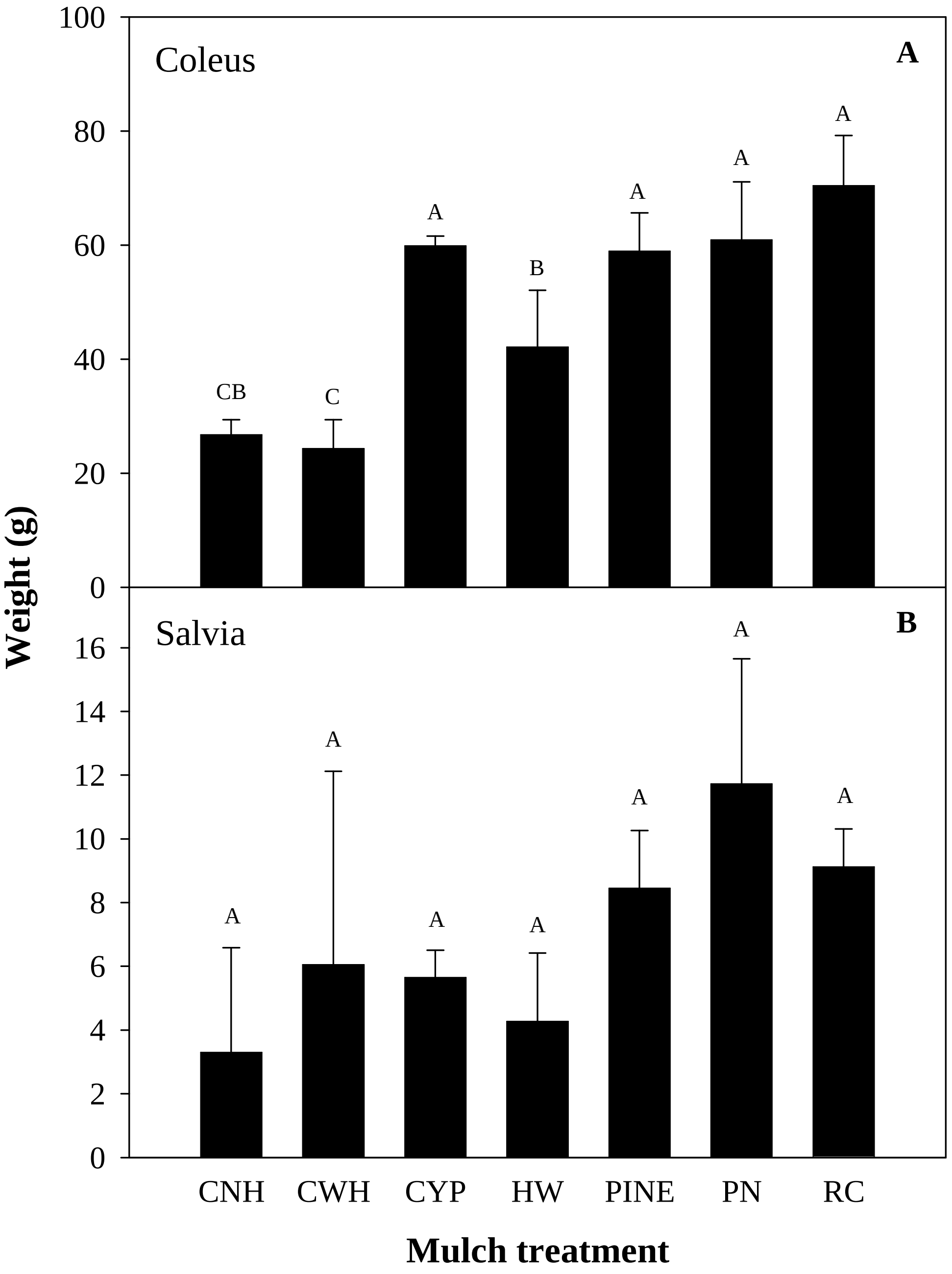

Fig. 12: Coleus growth (A) and salvia growth (B) (2009). Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=3).

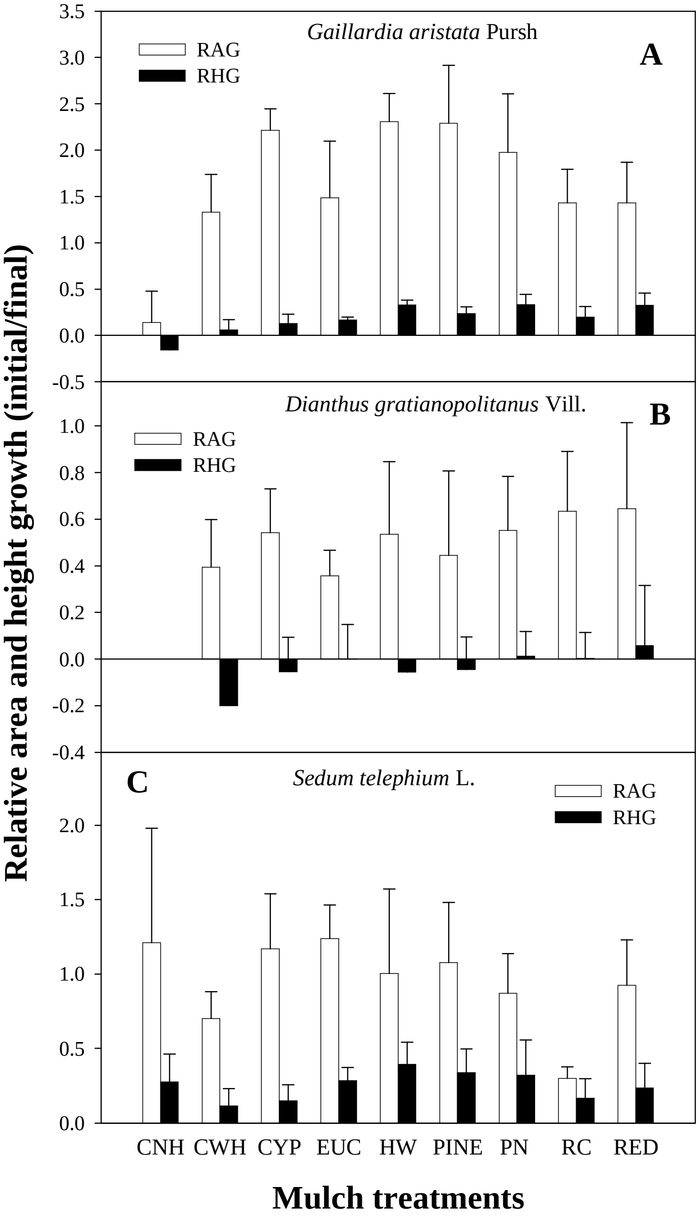

Fig. 13: Relative area growth (RAG) and relative height growth (RHG) of Arizona sun *(Gailardia aristata)* (A), Mountain mist *(Dianthus gratianopolitanus)* (B), and Autumn joy *(Sedum spectabile)* (C). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=5).

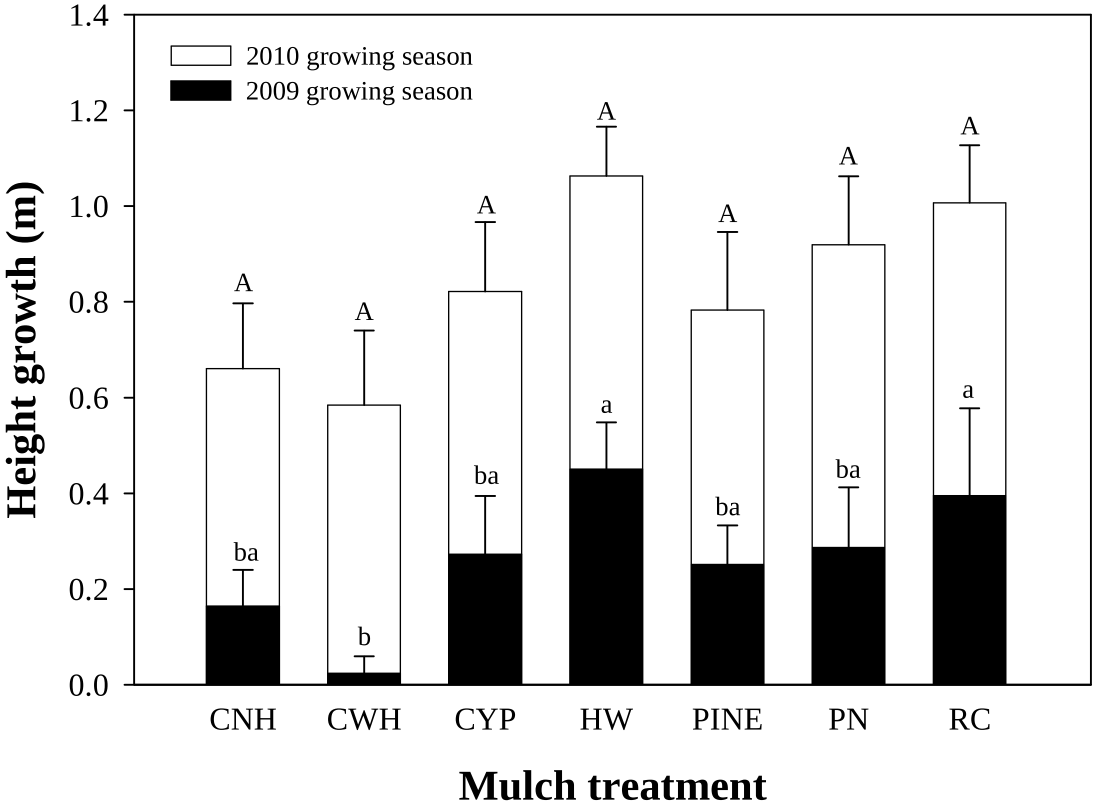

Fig. 14: Height growth of redbud (*Cercis canadensis*) over two years, 2009 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05) Lower case letters represent 2009 growing season and upper case letters represent 2010 growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

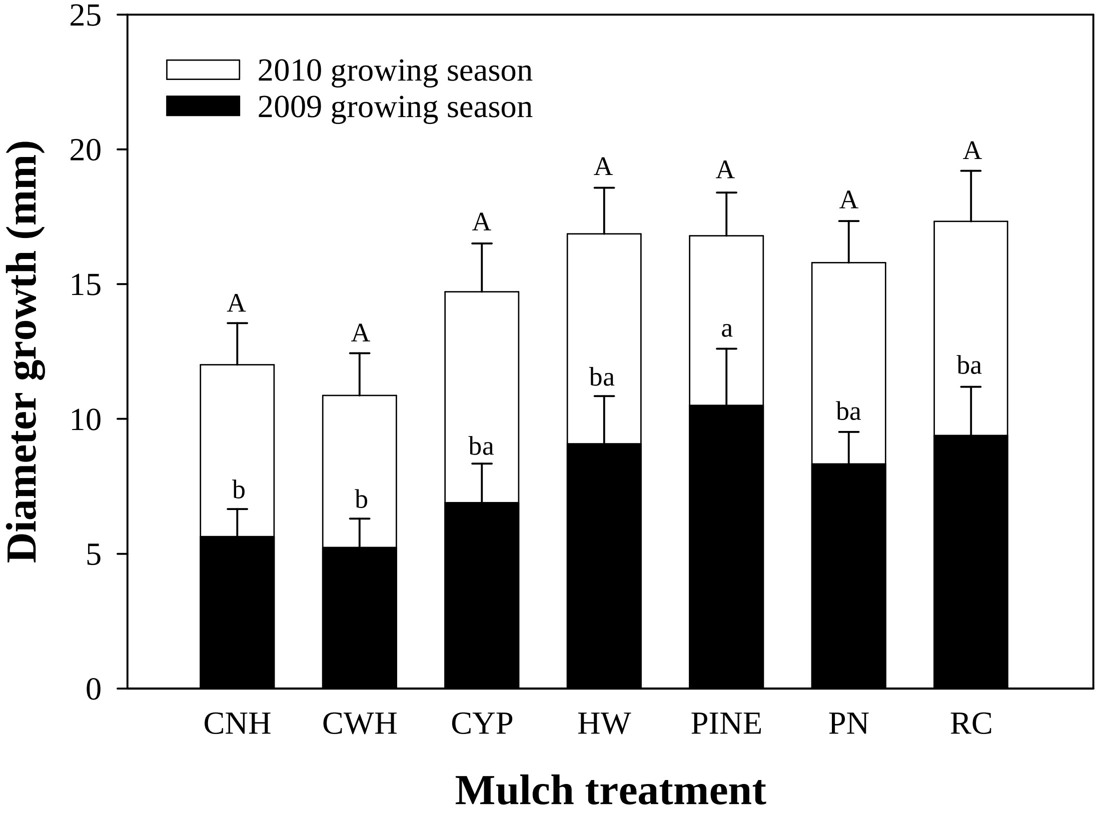

Fig. 15: Diameter growth of redbud (*Cercis canadensis*) over two years, 2009 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). Lower case letters represent 2009 growing season and upper case letters represent 2010 growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

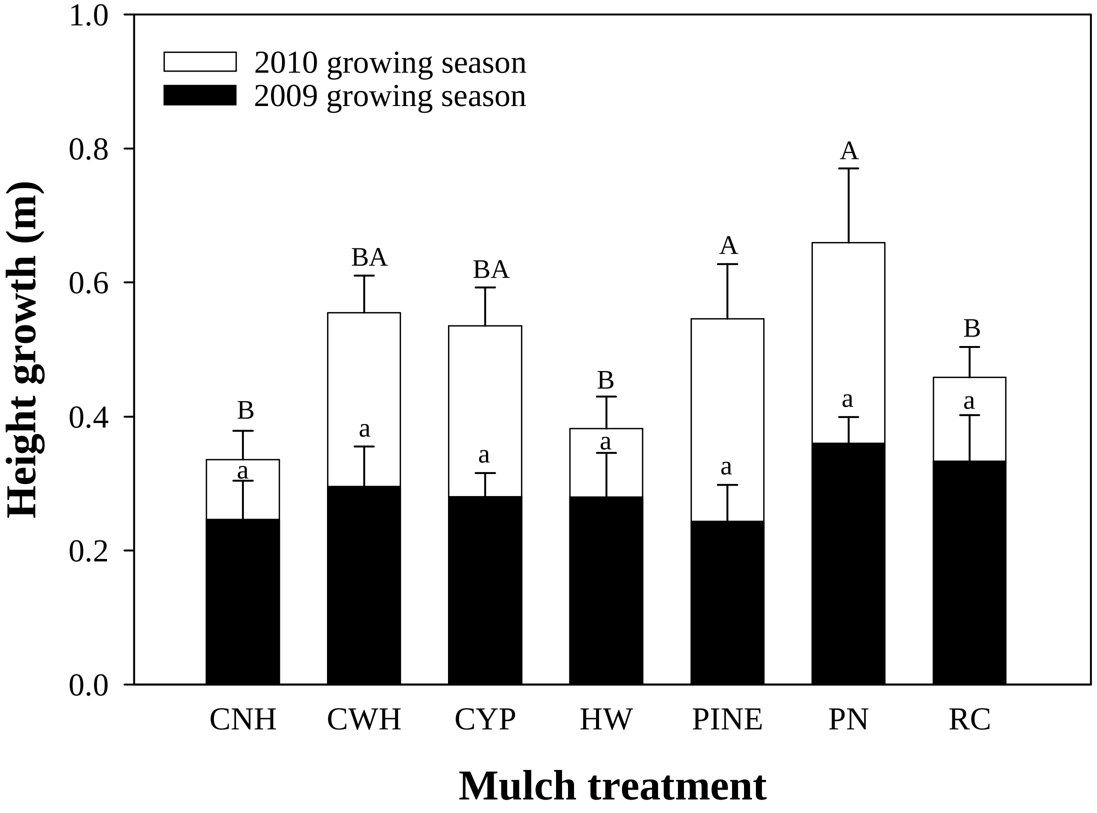

Fig. 16: Height growth of Shumard oak (*Quercus shumardii*) over two years, 2009 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). Lower case letters represent 2009 growing season and upper case letters represent 2010 growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

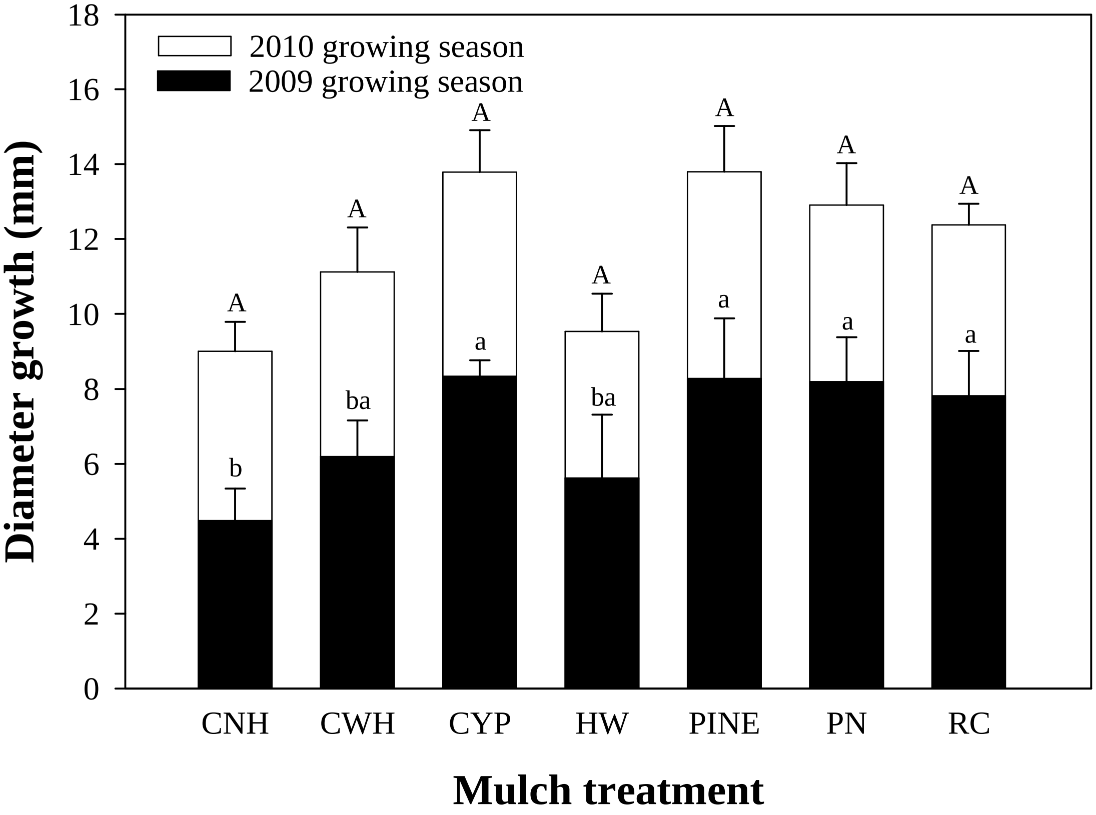

Fig. 17: Diameter growth of Shumard oak (*Quercus shumardii*) over two years, 2009 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). Lower case letters represent 2009 growing season and upper case letters represent 2010 growing season. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

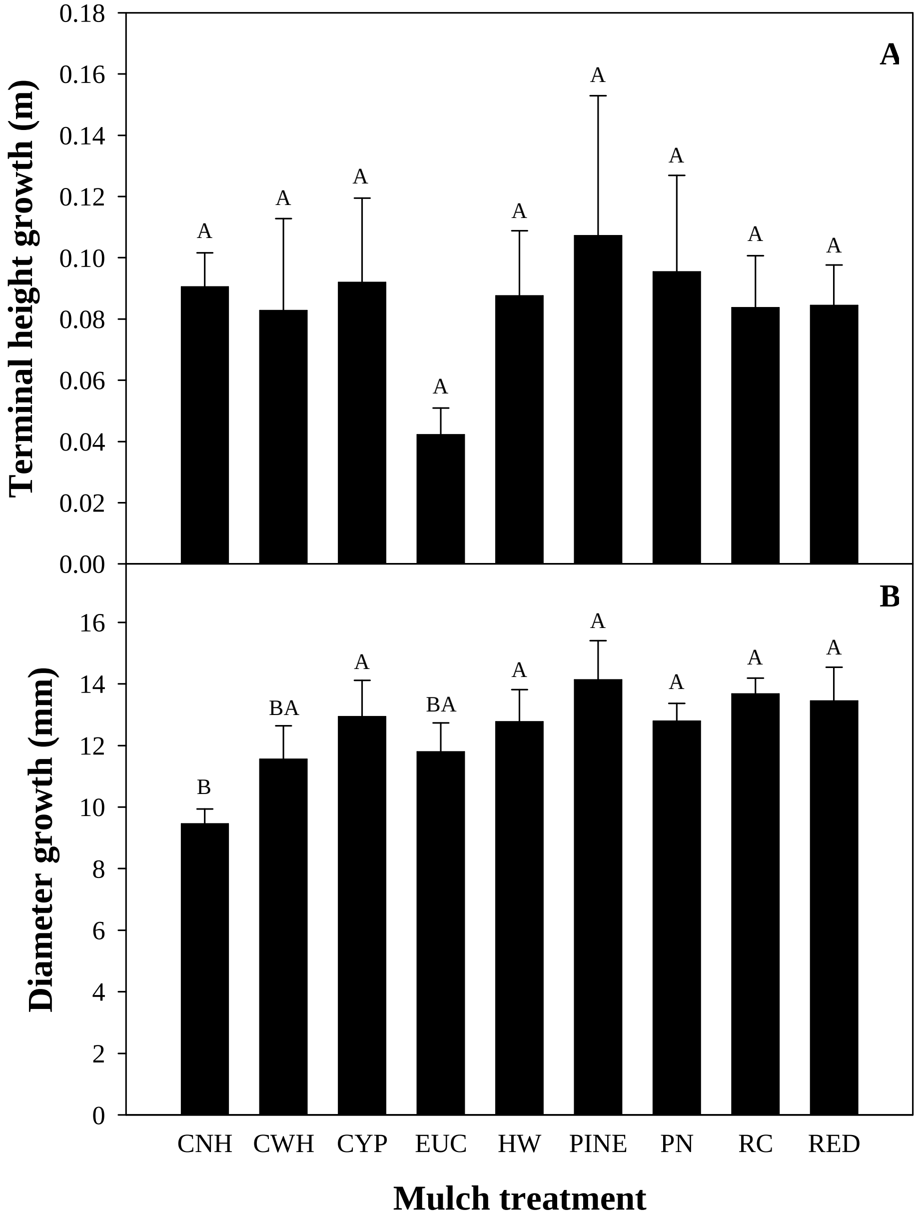

Fig. 18: Terminal growth (A) and diameter growth (B) of redbud (*Cercis canadensis*) 2010 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=5).

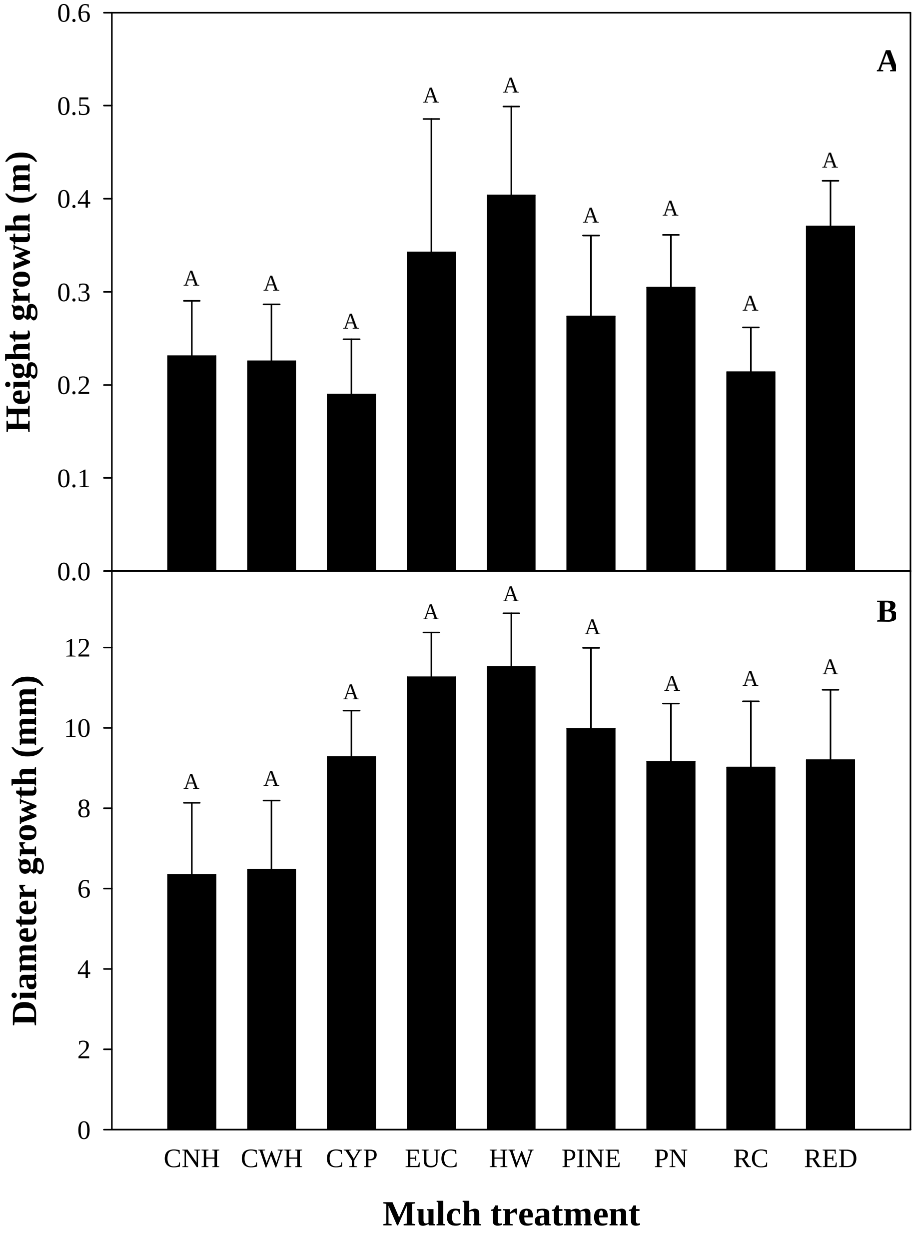

Fig. 19: Height growth (A) and diameter growth (B) of Shumard oak (*Quercus shumardii*) 2010 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=5).

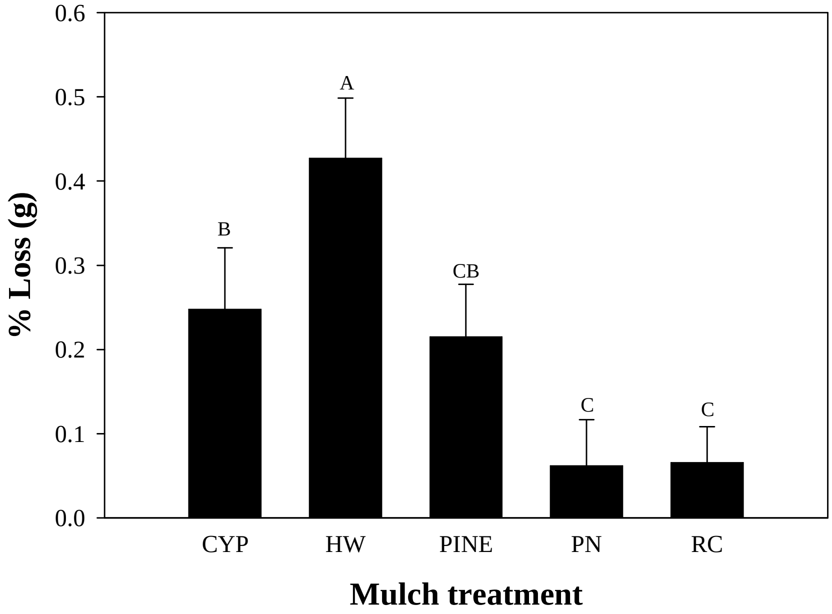

Fig. 20: Mulch decomposition rate measured as percent loss (g) over two years, 2009 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, $\alpha=0.05$). CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch (n=9).

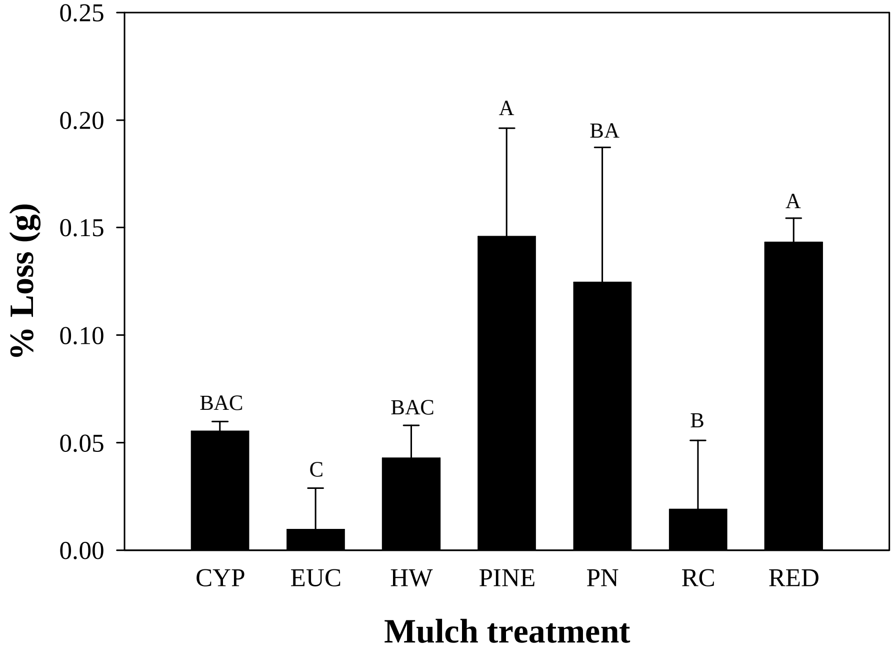

Fig. 21: Mulch decomposition rate measured as percent loss (g) over one year, 2010 planting. Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=4).

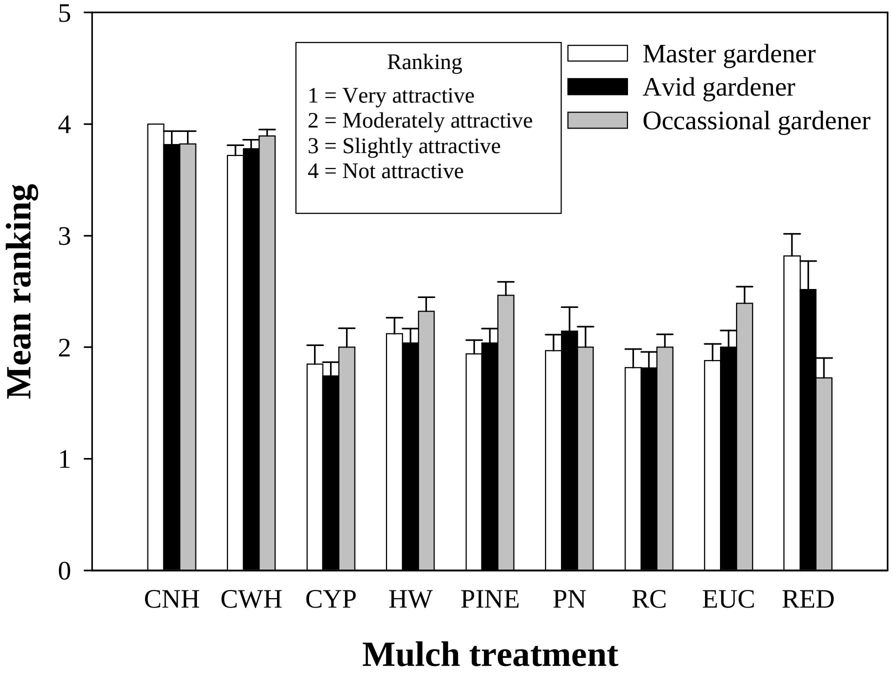

Fig. 22: Mulch appearance rankings determined by master gardeners (n=33), avid gardeners (n=28) and occasional gardeners (n=28). CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, EUC = eucalyptus mulch, RED = red-dyed mulch.

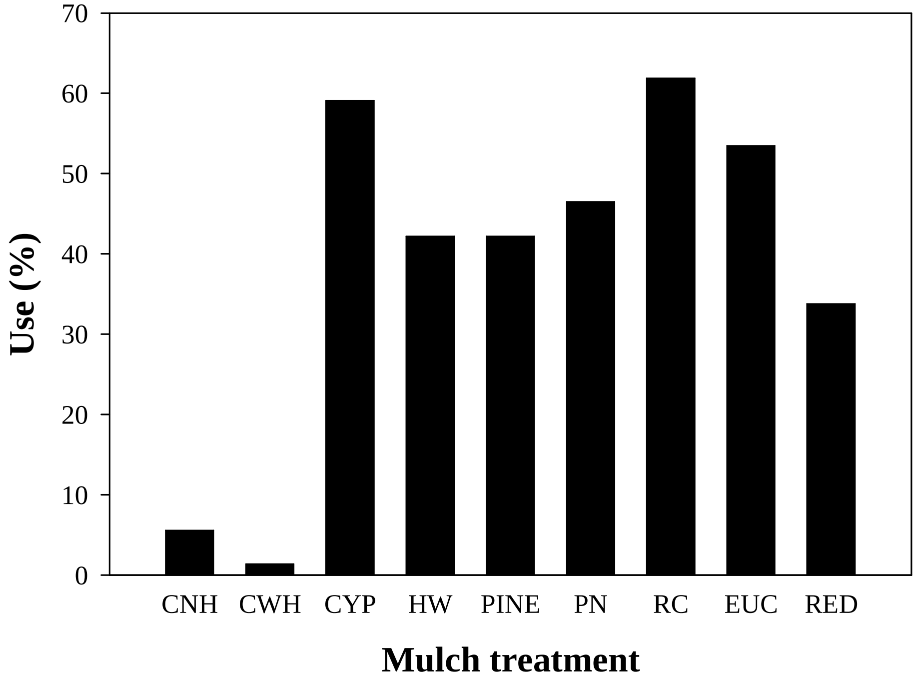

Fig. 23: Percent of gardeners surveyed that would use each mulch type. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, EUC = eucalyptus mulch, RED = red-dyed mulch (n=71).

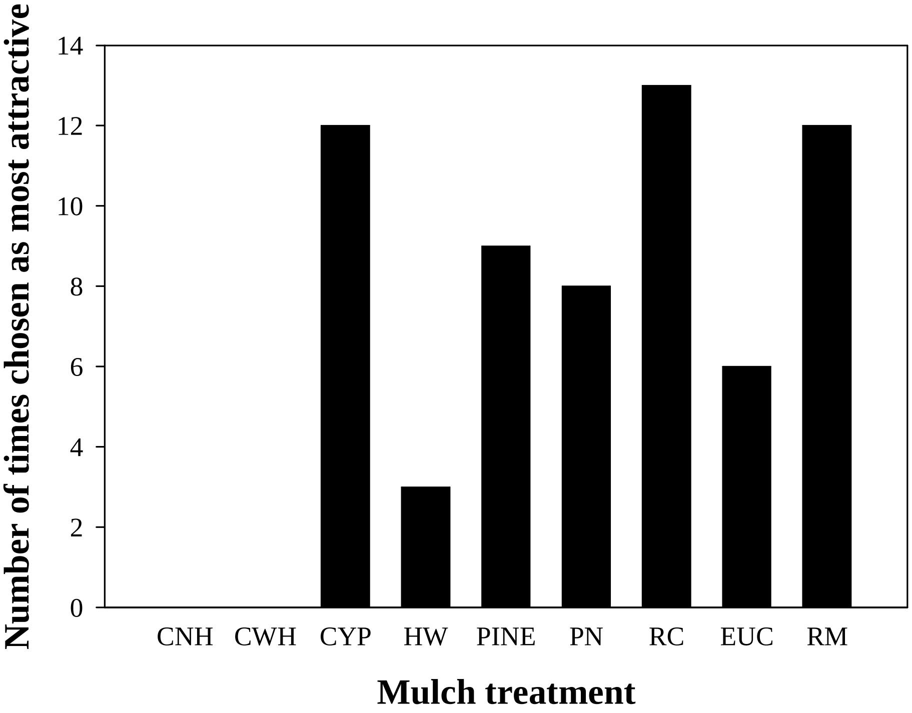

Fig. 24: Number of surveyors that chose each mulch type as the most attractive. CNH = control no herbicide, CWH = control with herbicide, CYP = cypress mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, EUC = eucalyptus mulch, RED = red-dyed mulch (n=63).

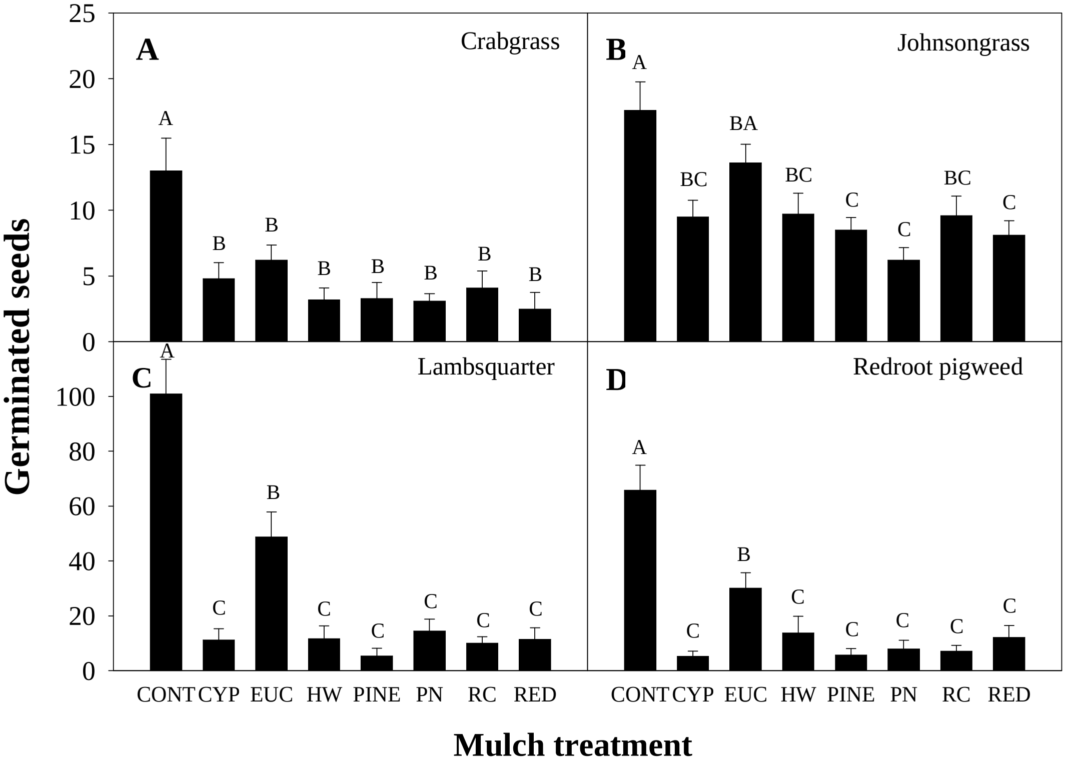

Fig. 25: Mean seed germination by mulch treatment for crabgrass (*Digitaria sanguinalis*) (A), Johnsongrass (*Sorghum halepense*) (B), lambsquarter (*Chenopodium album*) (C), and redroot pigweed (*Amaranthus retroflexus*) (D). Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CONT = control, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=10).

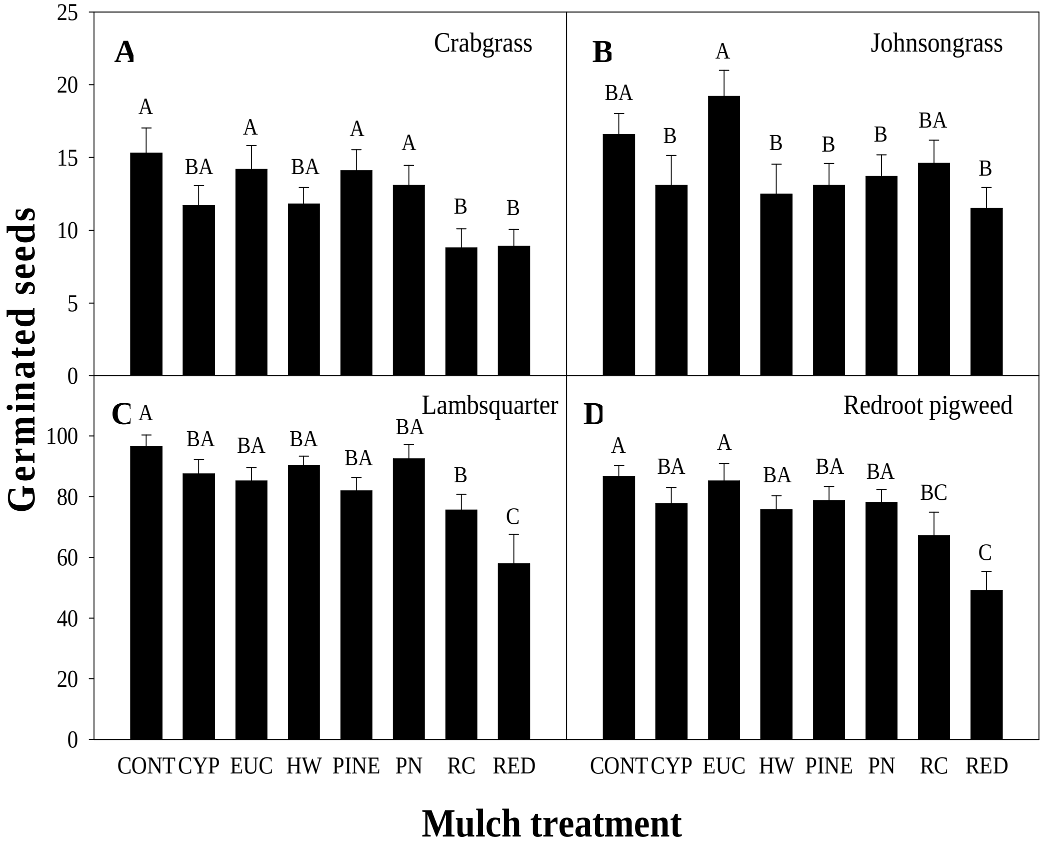

Fig. 26: Mean seed germination by mulch leachate type for crabgrass (*Digitaria sanguinalis*) (A), Johnsongrass (*Sorghum halepense*) (B), lambsquarter (*Chenopodium album*) (C), and redroot pigweed (*Amaranthus retroflexus*) (D). Means with the same letter are not significantly different (Duncan's *post hoc*, α=0.05). CONT = control, CYP = cypress leachate, EUC = eucalyptus leachate, HW = hardwood leachate, PINE = pine leachate, PN = pine bark nugget leachate, RC = redcedcar leachate, RED = red-dyed leachate (n=10).

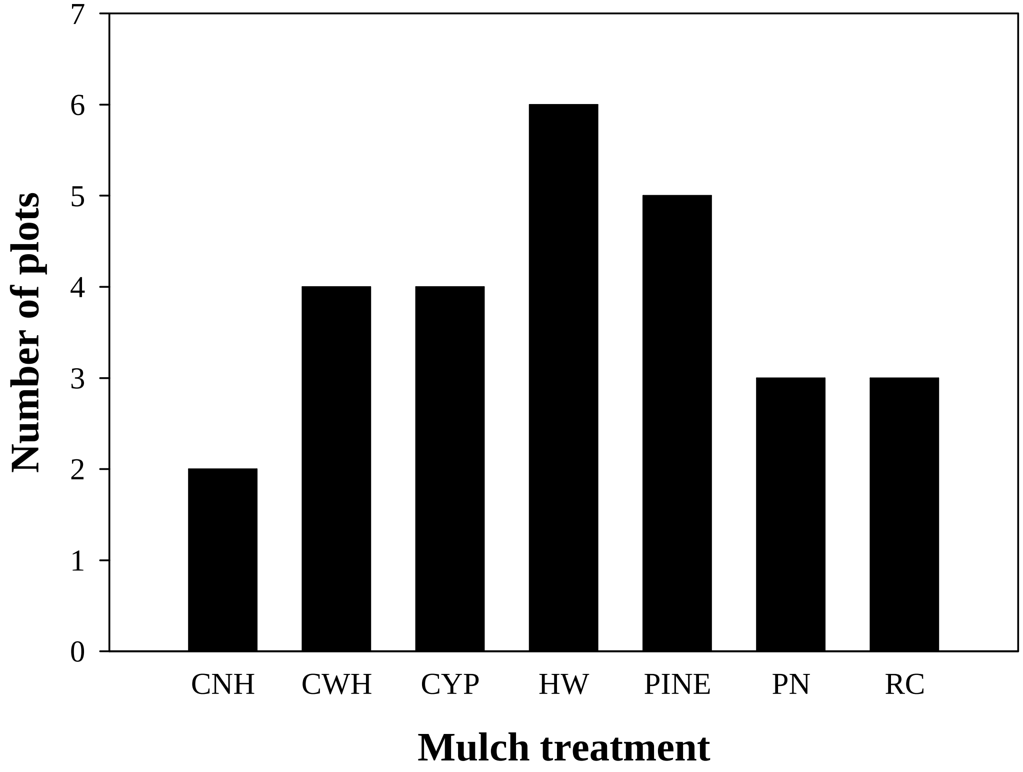

Fig. 27: Number of plots per mulch treatment that exhibited termite activity for the 2009 plantings when measured through 21 March 2010. CONT = control, CYP = cypress mulch, EUC = eucalyptus mulch, HW = hardwood mulch, PINE = pine mulch, PN = pine bark nugget mulch, RC = redcedar mulch, RED = red-dyed mulch (n=9).

CHAPTER V

DISCUSSION

Use of wood-based mulches in this study increased plant growth and survival, increased soil moisture, interfered with the growth and germination of weeds, and moderated fluctuations in soil temperature. Benefits were primarily associated with the use of mulch compared to not using mulch, rather than by specific mulch treatments. Other studies found similar results with the use of mulch (e.g., Cook et al. 2006, Johansson et al. 2006, Iles and Dosmann 1999).

Effects of Mulch on Soil Properties

Mulch increases soil moisture (Watson 1988). In our study, mulch had a positive effect during periods of low soil moisture. These results agree with previous studies, in which soils under organic mulch treatments contained higher moisture than other treatments during long periods without rainfall (Greenly and Rakow 1995, Zhang et al. 2008). Mechanisms for maintaining to greater soil moisture with mulch include, decreased soil temperatures resulting in lower evaporation, moisture in the mulch buffering losses from the soil, and decreased transpiration due to weed suppression. After heavy rainfall, soil moisture did not differ between mulched and non-mulched plots since all soils were fully saturated (Greenly and Rakow 1995). Although both the 2009 and 2010 plantings had similar treatment effects with soil moisture, the mulch effects were not as apparent in 2010 likely due to greater rainfall totals during May (18 cm) and June (14 cm) compared to May (8 cm) and June (4 cm) in 2009.

Shading and insulation by mulch moderate soil temperature (Cook et al. 2006, Skroch et al. 1992). In our study, mulch moderated soil temperatures keeping daytime temperature cooler and nighttime temperatures warmer compared to the non-mulched plots. Other studies have shown that mulch color affects soil temperatures (Harris 1992). A study conducted in the warmer months of August and September showed that soil temperature under organic mulches such as wheat straw, which is lighter in color, was lower than under darker mulches or no mulch (control) (Cook et al. 2006). Our study did not detect differences in soil temperature under the various mulch types tested, perhaps because the mulch was deep (7.6 cm) and perhaps because the color of all mulches tested was similar ranging from brown to red.

The effect of mulch on soil pH is inconsistent. Mulch can increase, decrease, or not alter soil pH. A study reported that soil pH under mulch was lower at 5.8 then under the non-mulched treatment at 6.7 (Himelick and Watson 1990). Similar results occurred in other studies in which mulch decreased soil pH (Billeaud and Zajicek 1989, Duryea et al. 1999a). In contrast, Iles and Dosmann (1999) reported that pH in mulched treatments increased and the pH in non-mulched treatments decreased. Other studies have shown that soil pH was unaffected by mulched treatments (Broschat 1997, Tukey and Schoff 1963). The effect of mulch appears to depend on the relative difference between the soil pH and that of the mulch. Based on our data, all treatments for the 2009 plantings decreased soil pH during the first and second year except for hardwood mulch which increased soil pH in year one. This effect lasted only one year. The initial soil pH was 6.4 while the pH of the mulches were 5.6 for redcedar, 7.9 for hardwood, 6.0 for cypress, and 4.5 for both pine bark nugget and pine. Therefore, our finding does make sense in that hardwood mulch had a pH higher than the soil while the other mulch treatments all had a pH lower than the soil.

Mulches can increase soil fertility from leaching and decomposition. Mulches create an environment favorable for microorganisms in the underlying soil, i.e., moisture and temperature are moderated, resulting in increased nutrient mineralization in the soil (Harris 1992). In our study, mulch treatments did not affect soil nitrate for the 2009 or 2010 plantings. The lack of response for soil nitrate may be due to several possibilities. Soil nitrate depends on moisture content and temperature at the time of sampling (Gaines and Gaines 1994), presenting a snapshot of nitrogen availability that changes with mineralization and uptake. More extensive measurements of *in situ* nitrogen mineralization would improve the estimates of mulch effects on nitrogen. Mulch did not affect soil P for the 2009 or 2010 plantings. The hardwood mulched treatment increased soil K in the 2009 plantings; although, soil K decreased between the first and second growing seasons in the non-mulched and other mulched treatments. Increased K under the hardwood mulch may be related to faster decomposition and release of nutrients.

The general lack of soil nutrient response to mulch differs from results of other studies in which, cypress mulch increased K concentration in the soil compared to non-mulched treatments (Broschat 1997) and increased available P concentration (Tukey and Schoff 1963). Immobilization of nutrients may occur with the application of high carbon, low nutrient materials such as wood based mulch (Pickering and Shepherd 2000). A lag time of nutrient release in these mulches from slower decomposition and mineralization rates may warrant the need to fertilize. However faster decomposition of some mulches such as the hardwood mulch, may lead to a quicker release of nutrients into the soil.

Mulch Effect on Weed Growth and Plant Growth

Mulch can control competition by suppressing weed seed germination and establishment. The reduced competition from weeds allows more water, light and nutrients to be available for plants used in the landscape (Harris 1992). Decreases in weed growth were related to the use of mulch and not mulch type in the field. Similar evidence was found in other studies (Abouziena et al. 2008, Broschat 1997, Stinson et al. 1990). Considerable variation in weed growth occurred due in part to type of weeds in our study. On several occasions large strong stemmed weeds grew through the mulch in some plots while other plots were affected by Bermuda grass (*Cynodon dactylon* Syn.) that spread over top and within the mulched plot. Applying herbicide before mulch would be beneficial, as previously discussed by Greenly and Rakow (1995), who noticed similar issues.

Mulch increased growth of redbuds and Shumard oaks (redbud diameter growth in the first year of each planting and Shumard oak height growth in year two). Another study showed similar results in which mulch increased diameter growth of trees (Greenly and Rakow 1995). Difference in growth response to mulch of the redbuds and Shumard oaks was probably related to their growth characteristics. Redbud trees are free growers, i.e., no predetermination of annual growth, making their response to the mulched treatments more immediate and able to manifest in the first year. Shumard oaks are semi-determinant growers, which can limit the amount of annual growth. As a result, Shumard oaks in our study may have expressed the benefits of mulch in the second growing season due to beneficial effects of the mulch from year one on carbon gain increasing the growth potential the subsequent year.

Mulch effect on annual plant growth was species specific. All annual species increased in growth throughout the growing season, with mulched plots typically having greater increases in annual growth than non-mulched plots. Similar results have occurred in studies where mulch increased crop growth and yield, with many reports stating that results were influenced by increased soil water storage provided by mulch (Chakraborty et al. 2008, Sarkar and Singh 2006, Zhang et al. 2008). In particular, the growth of lantana and coleus was increased by mulch. Both of these species were growing in full-sun treatments that might have experienced greater soil drying and perhaps benefited the most from mulch application. Mortality of salvia was greatest in the CNH treatments where competing vegetation was greatest. Increased growth of lantana and coleus in the mulched treatments and increased mortality of salvia in the CNH treatments could be related to increased soil moisture provided by the mulch, but not in the CNH treatments. Mulch conserved soil moisture during dry periods, making it available to the annuals. Light availability may be another reason for increased growth of lantana and coleus in the mulched treatments and increased mortality of salvia in the CNH treatment. Mulched treatments suppressed weed growth perhaps preventing shading effects from weed growth.

Mulch did not affect growth of perennial species, although growth of *Gaillardia aristata* tended to increase with mulch. The lack of mulch effects on growth of perennial species was due in part to a large variability in response within mulch treatments. This variability could have been due to initial plant size (although we calculated relative growth rate), initial vigor, or microsite and environmental variation. A more closely controlled greenhouse study might be useful to more precisely determine the potential mulch effects on perennials. As with mortality in salvia, greater mortality in *Dianthus gratianopolitanus* was associated with the CNH treatments and greater weed growth.

Overall, the mulch effects on weed growth, tree growth, annual and perennial growth were consistent among mulches. No mulch adversely affected desired plants.

Decomposition of Mulch

Hardwood mulch decomposed more than other mulches during the two year study for the 2009 plantings. Similar results were reported by Allison and Murphy (1962), where the hardwood mulched treatment decomposed faster than any other mulch treatment. We found different results for the hardwood when measured over one year in the 2010 plantings, where hardwood mulch did not have greater decomposition. The hardwood mulch we tested was a commercially available product that combines a mixture of various species. Hardwood mulch that we used in the 2009 plantings consisted of a mixture of oak (*Quercus* spp.) and honey locust (*Gleditsia triacanthos inermis*), where the hardwood used in the 2010 plantings consisted of a mixture of oak and maple (*Acer* spp.). The difference in decomposition for the hardwood mulch among the two plantings was probably related in part to the difference in species used in the mixtures. For the 2010 plantings, eucalyptus mulch decomposed least during showed the least the year, which contrasts results by Duryea et al. (1999a) who found that mulch comprised of hardwood prunings and clippings and eucalyptus mulch decomposed faster than all other mulch treatments tested. The differences in findings could be attributed to environmental effects such as temperature, moisture and shade. Mesh bags used in the study to measure decomposition allowed for potential contamination and weed and grass roots to be present within. These factors could have affected precision of mulch decomposition measurements.

Weed Seed Germination Study & Leachate Weed Seed Germination Study

Eucalyptus mulch was least effective at suppressing seed germination. This differs from the findings in the field study where the various mulch types had similar effects. The field study had greater variation due to weed species and environment while the controlled pot study eliminated those sources of variation. The ability of mulch to effectively control competition may be due to bulk density of the mulch used. For instance, all mulched treatments reduced weed growth compared to the non-mulched treatment, but mulch treatments with finer shredded particles like eucalyptus were least effective at suppressing weeds. Similar results were discussed by Billeaud and Zajicek (1989), where coarser mulch had the greatest effect on weed growth and by Greenly and Rakow (1995), who noted that weed growth was reduced with increased mulch depth. Duryea et al. (1999a) also noted that even when mulch treatments were evenly spread to a depth of 9 cm, their bulk densities quickly changed resulting in eucalyptus, cypress and pine straw having the least bulk density, supporting our results of eucalyptus having the least effect on germination.

In contrast, the leachate study was conducted to determine if germination effect from mulch could be related to chemical effects rather than physical effects. Since eucalyptus leachate treatment did not affect weed seed germination, the effect of eucalyptus mulch on germination and establishment appear to be related exclusively to physical properties. Red-dyed mulch leachate treatment consistently reduced seed germination more than any other leachate treatment. The decreased germination in the red-dyed leachate treatments is likely caused by the high concentration of chemicals used in the dye applied to the mulch. The red-dyed mulch wood properties are similar to that of the hardwood mulch, which showed no chemical effect. The dye used to color the mulch is proprietary, but includes a water base formulation of iron oxide pigments, resins, suspension aids and an antimicrobial agent (Color Biotics 2010). Contradicting the results of the leachate study were the results from the field study and germination study in which weed suppression was not affected by red-dyed mulch compared to the other mulch treatments. Differences in results among the studies are likely due to the increased concentration of chemicals in the leachate that do not occur when mulch is applied in the field. Other studies have shown similar results that some mulch treatments can have chemical effects on germination. For instance, a study by Duryea et al. (1999a) found that water extracts from several commonly used mulches inhibited germination of lettuce (*Lactuca sativa* L.) seeds.

Termite study

All mulch treatments in this study contained at least two plots with termite activity. More hardwood mulched plots contained termite activity than any other mulch treatment for the 2009 plantings. This result is similar to a study by Duryea et al. (1999b), who found that termites consumed more mulch composed of hardwood prunings and clippings than cypress, melaleuca (*Melaleuca quinquenervia* Cav.), or pine mulches. Greater termite activity in hardwood mulch is likely due to the fact that hardwood mulch lacks oils or resins in its heartwood, unlike redcedar, cypress, and pine mulches. Other studies have shown that termites feed on lighter colored sapwood of redcedar more than the darker, red colored heartwood because the heartwood contains higher concentrations of oils that are not preferred by termites when provided other options (Kard et al. 2007). The CNH treatments had the least termite activity in this study which could be related to soil moisture content. Termites prefer moist areas over drier ones (Duryea et al. 1999b). The CNH treatments in this study were drier compared to all other plots during long periods without rain.

The 2010 plantings in this study contained less termite activity than the 2009 plantings. Inadequate termite activity occurred to make conclusions based on different mulch treatments, but the overall decrease in activity among these plots could be related to weathering and decomposition of the mulch. Weathered wood mulches provide a good food source for termites because they have undergone decomposition that enhances the food quality for termites (Pinzon et al. 2006, Sun et al. 2006). This could explain the decreased termite activity in the 2010 plantings because the mulch used in the 2009 plantings was in the field undergoing decomposition a year longer than the mulch used in the 2010 plantings.

Conclusion

This study indicates that all mulch treatments increased soil moisture, moderated soil temperatures, reduced weed growth and increased plant growth and survival similarly, providing evidence that the use of mulch is beneficial in horticultural practices and landscape settings. In relation to our long-term goal of increasing the harvest and use of redcedar in the southern Great Plains, redcedar mulch provides the same benefits as other commonly used wood mulch products. As redcedar mulch was rated highly based on appearance, redcedar mulch should be considered as a viable option. Harvesting redcedar to make mulch removes an invasive plant from the ecosystem and aids in restoring ecosystem services and function.

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VITA

Adam Oakley Maggard

Candidate for the Degree of

Master of Science

Thesis: COMPARING ATTRIBUTES OF EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA* L.) MULCH TO OTHER COMMONLY USED WOOD MULCHES

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in July, 2011.

Completed the requirements for the Master of Science in Management at University of Florida, Gainesville, Florida/ United States, 2008.

Completed the requirements for the Bachelor of Science in Forest Resources and Conservation at University of Florida, Gainesville, Florida/ United States, 2006.

Experience:

6/06 to 8/06	Forest Technician Intern, Natural Resource Planning Services, Inc., San Antonio and Gainesville, Florida
8/09 to 7/11	Research Assistant, OSU Department of Natural Resource Ecology and Management, Stillwater, Oklahoma

Professional Memberships:

Society of American Foresters, National Wild Turkey Federation

Name: Adam Oakley Maggard Date of Degree: July, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: COMPARING ATTRIBUTES OF EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA* L.) MULCH TO OTHER COMMONLY USED WOOD MULCHES

Pages in Study: 91 Candidate for the Degree of Master of Science

Major Field: Natural Resource Ecology and Management

Scope and Method of Study: The goal of this study was to compare attributes of eastern redcedar (*Juniperus virginiana* L.) mulch to other commonly used wood mulches. The expansion of the redcedar mulch market has potential to make economic use of a low-value species while reducing the extent of redcedar encroachment in the Southern Great Plains. We compared redcedar mulch to cypress, pine bark nuggets, pine, hardwood, eucalyptus, and red-dyed mulch as well as two non-mulched controls (with and without herbicide). Measurements included soil moisture, soil temperature, growth and survival of planted annuals, perennials, and trees, weed growth and mulch decomposition.

Findings and Conclusions: Compared to the non-mulched controls, all the mulch treatments increased soil moisture, increased plant growth and decreased weed growth to a similar extent. Percent soil moisture ranged from 24 % to 28 % in the mulched plots. Mulched plots contained more moderate soil moisture than non-mulched controls. Mulched plots maintained lower soil temperatures during the day and warmer soil temperatures at night compared to the non-mulched controls. Annual plant growth in the non-mulched control plots averaged 25 g, compared to 49 g in the mulched plots. Weed growth in the non-mulched control plots averaged 221 g and decreased to 60 g in the mulched plots. Hardwood mulch decomposed the most with 45 % loss over two years. Redcedar and pine bark nugget decomposed the least with 5 % loss over two years. These results indicate redcedar mulch provides similar benefits as other common wood mulches and is a viable forest product.

ADVISER'S APPROVAL: Rodney E. Will