EFFECTS OF COMPOST AND TILLAGE ON SOILS AND NUTRIENT LOSSES IN A SIMULATED RESIDENTIAL LANDSCAPE

By

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To my family

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Soil and landscape management practices at new home sites have the potential to negatively impact soil and water quality. Research has shown that soil management practices such as organic amendment additions or tillage can improve the physical and chemical properties of soil. However, it is not known if these management practices can significantly improve soil conditions in urban settings, specifically new residential areas. The objectives of this study were to evaluate soil treatment effects on: 1) selected soil physical and chemical properties, 2) plant growth and quality, and 3) nutrient losses in runoff and leachate from simulated residential landscapes.

Six soil management treatments were evaluated with four replications (24 total plots) in mixed landscape (mixed ornamental species and turfgrass) plots that were established on compacted soils in a randomized complete block design. The soil management treatments were as follows: unamended soil, tillage only, aeration only, compost only, compost + tillage, and compost + aeration. Composted dairy manure solids were applied as an organic solid amendment at a rate of 508 m^3 ha^{-1} (25% by volume). Tillage treatments turned the soil to a depth of 10-15 cm. Soil physical and

chemical properties, plant growth and quality, plant tissue nutrients, leachate volume and leachate NO_3-N, NH_4-N and dissolved P were assessed periodically.

Applications of compost to soils reduced bulk density and pH and increased soil organic matter, electrical conductivity and concentrations of Mehlich 1 P, K, Ca, and Na. Growth data, with the exception of *Raphiolepis indica*, indicated more growth for ornamental plant species grown in soils amended with composted dairy manure solids. In most instances, plant quality and tissue nutrient content were higher for plants grown in soils receiving compost. Soil treatments and vegetative cover had no affect on P concentrations in leachate. However, there were soil treatment effects on of NO_3 + NO_2 and NH_4 concentration and load in leachate samples at various times throughout the study, where soil receiving compost leached more than unamended soils. Leachate volumes were higher under ornamentals than turfgrass. As a result, N losses (load and concentration) under ornamental cover often exceeded losses from turf. Losses of NO_3 + NO_2 were highest during the early weeks of the study, while NH_4 losses peaked during the warm season as organic N began to mineralize.

Results of our study suggest that the addition of compost to soils can improve soil properties and enhance plant growth in residential landscapes when fill soils are used. In contrast, it appears that shallow tillage and aeration had little effect on soil properties or plant growth and quality. Addition of compost did, however, increase nutrient loads in leachate. This creates concerns that one time application of low C:N ratio organic amendments at a rate of 25-35% by volume to the top six inches of soil may lead to significant N losses. The use of compost as a soil amendment in new residential lawns can be recommended only if the use of inorganic fertilizers is reduced.

CHAPTER 1
LITERATURE REVIEW AND RESEARCH OBJECTIVES

Population Growth and Urbanization

The impact of human activities on soils is intensifying as the world's population continues to grow (Kozlowski, 1999). When an area is urbanized, the natural environment is replaced by roads, homes, and commercial structures (Wickham et al., 2002). Based on amount of land covered, urban lands have a disproportional impact on regional and global systems (Collins et al., 2000; Pickett et al., 2008). Urbanization can lead to changes in local climate, biodiversity, and hydrology, as well as deposition of nutrients and soil disturbance over a large area (Jenerette et al., 2006; Pickett et al., 2008; Pouyat et al., 2006). As the population multiplies, the amount of urban land increases and it becomes more important to manage our soil resources properly. Soil conservation rarely occurs in urbanized areas and soils within these areas are simply labeled 'urban' on soil maps (Jim, 1998). Urban soils are described as 'soil having a non-agriculture, man-made surface produced by mixing, filling, or by contamination of land surface in urban areas" (Bockheim, 1974). Ideally, an urban soil would be able to resist compaction, have sufficient water-holding capacity and permeability, adequate root volume, appropriate soil reaction and fertility, and surface protection (Craul, 1985); however this is rarely the case. As the population grows, more value has also been placed on aesthetically pleasing ornamental landscapes (Hipp et al., 1993). The result is an increase in the use of water, fertilizers and pesticides in urban landscapes, which can lead to water quality and supply issues.

Home Site Construction and the Residential Landscape

During the construction of residential landscapes, most of the resources go toward plant materials and installation, with the soil receiving little attention (Jim, 1998). Often the topsoil is completely removed during preparation of the home site, which reduces soil organic matter and exposes the less fertile subsoil (Scharenbroch et al., 2005). Topsoil material may be stockpiled for future use at the site or removed from the site completely. Construction related activities, such as the use of heavy equipment, the use of fill soil materials, and the installation of impervious surfaces can alter the physical properties of the exposed subsoil.

The landscape is installed once construction is complete. The typical residential landscape contains turfgrass, one or two shade trees, and some shrubs. Plant species are often chosen with no regard for their water or fertilizer requirements or suitability to the area, but rather because they are available and cheap (Hipp et al., 1993). By choosing plants that are not suited to the area (e.g., soils, hardiness zone, etc.), homeowners often must apply supplemental fertilizers and irrigation to their landscapes. This ultimately increases the chance that nutrients will move offsite and pollute local water systems (Hipp et al., 1993). As a result, many homeowner landscape extension programs, such as the Florida Yards and Neighborhoods Program (Florida Yards and Neighborhoods Program, 2006), now encourage the use of landscape materials that are suited for local growing conditions and require less water and fertilizer inputs as a means to reduce pollution from urban areas. Residential landscapes management practices that minimize fertilizer runoff and leaching are advantageous to both public health and the environment (Cisar et al., 2004).

Urbanization and Soil Quality

Urban land management practices (e.g., physical disturbance to land, different cover material, management of inputs and vegetation harvest) play an important role in determining soil characteristics, and can have lasting effects on soil for a long period of time (Jenerette et al., 2006). Various construction practices (such as removal of the topsoil, heavy traffic, compaction of the site) during construction of urban landscapes, result in higher variability of soil conditions than would be found in undisturbed soils (Hamilton and Waddington, 1999). For example, Pouyat et al. (2007) found large variability in surface soil properties of sandy loam soils (e.g., soil bulk density, amount of organic matter, particle size, pH, and nutrient quantities) along an urban-rural land use gradient. Urban development can cause a loss of organic matter, loss of soil structure, decreased permeability, and increased compaction (Cogger, 2005).

Compaction has been documented in many urban soils and is generally acknowledged as an obstacle for plant establishment in urban systems (Randrup and Dralle, 1997; Smith and Lawrence, 1985). While compaction is often intentional for site stabilization, it can also be caused inadvertently by heavy equipment that is driven across the soil (Gregory et al., 2006). Soil compaction in urban soils is a common and persistent occurrence, with bulk densities ranging from normal (approximately 1.4 g cm^{-3}) to extremely packed (2.2 g cm^{-3}) (Jim, 1998). One study reported bulk densities around 1.8 g cm^{-3} in residential landscapes (Lichter and Lindsey, 1994). Individual site sensitivity to compaction is a function of local climate, soil characteristics (Whalley et al., 1995) and the type of construction equipment being used (Gregory et al., 2006). Changes to soil physical properties that occur as a result of compaction include: surface crusting, destruction of soil aggregates, reduction of average pore size, increased soil strength, and increased bulk density (Gregory et al., 2006; Jim, 1998; Shestak and Busse, 2005). These changes can lead to problems such as decreased infiltration, reduced water-holding capacity, and increased mechanical root impedance (Craul, 1994), all of which pose serious restrictions to plant development (Jim, 1998).

Proper land management is important to protect soil function (e.g. infiltration, nutrient cycling) and to maintain the health and durability of plants. Poor urban soil management decisions often lead to problems including: 1) limited root development, which is needed for healthy plant establishment and 2) a reduction in infiltration rates, which leads to runoff and nutrient loss. The current approach to soil management does not address the problems facing plant establishment and pollution concerns (Jim, 1998). Soil conservation and fertility management practices that are based on sound scientific principles are needed in urban areas. Specifically, it is important to take precautions to reduce the occurrence of compaction when developing a residential landscape (Randrup, 1997). Developers must plan appropriately to account for individual site sensitivity to compaction because plant and lawn failure and increased pollution can stem from improper planning. If the developer can factor in the significance of the soil from the beginning, management of the residential landscape after development will be less demanding (Randrup, 1997).

Urbanization and Soil Hydrology

Urbanization has a greater affect on the hydrology of an area than any other change in land use (Hamilton and Waddington, 1999). Conversion of land from natural conditions to agriculture or urban land use greatly alters the hydrologic characteristics of the land surface and modifies the pathway and rate of water flow (Bai et al., 2008). In urban ecosystems, the land is covered with impervious surfaces and artificial drainage systems are installed, both of which affect water movement by increasing runoff and limiting infiltration (Kaye et al., 2006). As a result, urban areas with large population densities have the potential to strongly influence water resources throughout the world (Cisar et al., 2004).

Soil compaction that results from construction activities also influences urban hydrology by affecting infiltration rates and other hydraulic properties of the soil that directly affect surface runoff, erosion, and groundwater recharge (Defossez and Richard, 2002; Gregory et al., 2006; Hamilton and Waddington, 1999). A study by Zhang et al. (2005) evaluated three different levels of soil compaction on the hydraulic properties of two silt loam soils from the Loess Plateau, China. Results showed that compaction of soils (bulk density range = 1.60 – 1.69 g cm^{-3}) changed the water retention curve and decreased the hydraulic conductivity of both soils. Gregory et al. (2006) quantified the effects of construction activities on soil infiltration rate of fine sand soils at urban development sites. They found that compaction caused by heavy construction equipment resulted in an overall decrease in infiltration rates from 733 to 178 mm hr^{-1}, which corresponded with an increase in soil bulk density from 1.34 to 1.40 g cm^{-3} after compaction. The study concluded that soil compaction has a negative effect on infiltration rates in sandy soils and advised avoiding soil compaction to reduce runoff. Meek et al. (1992) evaluated a sandy loam soil and found that infiltration and hydraulic conductivity decreased by 53 and 58%, respectively as bulk density increased from 1.6 to 1.8 g cm^{-3}. A study by Hamilton and Waddington (1999) observed infiltration rates in 15 lawns and suggested that activities, such as topsoil stripping, site traffic, disposal of construction debris, and soil stratification, can have a significant effect on soil infiltration rates. The potential for surface runoff from residential landscapes is increased if the soils are compacted and receive intense rainfall (Cisar et al., 2004).

Urbanization, Landscape Management and Water Quality

In the past, traditional agriculture has received most of the blame for off-site pollution of nutrients, however urban lands can also contribute nutrients to surface water and groundwater (Shuman, 2003). Urbanization and land use have been linked to water quality degradation. In fact, more than 50% of Florida's water resources are affected by urban non-point source pollution, which includes nutrients originating from residential landscape (Association of State and Interstate Water Pollution Control Administrators, 1984). For example, an increase in NO_3-N was highly correlated with county population growth at the Weeki Wachee Springs in Hernando County, FL (Cisar et al., 2004). The loss of nutrients from residential and commercial landscapes can pose economic losses to homeowners and nutrient losses to plants, as well as have ecological consequences (Cisar et al., 2004; Erickson et al., 2005; Gross et al., 1990). Both N and P pose a risk to water quality at relatively low levels, ranging from 0.01 to 0.035 mg L^{-1} for P and 10 mg L^{-1} for NO_3 (as set by EPA for human safety) (Erickson et al., 2001; Mallin and Wheeler, 2000). Coastal areas are often N-limited and may be degraded by NO_3-N levels lower than the drinking standard (10 mg L^{-1}) (Cisar et al., 2004). Residential land is managed more intensely than agricultural land, which can result in greater losses of N and P from urban systems than from agricultural systems (Bhattarai et al., 2008). As a result, the runoff from urban areas may contain significant levels of N, P, and pesticides due to excessive fertilizer application rates and improper timing of application (Hipp et al., 1993). The rate of chemicals (such as pesticides and fertilizers) applied, the soil moisture content, plant irrigation requirements, and the soil infiltration rate are important factors that affect amount chemicals and nutrients runoff from landscapes (Cisar et al., 2004; Erickson et al., 2005; Hipp et al., 1993).

A large amount of the land is devoted to turfgrass in urban areas (Gross et al., 1990). Considerable inputs of water and fertilizers are needed to establish and maintain healthy, high quality turf (King et al., 2001). Turf dominated landscapes may receive yearly nitrogen and phosphorus applications in excess of 450 kg N ha^{-1} and 100 kg P ha^{-1} (Hipp et al., 1993). For example, St. Augustine turfgrass, the most common turfgrass species used in Florida, receives 150 to 300 kg N ha^{-1} when properly fertilized (Cisar et al., 2004). It is recommended that turf irrigation be deep and infrequent to avoid wilting, with the time and amount of water to apply depending on application rates, month of the year and the climate of the area (Dukes, 2008). In Florida, turfgrass evapotranspiration (ET) demands during dry periods rates range from 3.2-3.3 in per month in cooler months and 5.1-5.7 in per month in warmer months (Dukes, 2008). These high nutrient and water requirements make turf systems a probable source of non-point source nutrient pollution to surface and groundwater bodies. Elevated levels of N in watersheds is thought to be a result of fertilizer N runoff and leaching from originating from residential landscapes where turfgrass is routinely fertilized (Erickson et al., 2001). However, slower runoff velocities and increased infiltration of water are expected when turf is intensely managed (Gross et al., 1990).

Turfgrass and ornamentals reside together in the landscapes and generally receive similar fertilization and irrigation (Saha et al., 2005), despite the fact that the nutrient and water requirements of ornamental plants differ widely from those of turfgrass species. There is significantly less information on te irrigation requirements of ornamentals are less known because of the wide range of plants and the lack of scientific research (Dukes, 2008). Similarly, information about the fertilizer requirements of annuals and perennials in the landscape is lacking. However, a few studies have investigated optimum fertilization of ornamental plants growing in the landscape; most have focused on the nutrient requirements of selected woody shrubs and tree species. In general, woody ornamentals likely require less N, P, and K than turfgrass species or more demanding landscape plant types (e.g., annuals, flowering perennials).

Homeowners may be inclined to add additional fertilizers to their plants when they are not performing as expected, regardless of whether the problem can be attributed to a nutrient deficiency problem. The application of nutrients in excess of plant needs in fertilizers increases the potential for nutrients to leach (Shuman, 2003) from or runoff the landscape. Therefore, residential landscape management practices that minimize fertilizer N in runoff and leachate are advantageous to both humans and the environment (Cisar et al., 2004). Alternatively, Hipp et al. (1993) suggested that establishment of low maintenance landscapes is a practical approach to help prevent pollution because it should reduce chemical input and also runoff from residential landscapes.

Urbanization and Plant Quality

Although urban soils differ from natural soils, the characteristics that support optimal plant growth are the same for both types (Jim, 1998; Whalley et al., 1995). Plants need adequate soil aeration (Unger and Kaspar, 1994), nutrients, and water supply to function and establish properly. However, urban soils often lack these characteristics due to disturbances that occur during construction. Soil compaction, is one of the most common problems stemming from construction in urban soils. Changes in bulk density that are associated with soil compaction can alter the volumetric water content of the soil, the movement of water in response to water content gradients, the root-soil contact, and the level of mechanical impedance to root growth (Stirzaker et al., 1996).

Research has shown that soil compaction impacts root length, root diameter, and the volume of soil that roots are able to explore (Stirzaker et al., 1996; Watson and Kelsey, 2005). For example, Montagu et al. (2001) showed that root growth of broccoli seedlings was slowed in a compacted soil. Smiley et al. (2006) reported longer root length and less shoot dieback when Snowgoose cherry (*Prunus serrulata*) and Bosque lacebark elm (*Ulmus parviflia*) trees were grown in uncompacted soils compared with plants grown in compacted or structural soils. A study by Stirzaker et al. (1996) found that root length of assorted grasses and clovers was greatest at lower bulk densities and began to shorten as soil bulk density increased. Agronomic crops grown in compacted soil have fewer lateral roots and less dry matter than plants grown under managed conditions at both low and high soil water contents (Hamza and Anderson, 2005).

Soil compaction affects root growth and development by restricting oxygen, water, and nutrient supply (Glab, 2007). Since most nutrients have limited mobility in soils, roots need to grow to the nutrients to absorb them. However, the air-filled pores that are needed to help roots penetrate the soil, and the water-filled pores that are responsible for plant uptake and nutrient transport are often destroyed when soils are compacted (Stirzaker et al., 1996). Plus, since root growth and spread is often restricted in compacted soils, the ability of plants to capture water and nutrients is also limited (Jim, 1998; Stirzaker et al., 1996; Unger and Kaspar, 1994; Whalley et al., 1995). Soil compaction also limits soil nutrient holding capacity, reducing the amount of nutrients held in available forms to a level that is inadequate to maintain vigorous plant performance (Jim, 1998).

The extent of root reduction is mostly dependent on the depth that the compacted restrictive layer occurred within the soil profile (Unger and Kaspar, 1994). A shallow compacted layer that prevents root penetration is very damaging to plant growth and yield when plants are dependent on only precipitation for their water supply; under these conditions plants will quickly remove plant-available soil water and the plant will exhibit water stress (Unger and Kaspar, 1994). While root limitation has been found to be detrimental, Smith et al. (2001) concluded that roots continued to establish in compacted soils when high levels of available water were maintained.

Restrictions on root growth that occur as a result of soil compaction can also affect shoot growth and plant vigor (Glab, 2007; Jim, 1998; Watson and Kelsey, 2005). Montague (2001) reported a strong correlation between root length and leaf area, indicating that shoot growth was reduced when total root length was reduced. Smiley et al. (2006) linked tree decline at development sites to soil compaction and degradation of the root environment. When roots growth is restricted in compacted soils, chemical signals within the plant can reduce the size of mature cell in leaves and the number of leaves so plants do not grow as full as they would in uncompacted soils (Beemster and Masle, 1996; Montagu et al., 2001; Mulholland et al., 1999).

Soil Management Practices

Proper soil management during construction may improve the survival rate of turfgrass and landscape plants and reduce the potential for nutrients losses in runoff or leachate. For plant survival, soil management should protect or improve conditions so that roots are able to form and penetrate different soil layers (Whalley et al., 1995). To reduce nutrient loss potential, soil management should protect or improve the hydraulic conditions. In both cases, soil management should protect the soil from compaction. Randrup (1997) made the following recommendations for dealing with compaction on construction sites: 1) expect the soil to be compacted, 2) prevent additional compaction, and 3) fence off planting sites to prevent compaction. While reducing compaction as much as possible is recommended, methods to prevent soil compaction should be considered prior to construction (Hanks and Lewandowski, 2003). However, once soil is compacted, there may be a few options for improving compacted soils.

Tillage

When topsoil is removed, tillage of the subsoil before development would be beneficial, since compaction often occurs in the subsoil. Tillage breaks up soil aggregates creating more pore space, thereby allowing water to infiltrate and roots to penetrate through the soil profile (Lipiec and Stepniewski, 1995; Vogeler et al., 2005). To alleviate compaction in subsurface soil horizons, tillage equipment needs to reach a depth of two feet or more (Randrup, 1997). Deep tillage allows root growth into deeper soil horizons that have more structure development and greater water-holding capacity (Busscher et al., 2006; Lipiec and Stepniewski, 1995). A study by da Silva et al. (1997) concluded that tillage contributed to a decrease bulk density by increasing the resistance of the soil aggregates to compaction or by increasing recovery of the compacted soil after the compressive pressure was removed. Research also suggests that spike and core aeration and rototilling can alleviate soil compaction (Jim, 1993; Kozlowski, 1999; Unger and Kasper, 1994).

Organic Amendments

The application of organic amendments to soil is gaining favor as an environmental waste management strategy and as a way to improve soil conditions in low-fertility soils (Flavel and Murphy, 2006). The addition of compost increases soil organic matter, which helps to retain soil water, thereby increasing plant available water (Hamza and Anderson, 2005). Studies have shown that organic amendments can also have a positive effect on soil bulk density and aggregate stability, especially in course-textured soils (Cogger, 2005; da Silva et al., 1997). Similarly, Rivenshield and Bassuk (2007) showed that a sandy loam soil and a clay loam soil, when amended with peat or food waste compost, had lower bulk density and higher macroporosity than those that were not amended, even after recompaction. Applying organic amendments at higher rates led to more pronounced improvements in density and macroporosity (Rivenshield and Bassuk, 2007). Johnson et al. (2006) also reported that soil bulk density in a clay loam soil decreased as the rate of compost (added as a topdress) increased. Another study attributed an increase in water content and soil water retention to the application of composted yard waste to a sandy soil (Pandey and Shukla, 2006). Organic amendments have been shown to improve soil's physical and hydraulic properties for years after application (Ginting et al., 2003). However, in a warm and moist climates , the rate of organic matter decomposition is fast and different characteristics in organic amendments can lead to large differences in the organic matter content of the soil (Albiach et al., 2001).

The use of organic amendments during turfgrass establishment has been shown to increase soil water-holding capacity, porosity, and surface area, thereby providing an environment that will allow for the growth of healthy root systems (Cogger, 2005). Studies showed that Kentucky bluegrass establishment could be enhanced by amending the soil with selected organic compost amendments (Landschoot and McNitt, 2004; Linde and Hepner, 2005). Compost amendment treatments provided longer turfgrass response than one-time fertilizer treatments and composted land is likely to have fewer weeds (Linde and Hepner, 2005).

The application rate of organic amendments in agricultural systems is often based on N content of the material, N mineralization, and crop requirement, and often leads to applications of P in excess of plant needs (Davis et al., 1997; Jaber et al., 2005). In contrast, organic amendments are usually added to soils in turf systems in addition to inorganic fertilizers without taking into account the nutrient content of the amendment (Gaudreau et al., 2002; Johnson et al., 2006). This can lead to an increase in soil nutrient concentrations and the potential for nutrients to be lost in runoff or leachate. Although compost is generally applied to add organic matter (OM) to the soil, the nutrients supplied by compost additions are also beneficial to plants (Landschoot and McNitt, 2004). Composts contain all essential plant nutrients; however, the amount and availability of these nutrients varies depending on the compost source (Cogger, 2005).

The availability of some nutrients, such as N, in composted materials is lower when compared with un-composted materials because decomposition of organic material converts soluble nutrients into organically-bound forms (Cogger, 2005). Wright et al. (2007b) found that water-extractable micronutrients concentrations in compost amended soils decreased to below recorded background levels because the addition of compost caused dissolved organic matter to occupy exchange sites to soil particles instead of micronutrients. Stamatiadis et al. (1999) found that despite applying a compost with high NO_3 content, NO_3 levels in the soil were low and similar to the unamended control soils, suggesting that NO_3 may have been lost through leaching, root uptake, or immobilization and denitrification processes. Johnson et al. (2006) reported no difference in soil NO_3 content when organic dairy cattle manure compost was applied at rates of 0, 33, 66, and 99 $m^3\ ha^{-1}$. The same study found that soil concentrations of P and K increased as compost application rates increased; soil P content of compost amended soils were 187% higher than the in unamended soils. Organic amendments (such as compost) should be managed in a way that minimizes the potential for nutrient loss but still optimizes the effects of the amendment on infiltration, root growth, and compaction (Wright et al., 2007a).

Current Research and Needs

Soil and landscape management practices at new home sites have the potential to negatively impact soil and water quality. Best management practices need to be developed and implemented in order to minimize the effect of urbanization on soil and water quality and supply. These management practices must be low cost, energy efficient, sustainable, and ecologically sound (Whalley et al., 1995). However, more studies are needed to fully understand the impact of soil damage to root systems and plant health (Watson and Kelsey, 2005). Land developers need to consider the importance of the root environment and implement practices that coincide with this into their management. Improved management of urban soils and landscapes will lead to an improvement in soil and plant properties and aesthetic enhancement of the landscape.

The purpose of this study was to determine the effects of application of composted dairy manure solids and tillage practices could reduce the negative impacts of poor soil management practices that lead to issues such as compaction, poor soil fertility, and nutrient loss in newly established landscapes. The specific objectives for the research were to evaluate soil treatment effects on: 1) selected soil physical and chemical properties, 2) plant growth and quality, and 3) nutrient losses in runoff and leachate. A secondary objective was to determine the effect of vegetative cover type (e.g., turf, ornamental landscape plants) on the potential for nutrient leaching from urban landscapes.

CHAPTER 2
EFFECTS OF TILLAGE AND ORGANIC AMENDMENTS ON SOIL PROPERTIES IN A SIMULATED RESIDENTIAL LANDSCAPE

Introduction

In recent years, Florida has been one of the fastest growing states in the United States. The U.S. Census Bureau forecasts that the population of Florida will increase from 17.8 million people in 2005 to approximately 23.4 million people by 2020 (U.S. Census Bureau, 2004). In many cases, rural land will be converted to urban uses to accommodate the growing population (Heimlich and Krupa, 1994). During urbanization, natural ecosystems are replaced by roads, homes, and commercial structures (Wickham et al., 2002). Construction and other human activities associated with urbanization also cause significant disturbance to soils. Studies have shown that urban soils often lack natural soil horizons (Jim, 1998), are significantly compacted (Gregory et al., 2006; Jim, 1998), can have alkaline pH as a result of carbonate release from the calcareous construction waste, and contain low amounts of soil organic matter (OM), N, and P (Jim, 1998; Law et al., 2004). As a result, urban soils often require different management strategies than those applied to natural or agricultural soils (Kaye et al., 2006).

Residential construction activities can drastically alter soil physical, chemical, and biological properties. During residential construction, topsoil is often removed from the site exposing the subsoil (Hamilton and Waddington, 1999). Topsoil material may be stockpiled for future use at the site or removed completely. Construction related activities, such as the use of heavy equipment, the use of fill soil materials, and installation of impervious surfaces can alter the physical properties of the exposed subsoil. Compaction, which is quantified by high bulk density, is one of the most common and persistent problems in urban soils (Jim, 1998). Compaction of the soil can be an unintentional result of heavy equipment use and lot grading, or an intentional result of preparing a site to increase structural strength of the soil (Gregory et al., 2006). Research has shown that bulk densities can range from 1.4 g cm^{-3} (normal) to 2.2 g cm^{-3} (extremely packed) in urban soils (Jim, 1998). Similarly, Lichter and Lindsey (1994) reported a bulk density of approximately 1.8 g cm^{-3} for residential landscapes. When soils are compacted, aggregates are destroyed and soil porosity decreases. As a result, water holding capacity of the soil is decreased, the movement of air and water is reduced and root spread is restricted, ultimately creating an environment that is unsuitable for plant growth (Craul, 1994).

Soil hydraulic properties are also impacted by compaction that occurs during urbanization. For example, a study by Zhang et al. (2005) found that a 10% and 20% increase in soil bulk density significantly reduced the saturated hydraulic conductivity of two silt loam soils, thereby affecting soil water retention. Gregory et al. (2006) reported an overall decrease of the infiltration rate of sandy soils at a residential construction site, which corresponded with the increase in soil bulk density after compaction that occurred from the use of heavy construction equipment. Infiltration rate directly affects surface runoff, erosion and groundwater recharge (Hamilton and Waddington, 1999). The potential for surface runoff from residential landscapes is increased when soils with low infiltration rates, resulting from soil compaction, receive intense rainfall or excessive irrigation (Cisar et al., 2004).

Tillage can be used to improve the physical properties of compacted soils. In compacted soils, tillage breaks up massive structure thereby increasing soil pore space and allowing water to infiltrate and roots to penetrate through the soil profile (Lipiec and Stepniewski, 1995). da Silva et al. (1997) reported that relative bulk density, which is the ratio of the bulk density of a soil to the bulk density under standard compaction treatment (i.e., samples placed under 200 kPa of pressure), was lower in soils receiving conventional tillage (0.79) when compared with no-till soils (0.87). Vogeler et al. (2005) also reported that conventional tillage decreased the soil strength and increased porosity in a sandy loam agricultural topsoil.

The addition of organic amendments (e.g., compost or manure) to soils has been shown to improve soil function by increasing water-holding capacity, porosity, and surface area (Cogger, 2005). Zhang (1994) found that moisture retention of silt loam and clay soil aggregates was enhanced when peat moss was added to the soil as a source of organic matter. Adding organic amendments to maintain adequate levels of soil OM by can help to stabilize soil structure (Thomas et al., 1996). Organic amendments have also been shown to decrease soil bulk density when applied to soils (Curtis and Claassen, 2009). Curtis and Claassen (2009) found that tillage and application of composted yard waste decreased the bulk density in four soils (with soil texture ranging from loam to sand) of severely disturbed soils in northern California compared to non-tilled treatment. Cogger et al. (2008) also reported a decrease in soil bulk density when compost was incorporated in to soils in landscape beds.

The addition of organic amendments can also affects soil chemical properties. Ginting et al. (2003) reported that the pH of soils amended with beef cattle manure or composted feedlot manure (mean pH = 6.5) was consistently higher than soils fertilized with inorganic fertilizers or unamended soils (mean pH = 6.2). Calcium carbonates found in land applied manures have been shown to increase soil pH (Eghball and Power, 1999). Ginting et al. (2003) also found that soil EC was higher when soils were amended with composted feedlot manure soils (0.49 dS m^{-1}) compared with unamended soils (0.34 dS m^{-1}).

Although compost is generally applied to add OM to the soil, the nutrients supplied by compost additions are also beneficial to plants (Landschoot and McNitt, 2004). Composts contain all essential plant nutrients; however, the amount and availability of these nutrients varies depending on the compost source (Cogger, 2005). The availability of some nutrients, such as N, in composted materials is lower when compared with un-composted materials because decomposition of organic material converts soluble nutrients into organically-bound forms (Cogger, 2005). Stamatiadis et al. (1999) found that despite applying a compost with high NO_3 content, NO_3 levels in the soil were low and similar to the unamended control soils, suggesting that NO_3 may have been lost through leaching, root uptake, or immobilization and denitrification processes. Johnson et al. (2006) reported no difference in soil NO_3 content when organic dairy cattle manure compost was applied at rates of 0, 33, 66, and 99 m^3 ha^{-1}. The same study found that soil concentrations of P and K increased as compost application rates increased; soil P content of compost amended soils were 187% higher than in unamended soils.

There is a need to develop soil management practices that can minimize the effects of soil disturbance in residential landscapes. While research has shown that soil management practices such as organic amendment additions or tillage can improve the physical and chemical properties of soil, much of the research has been conducted in agricultural systems (Martens and Frankenberger, 1992). However, it is not known if these management practices can significantly improve soil conditions in urban settings, specifically new residential areas, where disturbance of the soil may contribute to environmental degradation. The objective of this study was to determine the effects of adding compost and/or applying shallow tillage on soil physical and chemical properties in a simulated new residential landscape.

Material and Methods

Experimental Design

Twenty-four mixed landscape plots (3.05 m x 3.66 m) were established in a randomized complete block design at the University of Florida – Institute of Food and Agricultural Sciences (IFAS) Gulf Coast Research and Education Center in Wimauma, FL to simulate new residential landscapes. All vegetation was removed from the site before plot construction. The entire research area was prepared at a 2% grade (as is typically required by construction codes) and compacted (bulk density range: 1.7-1.9 g cm^{-3}) using a small plate compactor (Wacker Neuson, Munich, Germa0ny). Individual landscape plots were constructed inside water-sealed treated wooden boxes. Within each plot, the compacted field soil (Zolfo fine sand; sandy, siliceous, hyperthermic Oxyaquic Alorthods) (USDA-NRCS, 2004) was then buried under 1.13 m^3 of un-compacted soil fill material. Soil fill material was created by mixing three fill soil materials in equal parts to simulate a ‘top soil’ material that would be applied during residential construction. The three fill soil material sources included: a subsoil fill containing construction material and other debris; a clean topsoil material (St. Johns fine sand; sandy, siliceous, hyperthermic Typic Alaquod) obtained from depth of 30 to

60 cm (Hills Dirt Pit, LLC., Riverview, FL), and a clean subsoil fill (St. Johns fine sand) fill obtained from a depth of 122 to 213 cm (Hills Dirt Pit, LLC., Riverview, FL).

Composted dairy manure solids (compost; Agrigy, Palm Harbor, FL) were applied as an organic soil amendment at a rate of 508 m^3 ha^{-1} (approximately 256 Mg ha^{-1}) in combination with two mechanical soil treatments (tillage and aeration) for a total of five soil management treatments. The soil management treatments were as follows: 1) tillage only, 2) compost only, 3) compost + tillage, 4) aeration only, 5) compost + aeration. In plots receiving the tillage treatment, soil was turned to a depth of 10-15 cm using counter rotating tines tiller (Sears Brands, LLC, Hoffman Estates, IL). In plots receiving the aeration treatment, soil aeration plugs were mechanically removed using a core aerator (Billy Goat Industries, Inc., Lee's Summit, MO). An untreated control plot (no tillage or organic amendment) was included as the sixth soil treatment.

Once soil treatments were applied, each plot was split and 5.58 m^2 of the plot was planted with *Stenotaphrum secundatum* (Walter) Kuntze (St. Augustine turfgrass); the remaining 5.58 m^2 was planted with mixed ornamentals. Mixed ornamentals species included *Galphimia glauca* Cav. (Thryallis), *Rhaphiolepis indica* (L.) Lindl. ex Ker Gawl. (Indian hawthorn), *Ilex cornuta 'Burfordi'* Lindl. & Paxton (Buford holly), and *Liriope muscari* (Decne.) L. H. Bailey (Liriope). Turfgrass was fertilized at a total N rate of 220 kg ha^{-1} based on current University of Florida – Institute of Food and Agricultural Sciences (UF-IFAS) recommendations (moderate maintenance schedule for South Florida): 48.8 kg N ha^{-1} per application using Lesco Professional turf fertilizer (26-2-11) in February and October, 48.8 kg N ha^{-1} per application using polymer coated urea (42-0-0; Harrell's Professional Fertilizer Solutions, Lakeland, FL) as a slow-release N source in May and August, 24.4 kg N ha^{-1} with urea (46-0-0; Potash Corp., Northbrook, IL) as a soluble N source, and 6.34 L ha^{-1} of ferrous sulfate (Sunniland Corporation, Sanford, FL) in July (Sartain, 2007). Ornamental plants were fertilized every 3 months with urea (40-0-0) at an N rate of 97.6 kg ha^{-1} based on UF-IFAS recommendations for established woody ornamentals grown in the landscape (Knox et al., 2002).

The entire research plot area was equipped with a spray irrigation system, which allowed for individual landscape plots to be irrigated, as needed, based on UF-IFAS recommendations (Zazueta et al., 2005). During establishment, plots were watered daily for 30 d after planting to allow for establishment of turf and ornamental plant material. Irrigation frequency was then reduced to two days a week based on typical watering restrictions for landscape irrigation that would be mandated in times of drought (South Florida Water Management District, 2008; St. Johns River Water Management District, 2008). Irrigation was applied for 51 min (irrigation controller run time for two irrigation events per week at an application rate of 0.13 cm per hour, assuming system efficiency of 80% and considering effective rainfall) per plot on Mondays and Thursdays starting at 0300 HR and ending around 0900 HR.

Compost and Soil Characterization

Selected physical and chemical properties of the compost were determined before it was added to the plots as an organic soil amendment. A bulk sample was air-dried at room temperature (25 ± 2ºC) and sieved to pass a 2-mm screen. The pH and EC of the compost was determined using the slurry method and organic matter was determined by loss on ignition (US Composting Council, 2002). Total C and N concentrations were determined with a Carlo-Erba NA 1500 CNS Analyzer (Haak-Buchler Instruments, Saddlebrook, NJ) to determine C to N ratio. Nutrient content was determined on a separate compost sample collected from the same dairy as the compost used in our study (Shober, unpublished data). Nutrient content was determined by digesting the compost using the EPA 3050 hot-acid digestion (USEPA, 1986) and analyzing the sample for digestible P, Al, Fe, Ca, Mg, and K using inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Perkin Elmer, Waltham, MA).

Soil physical and chemical characteristics were measured before tillage and compost treatments were added and then repeated every 3 months (0, 13, 27, 40, and 52 weeks after treatment [WAT] for a period of one year. Composite soil samples were collected from each plot at 0-10 cm and 10-20 cm depths using a soil probe. Samples were then air-dried at room temperature (25 ± 2ºC) and sieved to pass a 2-mm screen. Soil pH (1:2 soil to deionized water ratio), electrical conductivity (EC; 1:2 soil to deionized water ratio) and organic matter (OM; loss on ignition) were determined by standard methods of the UF Extension Soil Testing Laboratory (Mylavarapu and Kennelley, 2002). Soil moisture content at field capacity was determined by the method described in Tan (1996) and particle size was determined by the hydrometer method (Bouyoucos, 1962). There were no significant changes in soil composition throughout the study; the soils were predominantly sand (mean = 88%), with very little silt (mean = 5%) and little clay (mean = 6%) (Appendix A). Bulk density was measured using the core method (Blake and Hartge, 1986) and infiltration rate was determined using a double-ring infiltrometer (Bouwer, 1986) separately for ornamental and turfgrass cover. The composite soil samples were analyzed for soil test P, K, Mg, Ca, Al, and Fe by Mehlich-1 extraction (1:4 ratio of soil to 0.0125 M H_2SO_4 + 0.05 M HCl). Mehlich-1 extracts were analyzed by ICP-AES. Results from 10-20 cm depth showed little treatment effects and, therefore, are reported in Appendix A.

Data Analysis

The experiment was designed as randomized complete block split-plot design with 4 blocks and 6 soil treatments in each block. Half of each plot was planted with ornamental plants and the other ½ was planted with turfgrass as described previously. The soil treatments were assigned randomly within each block. Soil properties were analyzed using the PROC MIXED procedure in SAS with soil treatment as a fixed effect and block as a random effect (SAS Institute, 2003). All comparisons were completed using the Tukey honestly significant difference (HSD) test with a significance level of $\alpha = 0.05$.

Results and Discussion

Compost and Initial Soil Characterization

Initial compost samples had a pH of 6.59, an EC of 1.02 dS m^{-1} and a total carbon to nitrogen (C:N) ratio of 13.6 (Table 2-2). Li et al. (2009) reported a pH of 6.9, an EC of 4.8 dS m^{-1} and a C:N ratio of 15.1 for a separate batch of compost produced at the same dairy as the compost used in our study. Compost nutrient analysis was reported in a previous study (Shober, unpublished data) (Table 2-2). Addition of compost to the plots supplied significant amounts of N, P, and other essential plant nutrients in addition to the inorganic fertilizers applied to the plots. Plots that received compost applications received approximately 3,277 kg total N ha^{-1}.

Initial soil samples were divided between the topsoil fill (0-10 cm depth) and the native field soil (10-20 cm). The topsoil had a pH of 7.5 and an EC of 0.30 dS m^{-1}. The field soil had a pH of 6.5 and EC of 0.49 dS m^{-1}. Initial nutrient content analysis of the native field soil showed lower nutrient concentrations, with the exception of P, when compared to the topsoil (Table 2-1). Phosphorus levels of the topsoil and the native field soil were very high (145 and 77.6 mg kg^{-1}, respectively). In addition, levels of Mehlich 1 K were medium, while Mg was very high. Only applications of N and K fertilizers would be recommended for these soils (Kidder et al., 1998). Initial soil texture classification indicated that the topsoil fill was loamy sand and the native field soil was sand.

Table 2-1**.** Selected chemical properties of the composted dairy manure solids applied to simulated residential landscapes as an organic soil amendment.

Chemical Property	Compost
pH	6.59
EC, dS m^{-1}	1.02
Total C, g kg^{-1}	174
Total N, g kg^{-1}	12.8
C:N ratio	13.6
EPA_{3050} P, mg kg^{-1}†	5410
EPA_{3050} Al, mg kg^{-1}†	1238
EPA_{3050} Ca, mg kg^{-1}†	12038
EPA_{3050} Fe, mg kg^{-1}†	9149
EPA_{3050} K, mg kg^{-1}†	5362
EPA_{3050} Mg, mg kg^{-1}†	2560
EPA_{3050} Mn, mg kg^{-1}†	76
EPA_{3050} Na, mg kg^{-1}†	1124

† EPA3050 nutrient concentrations determined on separate sample of composted dairy manure solids from the same dairy that supplied the compost for our study (Shober, unpublished data).

Table 2-2. Selected initial physical and chemical properties of topsoil fill and the native subsoil used in simulated residential landscape plots.

Soil Property	Topsoil Fill	Native Field Soil
pH	7.5	6.5
EC, dS m^{-1}	0.3	0.49
Soil texture	Loamy sand	Sand
Mehlich 1 P, mg kg^{-1}	145	77.6
Mehlich 1 K, mg kg^{-1}	20.2	9.7
Mehlich 1 Mg, mg kg^{-1}	81.7	18.3
Mehlich 1 Ca, mg kg^{-1}	2300	386

Bulk Density

Due to a significant soil treatment × vegetative cover interaction at 13, 40 and 52 WAT (week after treatment), soil bulk density was analyzed separately for each type of vegetation (i.e., mixed ornamentals, turfgrass). Soil bulk density under mixed ornamental vegetation was significantly lower for compost amended soils (1.00, 1.25, 1.09 and 1.07 g cm^{-3} at 13, 27, 40 and 52 WAT, respectively) when compared with unamended soils (1.65, 1.72, 1.59, and 1.68 g cm^{-3} at 13, 27, 40 and 52 WAT, respectively) (Table 2-3). In addition, soil bulk density was significantly lower when compost was tilled to 20 cm (1.40 g cm^{-3}) than composted soils that were aerated (1.68 g cm^{-3}). Under turfgrass cover, soil bulk density was significantly lower for composted soils at 27 and 40 WAT (1.37 and 1.41 g cm-3 at 27 and 40 WAT, respectively) than unamended soils (1.56 and 1.56 g cm^{-3} at 27 and 40 WAT, respectively) (Table 2-4). No soil treatment effects were reported at 13 or 52 WAT under turfgrass vegetation.

Rivenshield and Bassuk (2003) reported that amending both a sandy loam and a clay loam soil with peat or food waste compost resulted in lower soil bulk density and higher macroporosity than unamended soils. Johnson et al. (2006) also reported lower soil bulk density (1.17-1.46 g cm^{-3}) on a clay loam soil, under Kentucky Bluegrass turf at a depth of 0-15 cm when soils were amended with organic dairy cattle manure compost, when compared to the control.

Table 2-3. Bulk density of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	g cm^{-3}			
Control	1.66a‡	1.68ac	1.63a	1.65a
Tillage Only	1.63a	1.81a	1.58a	1.68a
Aeration Only	1.67a	1.67ab	1.58a	1.71a
Compost Only	0.92b	1.28bc	0.95b	0.85b
Compost + Tillage	1.14b	1.32ab	1.17b	1.25b
Compost + Aeration	0.95b	1.15b	1.16b	1.12b

† WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Table 2-4. Bulk density of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with St. Augustine turfgrass at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	g cm^{-3}			
Control	1.51a‡	1.57a	1.49ab	1.50a
Tillage Only	1.57a	1.52ab	1.64a	1.6a
Aeration Only	1.36a	1.58a	1.55ab	1.52a
Compost Only	1.49b	1.51ab	1.40b	1.45a
Compost + Tillage	1.32b	1.24b	1.33ab	1.3a
Compost + Aeration	1.52b	1.36ab	1.5ab	1.33a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Infiltration

Soil infiltration rates were not influenced by soil treatment at any time during the study (Table 2-5 and 2-6). These results differ from those of Weindorf et al. (2006), where infiltration rate increased when clay rich soils were amended with yard waste compost. Meek et al. (1992) also found that infiltration rate increased by >50% when bulk density of a sandy loam was decreased from 1.8 to 1.6 g cm^{-3}. Similarly, Gregory et al. (2006) reported an increase in the infiltration rate of a fine sand from 733 to 178 mm hr^{-1} when heavy construction equipment caused an increase in bulk density from 1.34 to 1.49 g cm^{-3}. The lack of treatment effect on soil infiltration in our study could be due to the high sand content and low clay content of the fill and field soils used in the landscape plots (Table 2-1). Even though our buried field soil was compacted (10-20 cm), the mean soil bulk density reported at the 0-10 and 10-20 cm depths were 1.42 and 1.60 g cm^{-1}, which is considered to be an ideal bulk density for sandy soils and is well below the 1.8 g cm^{-1} bulk density threshold for root restriction (Hanks and Lewandowski, 2003). In fact, the maximum soil bulk density we reported for soils at 0-10 and 10-20 cm depths were 1.81 and 1.85 g cm^{-1}, respectively.

Table 2-5. Infiltration rate of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	cm h^{-1}				
Control	41.0a‡	35.1a	39.6a	58.6a	66.7a
Tillage Only	41.9a	34.7a	29.8a	52.5a	64.9a
Aeration Only	38.9a	29.3a	50.0a	47.3a	78.2a
Compost Only	52.7a	23.6a	34.2a	52.3a	70.7a
Compost + Tillage	42.6a	32.9a	43.7a	48.3a	76.6a
Compost + Aeration	45.7a	92.7a	46.9a	46.1a	77.8a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at P < 0.05 using Tukey's HSD test.

Table 2-6. Infiltration rates of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with St. Augustine turfgrass at three sampling dates.

Treatment	13 WAT†	40 WAT	52 WAT
	cm h^{-1}		
Control	38.7a‡	50.6a	48.9a
Tillage Only	39.0a	45.4a	51.4a
Aeration Only	43.3a	49.3a	49.3a
Compost Only	49.4a	44.5a	48.7a
Compost + Tillage	42.5a	35.7a	38.0a
Compost + Aeration	46.7a	50.5a	51.4a

†WAT= week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at P < 0.05 using Tukey's HSD test.

Organic Matter

Application of compost increased the soil OM content compared with unamended soils through 40 WAT (Table 2-7). While the soil treatment effect on soil OM content at 52 WAT was not statistically significant, soil OM of composted soil was reported to be higher (31.2 g kg^{-1}) than for unamended soils (23.4 g kg^{-1}). Pandey and Shukla (2006) reported higher soil OM content in a sandy field soil amended with 100 Mg ha^{-1} of composted yard waste (22.6 g kg^{-1}) compared with the unamended soil (18.1 g kg^{-1}).

The amount of soil OM in composted soils decreased significantly with time due to oxidation of the compost material, suggesting that the benefits of adding organic matter to soil may eventually be negligible once all the organic matter has been oxidized. However, a review by Khaleel et al. (1981) concluded that repeated applications of organic soil amendments can sustain an increased soil organic matter content. Since our project was conducted for only one year, we were not able to determine if multiple applications would maintain higher levels of soil OM compared with unamended soils. Time effects of compost applications in Florida are influenced by rapid oxidation due to the warm moist climate. From our study we were unable to evaluate the persistence of the compost material and the related effects on soils after one year. Albiach et al. (2001) found that differences in the degradability of organic amendments can result in large differences in soil OM content in a short amount of time when applied in warm areas where the rate of OM decomposition is fast.

Table 2-7. Soil organic matter of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	g kg^{-1}				
Control	16.5a‡	22.2a	15.0ab	7.00a	14.5a
Tillage Only	19.0a	28.6a	8.50a	10.5a	17.5a
Aeration Only	17.5a	28.7a	10.0a	13.5ab	43.7a
Compost Only	46.3b	63.1b	31.7ab	32.6bc	30.3a
Compost + Tillage	44.8b	60.9b	33.0b	33.1c	31.4a
Compost + Aeration	54.4b	60.9b	37.6ab	46.3bc	32.0a

†WAT= week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Soil pH

Soil samples collected immediately after the initiation of soil treatments exhibited no soil pH differences at the 0-10 cm depth (data not shown). This is likely due to the natural buffering capacity of the soil. By 13 WAT, soils that received compost additions had a lower soil pH (mean pH = 7.29) than unamended soils (pH = 7.70); this trend persisted through 52 WAT (Figure 2-1). The decrease in soil pH after application of compost was a result of the pH of the compost (pH = 6.59; Table 2-2), which was lower than the pH of our fill soils (pH = 7.5; Table 2-1). Other researchers have documented that the pH of compost can influence soil pH when compost is applied to the soil (Eghball, 1999; Eghball, 2002). For example, the incorporation of yard waste compost with a pH of 7.4 raised the pH of several slightly acidic to neutral TX soils (Weindorf et al., 2006).

In our study, the pH of unamended soils increased significantly over time (Figure 2-1). This increase may be due to the use of alkaline water (pH = 7.83) for irrigation.

Irrigation of turf with alkaline water was indicated as the cause for a pH increase in a fine sandy loam soil (Wright et al., 2007b). Alternatively, the increase in soil pH could be due to the presence of construction debris in the fill soil material. Some construction debris can cause a rise in pH as the calcium carbonate rich materials weather (Craul, 1985).

Through 40 WAT, there was no temporal effect on soil pH for composted soils (Figure 2-1). While the pH at 52 WAT was significantly higher at 13, 27, and 40 WAT, it was not significantly different than the initial pH. It is likely that, when applied to the soil, compost acted to buffer to changes in pH. A study by Stamatiadis et al. (1999) found that surface application of composted dairy manure increased soil buffering capacity, thereby preventing changes in soil pH. Organic matter is able to buffer soil pH because it has many sites that H^+ ions can bond with in various strength; it can also buffer soil by the release of Al^{+3} ions from organic complexes (Brady and Weil, 2002). Alternatively, it is possible that as the compost decomposed over time, humic and other organic acids were released into the soil; thereby counteracting the liming effect of the irrigation water or construction debris (Brady and Weil, 2002). Albiach et al. (2001) found that application of municipal solid waste compost increased the level of humic acids in the soil.

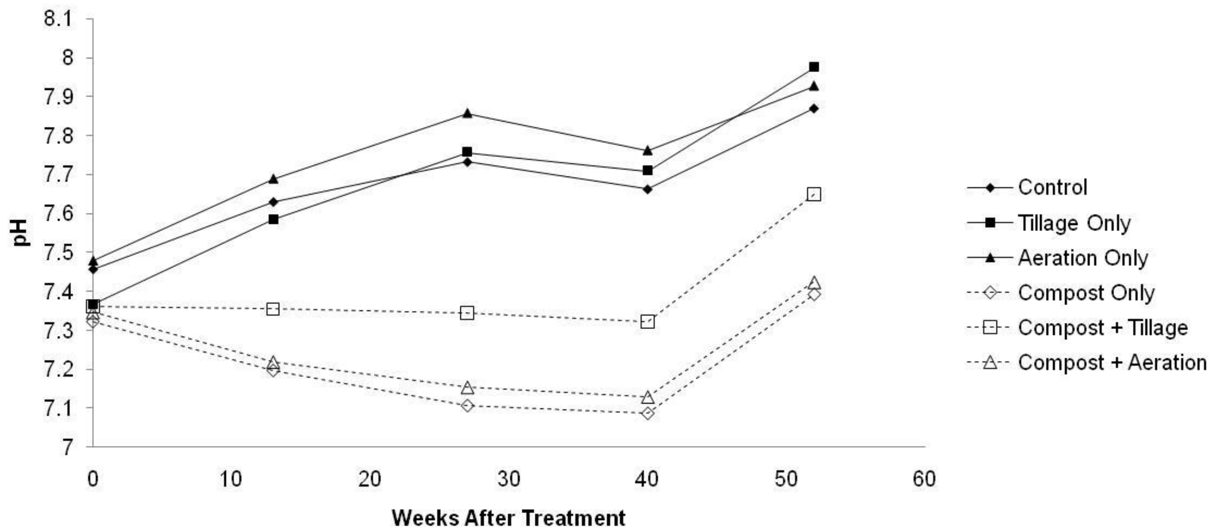

Figure 2-1. Temporal trends in soil pH of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Table 2-8. Soil pH of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
Control	7.46a‡	7.63a	7.73a	7.66a	7.87ab
Tillage Only	7.37a	7.59a	7.76a	7.71a	7.98a
Aeration Only	7.48a	7.69a	7.86a	7.76a	7.93ab
Compost Only	7.32a	7.2b	7.11b	7.09b	7.39c
Compost + Tillage	7.36a	7.36ab	7.35b	7.32b	7.65bc
Compost + Aeration	7.35a	7.22b	7.16b	7.13b	7.43c

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Electrical Conductivity

Following the application of compost, the amended soils had a significantly higher EC at 0-10 cm depth than unamended soils; this trend persisted through 27 WAT (Table 2-9). This was likely due to the high EC (1.02 dS m^{-1}) in the compost when compared with the soil fill (0.30 dS m^{-1}). Johnson et al. (2006) showed that amending soils with composted dairy manure increased soil EC when the compost application rate exceeded 99 m^3 ha^{-1}; the compost application rate in our experiment was 508 m^3 ha^{-1}. Stamatiadis et al. (1999) also reported an increase in soil EC following application of compost due to the presence of salts (other than nitrates) in the compost material. After 27 WAT, the salts likely leached out and we no longer have a difference among the treatments.

Table 2-9. Electrical conductivity of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	μs cm^{-1}				
Control	299a‡	299ab	132abc	400a	223a
Tillage Only	316a	291ab	103a	310a	352a
Aeration Only	306a	254c	126cd	224a	408a
Compost Only	583ab	399bc	177bcd	500a	292a
Compost + Tillage	592b	400a	196ab	423a	384a
Compost + Aeration	638ab	353c	156d	272a	407a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at P < 0.05 using Tukey's HSD test.

Field Moisture Capacity

Compost application significantly increased the soil field moisture capacity at 0-10 cm depth compared with unamended soils at 0 and 13 WAT (Table 2-10). By 27 WAT, there was a significant compost × tillage interaction, where soils receiving the compost + tillage treatment maintained a higher field capacity than soils receiving the compost only (52 WAT only) and the compost + aeration (40 and 52 WAT) treatments. Johnson et al. (2006) found that volumetric water content of a clay loam soil increased as compost application rates increased; at saturation soils amended with 66 and 99 m^3 ha^{-1} compost held 7.2 and 7.9% more water compared to the control (no compost added). Aggelides and Londra (2000) reported that applications of compost increased the water retention capacity of clay and loamy soils. In our study, applications of compost increased soil OM (Table 2-7), which helps to retain soil water (Hamza and Anderson, 2005) resulting in a higher field moisture capacity. The addition of OM increases water-holding capacity by increasing porosity and surface area; especially in coarse-textured soils (Cogger, 2005; Khaleel et al., 1981).

Table 2-10. Field moisture capacity of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
			%		
Control	10.5ab‡	12.3a	12.3ab	12.6ab	12.8c
Tillage Only	10.1a	12.0a	11.94ab	12.1ab	12.6c
Aeration Only	10.1a	12.3a	12.30a	11.1a	11.8c
Compost Only	21.3c	19.9b	14.54c	15.3bc	15.9b
Compost + Tillage	16.2c	19.9b	13.68d	13.9c	15.5a
Compost + Aeration	17.5bc	19.9b	16.78bc	17.2b	19.0b

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Nutrient Content

Soil test (Mehlich 1) P concentrations at 0-10 cm depth were significantly lower for soils receiving the aeration only treatment than soils receiving the only compost or tillage (Table 2-11). At 13 and 27 WAT, soil test P concentrations in composted soils were significantly higher than in the unamended soils. At 52 WAT, composted soils had significantly higher soil test P than the control and aeration only treatments. Gilley and

Eghball (2002) found that soil test (Bray 1) P at 0-5 and 5-15 cm was significantly greater after four years of corn production when composted beef manure was applied based on the N requirements of crops than P requirements. Wright et al. (2007a) reported that NH_4OAc-EDTA extractable P in soils increased with increasing compost application rates.

The increase in P associated with compost additions may increase the risk for P loss from these soils. Nair et al. (2004) reported a P saturation ratio threshold of 0.15 for sandy soils, above which the potential for P loss in runoff or leaching increases greatly. We calculated Mehlich 1 P saturation ratio for these soils and found that all soils exceeded this thresholds due to low concentrations of soil test Al and Fe (Table 2-11). However, additions of compost to these sandy soils increased the mean P saturation ratio from 0.23 for unamended soils to 0.34 for composted soils, thereby further increasing the risk of P losses from these soils. However, Gaudreau et al. (2002) found that P in compost was less soluble and transportable than fertilizer P, but dissolved P in runoff from compost soil treatments still raised environmental concerns.

Potassium concentrations were significantly higher for composted soils compared with non-composted soils at 0 and 13 WAT (Table 2-10). At 27 WAT, the soils receiving the compost + tillage or aeration only treatments were significantly higher than control and aeration only soils. Potassium concentrations in compost (5362 mg kg^{-1}) were much higher than that of the topsoil (20.2 mg kg^{-1}) and likely accounts for the difference found among the treatments. By 40 WAT, there were no significant soil treatment effects on Mehlich 1 K levels, suggesting that K was absorbed by plant roots or leached downward into the soil profile. Leaching of K was evident because K concentrations at

10-20 cm depth at 27 and 40 WAT were higher for compost amended soils than unamended soils (Table A-8).

Soil treatments had no effect on the concentration of Mehlich 1 Mg except at 27 WAT, when soils that received the tillage only treatment had significantly higher Mehlich 1 Mg concentrations than the other plots. While the compost added a large amount of EPA 3050 extractable Mg to the soil (Table 2-2), it did not result in an increase in soil test Mg. Wright et al. (2007a) suggested that Mg may form a complex with organic matter in the compost and leach below the soil surface.

Calcium concentrations at 0 WAT were significantly higher for soils receiving the compost + tillage and compost + aeration treatments compared with control and tillage only treatments. At 13 WAT, all composted soils had higher Mehlich 1 Ca concentrations then uncomposted soils. At 27 WAT, soils receiving the compost + aeration treatment had higher Mehlich 1 Ca than non-composted soils. These increases are likely due to the application of Ca associated with the compost materials (Table 2-2) due to Ca supplementation in dairy diets (Toor et al., 2006). By 40 WAT significant differences among treatments were gone. Wright et al. (2007a) theorized that Ca, as was suggested for Mg, complexes with organic matter and is leached downward into the soil profile.

The concentration of sodium was only affected by soil treatment at 0 WAT; where composted soils had higher concentrations than non-composted treatments. The higher Na concentration in composted manure was likely from the salts contained in the manure that were subsequently leached from the soil during irrigation and rainfall events.

Table 2-11. Mehlich I nutrient concentrations (mg kg^{-1}) of fill soil samples (0-10 cm) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	mg kg^{-1}				
			Phosphorus		
Control	141ab‡	127a	146a	127a	154ab
Tillage Only	157ab	150ab	167ab	180a	167abc
Compost Only	181b	200c	219c	216a	214c
Compost + Tillage	184b	191bc	219c	217a	193bc
Aeration Only	130a	135a	172ab	147a	122a
Compost + Aeration	171ab	208bc	193bc	226a	212c
			Potassium		
Control	23.3	27.8a	19.8a	17.5a	24.0a
Tillage Only	29.3a	35.3a	23.8ab	35.3ab	24.5a
Compost Only	212bc	64.3b	29.8ab	39.0b	25.0a
Compost + Tillage	268c	61.0b	37.3b	38.3b	29.5a
Aeration Only	86.5ab	32.5a	21.3a	27.5ab	27.0a
Compost + Aeration	233bc	55.8b	39.5b	37.8b	29.8a
			Magnesium		
Control	2303a	3096a	2681a	1697a	2306a
Tillage Only	2335a	3097a	3605b	2488a	2445a
Compost Only	2356a	2897a	2672a	2391a	2395a
Compost + Tillage	2376a	2869a	2788a	2353a	2392a
Aeration Only	2304a	2811a	2511a	2315a	2397a
Compost + Aeration	2335a	3023a	2644a	2310a	2416a
			Calcium		
Control	81.5a	173a	178a	128a	207a
Tillage Only	80.0a	172a	163a	228ab	182a
Compost Only	167ab	330b	215ab	289b	218a
Compost + Tillage	221bc	282b	207ab	249b	215a

Aeration Only	123ab	177a	185a	216ab	222a
Compost + Aeration	183c	325b	287b	268b	236a
			Aluminum		
Control	34.5ab	32.7a	32.2a	26.4a	25.6ab
Tillage Only	41.4b	38.0a	41.3b	40.5a	34.4c
Compost Only	27.3ab	32.1a	35.7ab	32.6a	30.6bc
Compost + Tillage	29.2ab	37.2a	37.1ab	35.6a	34.2c
Aeration Only	25.4a	30.3a	30.1a	28.8a	21.0a
Compost + Aeration	27.7ab	31.9a	32.7ab	35.1a	29.3bc
			Iron		
Control	977a	1000a	1227 a	730a	921ab
Tillage Only	1042a	1538b	1262a	1339a	1087b
Compost Only	925a	1086ab	1177a	1082a	889a
Compost + Tillage	839a	1145ab	1084a	1020a	818a
Aeration Only	922a	1279ab	1268 a	1139a	917ab
Compost + Aeration	843a	996a	1206a	1157a	948ab
			Sodium		
Control	10.0a	17.0a	19.7a	14.4a	19.2a
Tillage Only	10.3a	21.9a	20.0a	22.0a	17.9a
Compost Only	61.9bc	25.2a	22.4a	24.6a	22.1a
Compost + Tillage	69.6b	24.7a	23.2a	23.7a	22.6a
Aeration Only	25.5ac	21.9a	20.3a	19.3a	19.4a
Compost + Aeration	69.2b	20.8a	25.7a	22.0a	23.8a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

CHAPTER 3
EFFECTS OF SOIL TILLAGE AND ORGANIC AMENDMENTS ON PLANT GROWTH AND QUALITY IN A SIMULATED RESIDENTIAL LANDSCAPE

Introduction

The impact of construction activities and landscape installation not only affects soil properties and water resources, but also plant growth and performance. Urban construction typically involves land clearing, using heavy equipment, and importation of fill soils, all of which can negatively affect the ability of soils to function properly. For example, the use of heavy equipment at construction sites has been shown to increase soil bulk density, increase soil strength, and reduce porosity (Smith et al., 2001). Urban soils are often compacted (Gregory et al., 2006; Jim, 1998) exhibit an unnatural and varied soil structure (Jim, 1993), have alkaline pH as a result of weather of construction waste, and contain low amounts of soil organic matter, N and P (Jim, 1998; Law et al., 2004). As a result, the urban soil environment is usually not conducive to healthy root growth and function, leading to problems with plant establishment, growth and aesthetic quality (Cogger, 2005; Smith et al., 2001; Watson and Kelsey, 2005; Zhang et al., 2005). In addition, urban soils can impose serious constraints on tree establishment and growth due to the impact on root growth and function (Smith et al., 2001).

Soil compaction, which is quantified by high bulk density, is one of the most common and persistent problems in urban soils (Jim, 1998). While compacted soils provide a stable foundation for homes, they are not ideal for plant growth (Hanks and Lewandowski, 2003). For example, decline and death of trees on construction sites is commonly attributed to soil compaction and the resulting deterioration of the root environment (Watson and Kelsey, 2005). Compaction reduces the total volume of air-filled pores and soil pore size, increases mechanical resistance to root penetration and can increase or decrease water-holding capacity (Whalley et al., 1995). Research shows that compaction from construction can negatively impact root development and density (Watson and Kelsey, 2005) resulting in a loss of plant vigor. A study by Hirth et al. (2005) found that seedling mass, shoot length and root length decreased as the soil bulk density of a silt loam soil increased from 1.25 to 1.38 g cm^{-3}. Trees with rooting defects associated with compaction will show gradual dieback, reduced longevity, and premature death; new plants will lose vitality and fail to establish (Jim, 1993).

Compaction also limits the nutrient-holding capacity of the soil, resulting in concentrations of plant available nutrients that are inadequate for vigorous plant performance (Jim, 1998). The effect of soil compaction on nutrient transport to the roots ultimately depends on the extent of compaction and on the water and nutrient supply (Lipiec and Stepniewski, 1995). Short root length, restricted range of rooting or poor root-soil contact would ultimately limit the ability of a plant to capture water and nutrients (Stirzaker et al., 1996).

Soil management practices, such as organic amendment or soil tillage, have been reported to improve the growth of plants in urban soils. A study by Rivenshield and Bassuk (2007) found that the addition of organic amendments (sphagnum peat and food waste compost) increased macroporosity and reduced soil bulk density in a sandy loam and clay loam soil to levels that did not restrict root growth (approximately 1.4 g cm^{-3}). The use of organic amendments during turfgrass establishment has been shown to increase soil water-holding capacity, porosity, and surface area, thereby providing an environment that will allow for the growth of healthy root systems (Cogger, 2005). While the addition of compost is a common practice in agriculture, it is often neglected in urban soil management; however, it should be routinely adopted for long-term maintenance in urban landscapes (Jim, 1998). Studies showed that Kentucky bluegrass establishment could be enhanced by amending the soil with selected organic compost amendments (Landschoot and McNitt, 2004; Linde and Hepner, 2005).

Tillage has also been suggested as a way to improve plant growth and quality in urban landscapes. Tillage breaks up soil aggregates creating more pore space, thereby allowing water to infiltrate and roots to penetrate through the soil profile (Vogeler et al., 2005). Studies have shown that soil compaction can be alleviated by spike and core aeration and rototilling (Jim, 1993; Kozlowski, 1999; Unger and Kaspar, 1994). Deep tillage (to approximately 0.4 m) allows root growth into deeper soil horizons with more structural development and greater water-holding capacity (Busscher et al., 2006).

While several studies have demonstrated that these soil management practices can improve soil conditions for turfgrass or trees, there is still a need to determine the effects on in urban soils, specifically new residential areas. Soil disturbance in new residential landscapes may lead to plant failure or poor plant growth when container grown landscape plants and sod are installed. The objective of this study was to determine the effect of adding compost and/or or applying shallow tillage on plant growth and aesthetic quality in a simulated residential landscape.

Materials and Method

Experimental Design

Twenty-four mixed landscape plots (3.05 x 3.66 m) were established in a randomized complete block design at the UF — IFAS Gulf Coast Research and Education Center in Wimauma, FL. All vegetation was removed from the site before plot construction. The entire research area was prepared at a 2% grade (as is typically required by construction codes) and compacted (bulk density range: 1.7-1.9 g cm^{-3}) using a small plate compactor (Wacker Neuson, Munich, Germany). Individual landscape plots were constructed inside water-sealed treated wooden boxes. Within each plot, the compacted field soil (Zolfo fine sand: sandy, siliceous, hyperthermic Oxyaquic Alorthods (USDA-NRCS, 2004) was then buried under 1.13 m^3 of un-compacted soil fill material. Soil fill material was created by mixing three fill soil materials in equal parts to simulate a 'top soil' material that would be applied during residential construction. The three fill soil material sources included: a subsoil fill containing construction material and other debris; a clean topsoil material (St. Johns fine sand; sandy, siliceous, hyperthermic Typic Alaquod) obtained from depth of 30 to 61 cm (Hills Dirt Pit, LLC., Riverview, FL), and a clean subsoil fill (St. Johns fine sand) fill obtained from a depth of 122 to 213 cm (Hills Dirt Pit, LLC., Riverview, FL). Initial soil and compost properties are reported in Chapter 2, Table 2-1 and 2-2.

Composted dairy manure solids (compost; Agrigy, Palm Harbor, FL) were applied as an organic soil amendment at a rate of 508 m^3 ha^{-1} (approximately 256 Mg ha^{-1}) in combination with two mechanical soil treatments (tillage and aeration) for a total of five soil management treatments. The soil management treatments were as follows: 1) tillage only, 2) compost only, 3) compost + tillage, 4) aeration only, 5) compost + aeration. In plots receiving the tillage treatment, soils were turned to a depth of 10-15 cm using counter rotating tines tiller (Sears Brands, LLC, Hoffman Estates, IL). In plots receiving the aeration treatment, soil aeration plugs were mechanically removed using a core aerator (Billy Goat Industries, Inc., Lee's Summit, MO). An untreated control plot (no tillage or organic amendment) was included as the sixth soil treatment.

Once soil treatments were applied, each plot was split and 5.58 m^2 of each plot was planted with *Stenotaphrum secundatum* (Walter) Kuntze (St. Augustine turfgrass); the remaining 5.58 m^2 was planted with mixed ornamentals. Mixed ornamentals species included *Galphimia glauca* Cav. (Thryallis), *Rhaphiolepis indica* (L.) Lindl. ex Ker Gawl. (Indian hawthorn), *Ilex cornuta 'Burfordi'* Lindl. & Paxton (Buford holly), and *Liriope muscari* (Decne.) L. H. Bailey (Liriope). Turfgrass was fertilized at a total N rate of 220 kg ha^{-1} based on current University of Florida – Institute of Food and Agricultural Sciences (UF-IFAS) recommendations (moderate maintenance schedule for South Florida): 48.8 kg N ha^{-1} per application using Lesco Professional turf fertilizer (26-2-11) in February and October, 48.8 kg N ha^{-1} per application using polymer coated urea (42-0-0; Harrell's Professional Fertilizer Solutions, Lakeland, FL) as a slow-release N source in May and August, 24.4 kg N ha^{-1} with urea (46-0-0; Potash Corp., Northbrook, IL) as a soluble N source, and 6.34 L ha^{-1} of ferrous sulfate (Sunniland Corporation, Sanford, FL) in July (Sartain, 2007). Ornamental plants were fertilized every 3 months with urea (46-0-0) at an N rate of 97.6 kg ha^{-1} based on UF-IFAS recommendations for established woody ornamentals grown in the landscape (Knox et al., 2002).

The entire research plot area was equipped with a spray irrigation system, which allowed for individual landscape plots to be irrigated, as needed, based on UF-IFAS recommendations (Zazueta et al., 2005). During establishment, plots were watered daily for 30 d after planting to allow for establishment of turf and ornamental plant material. Irrigation frequency was then reduced to two days a week based on typical watering restrictions for landscape irrigation that would be mandated in times of drought (South Florida Water Management District, 2008; St. Johns River Water Management

District, 2008). Irrigation was applied for 51 min (irrigation controller run time for two irrigation events per week at an application rate of 0.13 cm per hour, assuming system efficiency of 80% and considering effective rainfall) per plot on Mondays and Thursdays starting at 0300 HR and ending around 0900 HR.

Plant Growth and Quality

Plant growth measurements and quality ratings were collected monthly to evaluate the effect of soil tillage or compost amendment on the establishment and growth of ornamental plants and turfgrass. Growth index (GI) was used as a quantitative indicator of ornamental plant growth rate and to compare the size of the plants grown under different soil treatments. Growth index for each plant was calculated as: GI (m^3)= H × W1 × W2; where H is the plant height (m), W1 is the widest width (m), and W2 is the width perpendicular to the widest width (m) (Scheiber et al., 2007). Turfgrass was mowed on an as needed basis, with most collections occurring during the summer months. Turf clippings were collected to determine clipping dry weight based on the method outlined by Ervin and Koski (2001) with some modifications. A 0.46 m wide section from the center of each plot was mowed to a height of 5.7 cm. The clippings were collected from a bag attached to the mower after every plot and then dried to a constant mass at 105ºC and weighed. Plant greenness readings were collected monthly using a SPAD meter (SPAD-502, Spectrum Technologies INC., Plainfield, IL).

Quality ratings, density and dieback, were used to put uniformity, color, density, and visual appeal into numerical representation. Quality ratings for ornamental plant species were taken on a 1-5 scale with the following rating system: 5 (dense, good plant quality) to 1 (very poor plant quality). Turfgrass ratings were taken on a scale of 1-5 based on the percentage of turf area exhibiting symptoms with the following rating system: 1 (75-100% stressed), 2 (50-75% stressed), 3 (25-50% stressed), 4 (1-25% stressed), and 5 (0% stressed). The plant was considered to be stressed is when it showed visible signs of strain such as discoloration, lack of growth, or even cessation.

Plant Tissue Analysis

Ornamental and turf tissue samples were collected by randomly sampling approximately 40-50 leaves or blades of grass from each plot every 3 months. Plant tissue samples were dried at 105ºC and digested using the standard method of the UF-IFAS Extension Soil Testing Laboratory (Mylavarapu and Kennelley, 2002) and analyzed for total Kjeldahl N, and total P and K by inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Data Analysis

The experiment was designed as randomized complete block split-plot design with 4 blocks and 6 soil treatments in each block. Half of each plot was planted with ornamental plants and the other ½ was planted with turfgrass as described previously. The soil treatments were assigned randomly within each block. Plant GI was analyzed using the PROC MIXED procedure in SAS with soil treatment as a fixed effect and block as a random effect (SAS Institute, 2003). Initial GI (0 WAP) was included in the model as a covariate to account for variation in initial plant size at different sampling dates. All comparisons were completed using the Tukey HSD test with a significance level of $\alpha = 0.05$. Plant quality data were analyzed using the PROC GLIMMIX program in SAS (SAS Institute, 2003) with the multinomial distribution and the cumulative logit link function. All comparisons were completed using the X^2 test with a significance level of $\alpha = 0.05$.

Results

Galphimia Glauca

The growth index (GI) of the *G. glauca* showed soil treatment effects starting at 19 WAT (weeks after treatment) (Figure 3-1). *G. glauca* grew larger in landscape plots where compost was applied to the soil than in soils that did not receive compost. Data collected from 15-24 WAT showed that tilling the compost into the soil to a depth of 20 cm resulted in more plant growth than applying compost to the soil surface.

Plants grown in composted soils displayed higher SPAD values than uncomposted soils. However, these differences were not statistically significant (Figure 3-2) until 37 WAT, at which time SPAD readings for plants grown in plots that received the compost + aeration treatment were significantly higher than for plants grown in the control (no compost/no tillage) plots. At 45 WAT, *G. glauca* SPAD readings were higher for plants grown in soils receiving the compost only treatment than those grown in the control and aeration only plots.

Soil treatments had a significant effect on density ratings at 11, 15, 19, 24, 28, 45, and 49 WAT (Figure 3-3). Dieback ratings were affected by treatment effect at 11, 15, 24, 28, 32, 27, 40, 45, and 49 WAT (Figure 3-4). For both density and dieback, *G. glauca* planted in compost amended soils were rated higher than shrubs grown in unamended soils (Figure 3-3 and 3-4). Tillage and aeration resulted in plants with comparable quality ratings to those grown in the control plots.

Soil treatments affected the nutrient content in plant tissue throughout the study (Table 3-1). Total Kejdahl N in the tissue of *G. glauca* shrubs grown in composted soils treatments at 13 and 27 WAT were significantly higher than tissue from shrubs grown on unamended soils. At 40 and 52 WAT, plants grown in the soils receiving the compost only treatment had significantly higher tissue TKN than plants grown in unamended soils. At 13 WAT, tissue total P was significantly higher for plants grown in soils receiving the compost only treatment compared to those grown in unamended soils; there were no significant differences in tissue P at any other time in the study. For total K in tissue, the tillage only treatment led to significantly higher tissue K levels than the aeration only, compost only, and compost + aeration treatments at 13 WAT only.

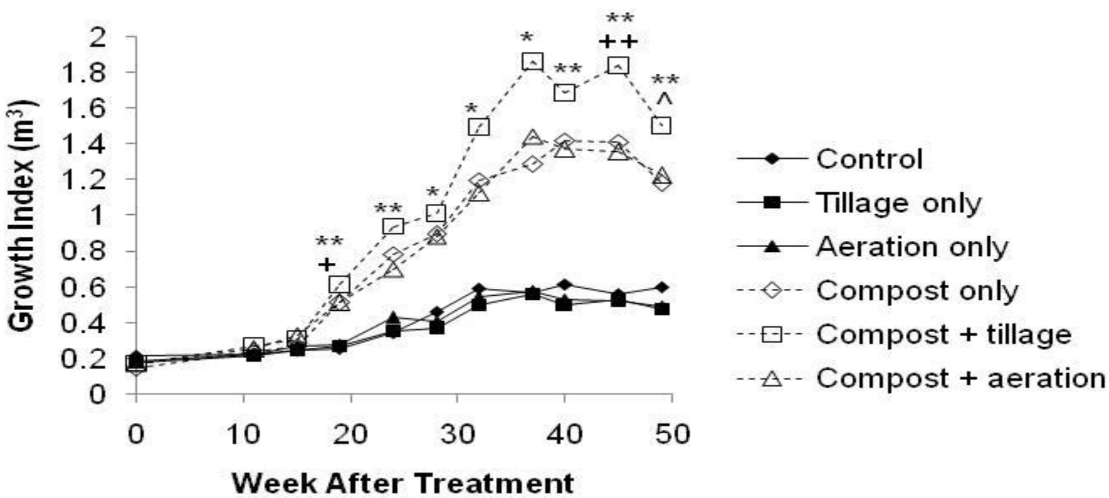

Figure 3-1. Mean canopy growth index from 0 to 52 weeks after treatment (WAT) of *G. glauca* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Star (*) indicates a significant difference (P <0.05) between composted treatments and non-composted treatments. Double star (**) indicates a significant difference (P <0.05) between compost + tillage and non-composted treatments. Plus sign (+) indicates a significant difference (P <0.05) between compost only, compost + aeration and control. Double plus sign (++) indicates a significant difference (P <0.05) between compost only and tillage only, aeration only. Arrow (^) indicates a significant difference (P <0.05) between compost only, compost + aeration and tillage only.

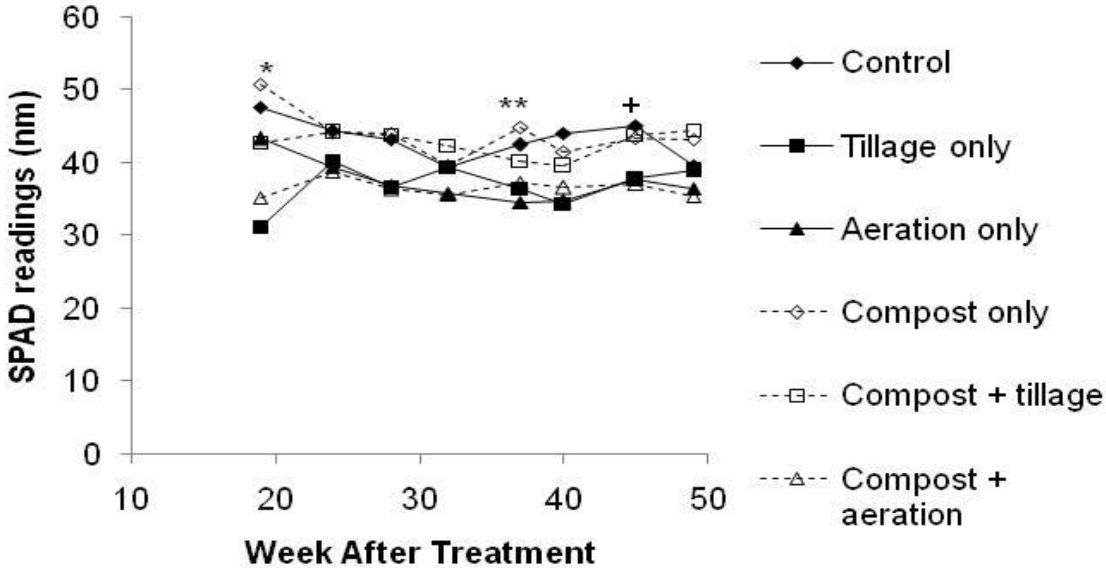

Figure 3-2. Mean SPAD readings from 0 to 52 weeks after treatment (WAT) of *G. glauca* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Star (*) indicates a significant difference (P <0.05) between compost +tillage, compost + aeration and non-composted treatments. Double star (**) indicates a significant difference (P <0.05) between compost + aeration and control treatment. Plus sign (+) indicates a significant difference (P <0.05) between compost only and control, aeration only plots.

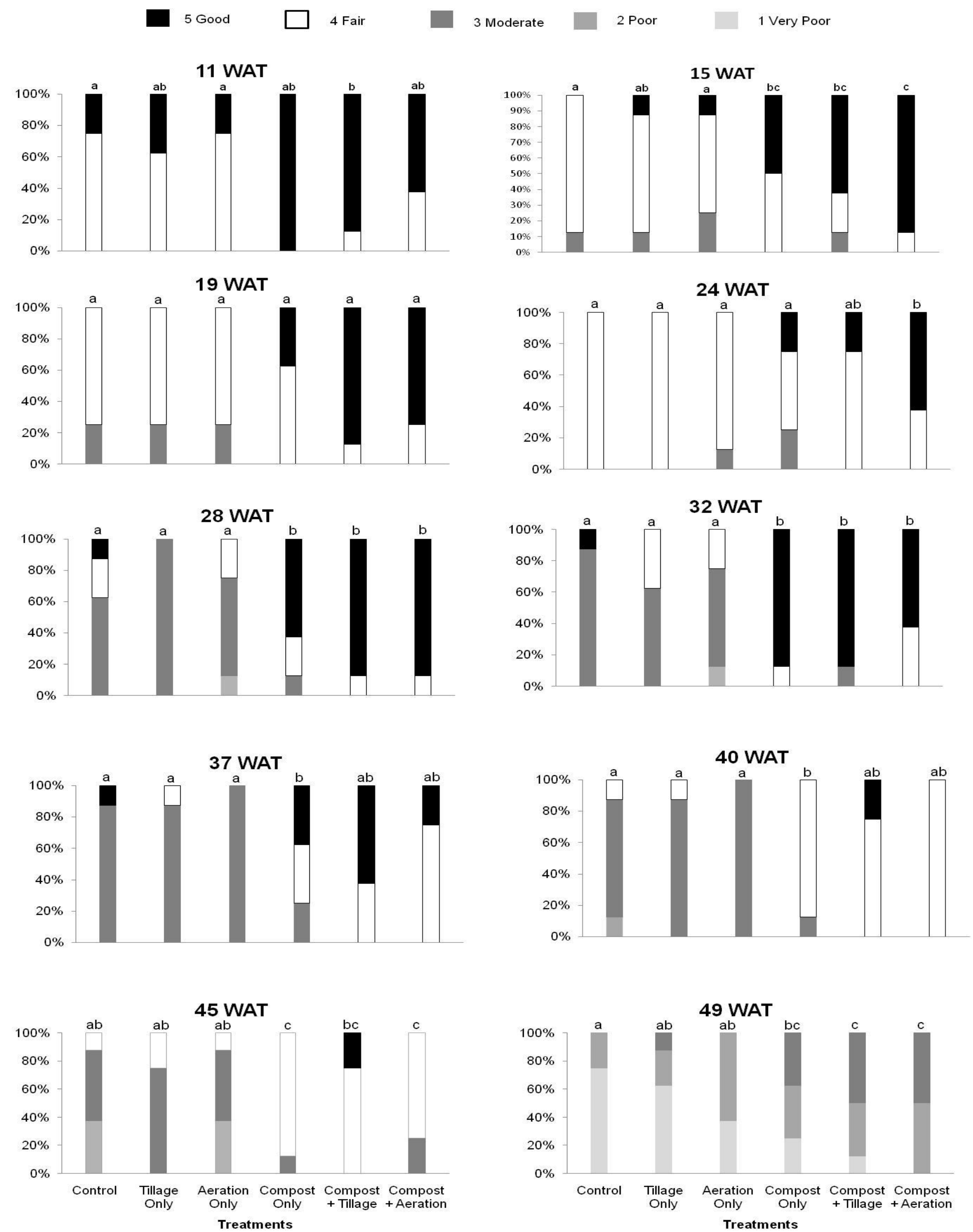

Figure 3-3. Dieback ratings from 0 to 52 weeks after treatment (WAT) of *G. glauca* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

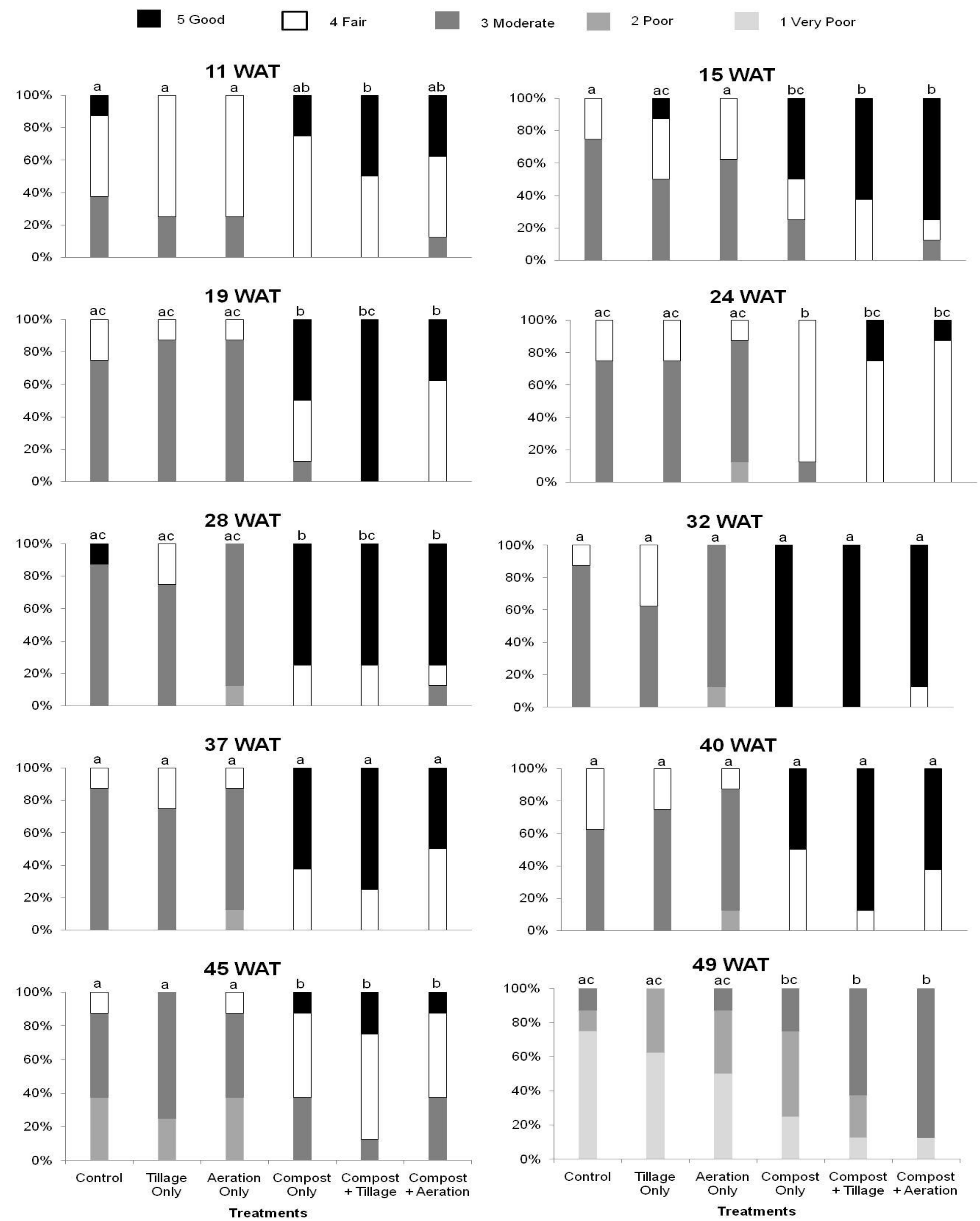

Figure 3-4. Density ratings from 0 to 52 weeks after treatment (WAT) of *G. glauca* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

Table 3-1. Nutrient content in plant tissue collected from *G. glauca* grown in sandy fill soils receiving compost, shallow tillage, and/or aeration treatments in simulated residential landscape plots at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	%			
	Total Kejdahl N			
Control	1.35a‡	1.45a	1.55a	2.25ab
Tillage Only	1.25a	1.32a	1.54a	2.07a
Aeration Only	1.31a	1.40a	1.46a	2.08a
Compost Only	2.33b	2.46b	3.16b	2.59b
Compost + Tillage	2.41b	2.24b	2.20ab	2.51ab
Compost + Aeration	2.05b	2.29b	2.15ab	2.40ab
	Total Phosphorus			
Control	1.56a	2.11a	2.90a	3.58a
Tillage Only	1.63ab	2.24a	2.74a	3.57a
Aeration Only	1.75ab	2.01a	2.82a	3.64a
Compost Only	3.13c	2.41a	2.84a	3.64a
Compost + Tillage	2.35bc	2.60a	2.55a	3.22a
Compost + Aeration	2.82bc	2.53a	2.62a	3.25a
	Total Potassium			
Control	4.56a	5.12ab	5.22a	9.32a
Tillage Only	5.45a	5.74b	5.17a	10.76a
Aeration Only	5.47a	4.60a	4.74a	9.76a
Compost Only	6.07a	4.53a	4.99a	8.09a
Compost + Tillage	5.78a	5.37ab	5.27a	9.02a
Compost + Aeration	5.26a	4.30a	5.07a	7.55a

†WAT =week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Raphiolepis Indica

There were no significant soil treatment effects on the GI of *R. indica* during the study period (Figure 3-5). Chlorophyll readings for *R. indica* grown in compost amended soils were significantly higher than shrubs grown in amended soils at 45 WAT only (Figure 3-6). Starting at 28 WAT, there were significant differences in dieback ratings, where composted treatments resulted in higher ratings than the non-composted treatments (Figure 3-7). Density ratings showed significant differences starting at 19 WAT for composted treatments when compared with non-composted treatments (Figure 3-8).

The nutrient content of *R. indica* tissue was affected by soil treatment throughout the study (Table 3-2). At 13 and 40 WAT, tissue had higher levels of TKN when plants were grown in composted soils when compared with unamended soils. At 27 WAT, the compost only treatment led to higher TKN levels than the non-composted treatments. At 40 WAT, tissue total P was significantly higher in *R. indica* plants grown in soils receiving the compost + aeration compared with the aeration only treatment. Tissue total K was significantly higher plants grown in soils receiving the compost + aeration compared with plants grown with the tillage only treatment at 27 WAT. At 40 WAT, the compost + aeration treatment led to higher tissue total K than the aeration only treatments. This trend was reversed at 52 WAT, where the tissue total K concentrations were significantly lower from plants grown in composted soils than those grown in unamended soils.

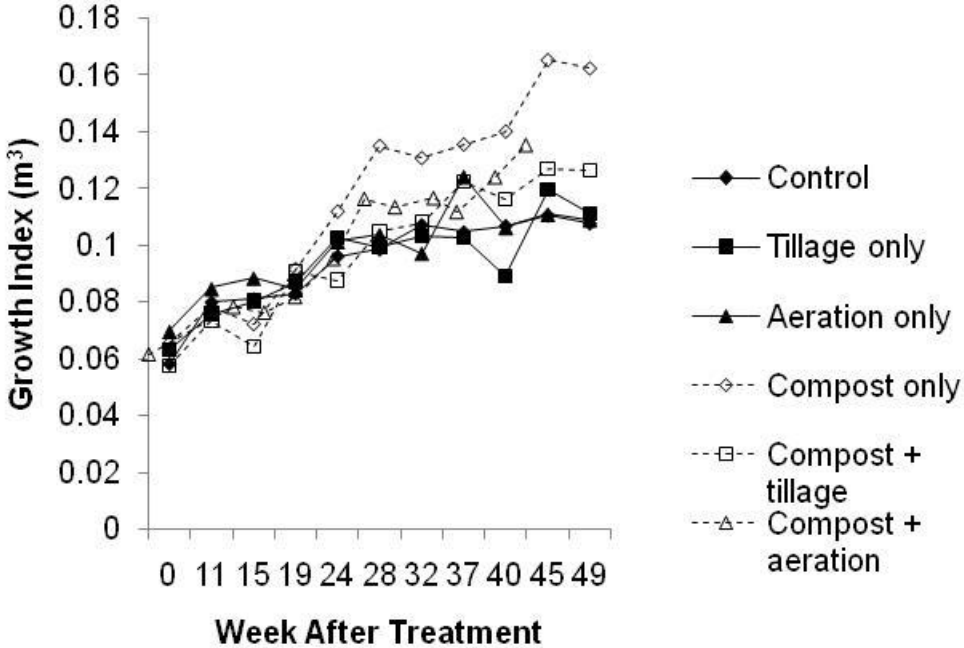

Figure 3-5. Mean canopy growth index from 0 to 52 weeks after treatment (WAT) of *R. indica* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.

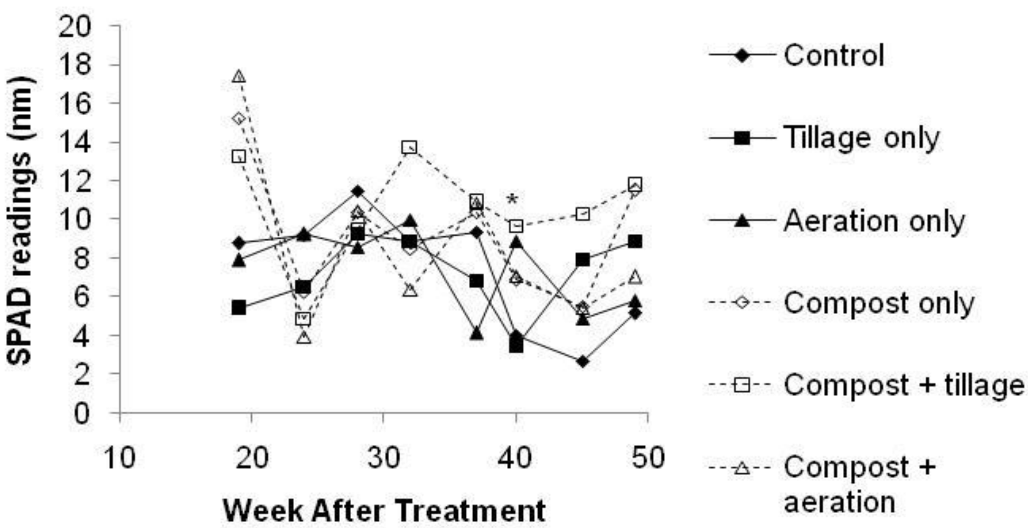

Figure 3-6. Mean SPAD readings from 0 to 52 weeks after treatment (WAT) of *R. indica* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Star (*) indicates a significant difference (P <0.05) between compost only, compost + aeration and tillage only.

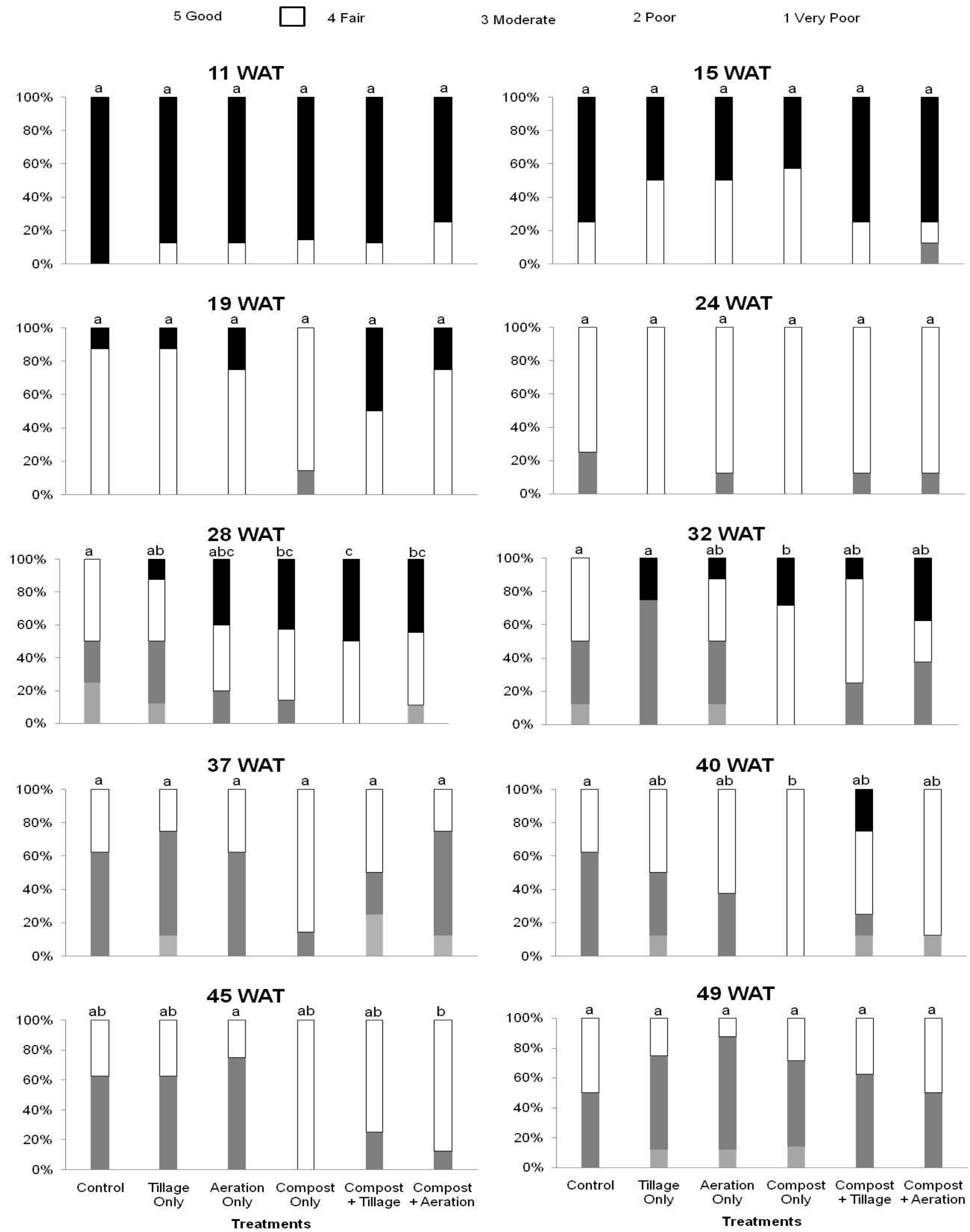

Figure 3-7. Dieback ratings from 0 to 52 weeks after treatment (WAT) of *R. indica* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

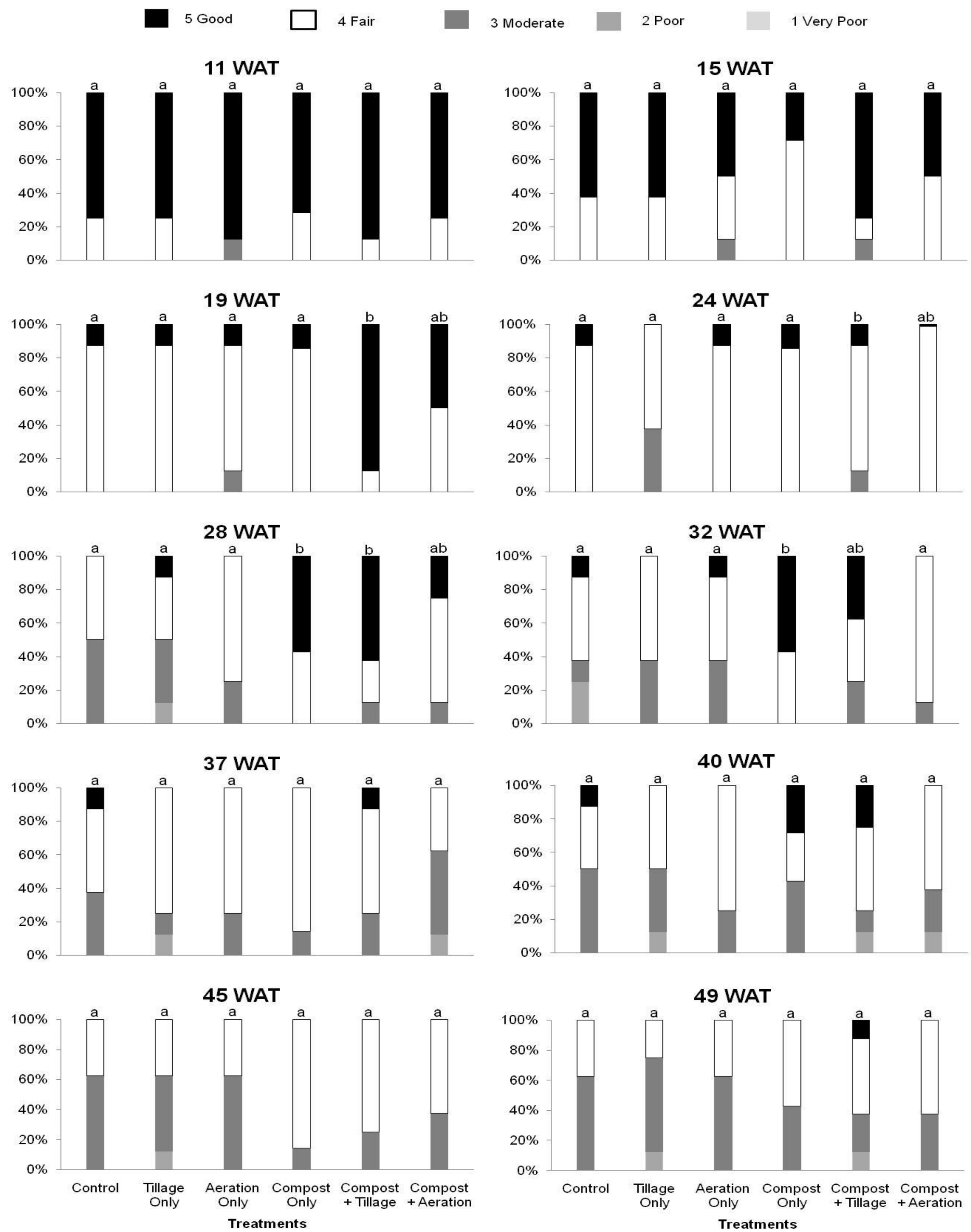

Figure 3-8. Density ratings from 0 to 52 weeks after treatment (WAT) of *R. indica* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

Table 3-2. Nutrient content in plant tissue collected from *R. indica* grown in sandy soils receiving compost, shallow tillage, and/or aeration treatments in simulated residential landscape plots at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	%			
	Total Kejdahl N			
Control	1.60a‡	1.56abc	1.53a	1.21a
Tillage Only	1.53a	1.35a	1.39a	1.20a
Aeration Only	1.59a	1.43ab	1.41a	1.23a
Compost Only	1.88b	1.84d	1.90b	1.68a
Compost + Tillage	1.90b	1.65bc	1.92b	1.65a
Compost + Aeration	1.91b	1.79cd	2.10b	1.67a
	Total Phosphorus			
Control	2.07a	2.30a	2.55ab	3.15a
Tillage Only	2.33a	2.41a	2.64ab	3.24a
Aeration Only	1.94a	2.13a	2.44a	3.19a
Compost Only	2.25a	2.77a	3.12ab	3.10a
Compost + Tillage	2.10a	2.30a	2.53ab	2.64a
Compost + Aeration	2.50a	2.71a	3.48b	3.57a
	Total Potassium			
Control	7.98a	9.14ab	8.42ab	8.00a
Tillage Only	7.77a	8.19a	8.83ab	8.72a
Aeration Only	7.75a	8.48ab	8.05a	7.96a
Compost Only	8.80a	9.77ab	9.25ab	6.08b
Compost + Tillage	8.72a	9.68ab	9.50ab	5.96b
Compost + Aeration	8.87a	10.02b	10.21b	7.12ab

†WAT = week after treatment

‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Ilex Cornuta 'Burfordii'

The GI of *I. cornuta* 'Burfordii' was affected by soil treatment from 28 to 49 WAT. After 28 WAT, shrubs grown in soils receiving applications of compost grew larger than shrubs grown in soils that received no compost (Figure 3-9). Tilling the compost into the top 20 cm of the soil did not improve plant growth at most sampling dates compared with treatments where no compost was applied to the soil.

Plant SPAD readings exhibited significant soil treatment effects at 32, 40 and 49 WAT (Figure 3-10). At 32 WAT, *I. cornuta* 'Burfordii' grown in plots receiving the compost only treatment (no tillage or aeration) had higher readings than shrubs grown in unamended soils (Figure 3-10). At 40 WAT and 49 WAT, SPAD readings were lower for *I. cornuta* 'Burfordii' grown in aerated soils than soils receiving the compost only or compost + aeration treatments, respectively. Density and dieback ratings were significantly affected by soil treatments starting at 28 WAT; in general density and dieback ratings were better for shrubs grown in compost amended soils than for shrubs grown in unamended soils (Figure 3-11 and 3-12).

Soil treatment had a significant effect on plant tissue nutrient content (Table 3-3). Total Kejdahl N in tissue collected from *I. cornuta* 'Bufordii' grown in soils receiving the compost + aeration and compost only treatments were significantly higher than in plants grown in unamended soils at 13 WAT. At 27 and 40 WAT, tissue collected from plants grown in composted soils had higher TKN than plants grown in unamended soils. At 52 WAT, tissue concentrations of TKN were higher for the compost only treatments than the unamended soils. Soil treatment effects on tissue total P began at 40 WAT, where compost treatments led to higher tissue concentrations of P than uncomposted treatments. By 52 WAT, only the compost + tillage led to higher tissue P concentrations than the tillage only and aeration only treatments. Tissue total K was only affected by soil treatments at 27 WAT, where the control and tillage only treatments led to lower tissue K concentrations than the other soil treatments.

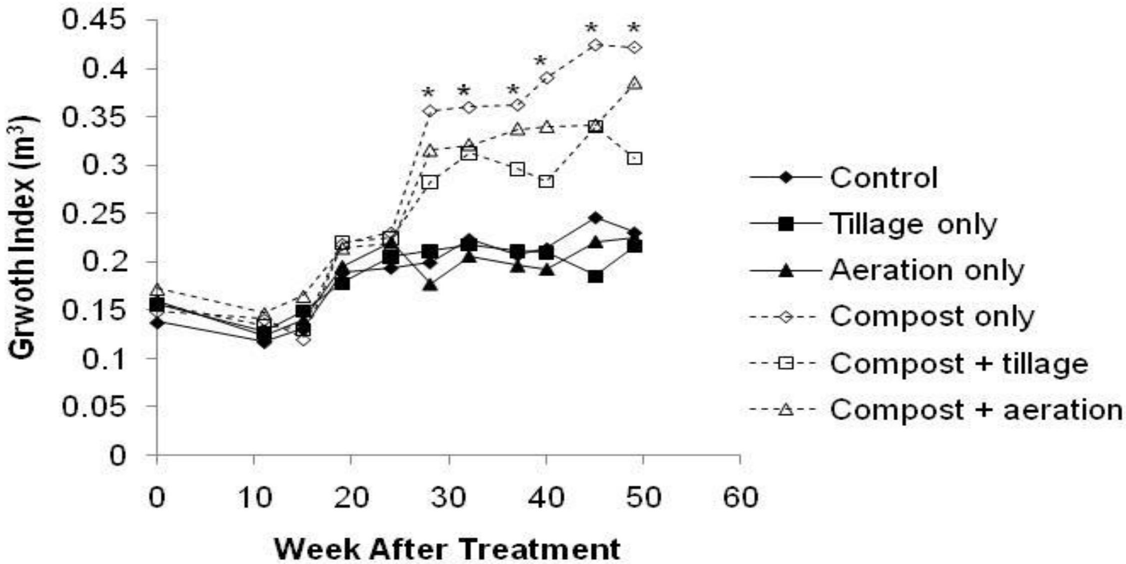

Figure 3-9. Mean canopy growth index from 0 to 52 weeks after treatment (WAT) of *I. cornuta* 'Bufordii' grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Star (*) indicates a significant difference ($P < 0.05$) between compost only, compost + aeration and non-composted treatments.

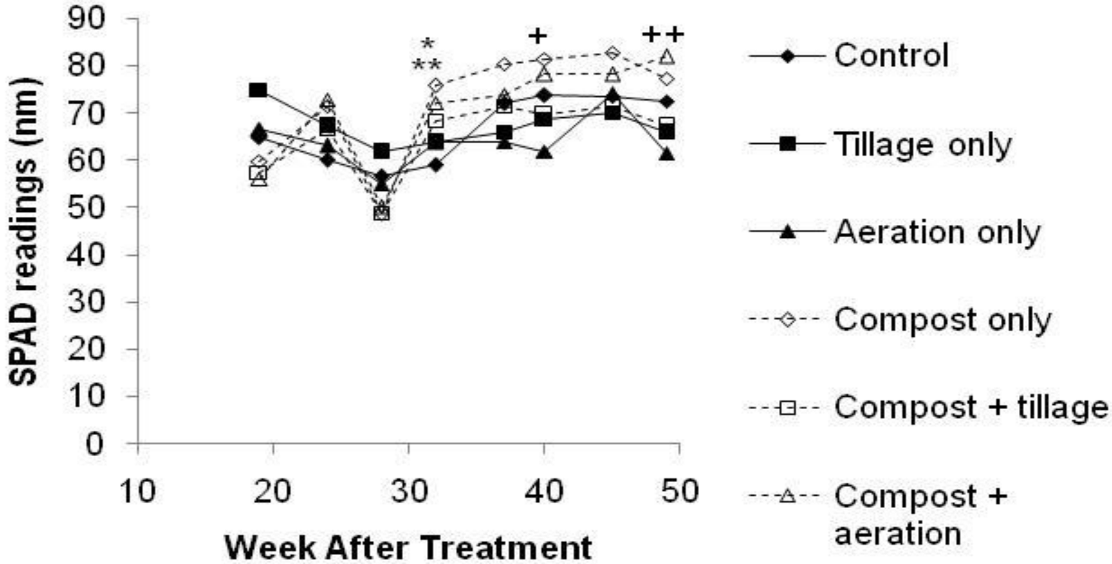

Figure 3-10. Mean SPAD readings from 0 to 52 weeks after treatment (WAT) of *I. cornuta* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Star (*) indicates a significant difference (P <0.05) between compost only and non-composted treatments. Double star (**) indicates a significant difference (P <0.05) between compost + aeration and control, aeration only treatments. Plus sign (+) indicates a significant difference (P <0.05) between compost only and aeration only treatments. Double plus sign (++) indicates a significant difference (P <0.05) between compost + aeration and aeration only treatments.

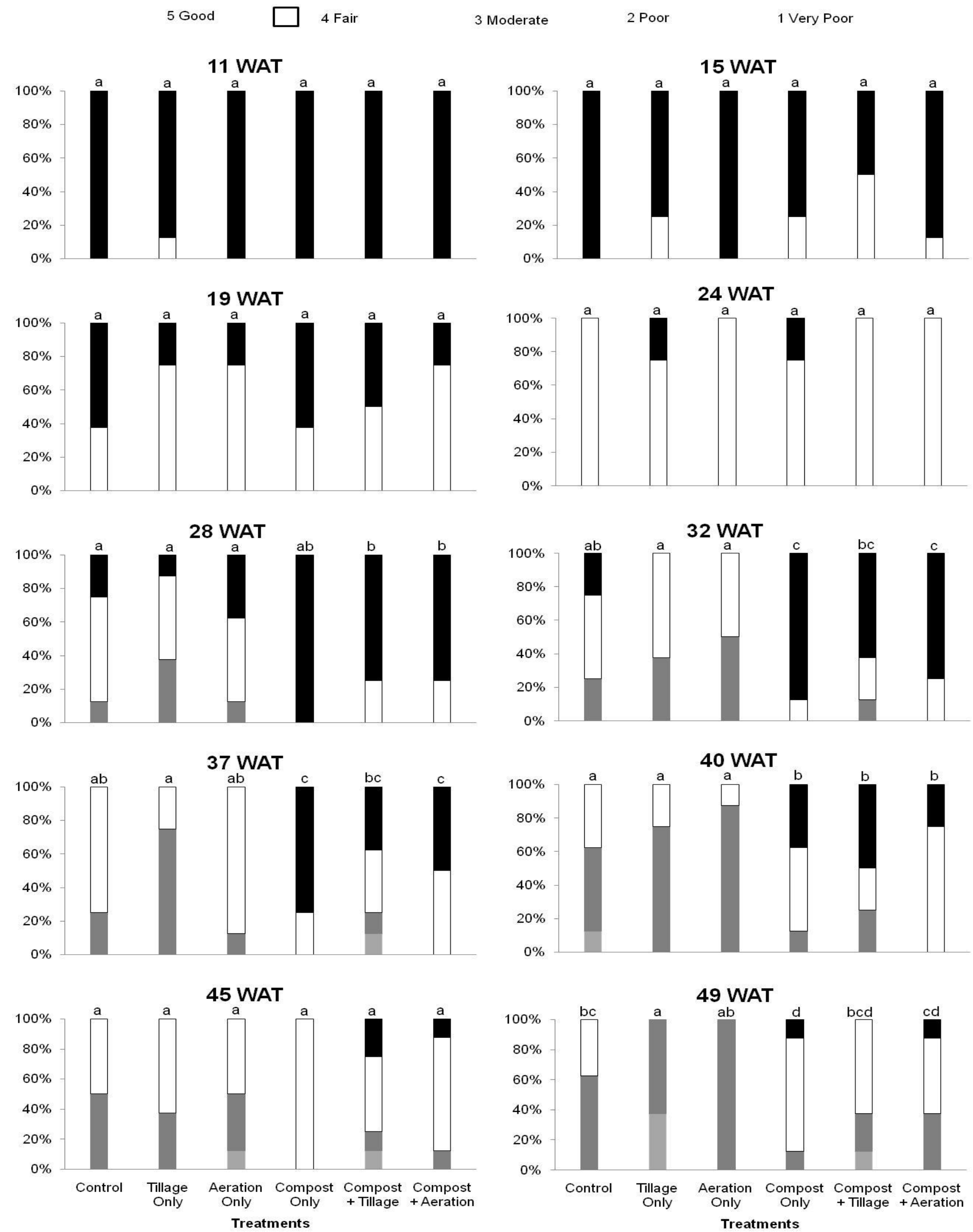

Figure 3-11. Dieback ratings from 0 to 52 weeks after treatment (WAT) of *I. cornuta* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

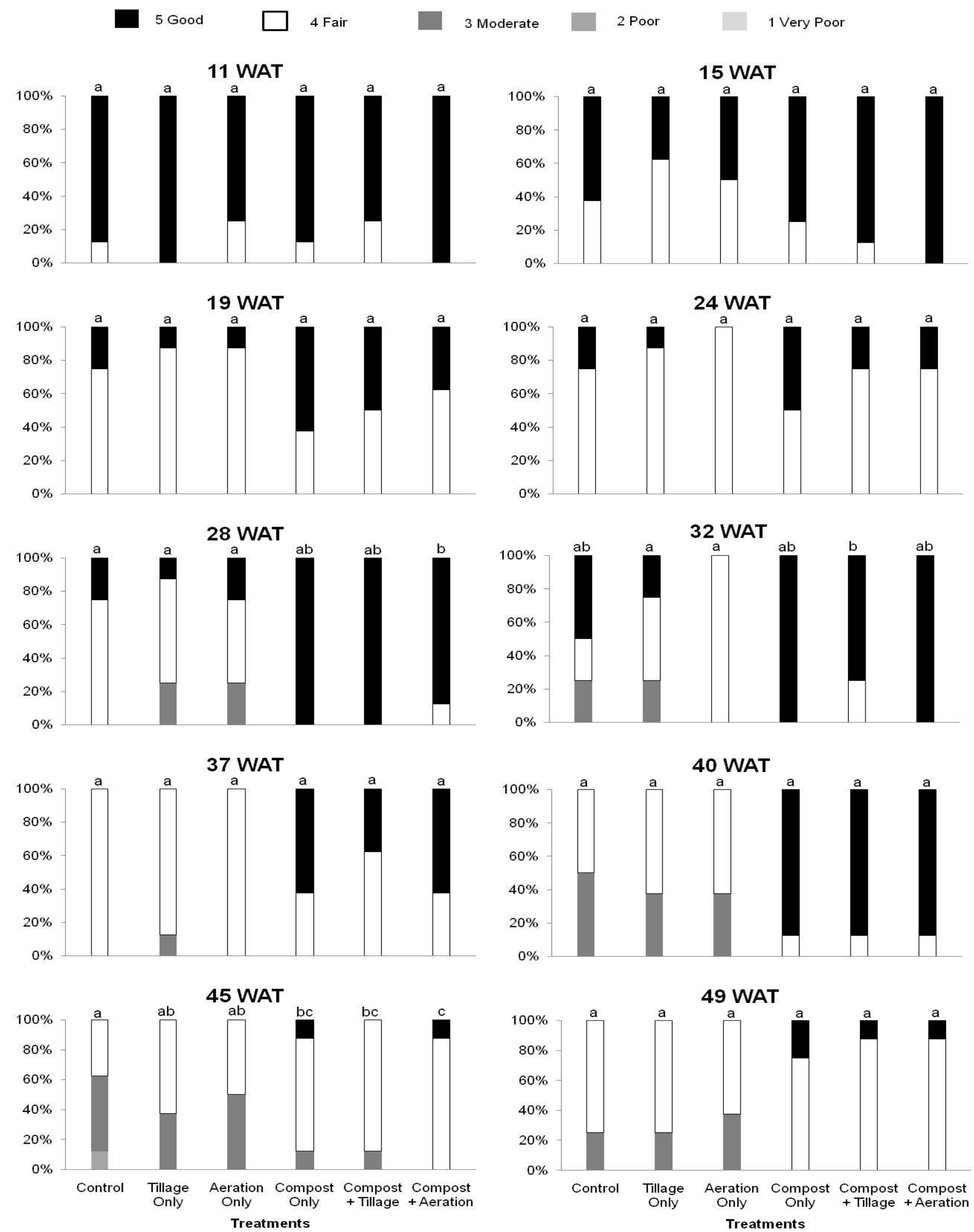

Figure 3-12. Density ratings from 0 to 52 weeks after treatment (WAT) of *I. cornuta* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ the X^2 test.

Table 3-3. Nutrient content in plant tissue collected from *I. cornuta* grown in sandy soils receiving compost, shallow tillage, and/or aeration treatments in simulated residential landscape plots at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
		%		
		Total Kejdahl N		
Control	1.61ab‡	1.27a	1.29a	1.40ab
Tillage Only	1.52a	1.24a	1.18a	1.18a
Aeration Only	1.60ab	1.29a	1.30a	1.24ab
Compost Only	1.79bc	1.68b	1.89b	1.77c
Compost + Tillage	1.71ab	1.59b	1.71b	1.65bc
Compost + Aeration	1.89c	1.59b	1.68b	1.76bc
		Total Phosphorus		
Control	1.21a	1.11a	1.29ab	1.23ab
Tillage Only	1.02a	1.09a	1.13a	1.06a
Aeration Only	1.10a	1.19a	1.24a	1.17a
Compost Only	1.18a	1.33a	1.60c	1.36ab
Compost + Tillage	1.01a	1.14a	1.55bc	1.59b
Compost + Aeration	1.31a	1.34a	1.66c	1.37ab
		Total Potassium		
Control	5.54a	5.33a	5.53a	4.36a
Tillage Only	4.74a	5.36a	5.40a	4.19a
Aeration Only	5.12a	5.48ab	5.52a	4.59a
Compost Only	5.32a	7.29b	5.48a	4.18a
Compost + Tillage	4.54a	6.58ab	5.46a	4.07a
Compost + Aeration	6.19a	7.16ab	5.88a	4.18a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Liriope Muscari

There was a significant soil treatment effect on the GI of *L. muscari* starting at 19 WAT (Figure 3-13). In general, soils amended with compost produced *L. muscari* with higher GI than plants grown in the unamended soils. Surface applications of compost (no tillage or aeration) produced larger *L. muscari* plants than unamended soils from 32 through 49 WAT, while composted soils that were aerated produced larger plants than unamended soils at 32, 40 and 49 WAT. Incorporation of the compost by tilling to a depth of 20 cm only improved growth over unamended soils at 19 and 49 WAT.

Plant SPAD readings for *L. muscari* were affected by soil treatment at 24, 37, 40 and 45 WAT (Figure 3-14). Treatment effects were mixed, however, at each date one or more of the compost treatments resulted in higher chlorophyll readings than plants grown in plants grown in unamended soils. By 11 WAT, soil treatments were significantly affecting plant density and dieback ratings for *L. muscari*. (Figure 3-15 and 3-16). In general, *L. muscari* grown in compost amended soils had better density and dieback ratings than plants grown in unamended soils.

Soil treatments affected the plant nutrient content of TKN and total P for *L. muscari* (Table 3-4). At 13 WAT, TKN in tissue was significantly higher from plants grown in composted soils compared with those grown on unamended soils. At 27 WAT, the compost + tillage and compost + aeration treatments led to TKN concentrations that were significantly higher than for plants grown in soils receiving the other treatments. At 40 WAT, TKN in plant tissue from *L. muscari* grown in composted soils were significantly higher than for plants grown in unamended soils. At 52 WAT, the compost only treatment resulted in plants with higher TKN than plants grown in unamended soils. Tissue total P exhibited soil treatment effects by 13 WAT, where the control and aeration only treatments led to higher tissue P than plants grown in soils receiving the compost only treatment. At 40 WAT, plants grown in soils receiving the control and aeration only treatments had significantly higher tissue P than plants grown in soils where compost was applied. At 52 WAT, the control treatment produced plants with higher tissue P than the compost + aeration treatment. Soil treatments did not affect levels of tissue total K at any time throughout the project.

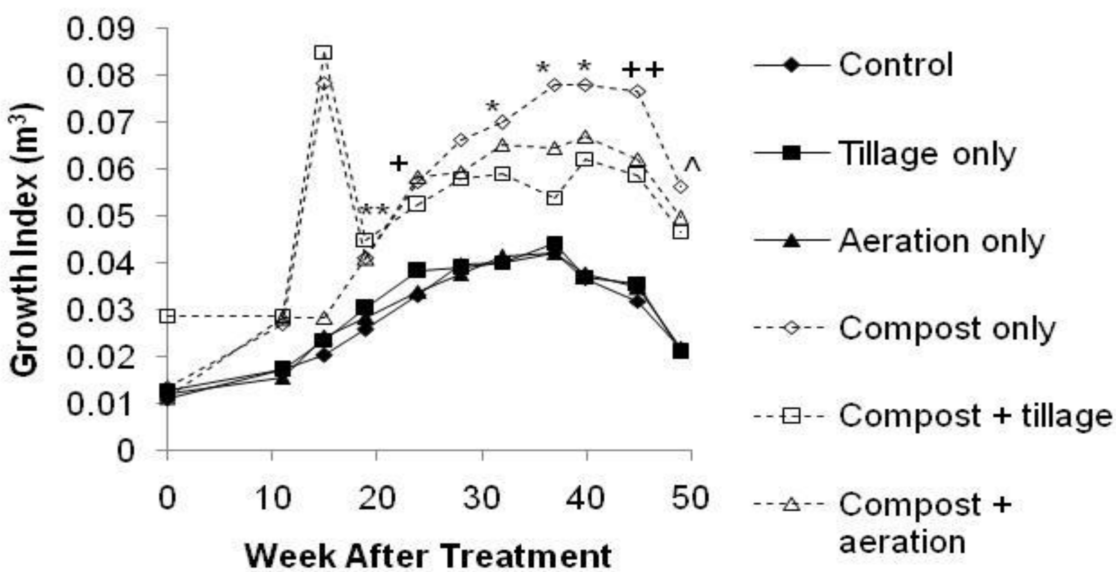

Figure 3-13. Mean canopy growth index from 0 to 52 weeks after treatment (WAT) of *L. muscari* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Star (*) indicates a significant difference (P <0.05) between compost only, compost + aeration and non-composted treatments. Double star (**) indicates a significant difference (P <0.05) between compost + tillage and control treatments. Plus sign (+) indicates a significant difference (P <0.05) between composted treatments and control, aeration only treatments. Double plus sign (++) indicates a significant difference (P <0.05) indicates significant difference between compost only and non-composted treatments. Arrow (^) indicates a significant difference (P <0.05) indicates significant difference between compost and non-composted treatments.

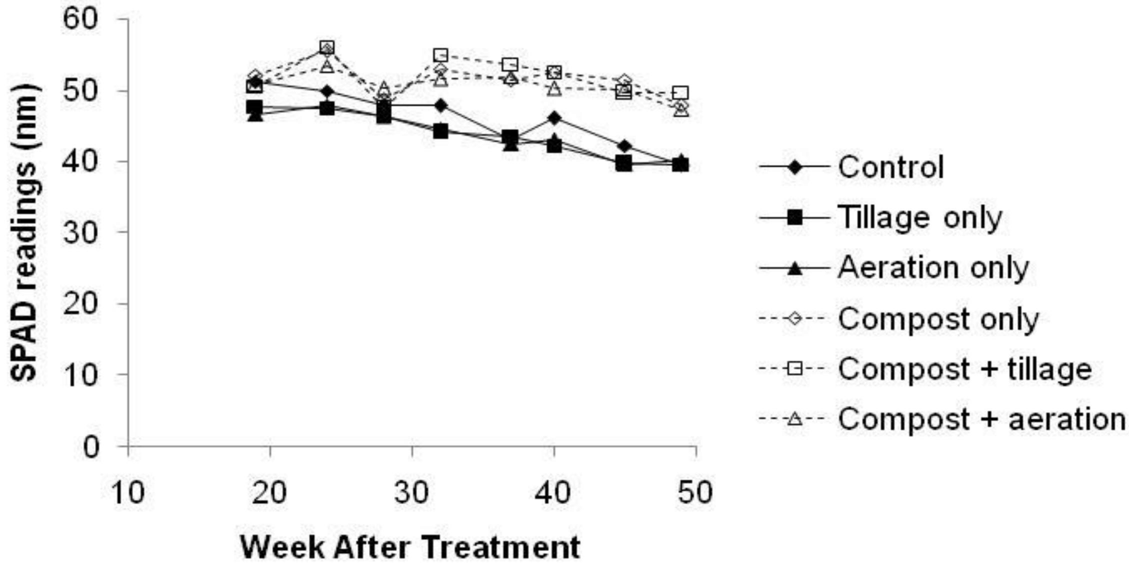

Figure 3-14. Mean SPAD readings from 0 to 52 weeks after treatment (WAT) of *L. muscari* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Star (*) indicates a significant difference (P <0.05) between composted treatments and tillage only, aeration only. Double star (**) indicates a significant difference (P <0.05) between compost + tillage and non-composted treatments. Plus sign (+) indicates a significant difference (P <0.05) between composted treatments and tillage only.

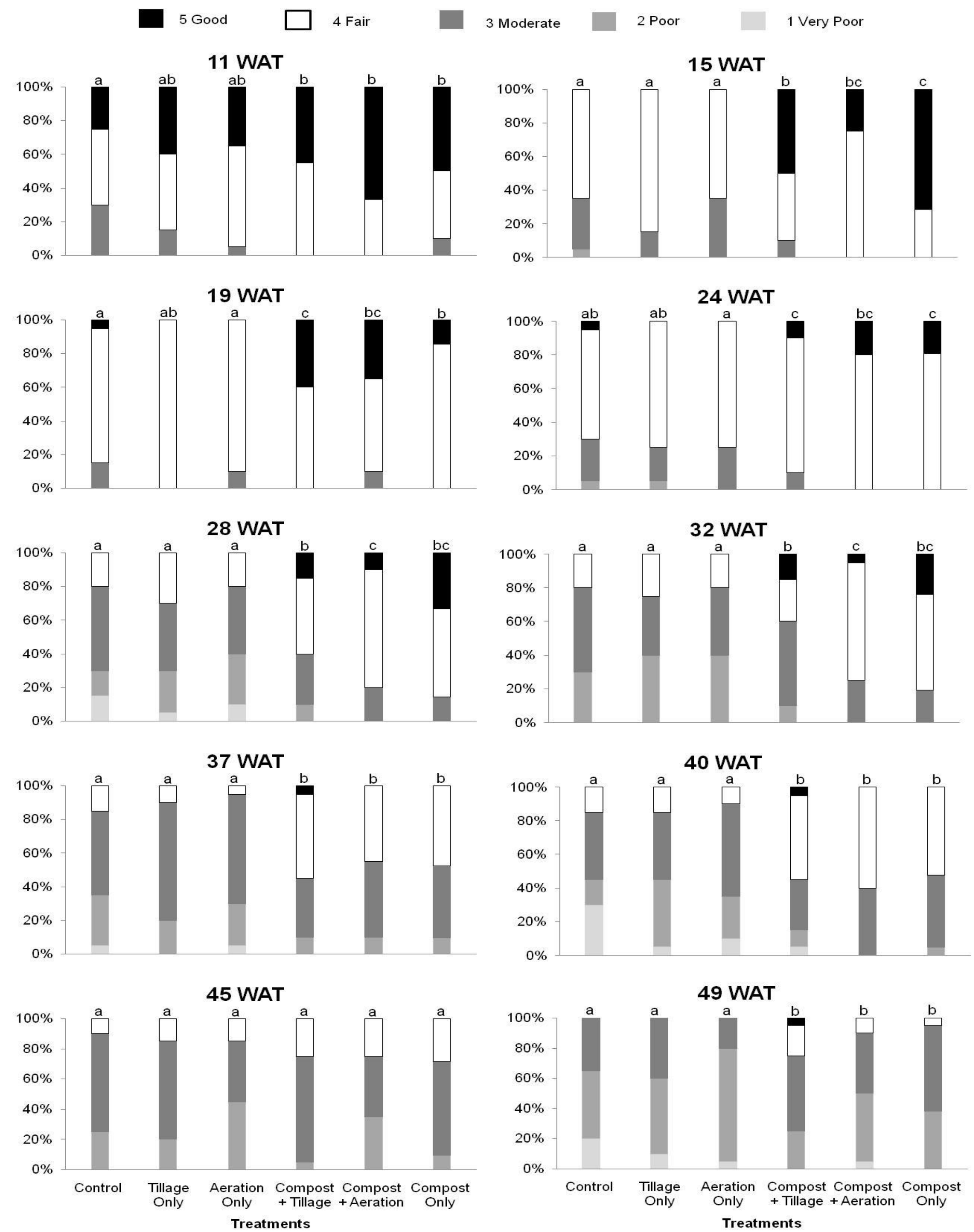

Figure 3-15. Dieback ratings from 0 to 52 weeks after treatment (WAT) of *L. muscari* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

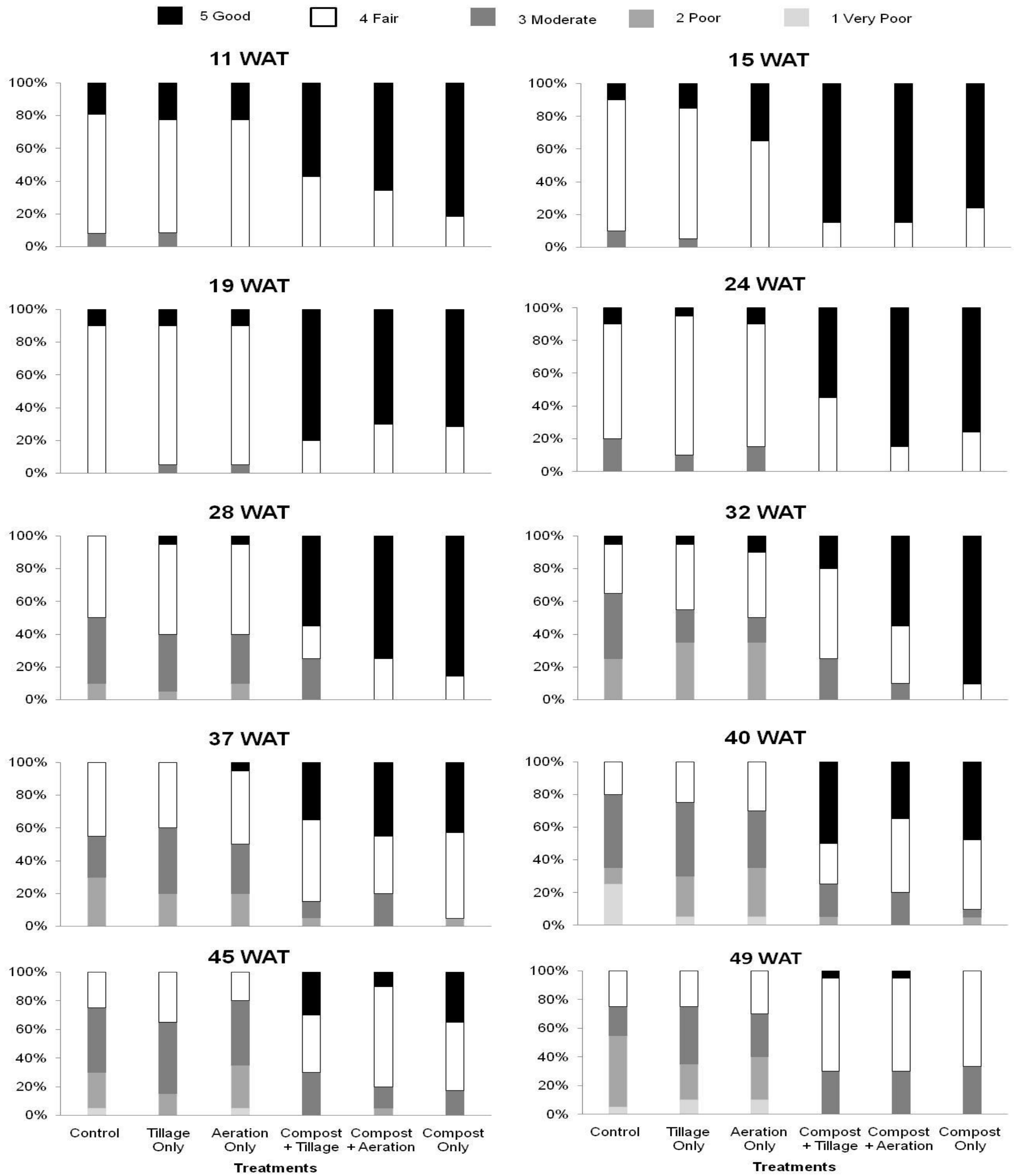

Figure 3-16. Density ratings from 0 to 52 weeks after treatment (WAT) of *L. muscari* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

Table 3-4. Nutrient content in plant tissue collected from *L. muscari* grown in sandy soils receiving compost, shallow tillage, and/or aeration treatments in simulated residential landscape plots at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	%			
	Total Kejdahl N			
Control	2.39ab‡	1.84a	2.00a	1.60a
Tillage Only	2.33a	1.89ab	1.91a	1.67ab
Aeration Only	2.34a	1.84a	2.05a	1.60a
Compost Only	2.60c	2.16ab	2.66b	2.10b
Compost + Tillage	2.73c	2.30c	2.45b	2.04ab
Compost + Aeration	2.64bc	2.19bc	2.46b	2.01ab
	Total Phosphorus			
Control	5.58b	6.77a	4.81c	5.00b
Tillage Only	5.06ab	5.08a	4.56bc	4.22ab
Aeration Only	5.91b	6.80a	5.07c	4.60ab
Compost Only	4.20a	4.59a	3.57ab	3.91ab
Compost + Tillage	4.28ab	3.74a	3.46a	3.91ab
Compost + Aeration	4.69ab	4.84a	2.90a	3.18a
	Total Potassium			
Control	9.46a	8.77a	5.76a	4.54a
Tillage Only	8.57a	5.98a	5.68a	4.70a
Aeration Only	9.56a	7.38a	5.10a	4.11a
Compost Only	8.92a	7.41a	4.55a	4.62a
Compost + Tillage	9.41a	7.01a	5.03a	4.23a
Compost + Aeration	9.43a	6.65a	4.59a	3.37a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Stenotaphrum Secundatum

During the summer months (15 - 28 WAT), the dry mass of turf clippings was greater from compost amended soils compared with uncomposted soils (Figure 3-17). During other times of the year, soil treatment had no effect on the mass of turf clippings collected. While soil treatment effects on turf SPAD readings were only significant at 19 and 28 WAT (where either the compost + tillage or compost only treatments resulted in higher SPAD readings than the aeration only treatment), there was a trend where turf grown on compost amended soils typically had higher SPAD readings (mean 37.74 nm) than unamended soils (mean 35.93 nm). Soil treatments had no effect on turf quality (Figure 3-19).

Soil treatments had a significant effect on tissue nutrient content (Table 3-5). Turf tissue concentrations of TKN were significantly higher when turf was grown on composted soils from 13 through 40 WAT. At 52 WAT, the compost + tillage and compost + aeration treatments produced turf with higher TKN than the unamended soils and the compost only treatment produced turf with higher TKN than the control and tillage only treatments.

Tissue total P was affected by soil treatment starting at 13 WAT, where composted treatments led to higher turf tissue P than the unamended soils (Table 3-5). At 27 WAT, turf grown on unamended soils had higher tissue P than when grown on composted soils. At 40 WAT, tillage only and aeration only treatments produced turf with significantly higher tissue P concentrations than the composted treatments, while the control treatment produced turf with higher P than the compost only treatment. By 52 WAT, there were no longer soil treatment effects on tissue P.

Soil treatments affected turf tissue total K had significant differences at 13 WAT, when composted treatments produced turf with higher K concentrations than non-composted treatments (Table 3-5). By 27 WAT, turf grown on soils receiving the compost + aeration treatment had higher K than turf grown on soils receiving the tillage only treatment. At 40 WAT, application of compost resulted in higher tissue K concentration than the non-composted treatments. As with total P, there was no significant effect of soil treatment on tissue total K content at 52 WAT.

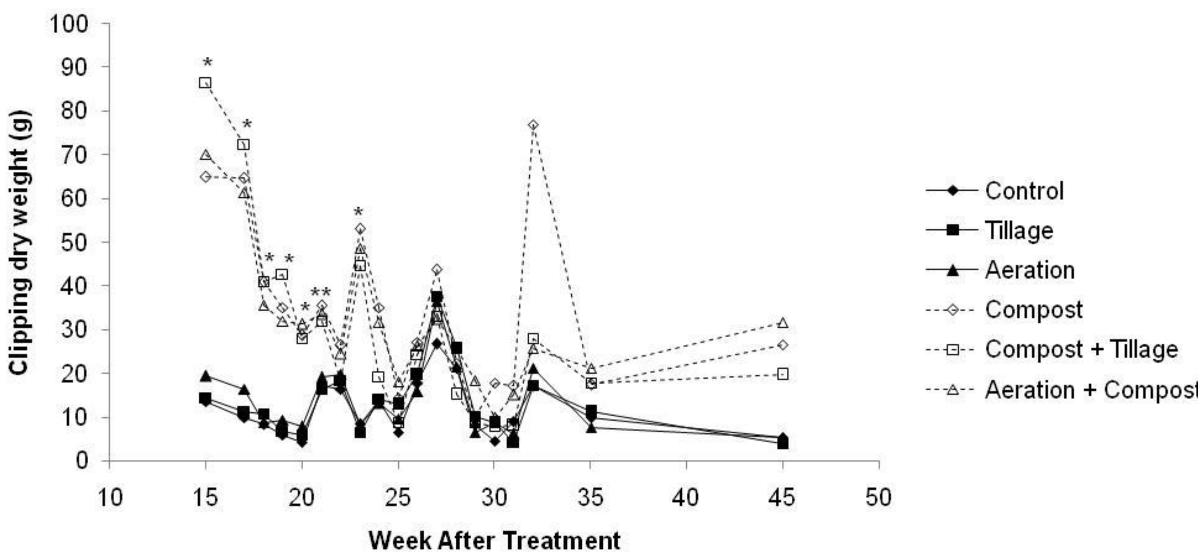

Figure 3-17. Clipping dry weights from 0 to 52 weeks after treatment (WAT) of *Stenotaphrum secundatum* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.
Star (*) indicates a significant difference ($P < 0.05$) between composted and non-composted treatments. Double star (**) indicates a significant difference ($P < 0.05$) between compost only and tillage only, control treatments.

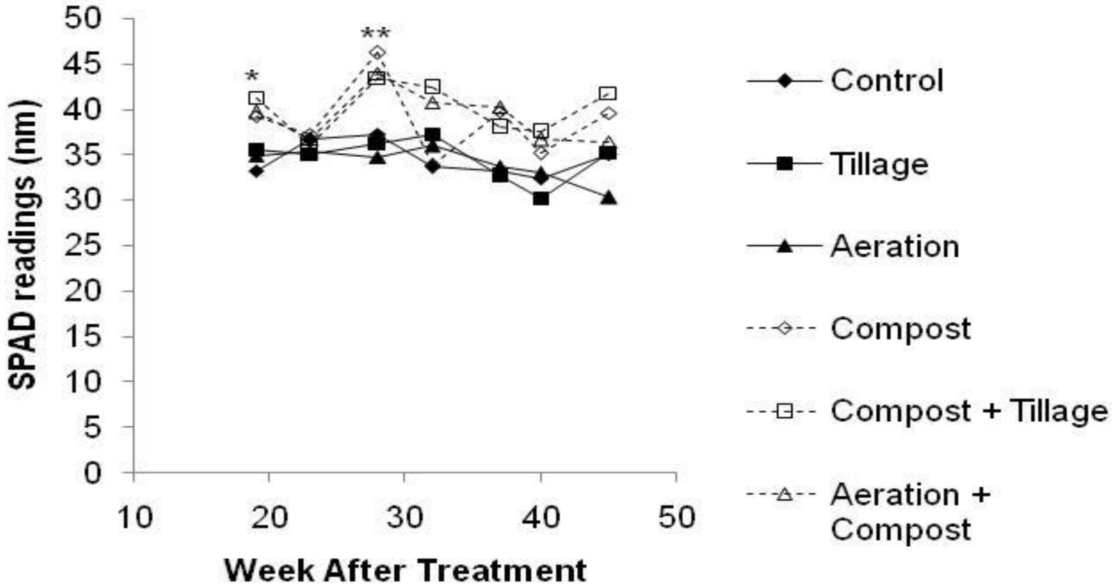

Figure 3-18. Mean SPAD readings from 0 to 52 weeks after treatment (WAT) of *Stenotaphrum secundatum* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots.

Star (*) indicates a significant difference (P <0.05) between compost + tillage and non-composted treatments. Double star (**) indicates a significant difference (P <0.05) between compost only and aeration only treatments.

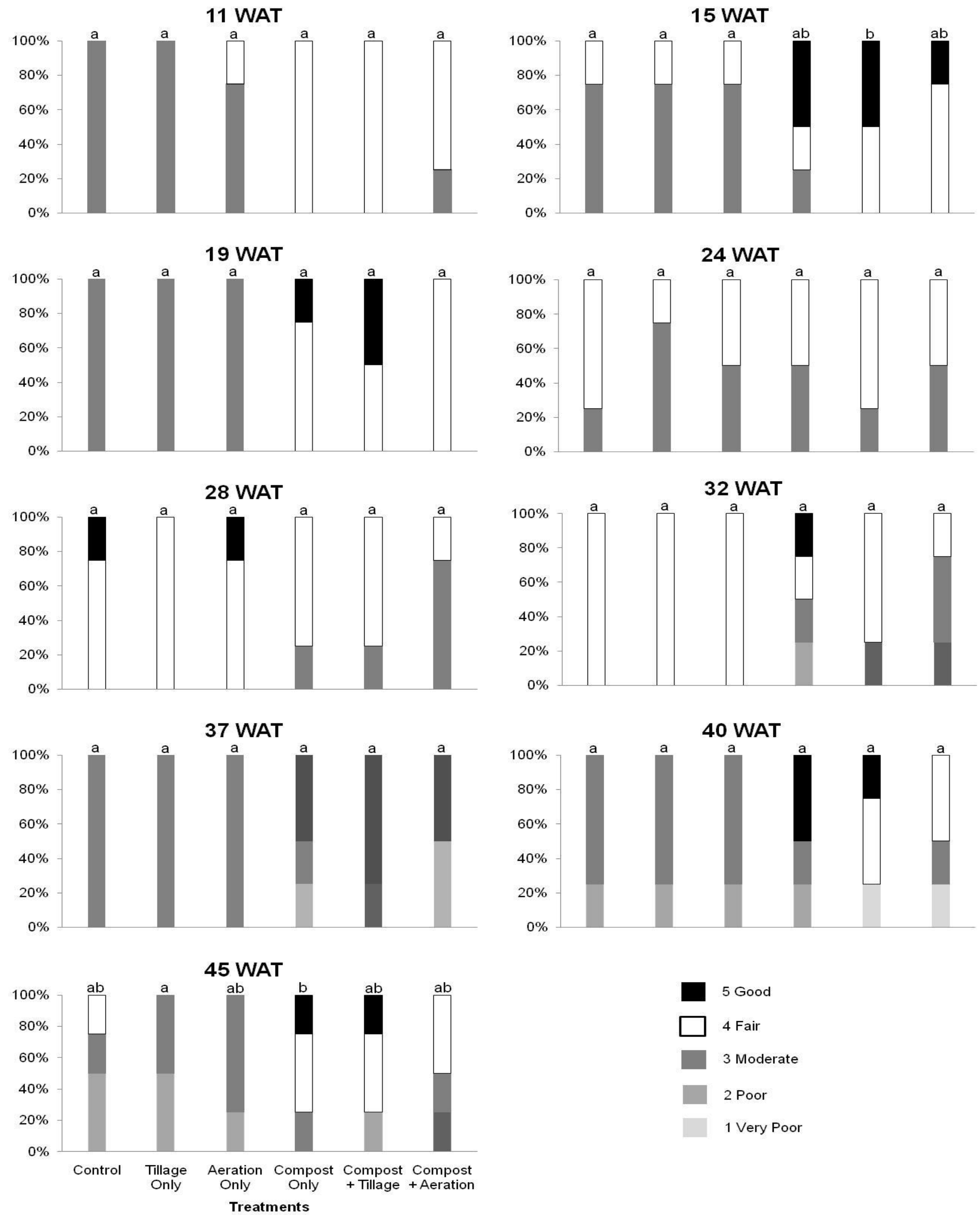

Figure 3-19. Quality ratings from 0 to 52 weeks after treatment (WAT) of *Stenotaphrum secundatum* grown in sandy fill soils receiving compost, shallow tillage and/or aeration treatments in simulated residential landscape plots. Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using the X^2 test.

Table 3-5. Nutrient content in plant tissue collected from *Stenotaphrum secundatum* grown in sandy soils receiving compost, shallow tillage, and/or aeration treatments in simulated landscape plots at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	%			
	Total Kejdahl N			
Control	1.81a‡	2.38a	1.73a	1.93a
Tillage Only	1.88a	2.31a	1.72a	1.85a
Aeration Only	2.03a	2.53a	1.68a	2.21ab
Compost Only	2.81b	3.31b	2.72b	2.78b
Compost + Tillage	2.87b	3.26b	2.61b	2.85bc
Compost + Aeration	2.62b	3.28b	2.81b	3.08c
	Total Phosphorus			
Control	4.51a	5.50b	4.91bc	4.39a
Tillage Only	4.44a	5.74b	5.13c	4.26a
Aeration Only	4.75a	5.83b	5.16c	4.86a
Compost Only	6.19b	4.47a	4.02a	4.69a
Compost + Tillage	6.81b	3.91a	4.36ab	5.14a
Compost + Aeration	6.66b	4.08a	4.24ab	4.24a
	Total Potassium			
Control	14.09a	17.15ab	10.14a	9.92a
Tillage Only	13.56a	16.78a	10.44a	9.66a
Aeration Only	15.13a	17.73ab	10.11a	10.92a
Compost Only	18.13b	17.93ab	13.58b	11.40a
Compost + Tillage	20.62b	19.46ab	16.09b	12.54a
Compost + Aeration	18.81b	20.11b	16.14b	11.72a

†WAT = week after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Discussion

The GI data for the ornamental plants, with the exception of *R. indica*, indicated more growth for plants grown in soils amended with composted dairy manure solids. A study by Rivenshield (2003) also found that additions of food waste compost to compacted urban soil increased plant vigor and growth of *Acer saccharum and Acer saccharinum* trees. The lack of significant effect on *R. indica* may be due to the plants adaptability to a wide range of soil conditions. The improved growth of plants in composted soils may be explained by the additional nutrients contained in the compost (Table 2-3). In most instances, plant tissue nutrient content was higher when plants were grown in soils receiving composted compared with those grown in unamended soils. Compost applications have been shown to improve turf establishment and provide a healthy environment for root establishment (Cogger, 2005).

In our study, the bulk density of compost amended soils was lower (1.00, 1.25, 1.09 and 1.07 g cm^{-3} at 13, 27, 40 and 52 WAT, respectively) than non-composted soils (1.65, 1.72, 1.59, and 1.68 g cm^{-3} at 13, 27, 40 and 52 WAT, respectively) (Table 2-3). However, the bulk density of the unamended soils was below the 1.8 g cm^{-1} bulk density threshold for root restriction for a sandy soil (Hanks and Lewandowski, 2003), suggesting that bulk density wasn't likely to influence plant growth in our study. In addition, we found that application of compost improved soil field moisture capacity (Table 2-10), thereby increasing the volume of plant available water in the soil. Pandey and Shukla (2006) reported that the application of 100 Mg ha^{-1} yard trimming compost to soils at a commercial vegetable farm increased the soil moisture content compared with soils where no compost was applied. However, since plant water stress was not measured in this study, we cannot definitively say that the increase in the water holding capacity of the soil was responsible for the increase in plant growth.

Plant SPAD readings were typically higher for plants grown in soils receiving composted treatments versus non-composted treatments in our study. Similar results were reported by Smiley et al. (2006), who found that the mean SPAD readings of *Prunus serrulata* and *Ulmus parvifolia* grown in a sandy clay loam soil were significantly higher when grown in non-compacted/suspended pavement treatment than when grown in a gravel/soil mixture, Stalite/soil mixture, Stalite, or a compacted soil. In our study, high SPAD readings were likely due to the addition of nutrients in the compost. In our study, plant tissue N content was typically higher for plants grown in composted soils than for plants grown in the unamended soils. SPAD readings measure the ratio of the amount of light transmitted through a leaf at two wavelengths; one that is absorbed by chlorophyll and the other one is not (Ntamatungiro, 1999). SPAD readings indicate degree of greenness of the plant, that correlates to amount of chlorophyll present (Ntamatungiro, 1999).

All plants in the study showed significant soil treatment effects on quality ratings at some point during the study. Composted treatments typically resulted in plants with higher quality ratings than the non-composted treatments. In instances when there were no statistical differences, visual differences in appearance may have still been observed in the field, where plants grown in composted soils tending to have higher quality. The lack of difference in quality ratings could be caused by human error, as the same people did not evaluate the plants every time and the ratings were based on personal judgment. Linde and Hepner (2005) reported Kentucky bluegrass grown in coarse-loamy sand with compost addition outperformed one-time fertilized plots in turfgrass color and density after 2-3 weeks. They attributed the observed difference in turf response, in part, to nutrients added to the soil in the compost. Landschoot and McNitt (2004) reported that compost source and rate of application greatly influenced turf establishment and that most compost treatments increased rate of Kentucky bluegrass establishment when compared to control plots.

During the course of our study, soil treatments affected plant nutrient content at some point for all plants. Warman et al. (2009) that the higher the application rate of a municipal solid waste significantly increased the levels of N, P, and K in blueberry leaves in a sandy loam soil. In most cases the plant tissue nutrient content was higher for plants grown in compost amended soils when compared with those grown in unamended soils; this follows the pattern for soil nutrient content in our study. A study by Yavari et al. (2009) found that high concentration of N in soil often resulted in increased N concentration in plant tissues. However, plant nutrient content in each species varied, and was possibly a result of differences in plant physiology that influenced the ability of plant to take up and use specific nutrients. Grigatti et al. (2007) found that plant nutrient composition of four different plant species (*Begonia semperflorens, Mimulus, Salvia splendens, and Tagete* patula) varied within the species, showing notable species differences in nutrient utilization as compost nutrient concentration increased. Similarly, a study by Wright et al. (2007a) suggested that the higher levels of macronutrients in the tissue of Bermudagrass compared with St. Augustinegrass tissue were due to differences in plant uptake and absorption between the species when grown in compost amended soils.

CHAPTER 4
NUTRIENT LEACHING FROM SIMULATED RESIDENTIAL LANDSCAPES AS AFFECTED BY COMPOST AND TILLAGE

Introduction

Urban growth has been linked to water quality degradation and supply issues (Kaye et al., 2006). Urbanization of land results in disturbances to the soil profile, soil compaction and an increase in impervious cover, all of which can alter infiltration rates and other hydraulic properties of the soil. In turn, soil disturbances associated with urbanization directly affect surface runoff, erosion, and groundwater recharge (Defossez and Richard, 2002; Gregory et al., 2006; Hamilton and Waddington, 1999; Kaye et al., 2006). Runoff from urban areas is one of the leading sources of nutrients and other pollutants to surface waters (Shuman, 2004; USEPA, 2000). In fact, more than 50% of water bodies in Florida are affected by urban non-point source pollution, which includes pollution originating from residential landscapes (Association of State and Interstate Water Pollution Control Administrators, 1984).

Residential land is managed more intensively than agricultural land, which can result in greater losses of nitrogen and phosphorus from urban systems compared to agriculture (Bhattarai et al., 2008; Johnson et al., 2006). Once these nutrients are lost from residential landscapes, they have the potential to degrade surface and groundwater bodies (Erickson et al., 2005). Excess applications of N or P to the soil in fertilizers increase the potential for nitrate movement to groundwater and phosphate movement to surface waters (Confesor et al., 2007; Johnson et al., 2006). An increase in water, and fertilizer use is often a direct result of by the urban landowner’s desire for a beautiful landscape (Hipp et al., 1993).

The application of organic amendments (e.g., composted materials, manures) to soil is gaining favor as an environmental waste management strategy and a way to improve soil organic matter content in low-fertility soils (Flavel and Murphy, 2006). However, the use of manure and compost as a nutrient source or soil amendment can also lead to pollution of water systems (Gilley and Eghball, 2002). When used in agricultural systems, organic amendments are often applied at rates that are based on N content of the material, an estimation of potential N mineralization, and crop requirement (Jaber et al., 2005). Application of organic amendments based on crop N requirements often results in applications of P that exceed crop requirements (Davis et al., 1997; Gaudreau et al., 2002). Research has linked the degradation of water quality to increased losses of dissolved and particulate P from agricultural soils that received repeated applications of organic amendments based on crop N requirements (Sims et al., 1998).

Hawver and Bassuk (2007) recommend well composted organic amendments be applied at a rate of >25% (>50% for loam or clayey soils) by volume to the top 46 cm of compacted urban soils to improve soil conditions. However, Urban (2008) suggests that application of organic amendments to the top 30 cm of soils urban landscapes should not exceed 10 to 15% of the soil (by volume) to prevent subsidence. But, applications of 25 to 35% organic amendments by volume to the top 15 cm of soil have been suggested to increase soil biology and enhance the formation of topsoil in urban landscapes (Urban, 2008). These suggested rates for urban applications are likely to far exceed the N and P requirements of ornamental landscape plants. Both N and P have been shown to pose a risk to water quality at relatively low levels, ranging from

0.01 to 0.035 mg L^{-1} for P and 10 mg L^{-1} for NO_3 (as set by EPA for human safety) (Erickson et al., 2001; Mallin and Wheeler, 2000). Nitrate leaching is a concern when high rates of compost with a low C to N ratio is applied to landscapes that are unable to utilize large amounts of N (Cogger, 2005). In addition, organic amendments are usually applied to the urban landscapes in addition to inorganic fertilizers, without taking into account the nutrient requirements of plants in the landscape (Gaudreau et al., 2002; Johnson et al., 2006).

Tillage has also been suggested as a way to improve plant growth and quality in urban landscapes. Soil tillage can improve soil physical properties thereby improving the plant environment and allowing deeper root growth (Lipiec and Stepniewski, 1995). Tillage breaks up soil aggregates creating more pore space, thereby allowing water to infiltrate and roots to penetrate through the soil profile (Vogeler et al., 2005). Studies have shown that soil compaction can be alleviated by spike and core aeration and rototilling (Jim, 1993; Kozlowski, 1999; Unger and Kaspar, 1994). Deep tillage (to approximately 0.4 m) allows root growth into deeper soil horizons with more structural development and greater water-holding capacity (Busscher et al., 2006). However, it has been suggested that tillage practices have the potential to release greater amounts of NH_4 and NO_3 in surface runoff from agricultural soils than no-till practices, as they compact the soil when machines run over the soil and decrease infiltration (Drury et al., 1993).

Considerable inputs of water and fertilizers are needed to establish and maintain healthy, high quality turf (King et al., 2001). Turf dominated landscapes may receive yearly nitrogen and phosphorus applications in excess of 450 kg N ha^{-1} and 100 kg P ha^{-1} (Hipp et al., 1993). In Florida, turfgrass should receive 150-300 kg N ha^{-1} yr^{-1} when fertilized on a moderate maintenance schedule (Sartain, 2007). In contrast, the recommended N rate for ornamentals on a moderate maintenance schedule in Florida is 97.6 kg N ha^{-1} yr^{-1} (Florida Yards and Neighborhoods Program, 2006). However, turfgrass and mixed ornamentals generally receive similar rates of fertilization when they are situated in close proximity within the landscape (Saha et al., 2005). Elevated levels of N in watersheds is thought to be a result of fertilizer N runoff and leaching from originating from residential landscapes where turfgrass is routinely fertilized (Erickson et al., 2001). However, slower runoff velocities and increased infiltration of water are expected when turf is intensely managed (Gross et al., 1990).

Research has suggested that adding organic amendments and tillage can help with plant establishment in urban landscapes. However, there is limited research that evaluates how these practices may affect nutrient losses in runoff or leachate from mixed residential landscapes. The objectives of this study were to determine the effects of 1) compost additions and tillage or aeration and 2) vegetative cover (e.g. mixed ornamental species, turfgrass) on the potential for nutrient losses in runoff or leachate from simulated urban landscapes.

Materials and Method

Experimental Design

Twenty-four mixed landscape plots (3.05 x 3.66 m; 1.12×10^{-3} ha) were established in a randomized complete block design at the UF - IFAS Gulf Coast Research and Education Center in Wimauma, FL. All vegetation was removed from the site before plot construction. The entire research area was prepared at a 2% grade (as is typically required by construction codes) and compacted (bulk density range: 1.7-1.9

g cm^{-3}) using a small plate compactor (Wacker Neuson, Munich, Germany). Individual landscape plots were constructed inside water-sealed treated wooden boxes. Within each plot, the compacted field soil (Zolfo fine sand: sandy, siliceous, hyperthermic Oxyaquic Alorthods (USDA-NRCS, 2004) was then buried under 1.13 m^3 of un-compacted soil fill material. Soil fill material was created by mixing three fill soil materials in equal parts to simulate a 'top soil' material that would be applied during residential construction. The three fill soil material sources included: a subsoil fill containing construction material and other debris; a clean topsoil material (St. Johns fine sand; sandy, siliceous, hyperthermic Typic Alaquod) obtained from depth of 30 to 61 cm (Hills Dirt Pit, LLC., Riverview, FL), and a clean subsoil fill (St. Johns fine sand) fill obtained from a depth of 122 to 213 cm (Hills Dirt Pit, LLC., Riverview, FL).

Composted dairy manure solids (compost; Agrigy, Palm Harbor, FL) were applied as an organic soil amendment at a rate of 508 m^3 ha^{-1} (approximately 256 Mg ha^{-1}) in combination with two mechanical soil treatments (tillage and aeration) for a total of five soil management treatments. The soil management treatments were as follows: 1) tillage only, 2) compost only, 3) compost + tillage, 4) aeration only, 5) compost + aeration. In plots receiving the tillage treatment, soils were turned to a depth of 10-15 cm using counter rotating tines tiller (Sears Brands, LLC, Hoffman Estates, IL). In plots receiving the aeration treatment, soil aeration plugs were mechanically removed using a core aerator (Billy Goat Industries, Inc., Lee's Summit, MO). An untreated control plot (no tillage or organic amendment) was included as the sixth soil treatment.

Once soil treatments were applied, each plot was split and 5.58 m^2 of the plot was planted with *Stenotaphrum secundatum* (Walter) Kuntze (St. Augustine turfgrass); the remaining 5.58 m^2 was planted with mixed ornamentals. Mixed ornamentals species included *Galphimia glauca* Cav. (Thryallis), *Rhaphiolepis indica* (L.) Lindl. Ex Ker Gawl. (Indian hawthorne), *Ilex cornuta 'Burfordi'* Lindl. & Paxton (Buford holly), and *Liriope muscari (Decne.)* L. H. Bailey (Liriope). Turfgrass was fertilized at a total N rate of 220 kg ha^{-1} based on current UF-IFAS recommendations (moderate maintenance schedule for South Forida): 48.8 kg N ha^{-1} per application using Lesco Professional turf fertilizer (26-2-11) in February and October, 48.8 kg N ha^{-1} per application using polymer coated urea (42-0-0; Harrell's Profession Fertilizer Solutions, Lakeland, FL) as a slow-release N source in May and August, 24.4 kg N ha^{-1} with urea (46-0-0; Potash Corp., Northbrook, IL) as a soluble N source, and 6.34 L ha^{-1} of ferrous sulfate (Sunniland Corporation, Sandord,FL) in July (Sartain, 2007). Ornamental plants were fertilized every 3 months with urea at an N rate of 97.6 kg ha^{-1} based on UF-IFAS recommendations for established woody ornamentals grown in the landscape (Knox et al., 2002).

The entire research plot area was equipped with a spray irrigation system, which allowed for individual landscape plots to be irrigated as needed, based on UF-IFAS recommendations (Zazueta et al., 2005). During establishment, plots were watered daily for 30 d after planting to allow for establishment of turf and ornamental plant material. Irrigation frequency was then reduced to two days a week based on typical watering restrictions for landscape irrigation that would be mandated in times of drought (South Florida Water Management District, 2008; St. Johns River Water Management District, 2008). Irrigation was applied for 51 min (irrigation controller run time for two irrigation events per week at an application rate of 0.13 cm per hour, assuming system efficiency of 80% and considering effective rainfall) per plot on Mondays and Thursdays starting at 0300 HR and ending around 0900 HR. Cumulative weekly rainfall data was collected from the Florida Automated Weather Network (FAWN) located within 50 m of the landscape plots (Figure 1).

Leachate Collection and Analysis

Each plot was outfitted with gutters to direct runoff from rain and irrigation events into collection containers at the bottom of the graded plots. Two 38-L capillary wick lysimeters (53 cm × 36 cm) were also buried at a depth of 15-25 cm below the soil surface in each plot to allow for leachate collection. Leachate samples were collected weekly and the volume was recorded. Leachate subsamples were collected for analysis every three months except during periods where rainfall produced significant volumes of leachate (summer months) (2, 3, 4, 5, 6, 7, 14, 18, 21, 24, 27, 32, 42, 55 weeks after treatment [WAT]). The leachate subsamples were passed through a 0.45 µm filter and stored at 4ºC until analysis. Leachate pH was measured using a combination electrode and electrical conductivity (EC) was analyzed using an EC meter. Leachate samples were analyzed colorimetrically for NO_3 + NO_2 (USEPA, 1993a), NH_4 (USEPA, 1983), and dissolved phosphorus (USEPA, 1993b) using a discrete analyzer (Seal Analytical, West Sussex, UK). The volume of leachate collected in each collector was adjusted based on the land area (2.11×10^{-5} ha) drained to each collector. Nutrient load was then calculated by multiplying the area adjusted leachate volume by the nutrient concentration.

Data Analysis

The experiment was designed as randomized complete block split-plot design with 4 blocks and 6 soil treatments in each block. Half of each plot was planted with ornamental plants and the other ½ was planted with turfgrass as described previously.

The soil treatments within each block were assigned randomly. Data were analyzed using the PROC MIXED procedures in SAS with soil treatment as a fixed effect and block as a random effect (SAS Institute, 2003). Leachate volume, EC, NO_3 + NO_2, NH_4 and dissolved P data were log transformed prior to statistical analysis. All comparisons were completed using the Tukey honestly significant difference (HSD) test with a significance level of α= 0.05.

Results and Discussion

Leachate and Runoff Volume

Most of the landscape plots produced no measurable runoff during the entire study period. Runoff was only collected at 16 WAT (June 2008) from five plots receiving the compost only (3) or compost + aeration (2) treatments; the average volume of runoff collected from these landscape plots was 1.02 L. This runoff event occurred during the rainy season (Figure 4-1) and it was probably a result of soil saturation from a previous rainfall event. A similar study by Erickson et al. (2001) measured only one runoff event from simulated landscapes constructed on a 10% slope in a sandy soil in southern Florida despite frequent intense rainfall events occurring throughout the study. Our study did not account for the proportion of land area at a residential home site that would be covered with impervious surfaces (e.g., roof, driveway, sidewalks, etc.). The presence of these impervious surfaces would essentially increase the volume of rainfall that would be delivered to the landscaped areas. It is probable more runoff events would have been reported from our plots if a portion of the plot was covered with impervious surfaces.

The volume of leachate collected from the landscape plots was influenced by irrigation, time of year, and rainfall received. The landscape plots received 5.72 cm of irrigation per week, split into two applications, during the initial plant establishment period (30 days) and 2.16 cm of irrigation per week throughout the remainder of the study based on UF-IFAS recommendations (Zazueta et al., 2005). Higher leachate volumes were collected from landscape plots in the summer months (12-28 WAT) due to the higher amount of rainfall (Figures 4-1 and 4-2). Soil treatments (e.g., compost, tillage, and aeration) had no effect on the volume of leachate collected at any date during the study (Figure 4-2). This could be due to the high sand content and low clay content that is common in Florida soils. Even though our soil was compacted at a depth of 10 cm, the mean soil bulk density reported was 1.42 g cm^{-1}, which is considered to an be an ideal bulk density for sandy soils and is well below the 1.8 g cm^{-1} bulk density threshold for root restriction (Hanks and Lewandowski, 2003).

There was, however, a vegetative cover effect on the volume of leachate collected between 16-52 WAT. Generally, higher leachate volumes were collected from under ornamentals (mean = 60221 L ha^{-1}) than under turfgrass (mean = 30421 L ha^{-1}). While our study found an effect of vegetative cover on leachate volume, Erickson et al. (2005) reported no significant differences in leachate volume from mixed ornamental cover (e.g., groundcovers, woody shrubs, and trees; 3,437 mm) compared with a monoculture of turfgrass (3,802 mm) in simulated mixed landscapes in South Florida, when both were irrigated as needed to avoid wilt. The higher leachate volumes collected under mixed ornamentals in our study could be due to the fact that the canopy of the ornamental plants did not cover the entire plot and that these plants had a lower root density than the turf. Erickson et al. (2008) noted that root biomass was significantly greater for St. Augustinegrass monoculture than for mixed ornamental species in the landscape. Higher leachate volumes could also be the result of over-irrigating the ornamentals. Previous studies suggested that many ornamental plants will exhibit acceptable growth and quality once established when irrigation is significantly reduced (e.g., <50% of reference evapotranspiration) (Montague et al., 2007; Pittenger et al., 2001; Staats and Klett, 1995).

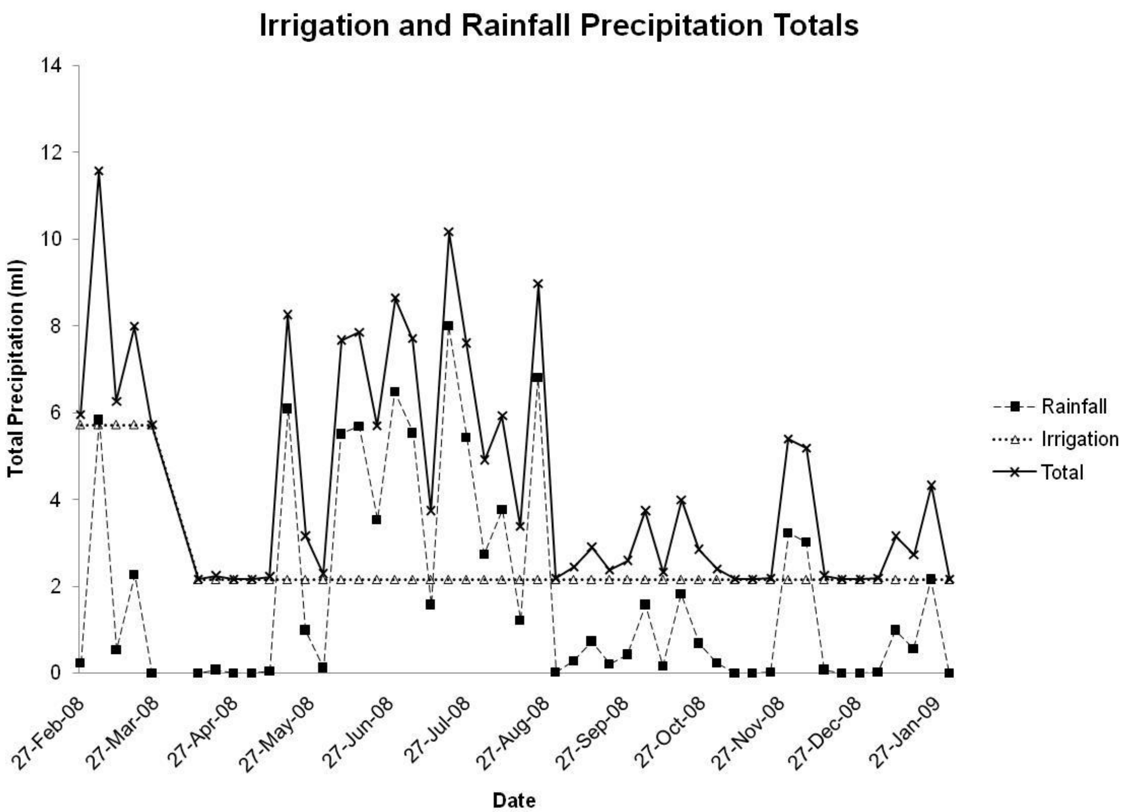

Figure 4-1. Actual weekly rainfall and irrigation applied to simulated residential landscapes established in a sandy soil in Balm, Florida.

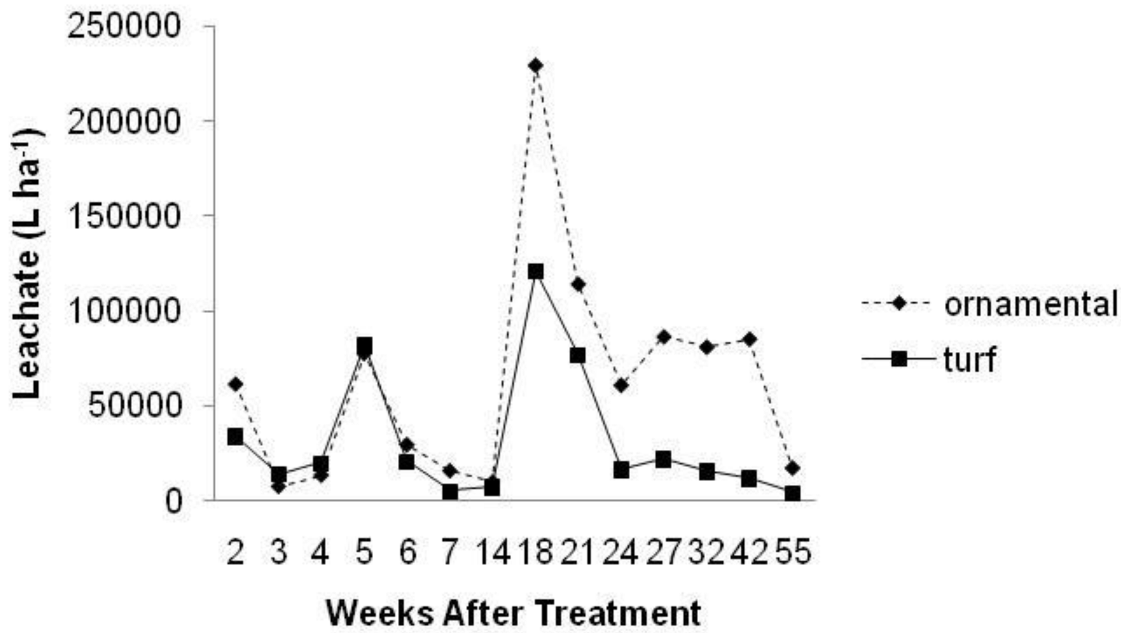

Figure 4-2. Mean leachate volume from 0-52 weeks after treatment (WAT) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass.

Leachate pH and Electrical Conductivity

Leachate pH was not affected by soil treatment or vegetative cover (data not shown). The pH ranged from 5.11 to 9.09 throughout the study. The pH of the leachate was likely a factor of the soil pH, which varied as a result of soil treatments. Landscape plots receiving compost had a mean pH of 7.29, while uncomposted plots had a mean pH of 6.59. The irrigation water used in the study had a pH of 7.83. There is also a trend for higher leachate pH during times where significant rainfall was reported (12-28 WAT) (Figure 4-1).

Electrical conductivity values in leachate from plots amended with compost typically exhibited higher EC values (0.22 to 0.73 dS m^{-1}) than the unamended plots (0.17 to 0.54 dS m^{-1}). However, results were significant at 5 and 6 WAT only, when composted treatments had significantly higher EC than non-composted treatments

(Figure 4-3). At 21 and 24 WAT, plots that received compost + aeration treatments had significantly higher EC than unamended soils. After 27 WAT, there is no longer any soil treatment effect on leachate EC. Similar results were reported for soil EC (Table 2-9). The elevated EC in leachate collected from composted soils is likely due to the presence of soluble salts in the composted dairy manure solids (EC = 1.02 dS m^{-1}) that were applied. These salts were leached from the landscape plots with repeated application of rainfall and irrigation.

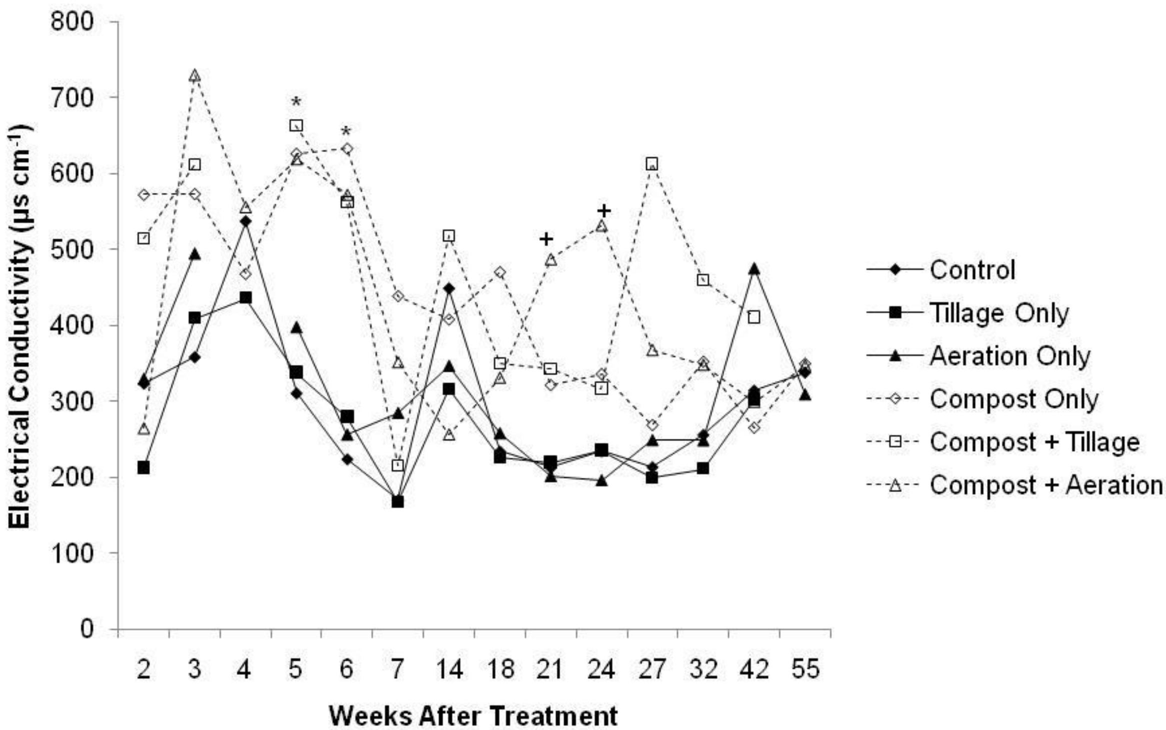

Figure 4-3. Mean electrical conductivity (EC) of leachate samples collected from simulated residential landscape plots where sandy fill soils received compost, tillage and/or aeration soil treatments.
Star (*) indicates a significant difference (P <0.05) between composted treatments and non-composted treatments. Plus sign (+) indicates a significant difference (P <0.05) between compost + aeration and non-composted treatments.

Dissolved Phosphorus

Leachate P concentrations ranged from 0.08 to 0.52 mg L^{-1}. Soil treatments (compost, tillage, aeration) and vegetative cover had no affect on P concentrations in leachate (Figure 4-4). Toth et al. (2006) reported no significant differences in leachate total P when corn or alfalfa grown in a silt loam soils received inorganic fertilizer, dairy manure, or no nutrient source; however the highest annual mean leachate total P concentrations (0.18 to 0.19 mg L^{-1}) were collected from manure amended soils. There was no soil treatment effect on P load; however, there was a vegetative cover effect on P load from 18 WAT through the completion of the study (Figure 4-5). Phosphorus load was higher under ornamental cover (21.8 g ha^{-1}) compared with turf cover (11.7 g ha^{-1}). This was a direct result of the higher volume of leachate collected under ornamental plant cover (Figure 4-2).

A study by Erickson et al. (2005) found greater P and K leaching from mixed ornamentals that were fertilized during establishment, than St. Augustine turfgrass that was routinely fertilized, with the greatest concentrations reported during periods of high drainage. Reed et al. (2006) reported a decrease (not statistically significant) in P movement through the soil when biosolids, clean organic waste, and Bedminster composts (contains 75% municipal solid waste and 25% biosolids) were applied to a Krome (loamy-skeletal, carbonatic, hypertermic, Lithic Udorthents) soil in south Florida. The decrease of P movement following compost applications could be due to the presence of organic matter in the compost, which increased the soil's ability to sorb P. Another possibility of P loss could be attributed the decrease in P leaching to P association with soil cations such as Fe, Al, and Ca (Reed et al., 2006).

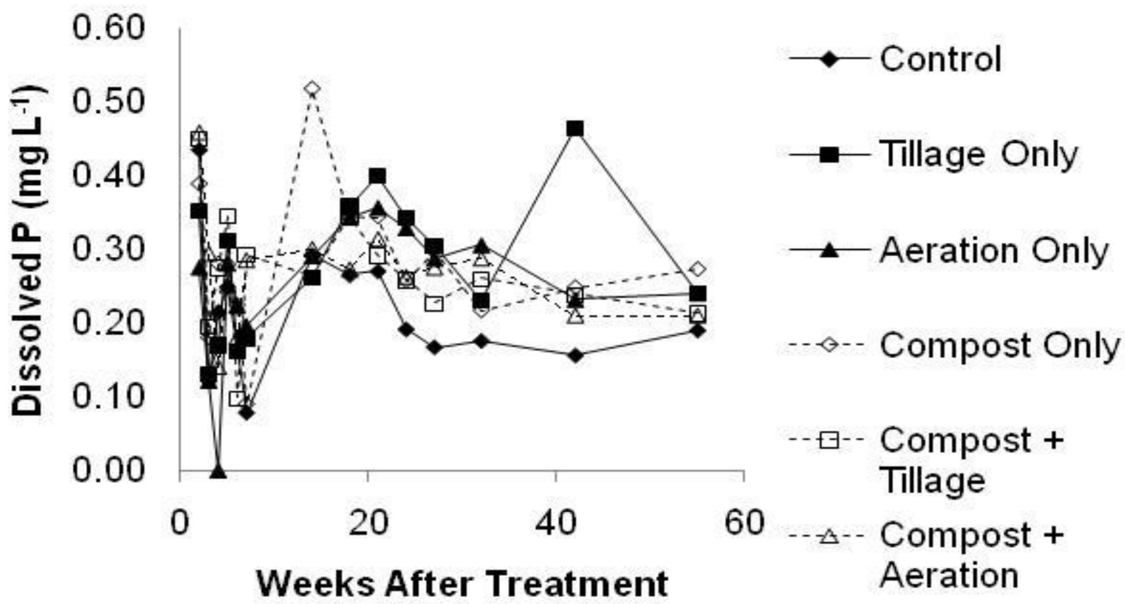

Figure 4-4. Mean concentration of dissolved phosphorus from 0-52 weeks after treatment (WAT) in leachate collected from simulated residential landscapes in Florida where soils were amended with composted dairy manure solids.

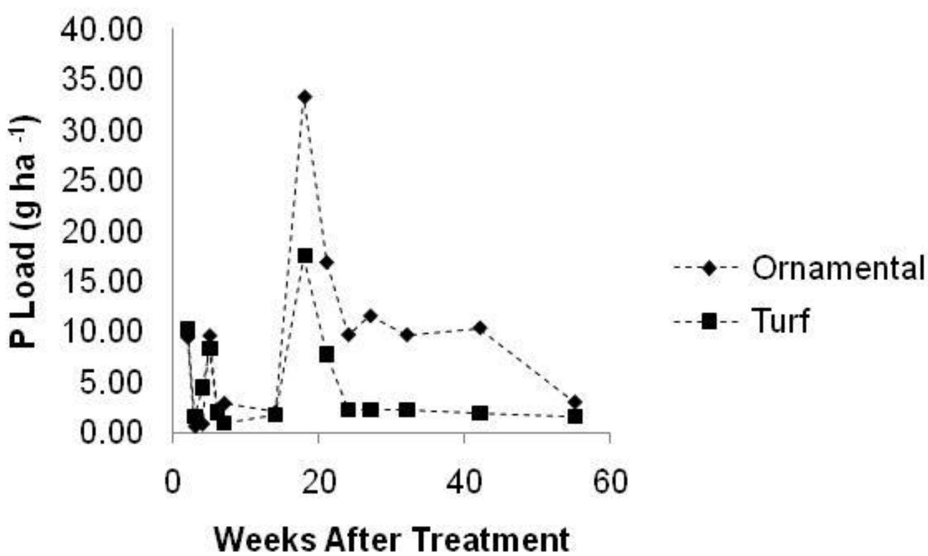

Figure 4-5. Mean P load from 0-52 weeks after treatment (WAT) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass.

Leachate Nitrate (+ Nitrite)

There were soil treatment and vegetative cover effects on the concentration of NO_3 + NO_2 in the leachate samples between 2-7 WAT (Figure 4-6). From 2 to 5 WAT, compost amended soils leached more NO_3 + NO_2 than unamended soils. By 6 WAT, plots where compost was tilled into the soil were no longer producing higher leachate NO_3 + NO_2 concentrations than the unamended soils. We likely see higher NO_3 + NO_2 concentrations at the beginning of the project because the NO_3 was leaching out from the compost (original compost samples reported NO_3 <4.00 mg kg^{-1}). In contrast, Jaber et al. (2005) found no differences, for approximately a year and a half, in leachate NO_3 + NO_2 concentrations when yard and food waste compost, biosolids compost, municipal solid waste-biosolids compost, or an inorganic N fertilizer were applied to a sandy, calcareous soil. According to Burgos et al. (2006), NO_3 leaching is normally high when stabilized organic materials rich in N are applied, but loss of NO_3 in soils treated with composted materials is usually very low.

Vegetative cover effects on NO_3 + NO_2 leachate concentrations were seen at 5, 6, 14 and 18 WAT. In all cases, NO_3 + NO_2 concentrations in leachate were higher when collected under ornamental plant cover than under turf (Figure 4-7). By 21 WAT, there was no longer any soil treatment or vegetative cover effects on concentrations of NO_3 in leachate. Higher concentration of NO_3 + NO_2 collected under the ornamentals is likely due to the root density of the ornamental plants. Erickson et al. (2008) noted that root biomass was significantly greater for St. Augustine turfgrass monoculture than for mixed ornamental species in the landscape after one year; which was the timeframe of our study. The differences in root biomass could affect nutrient uptake and well as infiltration rates, which influence the concentration of NO_3 in leachate moving through the soil profile. Immediately after installation, the roots of ornamental plants are confined to the planting hole. As a result, there is a large volume of soil in ornamental plant beds that does not contain roots until the plants begin actively send roots laterally from the plant base. Therefore, it is likely that when fertilizers or compost are broadcast on the soil surface, some of the NO_3 + NO_2 will be subject to leaching as it was applied in areas where plant roots are not available to intercept the nutrients. Brauen and Stahnke (1995) reported that NO_3 from nitrogen fertilizers moved freely through a pure sand rooting medium during turf establishment from seed, when there were few roots, no thatch and no organic matter accumulation.

Nitrate load was affected by soil treatment only at 3 WAT, when NO_3 loads from the plots receiving the compost only or the compost + aeration treatments were significantly higher than loads from the plots receiving all other treatments. However, there was a significant vegetative cover effect on NO_3 + NO_2 load at 18, 27, 32, and 42 WAT; where the NO_3 + NO_2 load was higher from ornamentals than turf. This was due to the higher volume of leachate collected under ornamental cover (Figure 4-2), which could be a result of overwatering or limited root spread. Erickson et al. (2001) also found that losses of N concentration (both NO_3 and NH_4) were higher from mixed ornamentals than St. Augustine turfgrass, which indicates that turfgrass may be more efficient at N utilization than woody ornamentals. Mangiafico and Guillard (2006) found greater concentrations of NO_3 in leachate during turfgrass establishment from sod and attributed it to mineralization that was stimulated by soil disturbance during planting; once turf was established NO_3 losses were reduced. Cisar et al. (2004) hypothesized that as the landscape continues to develop N-leaching would be greatly reduced, for both turf and ornamentals.

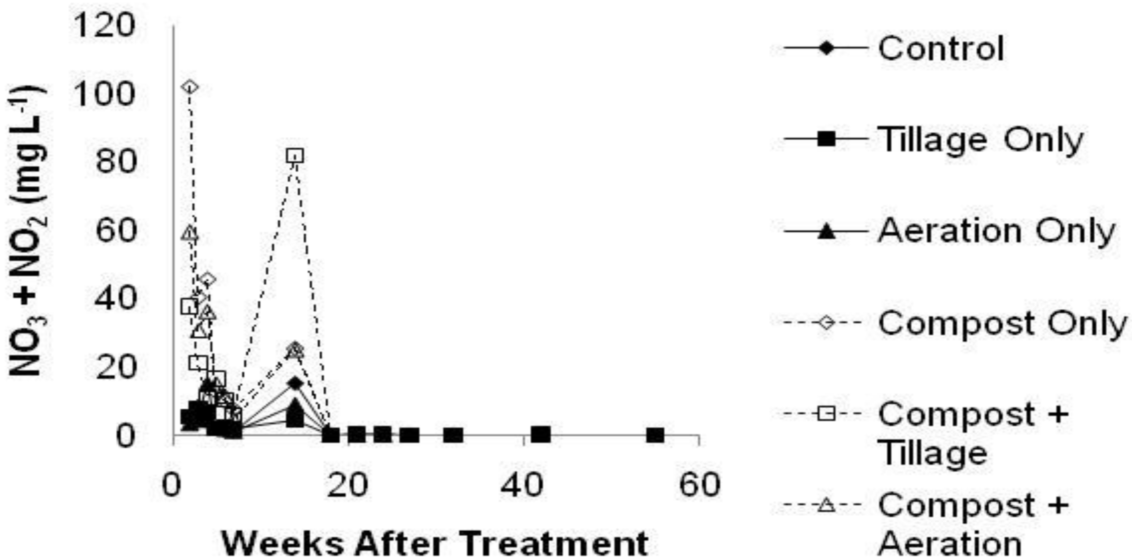

Figure 4-6. Mean concentration of nitrate in leachate collected from simulated residential landscapes in Florida where soils were amended with composted dairy manure solids.

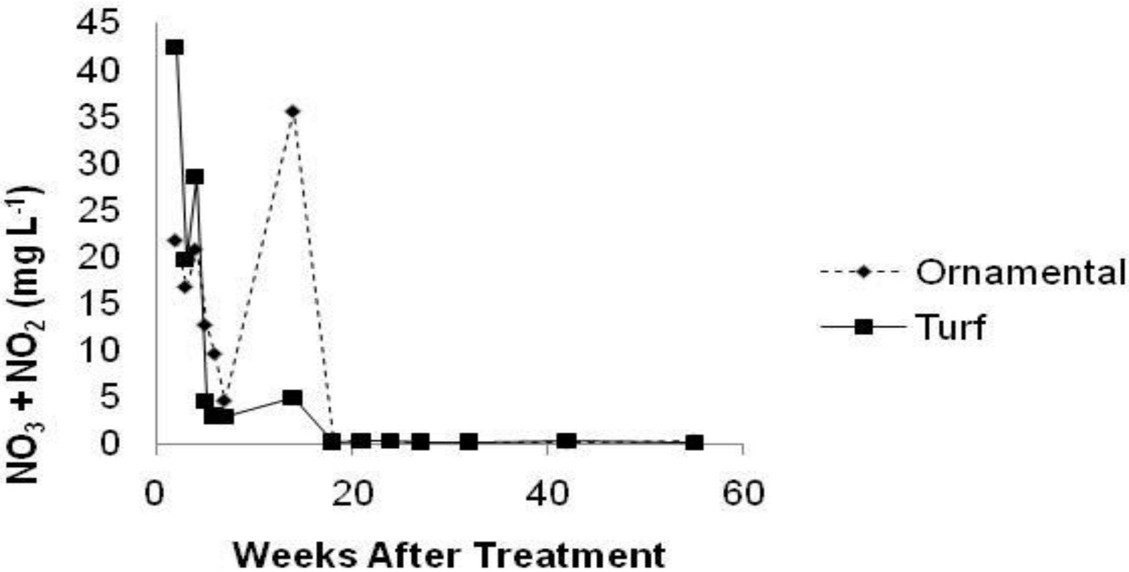

Figure 4-7. Mean concentration of nitrate in leachate collected from simulated residential landscapes in Florida planted with mixed ornamentals and St. Augustine turfgrass.

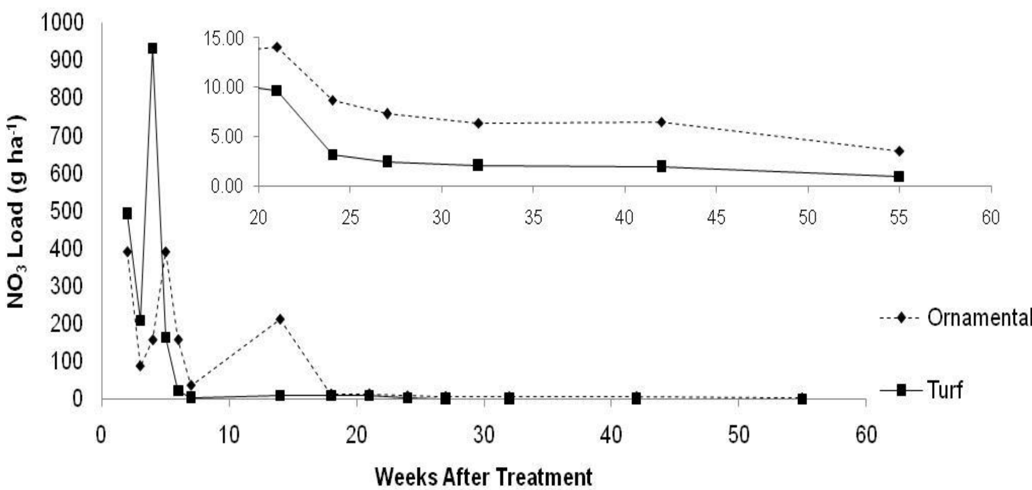

Figure 4-8. Mean nitrate load from 0-52 weeks after treatment (WAT) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass.

Leachate Ammonium

The concentration of NH_4 in leachate was affected by soil treatments from 18 through 42 WAT. In general, NH_4 concentrations in leachate collected from soils receiving one or more of the treatments where compost was applied were significantly higher than in leachate collected from unamended soils (Figure 4-9). Vegetative cover effects on NH_4 concentration in leachate were significant at 18 and 21 WAT only. At both sampling dates, leachate NH_4 concentrations were higher under ornamental cover when compared with NH_4 leached from turf. Ammonium concentrations were highest between July and September (12-28 WAT), which corresponds with high rainfall amounts (Figure 4-1) and warm temperatures (warm season lasting May to August with temperatures ranging from 20.6 to 32.5 ^{o}C). Under these conditions, microorganisms in the soil are actively mineralizing organic N (from the compost and soil organic matter) into NH_4 (Brady and Weil, 2002). We hypothesize that this mineralized N is then lost in leachate due to concentrations that exceed plant requirements or due to low soil sorption capacity, high rainfall and, in the case of ornamentals, low root density.

Soil treatment effects on NH_4 load were significant at 18, 21, 27, and 32 WAT (Figure 4-10). At 18 WAT, leachate NH_4 load was significantly higher from the plots receiving the compost + aeration treatment then from unamended soils. Compost only and compost + aeration soil treatments led to higher NH_4 loads in leachate than the aeration only treatment at 32 WAT and the control or tillage only treatments at 21, 27 and 32 WAT. Ammonium loss from composted treatments could likely be reduced if inorganic N fertilizer was not applied in conjunction with compost. Leachate NH_4 load was affected by vegetative cover only at 18 and 21 WAT. As was reported for NO_3

load, the increase in NH_4 load under ornamentals was related to the increased volume of leachate collected under the ornamental plant cover.

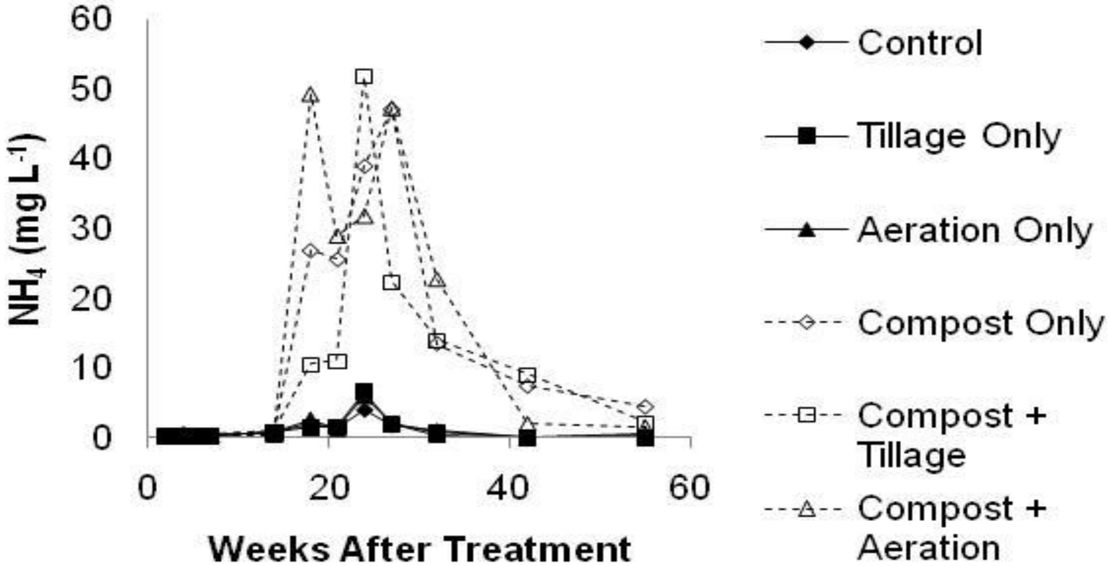

Figure 4-9. Mean concentration of ammonium in leachate collected from simulated residential landscapes in Florida where soils were amended with composted dairy manure solids.

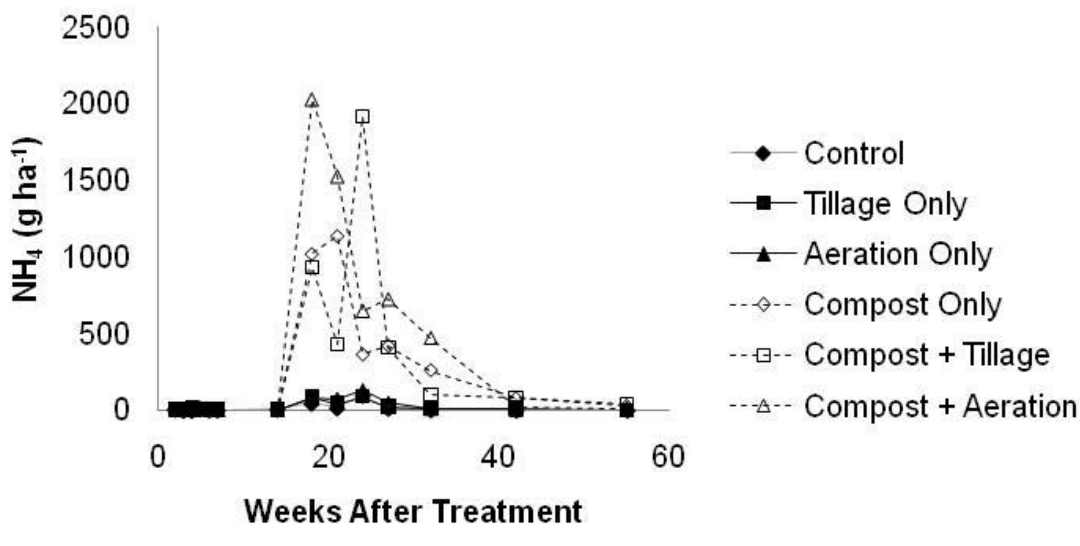

Figure 4-10. Mean ammonium load from 0-52 weeks after treatment (WAT) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass.

CHAPTER 5
CONCLUSIONS

Soils are often drastically disturbed during residential construction, resulting in inadequate conditions for landscape establishment. Results from our study indicate that the addition of compost (or other organic amendments) to soils can improve soil physical and chemical properties in residential landscapes when fill soils are used. Application of compost will also enhance the establishment and improve growth and quality of selected ornamental landscape plants. However, it appears that the topdressing with compost will enhance plant growth and quality as well, if not better, than when the material was incorporated to a depth of 20 cm by tillage. In contrast, it appears that shallow tillage and aeration have little effect on measured soil properties; results may have been different if finer-textured soils had been evaluated, where the threshold for bulk density above which root growth would be compromised are lower. Similarly, there were no significant effects of aerating the soil on plant establishment, growth, or quality.

Over the course of one year, the use of compost as a soil amendment in a simulated residential landscape did result in an increase in N losses in leachate. Most NO_3 + NO_2 losses occurred immediately after application of compost, while mineralization of organic N increased NH_4 losses during the summer months. Nutrient losses in leachate under ornamental cover were highest during the first few months of establishment, when the root density was limited and large amounts of rainfall were received. Since the addition of compost helps increase plant quality but does increase nutrient load to the system, using it as an addition to new residential lawns can be recommended, but only if the use of inorganic fertilizers is reduced. However, there are concerns that recommendations for one time application of organic amendments at a rate of 25-35% by volume to the top six inches of soil may lead to significant N losses, especially with low C:N ratios. In contrast, if the organic material has a high C:N ratio, it is possible that applications at this rate could lead to N immobilization at the detriment of the plant material.

While the results of this study can only show the benefits of compost additions during the first year after planting, data indicates that applications of compost may prevent plant failure, which results in less money and time dedicated to residential landscapes. Future research should determine if improved plant growth in composted amended soils was a result of additional nutrients added to the soil in the compost or due to the improvements in soil conditions. Future research should also evaluate the long-term effects of compost addition after plant establishment period. Also, more research needs to be conducted to determine if an increase in root density for ornamental plants will reduce the potential for N losses in leachate when compost and fertilizers are applied in the landscape.

APPENDIX A
ADDITIONAL SOIL ANALYSIS

Particle Size Analysis

All soils were classified as a loamy sand or sand, according the soil textural triangle (Tables A-1 and A-2). Soil particle size was determined by using the particle size was determined by the hydrometer method (Bouyoucos, 1962). There were no significant changes in soil composition throughout the study; the soils were predominantly sand (averaged 88.22%), with very little silt (5.48%) and little clay (6.30%).

Table A-1. Particle size distribution of fill soil samples (0-10 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	%				
			Sand		
Control	88.6	85.4	91.2	87.5	90.8
Tillage Only	90.6	86.7	91.2	87.7	89.7
Compost Only	87.8	83.8	90.7	84.8	89.0
Compost + Tillage	89.2	84.4	89.3	86.2	89.6
Aeration Only	89.9	85.8	91.5	88.0	89.4
Compost + Aeration	89.5	83.5	90.6	86.4	89.3
			Silt		
Control	7.30	9.26	3.01	4.04	3.74
Tillage Only	6.28	7.70	3.33	5.60	4.16
Compost Only	6.28	7.16	3.64	4.44	4.47
Compost + Tillage	7.30	8.24	3.95	3.95	3.53
Aeration Only	6.90	8.73	3.95	7.75	5.09
Compost + Aeration	6.68	8.64	3.33	4.44	4.47
			Clay		
Control	4.15	5.39	5.80	8.45	5.43
Tillage Only	3.09	6.63	5.49	6.68	6.17
Compost Only	5.90	9.06	5.70	10.8	6.59
Compost + Tillage	3.52	7.35	6.75	9.90	6.92
Aeration Only	3.20	5.49	4.57	7.22	5.55
Compost + Aeration	3.84	7.90	6.13	9.20	6.26

† WAT = weeks after treatment

Table A-2. Particle size distribution of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	——	——	%	——	——
			Sand		
Control	90.7	87.7	94.2	90.8	90.3
Tillage Only	90.0	87.7	94.8	89.9	91.2
Compost Only	89.1	85.2	92.7	89.5	89.9
Compost + Tillage	90.4	86.8	92.8	88.8	88.9
Aeration Only	90.6	87.8	95.4	90.2	90.5
Compost + Aeration	91.4	87.3	93.2	89.1	90.4
			Silt		
Control	7.08	7.39	3.33	4.89	5.51
Tillage Only	7.30	6.45	3.33	5.20	6.76
Compost Only	6.99	7.39	3.01	5.51	6.76
Compost + Tillage	6.76	7.39	2.71	5.20	6.66
Aeration Only	7.08	7.08	3.01	4.89	6.14
Compost + Aeration	7.30	7.39	3.01	5.20	5.82
			Clay		
Control	2.28	4.97	2.49	4.27	4.18
Tillage Only	2.69	5.82	1.87	4.90	2.09
Compost Only	3.92	7.38	4.25	5.00	3.34
Compost + Tillage	2.81	5.79	4.57	6.04	4.49
Aeration Only	2.35	5.18	1.55	4.90	3.34
Compost + Aeration	1.32	5.31	3.84	5.73	3.76

† WAT = weeks after treatment

Bulk Density

Soil bulk density under ornamentals at 10-20 cm was affected by soil treatments at 13 and 52 WAT only (Table A-3). At 13 and 52 WAT, soil bulk density was significantly lower when compost was tilled to a depth of 15 cm compared with soils where no compost was applied. These results are likely due to the fact that surface applications of compost did not impact soil bulk density at the 10-20 cm soil depth, while tillage of compost to 15 cm was able to reduce bulk density under ornamentals. Soil bulk density under turf was not impacted by soil treatment (Table A-4).

Table A-3. Bulk density of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals at four sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	g cm^{-3}			
Control	1.79a‡	1.63a	1.75a	1.76a
Tillage Only	1.76a	1.79a	1.72a	1.60a
Aeration Only	1.69ab	1.73a	1.70a	1.77a
Compost Only	1.66ab	1.54a	1.63a	1.54ab
Compost + Tillage	1.51b	1.56a	1.55a	1.40b
Compost + Aeration	1.64ab	1.56a	1.70a	1.68a

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Table A-4. Bulk density of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with St. Augustine turfgrass at five sampling dates.

Treatment	13 WAT†	27 WAT	40 WAT	52 WAT
	g cm^{-3}			
Control	1.64a‡	1.39a	1.49a	1.60a
Tillage Only	1.75a	1.62a	1.58a	1.57a
Aeration Only	1.73a	1.63a	1.46a	1.52a
Compost Only	1.64a	1.52a	1.47a	1.52a
Compost + Tillage	1.73a	1.53a	1.36a	1.47a
Compost + Aeration	1.62a	1.50a	1.56a	1.43a

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Soil Organic Matter

At the 10-20 cm depth, soil organic matter content was influenced by soil treatment at 13 and 52 WAT only (Table A-5). At 13 WAT, soils amended with compost had significantly higher organic matter (OM) content compared with soils receiving the control and tillage only treatments; soils receiving the aeration only treatment had significantly lower OM content than soils receiving the compost + tillage treatment. By 52 WAT, there was a significant difference between soils receiving the compost + tillage and tillage only treatments. Overall, composted soils maintained a higher OM content (9-23 g kg^{-1}) than the non-composted treatments (1-13 g kg^{-1}).

Table A-5. Soil organic matter of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	$g\ kg^{-1}$				
Control	9.00a‡	11.5a	4.50a	4.50a	10.5ab
Tillage Only	9.00a	12.0a	1.00a	5.50a	8.50a
Aeration Only	10.5a	13.0a	1.00a	8.00a	10.5ab
Compost Only	9.00a	20.0b	10.0a	9.00a	15.5ab
Compost + Tillage	9.50a	18.5b	9.00a	10.6a	14.0b
Compost + Aeration	9.00a	23.1b	12.0a	15.6a	16.0ab

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Electrical Conductivity

Soil treatments affected EC at 10-20 cm at 13 and 27 WAT only. At 13 WAT, the soils receiving the compost only treatment had significantly higher EC than soils receiving the other treatments (Table A-6). At 27 WAT, soils receiving the compost only and compost + aeration treatments had significantly higher EC than non-composted plots. The increase in EC in composted soils is likely due to the leaching of salts that were added with the compost through the soil profile. These effects disappear by 40 WAT after large rainfall events removed most of the salts from the root zone.

Table A-6. Electrical conductivity (EC) of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	$\mu s\ cm^{-1}$				
Control	454a‡	220ab	173a	837a	334a
Tillage Only	481a	187a	160a	594a	297a
Aeration Only	496a	195a	164a	763a	426a
Compost Only	519a	301b	328b	591a	422a
Compost + Tillage	534a	263ab	331ab	693a	357a
Compost + Aeration	441a	248ab	247b	715a	261a

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Field Moisture Capacity

The field moisture capacity at the 10-20 cm depth was not influenced by soil treatment throughout the duration of the study (Table A-7).

Table A-7. Field moisture capacity of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	%				
Control	8.12a‡	22.82a	11.4a	11.2a	15.3a
Tillage Only	8.12a	9.50a	10.0a	10.0a	10.6a
Aeration Only	8.52a	12.4a	12.4a	12.4a	11.5a
Compost Only	10.1a	20.8a	12.1a	12.3a	12.0a
Compost + Tillage	8.26a	10.5a	11.6a	11.6a	11.0a
Compost + Aeration	8.91a	10.7a	12.2a	12.2a	15.6a

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at $P < 0.05$ using Tukey's HSD test.

Mehlich 1 Nutrients

Phosphorus concentrations at the 10-20 cm depth were affected by soil treatments from 13 WAT through 52 WAT. At 13 WAT, soils receiving the compost only treatment had higher concentrations of P than the control plots (Table A-8). At 27 WAT, the compost + aeration treatment resulted in higher P concentrations than the non-composted treatments. At 40 WAT, all composted soils had higher P concentrations than soils receiving the control treatment. At 52 WAT, the compost only treatment resulted in higher P concentrations than the tillage only treatment. These results suggest that some of the P applied in compost was moving downward through the soil profile.

Soil test K concentrations at 10-20 cm depth were significantly higher for the composted treatments compared with the non-composted treatments at 27 WAT only (Table A-8). This suggests that K added in compost was leaching downward through the soil profile.

At the 10-20 cm depth, significant soil treatment effects were reported for soil Mg concentration at 13 and 27 WAT (Table A-8). At 27 WAT, compost only and compost + aeration treatments had higher Mg concentrations than non-composted soils. At 40 WAT, the compost + aeration plots had significantly higher soil Mg than soils receiving the tillage only treatment.

Soil Ca concentrations at 10-20 cm depth were affected by soil treatments at 13, 27 and 52 WAT (Table A-8). At 13 WAT, composted soils had higher Ca concentrations than unamended soils. At 27 WAT, the compost only and compost + aeration treatments maintained higher soil Ca than the non-composted treatments. At 52 WAT, the compost only treatment led to higher soil Ca than the non-composted treatments.

Table A-8. Mehlich I nutrient content (mg kg^{-1}) of fill soil samples (10-20 cm depth) collected from simulated residential landscape plots planted with mixed ornamentals and St. Augustine turfgrass at five sampling dates.

Treatment	0 WAT†	13 WAT	27 WAT	40 WAT	52 WAT
	mg kg^{-1}				
			Phosphorus		
Control	94.4a‡	128a	129a	131a	151ab
Tillage Only	101a	1375ab	125a	152ab	137a
Compost Only	119a	179b	164ab	197b	189b
Compost + Tillage	99.7a	1776ab	153ab	188b	162ab
Aeration Only	115a	170ab	141a	168ab	161ab
Compost + Aeration	120a	174ab	181b	188b	169ab
			Potassium		
Control	6.55a	12.8a	11.8a	14.3a	10.7a
Tillage Only	7.45a	12.6a	10.9a	13.3a	15.6a
Compost Only	8.10a	30.0b	16.5ab	22.4a	12.6a
Compost + Tillage	9.78a	30.7b	16.9ab	22.4a	12.6a
Aeration Only	7.15a	15.8a	13.3a	16.9a	11.8a
Compost + Aeration	9.40a	32.9b	23.2b	16.9a	14.9a
			Magnesium		
Control	345a	1784a	1498ab	1730a	1570a
Tillage Only	343a	1611a	1120a	1712a	1426a
Compost Only	430a	3131b	1600ab	2571a	2200a
Compost + Tillage	352a	2452ab	1518ab	2158a	1713a
Aeration Only	4438a	1916a	1602ab	1952a	2151a
Compost + Aeration	431a	3206b	2131b	2020a	1918a
			Calcium		
Control	15.5a	49.4a	56.1ab	95.9a	60.3a
Tillage Only	16.4a	49.1a	49.3a	75.8a	64.3a
Compost Only	21.9a	118b	90.7ac	130a	93.5b
Compost + Tillage	17.4a	128b	73.1ab	118a	70.7ab

Aeration Only	25.0a	53.5a	56.2ab	77.9a	67.4a
Compost + Aeration	20.2a	124b	111c	109a	83.5ab
			Aluminum		
Control	42.5a	38.5a	42.3a	42.0a	45.2a
Tillage Only	44.2a	46.1a	44.4a	50.8a	47.8a
Compost Only	44.3a	40.6a	43.3a	44.5a	44.7a
Compost + Tillage	42.7a	40.6a	42.8a	46.6a	47.1a
Aeration Only	46.6a	42.0a	42.9a	47.3a	45.1a
Compost + Aeration	42.4a	39.4a	41.5a	43.1a	45.6a
			Iron		
Control	288a	537a	578a	660a	532a
Tillage Only	296a	645a	628a	621a	578a
Compost Only	331a	976a	677a	729a	673a
Compost + Tillage	289a	578a	568a	593a	561a
Aeration Only	318a	630a	610a	615a	597a
Compost + Aeration	310a	749a	744a	714a	655a
			Sodium		
Control	5.91a	12.1a	13.7a	11.9a	10.6a
Tillage Only	5.85a	12.1a	12.7a	12.3a	10.2a
Compost Only	5.76a	15.9a	15.1a	13.9a	13.3a
Compost + Tillage	5.63a	15.5a	14.0a	14.6a	12.2a
Aeration Only	5.69a	14.7a	13.8a	13.4a	12.2a
Compost + Aeration	5.94a	17.5a	17.9a	12.1a	11.8a

† WAT = weeks after treatment
‡Values within the same sampling date (WAT) with the same letter are not significantly different at P < 0.05 using Tukey's HSD test.

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BIOGRAPHICAL SKETCH

Shawna Loper started her education at Silo Public School in the southeast part of Oklahoma. Growing up in rural Oklahoma, she first got her love of the outdoors and decided to pursue a field that would allow her to express that. From high school, she then decided the best choice for higher education was Oklahoma State University. At OSU, she majored in Plant and Soil Sciences, with an emphasis in agronomy. While attending OSU, she worked for a soil science professor. Her job duties included assisting with the collection and analysis of swine effluent application in a no-till, semi-arid, corn and soybean rotational cropping system. She also assisted graduate students in the department with their collection of crop and soil samples during her time there. During her undergraduate studies, she was highly involved in the Agronomy Club and represented OSU's College of Agricultural Sciences and Natural Resources as an Agricultural Ambassador for three years.

From OSU, she decided to further pursue her interest in soil science and attend the University of Florida and focus on soil and water sciences. Florida offered a unique opportunity that allowed her to explore urban soil/environmental issues. Having a strong agricultural background and pursuing a bachelor in "traditional" agriculture, she felt the need to explore a different area and felt this would broaden her studies and skills. She enjoyed her time at Florida and would like to apply what she's learned in the environmental job field.