EFFECT OF LANDSCAPE SOIL AMENDMENTS ON SOIL WATER AND NITROGEN

by

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(Under the Direction of TIMOTHY SMALLEY)

ABSTRACT

This study examined the effects of landscape soil amendments on Cecil sandy clay loam soil nitrogen and soil water. Mushroom compost and Erthfood™ compost increased soil inorganic nitrogen. Peat moss amended soil did not differ from control nitrogen, and pine bark amended soil immobilized nitrogen for 56 days.

Pine bark and composted broiler litter incorporated into soil amended annually for 5 years increased plant available water (PAW), readily available water (RAW), and air-filled porosity, and lowered bulk density. Permatill™ increased PAW, air-filled porosity, and lowered bulk density. Soil water curves differed between intact cores and packed cores indicating that the packing technique is not applicable to a field situation.

INDEX WORDS: Soil water curves, plant available water, readily available water, air-filled porosity, bulk density, pore size distribution, soil cores, nitrogen release, immobilized nitrogen, net mineralization

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DEDICATION

I would like to dedicate this to my family, friends, and future wife who have supported me throughout my graduate career. They have and will in the future hear me babble about soil amendments until they become soil amendment experts.

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CHAPTER 1

INTRODUCTION

Topsoil on landscape sites is often compacted during construction or bulldozed and hauled away for fill. Many landscapers and homeowners use organic and inorganic amendments to improve the remaining poor subsoil. For example, pine bark, composted broiler litter, and Erthfood™ compost, a composted peanut hull and biosolid product, is used to increase soil fertility. Other products, such as Stalite, Profile, and Hydrocks are touted for increasing drainage and plant available water.

During drought, one of the first steps in water conservation is limiting the irrigation of landscape plants (Warren and Fonteno, 1993). Several organic and inorganic amendments may increase the plant available water in the soil.

Applying organic matter to soils may increase available soil nitrogen (N), and organic matter increases cation exchange capacity (Dick and McCoy, 1993). The ability of several organic amendments such as broiler litter, pine bark, mushroom compost, Erthfood™ compost, and peat moss to supply N to the plant has not been well documented.

The objective of this study is to determine the effects of amendments on plant available water and soil nitrogen. Organic amendments to be evaluated for their ability to supply N are pine bark, mushroom compost, Erthfood™ compost, and peat moss. Amendments to be evaluated for the ability to increase plant available water are Permatill™, Profile, Hydrocks, broiler litter compost, and pine bark.

CHAPTER 2

LITERATURE REVIEW

Soil Amendments

Organic amendments

Common soil amendments are mushroom compost, peat moss, biosolids, composted poultry litter, and pine bark. The components of mushroom compost, a byproduct of mushroom farming, can vary depending upon the type of mushroom grown, but usually contains horse manure, lime, and straw. Peat moss is mined from slowly decomposing sphagnum peat bogs. Peat moss is usually readily available in temperate zones at a low cost. Biosolids (sewage sludge) are produced during wastewater treatment. Biosolids are primarily nutrient rich organic matter and accumulated solids separated from wastewater. Biosolids may be fresh or composted. Pine bark is a byproduct of paper mills and saw mills. Two different types of pine bark are old pine bark, which is more composted and contains fine particles, and new bark, which is less composted and contains coarse particles. Poultry litter is a mixture of feces, feathers, bedding materials, and waste feed. Fresh or composted poultry litter is created in large amounts by the layer and broiler poultry industry.

Inorganic amendments

Some inorganic soil amendments are Stalite, Profile, and Hydrocks. Stalite is a kiln-fired slate that is cooled quickly. This heating and cooling forms an expanded slate product sold commercially as Permatill™. The Stalite Company claims this process creates micropores that could greatly benefit soils by increasing plant available water. Profile is an inorganic amendment that is created by combining silica and illite clay in a kiln to create a porous ceramic. According to the Profile Company, this ceramic particle is 74% pore space, of which 39% is capillary pores and 35% is non-capillary pores. Hydrocks is an inorganic amendment that is created by firing clay in a kiln.

Soil Nitrogen

Nitrogen mineralization

Nitrogen is an essential nutrient for plants, and nitrogen deficiency often limits plant growth. Most nitrogen in the soil is found in organic forms, and this organic nitrogen serves as a reservoir of nitrogen, slowly releasing inorganic nitrogen as it decomposes (Sylvia, 1999). The mineralization of nitrogen occurs when inorganic forms of an element are released during energy-yielding enzymatic reactions that transform complex organic compounds into simpler ones (Haynes, 1986). Ammonification is the final result of nitrogen mineralization. The environmental factors that influence the mineralization and immobilization of nitrogen are water content, aeration, pH, temperature, and litter quality, which includes C/N ratio, and lignin and polyphenol content (Haynes, 1986).

Mineralization generally occurs best in a neutral, warm, moist soil. As soil pH declines, the microbial population shifts from bacteria to actinomycetes to fungi (Haynes,1986). Within similar climates, vegetation, and topography, fine-textured soils have higher organic matter and nitrogen content than coarse-textured soils (Haynes, 1986).

Ammonification

The last step in mineralization of nitrogen (N) is ammonification, in which simple organic nitrogenous compounds are converted to NH_4 (Haynes, 1986). Protozoa and nematodes are responsible for 30% of the yearly net nitrogen mineralization released into soils (Sylvia, D.M., et al, 1999). In most cases, extracellular enzymes are produced that convert organic-nitrogen polymers into monomers. The monomers pass across cell membranes and are metabolized, and ammonium is released as a waste product (Sylvia et al, 1999). Net immobilization of ammonium occurs if nitrogen is limiting (Sylvia, D.M., et al, 1999). If the organic amendments added to the soil have C:N ratios of less than 20:1, then net ammonium occurs. If a material is high in carbon such as sawdust (400:1), then ammonium will be immobilized within the microbial population. (Sylvia et al, 1999,Haynes, 1986)

The optimum soil moisture potential for ammonification is between -10 to -50 kPa soil matric potential, and does not occur below -4000 to -5000 kPa, but little ammonification occurs below -1500 kPa (Haynes, R.J., 1986). Most ammonifiers are aerobes thus, ammonification is less under anaerobic conditions (Sylvia, D.M., et al 1999, and Haynes, R.J.,1986).

The optimum temperature for ammonification is between 45 to 60ºC, and the lower limit is around 0°C (Haynes. R.J.,1986). A combination of optimal moisture and high temperature increases the ammonification rate greater than just optimal temperature or moisture alone (Haynes, R.J.,1986). Ammonification can proceed at low pH as indicated by the fact that highly acidic soils generally have higher amounts of ammonium than nitrate (Haynes, R.J., 1986).

In the soil, ammonium can be held on CEC sites, fixed on to the clay mineral lattices (ammonium fixation) such as illite and vermiculite, bound to organic compounds, volatized at high pH, oxidized to nitrate by nitrifiers, or assimilated by plants or microbes (Sylvia, D.M., et al, 1999).

Nitrification

Nitrification is the process in which NH_4^+ is oxidized to NO_2^- and then to NO_3^-. The reaction is mediated in soil by two small groups of chemoautotrophic bacteria (Haynes, 1986). Autotrophic nitrification is a two-step process involving two organisms in which the inorganic nitrogen serves as an energy source for the nitrifying bacteria (Sylvia, et al, 1999). Heterotrophic nitrification does occur under extreme circumstances such as anaerobic conditions, and these organisms gain no energy from this activity. In pure culture, the highest rates of heterotrophic nitrification are one-tenth that of autotrophic nitrifiers, and this suggests that heterotrophic nitrifiers are of minor importance (Sylvia, 1999).

The autotrophic nitrifiers are strict aerobes and depend upon cytochrome systems for electron transport and eventually oxygen (Haynes, 1986). They synthesize their cell constituents from CO_2 via the Calvin reduction pentose phosphate cycle, present in plants and other autotrophic microorganisms.(Haynes, 1986) The driving force behind the reduction of CO_2 is the production of ATP during the oxidation of NH_4^+ or NO_2^-(Haynes, 1986).

The first step of the two-step process of nitrification is conversion of ammonium to nitrite accomplished by the “Nitroso” genera of bacteria (Sylvia,1999). The chemical equation for ammonification is: $NH_3 + 1.5O_2 \rightarrow NO_2^- + H^+ + H_2O$ (Haynes, 1986, Sylvia, 1999, Focht and Verstate, 1977). This oxidation transfers $6e^-$ and yields 271KJ (65 Kcal) mol^{-1} NH_3 (Sylvia, 1999). Ammonium oxidation produces nitrite (NO_3^-) and nitrous oxide (N_2O). Ammonium oxidizers reduce NO_2^- to N_2O with nitrate reductase, but this usually only occurs under anaerobic conditions (Haynes, 1986 and Sylvia, 1999). Ammonium oxidation releases one mole of H^+ for every mole of ammonium oxidized (Haynes, 1986, and Sylvia, 1999). This acidification occurs in natural ecosystems and agricultural situations (Sylvia, 1999).

In most systems, nitrite is immediately oxidized to nitrate by nitrite-oxidizing bacteria of the "Nitro" genera (Sylvia, 1999). Nitrite is oxidized to nitrate by a membrane-bound *nitrite oxidoreductase*, which transfers oxygen from water and transfers a pair of electrons to the electron-transport chain for the production of ATP via oxidative phosphorylation (Sylvia, 1999)

The stoichiometry for nitrite-oxidation is: $NO_2^- + \frac{1}{2}O_2 \rightarrow NO_3^-$ (Sylvia, 1999, and Haynes, 1986). Nitrite oxidation yields 77KJ (18 Kcal), which is about one-third that of ammonia oxidation (Sylvia, 1999). Ammonium oxidation can be inhibited by acetylene, and nitrite oxidation can be inhibited by chlorate (ClO_4^-) (Sylvia, 1999).

The optimum pH for nitrification is 7 to 9 (Haynes, 1986, Focht, 1977, Sylvia, 1999). At soil pHs above 7.5, ammonium levels can be toxic and inhibit nitrobacter resulting in the accumulation of nitrite (Focht, 1977, Haynes, 1986, Sylvia, 1999). Nitrifiers are reduced below pH 6 and become negligible below pH 5 (Alexander, 1977 and Tyson and Cabrera, 1993), but nitrification does occur in acidic soil sites by some unknown mechanism. Nitrification in these unusually acidic soil sites may occur by means of higher pH microsites, acidophilic autotrophic nitrifiers, or heterotrophic nitrifiers (Focht, 1977; Haynes, 1986; Sylvia, 1999). In acidic soils of pH 5 or less, nitrogen gas can be produced chemically mainly from nitrite (Sylvia, 1999).

Nitrifiers may be more sensitive to temperatures than common heterotrophs because of their slow growth rate and inefficient metabolism. The optimal temperate temperature at which nitrification occurs is 25 to 35°C (Focht, 1977, Haynes, 1986). Indigenous nitrifiers have adapted to their climatic regions, the optimum temperature for the tropics is 50°C, for temperate zones is 35°C, and for Ontario, Canada is 20°C. Interestingly, the adapted nitrifiers for Canada ceased to be active at 35°C, but nitrification can occur in frozen soil (Haynes, 1986). Gradual fluctuating temperatures do not affect nitrification, but a sudden cold spell or late frost can kill microorganisms and a flush of nitrate is released (Haynes, 1986). Total nitrogen availability is promoted by freezing and thawing (Focht, 1977).

The maximum rate of nitrification occurs at soil moisture potentials near field capacity in the range of -10 to -33 kPa, depending upon soil physical properties (Haynes, 1986, and Sylvia, 1999). At 0 kPa, nitrification is inhibited because of the low oxygen content, as nitrifiers are almost exclusively aerobic microorganisms (Haynes 1986, and Sylvia, 1999). As oxygen becomes more limiting, autotrophic nitrifiers produce more nitric oxide and nitrous oxide (Sylvia, 1999). Nitrification does occur at -1500 kPa, but nitrifiers tend to be more inhibited than ammonifiers (Haynes, 1986). Wetting and drying cycles in soil has a pronounced effect on all microbial processes by physically breaking bonds to liberate smaller organic molecules. The rewetting of soils even by small amounts of precipitation or dew can cause a flush of mineralization and a flush of nitrification (Focht, 1977, and Haynes 1986).

Given aerobic conditions, the most important regulating factor for nitrification is ammonium availability (Haynes, 1986, Sylvia, 1999). Nitrifiers are poor competitors for ammonium compared to roots and the rhizosphere microbial biomass. This poor ability to compete explains the low concentrations of nitrate in soils of climax communities in natural ecosystems (Sylvia, 1999).

Soil Organic Matter

Soil structure and decomposition

Addition of organic amendments builds soil humus content and improves the soil fertility (Khaleel et al., 1981). Addition of organic amendments, sewage sludge compost, and beef manure increased organic matter over a 4-year period (Tester, 1990). However, soil application of poultry litter on a one-time basis did not increase organic matter levels, but Warren and Fonteno (1993) suggested regular application over time will increase organic matter in soil.

Organic matter increases soil aggregation, water holding capacity, and hydrologic conductivity, and decreases bulk density (Khaleel et al., 1981). Organic matter, also, maintains the structure and stability of soil (Nelson et al., 1997), and results in less runoff and less erosion of soil during heavy rainfall events (Khaleel et al., 1981). Amending urban soils with wood chips, sewage sludge, and composted leaves diminishes compaction (Patterson, 1974).

The percent clay of a soil affects the rate of decomposition of organic matter in soil. Nelson et al. (1997) found that clay mineral surfaces affected biological activity directly by interacting with soil microorganisms and indirectly by changing the soil environment. Soils with high clay content have higher microbial biomass and lower rates of organic decomposition, which caused organic residues to increase (Saggar et al. 1996). For example, Stevenson (1974) found that peat moss added to sandy soils shifted pore size to a smaller pore diameter, peat moss did not shift the pore size of silty soils, and peat moss shifted pore size to a larger pore size in clayey soils. Incorporating increasing amounts of peat moss into a clay or sandy soil can increase aggregate porosity and moisture retention (Zhang, 1994). Addition of peat moss into a clay or sandy soil decreased aggregate tensile strength (Zhang, 1994), which increases erosion potential of a soil.

Root growth

Percent clay can affect root growth. Root growth and penetration in clay soil is dependent upon physical, biological, and chemical characteristics (Gerard et al., 1971). In clayey soils, *Pisum sp.* (peas), and *Gossypium sp.* (cotton) formed high root densities that physically cracked and aerated the soil (Gerard et al., 1971). Roots grow better in less clayey soils, and adding organic and inorganic amendments may ameliorate the density characteristics of clay that restrict root growth.

Water content

Tester (1990) determined that water content and surface area of a sandy soil increased with increasing amounts of organic matter. Warren and Fonteno (1993) found that an application of 20% composted poultry litter by volume increased available water capacity by 50% with only a 6 to 9% decrease in air space. Peat moss has a high water holding capacity, and dry peat moss exhibits hydrophobic properties, which may cause problems with rewetting the soil (da Silva et al., 1993). An incorporated pine bark can improve water drainage in the root zone, which may suppress some disease organisms such as *Phytopthora* spp. (Odneal and Kaps, 1990).

pH

Organic matter can modify the soil pH to the depth of incorporation (Tester 1990). Organic matter has variable charge, and soil pH will affect the ability of nutrients to be held on these variable sites. Composted poultry litter increases soil pH, which is beneficial for acidic soils (Tyson and Cabrera, 1993, Warren and Fonteno, 1993). Bugbee and Frink (1989) found peat moss with a pH of 3.6 increased soil acidity when added to the soil. The addition of spent mushroom compost raises the soil pH (Shuman, 1998).

Fertility and CEC

Organic matter can increase soil fertility. Periwinkle (*Catharanthus roseus*) growth in a biosolid treatment exceeded growth of a fertilized control by 7.5% (Devitt et al., 1991). First season growth of 'Royal Gala' (apple) was increased when manure was mixed into planting hole (Autio et al., 1991).

Poultry litter can supply essential elements needed for plant growth because poultry litter contains all the macronutrients and several micronutrients (Tyson and Cabrera, 1993). Tyson and Cabrera (1993) showed that composted broiler or broiler litter increased inorganic N slowly and steadily over a 56-day period. The application of poultry litter can increase the rate of N volatilization and mineralization, and the rate of N mineralization can cause soluble salt damage. Brinson et al. (1994) found that surface-applied poultry composts have low NH_3 volatilization and low net N immobilization. Poultry litter is a good source of P (phosphorous) for poor soils (Hue and Sobieszczyk.

1999). Available P and exchangeable K, Ca, and Mg increase with the application of composted poultry litter. Warren and Fonteno (1993) recommended a 20% application rate of poultry litter to provide adequate nutrients for landscape plants.

The addition of pine bark does not supply nutrients for plants; fertilizer must be added to compensate for this (Dunn, 1956). Because of its high C:N ratio, pine bark amendments can deplete soil N (Odneal and Kaps, 1990). Soil application of new pine bark caused a decrease in yield in *Zinnia elegans* when incorporated into the soil because of the high C/N ratio (Dunn, 1956).

The effect of biosolids application is also dependent upon their C/N ratio. Incorporation of composted biosolids can increase inorganic soil N content by nearly 3-to 6-fold depending upon the rate of biosolid application (Hue and Sobieszczyk, 1999). If the biosolid's C/N ratio <15, then inorganic N will be released (Hue and Sobieszczyk, 1999). If biosolids have a C/N ratio of >20, then N immobilization will occur in a fertile mollisol (Hue and Sobieszczyk, 1999). In a mollisol, a study found that uncomposted biosolids bound some of the soil N when compared to a control soil (Hue and Sobieszczyk, 1999). Biosolids are not a good source of P (Phosphorous) (Hue and Sobieszczyk, 1999).

Peat moss contains NO_3 10mg·kg^{-1}, NH_4 1mg·kg^{-1}, P 23mg·kg^{-1}, K 258mg·kg^{-1}, Ca 696mg·kg^{-1}, Mg 609mg·kg^{-1}, Cd 0.3mg·kg^{-1}, Cu 1.4mg·kg^{-1}, Fe 23mg·kg^{-1}, Mn 7.8mg·kg^{-1}, Ni 0.5mg·kg^{-1}, and Zn 5.5mg·kg^{-1} (Hue and Sobieszczyk, 1999). A 50% application of peat moss with a C/N ratio of 30 did not immobilize soil N, but actually increased the nitrogen level by 22 ppm because of the high stability of peat moss and the unavailability of its carbon for microbial decomposition (Hue and Sobieszczyk, 1999). Peat moss can cause nutritional problems, because of the low levels of P in peat moss (Hue and Sobieszczyk, 1999). Dunham (1967) found that addition of peat moss decreased soil content of Ca and K, and plants were severely stunted from N deficiency unless N was added. The addition of peat moss to a loam soil increased the CEC, decreased bulk density, which caused a lowered CEC per unit of volume (Dunham, 1967).

Spent mushroom compost contains 0.7 to 2.1% K, 5.9 to 16% Ca, 0.2 to 0.5% Mg, and 1.3 to 1.4% S (Stewart et al., 1998a). The addition of mushroom compost increases the CEC of soils (Shuman, 1999a), and can be used as a slow release N source for crops (Stewart et al., 1998b). Incorporation of mushroom compost increased the productivity of tomatoes (Steffen et al., 1995). Spent mushroom compost can cause deficiencies in Ca or Mg because of its high K content (Wang et al., 1984). Soluble salt contents should be monitored if spent mushroom compost is added repeatedly (Wang et al., 1984). In potato, mushroom compost increased nitrogen, potassium, phosphorus, and shoot length but delayed tuber filling (Gent et al., 1998).

Pollution

Application of soil amendments may be beneficial or detrimental to the environment. Poultry litter can cause water pollution because of its high N and phosphorous (P) content. Properly monitoring soils nutrient levels after poultry litter applications is important to limit N leaching. Fresh poultry litter had high N volatilization and high N mineralization, and adding a thatch layer over fresh poultry litter delayed N mineralization and ammonium volatilization, but this did not affect overall N mineralization or ammonium volatilization (Brinson et al., 1994). Uncomposted fresh poultry litter releases a large amount of inorganic N in the first week after application, which can lead to nitrate leaching and water pollution problems (Tyson and Cabrera, 1993). Cabrera et al. (1994) found that N_2O emissions of incorporated pellets versus fine-particle poultry litter compost varied with the soil water regimen; N_2O emissions increased with increasing water content. Because composted broiler litter releases N slowly, water contamination is less probable (Tyson and Cabrera, 1993). High P (phosphorous) levels in poultry litter can increase over time in soils already adequate in P (Hue and Sobieszczyk, 1999). Van der Watt et al. (1994) found that the short-term effect of Cu and Zn in poultry litter is not toxic, but continuous application of poultry litter in fields may result in heavy metal build up.

Application of biosolids did not cause runoff problems with any minerals (Edwards et al. 1999). Zn runoff did approach the recommended threshold for marine wildlife protection, and nutrients should be monitored (Edwards et al. 1999).

The addition of mushroom compost can be helpful in controlling and cleanup of certain toxic nutrients and metals. Mushroom compost can redistribute Pb in the soil, reducing the threat of Pb to the environment (Shuman, 1998). Mushroom compost amendments redistribute Zn to a less bio-available fraction and can be used on Zn-contaminated soil to decrease plant available Zn (Shuman, 1999b). Also, mushroom compost microorganisms may degrade Sevin (Carbaryl (1-naphthyl N-methylcarbamate)) to help prevent environmental contamination (Kuo and Regan, 1992).

Disease suppression

Mushroom compost is able to prevent diseases. Mushroom compost reduced early dying disease in potatoes (LaMondia et al., 1999). Furthermore, a water extract of spent mushroom compost significantly reduced apple scab in the field, but not enough to be a realistic substitute for fungicides. Further studies are needed to determine the cause of this reduction (Yohalem et al., 1996).

Spent mushroom compost is naturally high in *Bacillus thuringiensis*, a bioinsecticide (Bernhard et al., 1997). However, mushroom compost added to the soil did not affect the density of Colorado potato beetle in potatoes (Stoner et al., 1996).

Soil Water

Water availability

Decreasing water resources due to drought are prompting restrictions of water use by landscape professionals and homeowners. Water is a major limiting factor in plant growth in many regions of the world. Even where water is plentiful, concerns are growing about the future availability of water (Gregory et al., 2000). Increasing plant available water by adding soil amendments could alleviate this problem of limited water resources. Previous research by Veihmeyer and Hendrickson (1950) showed that various soil amendments may improve soil structure, consequently increasing plant available water (PAW) and decreasing the need for supplemental watering.

Soil water curves

A powerful method for describing soil water potential is the soil water curve (SWC), which is an indirect method for determining matric potential (ψ_m in units of pressure or h in units of head), the potential at which water is held in the soil matrix. As water content decreases, the matric potential decreases and becomes more negative. The typical range of a SWC curve is from $\psi_m = 0$ to -15 bars or $h = 0$ to -15,330 cm of H_20.

The SWC curve can be divided into three regions of matric potential. The hygroscopic or adsorption region has low water content and very negative matric potentials. The low water content of the adsorption region is sometimes called residual water content or θ_r. Residual water content is held by the clay surfaces and not by capillary action, so it is unaffected by soil structure. Clay has a higher θ_r than sand because of clay's higher surface area. It is commonly assumed that θ_r corresponds to wilting point, or the water content at h = -15,330 cm or ψ_m = -15 bars.

The second region, the capillary region, has a wide range in pore sizes and the shape of this region indicates pore-size distribution. Since structure is important in this section, using intact cores that retain the soil's structure is critical. The capillary region is found between wilting point and air-entry matric potential.

The final section of the SWC curve is the air-entry region. The boundaries of this region are between the air-entry matric potential and zero matric potential. This region contains air filled porosity, macropores and mesopores. The air-entry region of the SWC curve is were most compaction of soil occurs.

Several equations describe soil water curve data, and the most popular one is van Genutchen's equation:

$$\theta(h) = (\theta_s - \theta_r) \bullet \left(\frac{1}{1 + (\alpha \bullet h)^n}\right)^m + \theta_r \qquad m = 1 - \frac{1}{n}.$$

θ_s= Saturated water content; θ_r=residual water content; θ(h)= volumetric water content; α= is related to (approximately the inverse of) the air-entry potential; h_a is the matric potential where air first enters (θ first decreases); h= matric potential (kPa); n= controls the steepness of the curve in the capillary region.

The equipment used to measure SWC curves are small pressure chambers called Tempe cells, which hold single intact soil cores. Tempe cells were first manufactured in Tempe, AZ hence the name. The soil sample rings are usually 8.89 cm in diameter and

5.08 cm in height. A positive pressure is applied to each cell. The ceramic plates have small pores that will not allow air to pass through, but will allow water to move through when air pressure is applied. Compressed air is applied through tubing at the top of the Tempe cell. The Tempe cell is weighed daily to determine when equilibrium is reached. Once equilibrium is reached, the weight of the cell is recorded and the pressure increased. For matric values of more than -1 or -3 bars, Tempe cells are not used. A large pressure chamber is used to get a single value beyond this range.

Plant available water

Plant available water is in the capillary region of the soil water curve. Plant available water (PAW), as defined by Veihmeyer and Hendrickson in 1931, 1949, 1950, is the water in the soil usable by plants and is found between field capacity, $\theta_{fc,}$ (wet upper limit), and permanent wilting point, θ_{wp}. The equation for plant available water is $PAW = \theta_{fc} - \theta_{wp}$. Field capacity is the amount of water held in a soil after excess water has drained away and the rate of downward movement of water has naturally decreased, usually occurring at a matric potential pressure of about -0.1 bars (da Silva 1994). Permanent wilting point is the moisture content at which insufficient water exists to maintain normal plant growth and development, having a matric potential pressure of -15 bars (Veihmeyer and Hendrickson, 1931). The permanent wilting point can be species dependent, and the permanent wilting point for grasses is lower than for trees (Childs, 1972). PAW can be affected by the texture, clay content, state of aggregation, weather, and type of plants (Groenevelt et al., 2001).

Readily available water

In landscape culture, plants are not usually allowed to reach permanent wilting point because plants die at permanent wilting point. For the landscape, estimating the amount of water that can be depleted from the soil without adversely affecting plant quality and appearance is important. For most crops, the maximum allowed depletion of soil water is 60% of PAW, and is called readily available water (RAW)(Galbiati and Savi, 1997). The equation for readily available water is: $RAW = (F_c - RWC)d$, where F_c=Field capacity, d=Depth of root zone, RWC = 60% of PAW. Depth of root zone is important because we are not just looking at the top one centimeter but the whole rooting zone (Galbiati and Savi, 1997). For landscape plants, we will define RAW for our soil as between -10 kPa (-.1 bars) and -70 kPa (-.7 bars) (Harris et al., 1999).

Pore size distribution

The soil water characteristic (SWC) curve can be expressed as a function of the equivalent pore radius(*R)* using the capillary equation of Vomocil (1965)

$$D = -\frac{4\sigma\cos\gamma}{pgh} = -\frac{C}{h}$$

where γ (degrees) is the contact angle between pore wall and water, σ ($kg\cdot s^{-2}$) is the surface tension of water, p($kg\cdot m^{-3}$) is the density of water, g ($m\cdot s^{-2}$) is the acceleration due to gravity, h is matric potential in cm, and C is a constant which equal 0.286 cm^2 ($4\cdot\sigma\cdot\cos\gamma/p\cdot g$). From the soil water release curve, the capacitance function can be derived, which is the slope of the SWC curve. The capacitance function plotted verse pore radius produces a frequency distribution of relative pore volumes as a function of pore radius.

Soil pores

The pores size distribution curve derived from the soil water characteristic curve can help explain how soil amendments may change soil structure. Increasing organic matter generally causes an increase in total porosity and pore size distribution and varies with different types of soils (Kay and Angers, 2000).

The Soil Science Society of America pore size classification system (Kay and Angers, 2000) is used to classify pore sizes:

Class	Class Limits equivalent diameter (µm)
Macropores	>75
Mesopores	30-75
Micropores	5-30
Ultramicropores	0.1-5
Cryptopores	<0.1

A large pore volume in the mesopore and macropore area translates into improved soil aeration and drainage (McCoy, 1992). The pores with a diameter greater than 30 µm influence water and solute flow, aeration, and root development (Kays and Angers, 2000). Macropores and mesopores can be influenced by organic carbon content, and texture of a soil (Kays and Angers, 2000). Macropores are susceptible to compaction, and are the least stable of all pore sizes (Kay and Angers, 2000). Startsev and McNabb (2001) found that soil dryer than field capacity was less likely to compact and that most compaction affected the air entry and large pore sizes of boreal forest soils.

Micropores contain most of the RAW, capillary water and most of PAW (McCoy, 1992, Kays and Angers, 2000)). Ultramicropores contain little available water to plants and water unavailable to plant uptake (McCoy, 1992, Kays and Angers, 2000). Utramicropores and micropores are often considered storage pores and provide a habitat for microorganisms and smaller soil fauna (Kays and Angers, 2000). Texture and organic carbon content can influence micropores and ultramicropores, but increased bulk density and compaction usually do not affect micropores and ultramicropores (Kays and Angers, 2000, Startsev and McNabb, 2001).

Cryptopores usually do not contain plant available water because roots can not penetrate, and are inaccessible to most microorganisms, and their most important function is to physically protect organic carbon (Kays and Angers, 2000).

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CHAPTER 3

EFFECT OF LANDSCAPE SOIL AMENDMENTS ON SOIL WATER[1]

[1] **McBee, O., T.J. Smalley, D.E. Radcliffe, and M.L. Cabrera. To be submitted to HortScience.**

Abstract:

This study determined the effect of soil amendments on plant available water. Intact soil cores were collected from a Cecil sandy clay loam soil landscape planting beds that had been amended annually for five years with 5 cm (25% by volume) of pine bark and broiler litter. Soil cores were also collected from a landscape bed that had been amended once in April 2000 with 5 cm (25% by volume) of Permatill™ (expanded slate). Additionally, soil cores were packed by applying a pressure of 71.8 kPa to a Cecil sandy clay loam soil amended (25% by volume) with Permatill™, Profile (porous ceramic), and Hydrocks (fired clay). The results indicate that pine bark and broiler litter increased readily available water (RAW), plant available water (PAW), and air-filled porosity, and lowered bulk density when compared to unamended soil. Amending with Permatill™ increased PAW, air-filled porosity, lowered bulk density and did not increase RAW when compared to unamended soil. Bulk densities of packed and intact soil cores differed, indicating that packed core data are not applicable to a field situation.

Introduction:

Decreasing water resources due to drought and increased irrigation are prompting restrictions on water use by landscape professionals and homeowners. Increasing plant available water (PAW) by adding soil amendments could alleviate this problem of limited water resources. Plant available water is water held between -10 kPa and -1500 kPa. Various soil amendments may improve soil water holding capacity (Veihmeyer and Hendrickson, 1950) and consequently may increase plant available water (PAW) and may decrease the need for supplemental watering.

Estimating the amount of water that can be depleted from the soil without adversely affecting plant vigor is important. For most crops, the maximum allowed depletion of soil water is 60% of PAW, and is labeled readily available water (RAW) (Galbiati, and Savi, 1997). For landscape plants, RAW for a sandy clay loam is between -10 kPa (-0.1 bars) and -70 kPa (-0.7 bars) (Harris et al., 1999). For landscape plants in particular, watering when readily available water is depleted is critical to prevent loss of aesthetic quality.

Little research has been conducted examining the effect of soil amendments on readily available water. The objective of this study was to determine the effect of amending a Cecil sandy clay loam with pine bark, Permatill™, broiler litter compost, Profile, and Hydrocks on PAW and RAW.

Materials and Methods:

Experiment 1: Intact soil cores

On 26 June 2002, intact Cecil sandy clay loam (clayey, kaolinitic, thermic Typic Kanhapludult) soil cores (6 cm high by 8.5 cm diameter) were taken from plots at the University of Georgia, Horticulture Farm, Watkinsville, GA. Intact soil cores were taken from plots amended and tilled annually to a depth of 15 cm with 5 cm of pine bark (Smith Garden Products, Cummings, GA) and 5 cm of broiler litter compost (Georgia Natural Compost, Murrayville, Georgia) since March 1997. Additionally, soil cores were taken from plots that had been amended once with 5 cm of Permatill™, an expanded slate, (Carolina Stalite Company, Salisbury, North Carolina) in March, 2000. Cores taken from unamended and amended plots that have been tilled to a depth of 15 cm annually since 1997 served as the control.

Five replications of soil cores were saturated with 0.01 M $CaCl_2$ for 24 h, placed into Tempe cells, and subjected to the following pressures: -1.4 kPa, -2.94 kPa, -9.3 kPa, -18.7 kPa, and -74 kPa. The same soil cores were oven dried at 105ºC for 24 h to obtain bulk density. Soil samples were crushed and placed in a ring on the 15-bar ceramic plate and saturated with 0.01 M $CaCl_2$. After 14 days, the samples were removed, weighed, and oven dried at 105ºC to obtain water content.

Intact soil cores data were fit to a four-parameter equation (van Genuchten, 1980) using Minerr (Mathcad, 1998). Volumetric water content (θ, $cm^3 \cdot cm^{-3}$) as a function of water potential (h, kPa) is given by:

$$\theta(h) = (\theta_s - \theta_r)(\frac{1}{1+(\alpha h)^n})^m + \theta_r \qquad m = 1 - \frac{1}{n}$$

where θ_s ($cm^3 \cdot cm^{-3}$) is the saturated water content, θ_r ($cm^3 \cdot cm^{-3}$) is the residual water content, and α is related to approximately the inverse of the air-entry potential, and n controls the steepness of the curve in the capillary region.

The soil water characteristic (SWC) curves were expressed as a function of the equivalent pore diameter (D) using the capillary equation of Vomocil (1965)

$$D = -\frac{4\sigma\cos\gamma}{pgh} = -\frac{C}{h}$$

where γ (degrees) is the contact angle between pore wall and water, σ ($kg \cdot s^{-2}$) is the surface tension of water, p ($kg \cdot m^{-3}$) is the density of water, g ($m \cdot s^{-2}$) is the acceleration due to gravity, h is matric potential in cm, and C is a constant which equal 0.286 cm^2 ($4 \cdot \sigma \cdot \cos\gamma / p \cdot g$). From the soil water release curve, the capacitance function is derived, which is the slope of the SWC curve. The capacitance function plotted versus pore radius produces a frequency distribution of relative pore volumes as a function of pore radius.

Experiment II: Packed soil cores

The second part of this study was conducted with soil from the same site as used in Experiment I. Soil from the upper 10 cm of the profile was air-dried in the laboratory, crushed, and then sieved through a 1-mm sieve to remove small rocks and plant residue. Soil amendments, Permatill™ (expanded slate), Profile (porous ceramic) (Profile Products, LLC., Buffalo Grove, Illinois), and Hydrocks (fired clay) (Rock and Earth technologies, Rockmart, Georgia), were mixed at a 3:1 (volume: volume) soil to amendment. Five replications of soil cores were packed by applying pressure of 71.85 kPa (0.71 bars) in three consecutive layers with a hydraulic press (Midvale-Heppenstall Co., Philadelphia, PA) 2.54 cm deep. In preliminary experiments with the unamended soil, we discovered that applying 71.85 kPa of pressure to each layer produced a bulk density similar to the bulk density of intact unamended soil cores. Soil cores were saturated with 0.01 M $CaCl_2$ for 24 h. Water content at -1.4 kPa, -2.94 kPa, -9.3 kPa, -18.7 kPa, -32 kPa, and -74 kPa and 1500 kPa, air-filled porosity, RAW, and PAW were determined as described in Experiment I.

Results and Discussion:

<u>Experiment 1</u>

Intact soil cores data were fit (Mathcad, 1998) to a four-parameter equation (van Genuchten, 1980). (Figure 3.1) Curve parameters differed among treatments for intact cores indicating differences among intact SWC curves (data not presented). However, curve parameters did not differ among treatments for packed curves (data not presented). This variation in results between the two techniques (intact vs. packed) questions the applicability of using packed cores to determine field soil water availability.

All amending treatments lowered bulk density (Table 3.1). The unamended soil had the highest bulk density, and pine bark amended soil had the lowest bulk density. Lowering bulk density changes air-filled porosity, pore size distribution, and gravimetric water content, which affect PAW and RAW. These changes prompted by decreasing bulk density can increase plant root shoot growth compared to an unamended high bulk density soil (Agnew and Carrow, 1985).

Soil amended with pine bark, broiler litter, and Permatill™ increased PAW compared to the unamended control (Table 3.1). Pine bark had the highest PAW, and unamended soil had the lowest PAW. Warren and Fonteno (1993) found that an application of composted poultry litter to a loamy sand soil increased available water capacity. Tester (1990) determined that water content and surface area of a sandy soil increased with increasing amounts of organic matter. The increase in PAW implies that all three soil treatments may decrease the frequency of water usage.

Pine bark and broiler litter compost had higher RAW content than Permatill™ and unamended soil, which did not differ (Table 3.1). Amending the soil with pine bark and broiler litter compost may decrease frequency of watering because of this increase in RAW. Plants grown at water contents below RAW may survive, but their appearance and quality may be diminished, because the plant experiences water stress. For ornamental plants, appearance is important, and thus differences in RAW are more important than differences in PAW. Most irrigation schedules call for irrigation at -70 kPa soil water potential, which is 100% depletion of RAW as defined by this paper (Galbiati, and Savi, 1997). An improvement in PAW but not in RAW indicates improvement not applicable to landscape horticulture unless there are irrigation restrictions that allow the soil to become dryer.

Pine bark amended intact cores had the highest air filled porosity indicating that pine bark improves water drainage and aeration in the root zone (Table 3.1). Odneal and Kaps (1990) found similar results with pine bark-amended soil and suggested that this improved drainage may suppress disease organisms such as *Phytopthora* spp. Permatill^{TM} and broiler litter compost also had higher air-filled porosities than the unamended control. Warren and Fonteno (1993) found that an application of 20% composted poultry litter by volume decreased air space in soil by 6 to 9%. This research indicates that soil amended with pine bark, broiler litter compost, and Permatill^{TM} improve soil aeration and drainage.

Organic products decay with time, but Permatill^{TM}, an expanded slate, can affect soil characteristics permanently. Permatill^{TM} had higher PAW, air-filled porosity, and lower bulk density than unamended soil indicating that amending once with Permatill^{TM} may permanently change soil dynamics by improving drainage, soil aeration, and PAW.

Experiment 2

Packed soil core bulk densities did not differ (Table 3.2). Unamended soil had the highest RAW, PAW, and air-filled porosity. RAW and air filled porosity were similar for all soils amended with Hydrocks, Profile, and Permatill^{TM}. Permatill^{TM} had the lowest PAW for packed soils, while Profile had the next lowest PAW but was not different from Permatill^{TM} or Hydrocks. Packed amended soil cores showed no improvement over unamended soil. With intact cores a change in bulk density was observed while packed soil cores did not differ, which questions the value the packing technique, and its applicability to a field situation.

The pore size distribution curve derived from the intact SWC curve can help explain how soil amendments change soil structure (Figure 3.2). The volume of macropores and mesopores in all treatments increased. A large pore volume in the mesopore and macropore area translates into improved soil aeration and drainage (McCoy, 1992). The pores with a diameter greater than 30 μm influence water and solute flow, aeration, and root development (Kays and Angers, 2000). Macropores and mesopores can be influenced by organic carbon content, and texture of a soil (Kays and Angers, 2000). All amended soils showed an increase in the volume of micropores and the greatest increase of larger micropores, when compared to the unamended soil. Micropores contain most of the RAW and PAW (McCoy, 1992) indicating that the addition of soil amendments to a Cecil sandy clay loam soil may increase RAW, PAW and capillary water. For all treatments, ultramicropores changed only slightly. Ultramicropores contain water less available to plants and water unavailable to plant uptake (McCoy, 1992). The volume of pores that increased with the addition of soil amendments could explain how an increase in PAW and RAW could occur without a decrease in air-filled porosity.

The results of this study indicated that amending soil with broiler litter compost, Permatill™, and pine bark increased drainage and provides more water to plants. This implies that the frequency of irrigation of soil amended with these amendments could be less than that of unamended soil.

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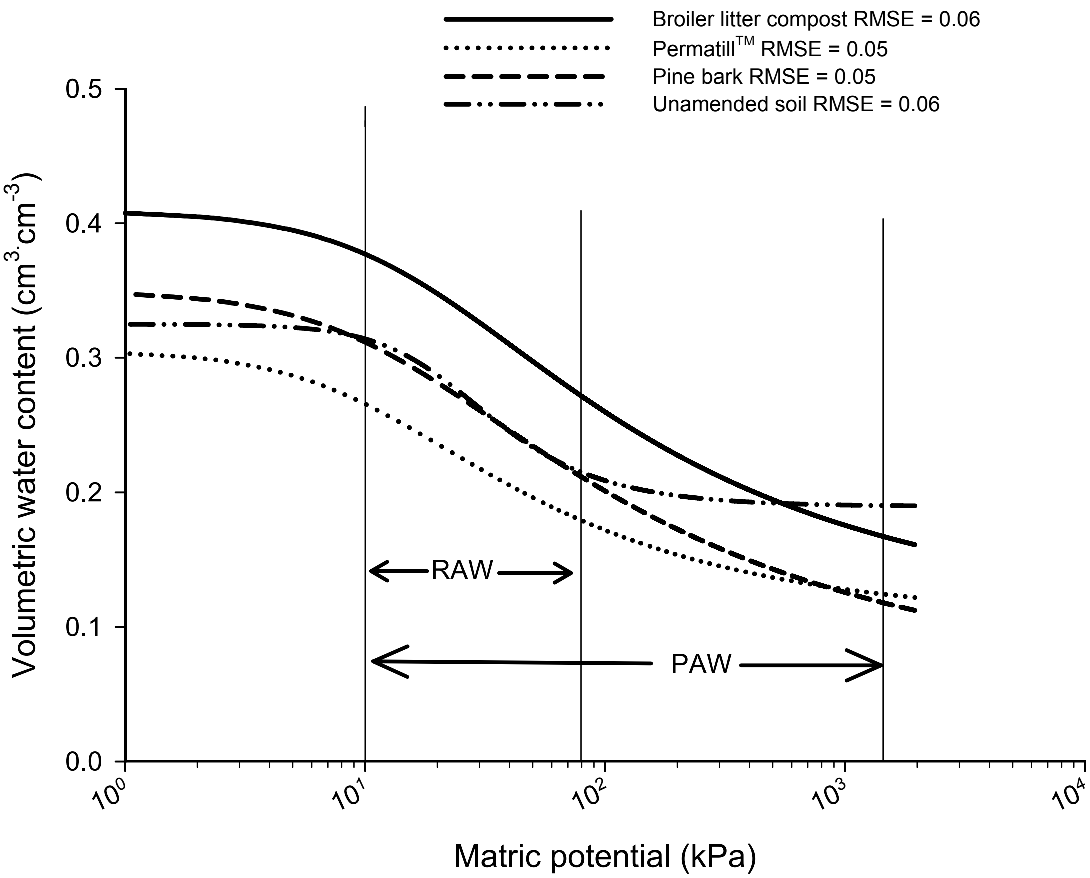

Figure 3.1: Soil water release curves for landscape beds amended with broiler litter compost, Permatill™, and pine bark.

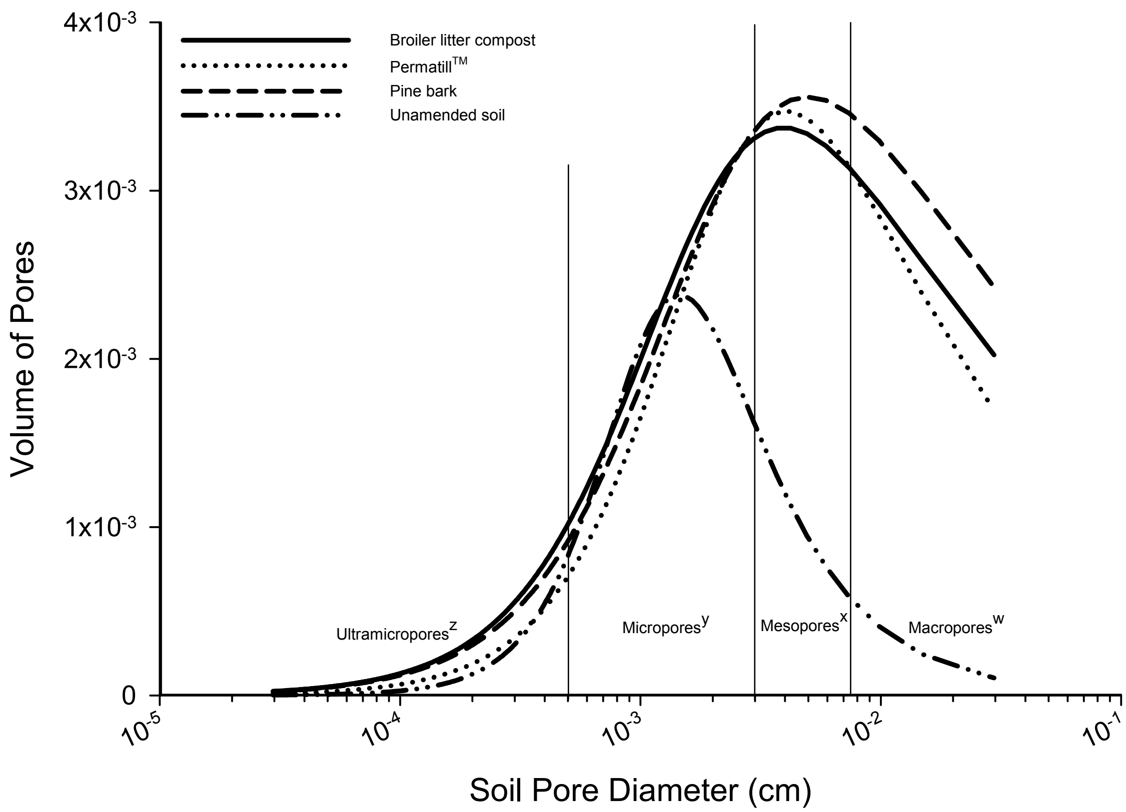

Figure 3.2: Pore size distribution of a Cecil sandy clay loam soil amended with broiler litter compost, Permatill™, and pine bark. Soil Science Society of America pore size classification system was used (Kay and Angers, 2000). [z]Ultramicropores are 0.00001 to 0.0005 cm in diameter. [Y]Micropores are 0.0005 to 0.003 cm in diameter. [x]Mesopores are 0.003 to 0.0075 cm in diameter. [w]Macropores > 0.0075 cm in diameter.

Table 3.1: Bulk density, readily available water (RAW), plant available water (PAW), and air filled porosity of a Cecil sandy clay loam soil amended with pine bark, broiler litter compost, and Permatill™.

Intact soil curves						
Treatments	Bulk density $g \cdot cm^{-3}$	Air-filled porosity [z] $cm^3 \cdot cm^{-3}$	Vol. PAW [y] $cm^3 \cdot cm^{-3}$	Grav. PAW $g \cdot g^{-1}$	Vol. RAW [x] $cm^3 \cdot cm^{-3}$	Grav. RAW $g \cdot g^{-1}$
Unamended soil	1.32a [w]	18%c	12%b	9%d	10%a	8%c
Pine bark	0.56d	44%a	21%a	37%a	10%a	18%a
Chicken litter compost	0.75c	31%b	22%a	30%b	11%a	14%b
Permatill™	0.99b	31%b	15%b	15%c	10%a	10%c

[z]Air filled porosity = $\theta_{fc} - \theta_s$

[y] Vol. PAW = θ_{fc}-θ_{wp} Field capacity at 10 kPa bars and wilting point at 1500 kPa.

[x] Vol. RAW = $\theta_{fc} - \theta_{rwc}$ Field capacity at 10 kPa and RWC = 70 kPa

[w] Means followed by the same letter within a column are not significantly different using Fishers lsd, $p \leq 0.05$.

Table 3.2: Bulk density, readily available water (RAW), plant available water (PAW), and air filled porosity of packed Cecil sandy clay loam soil cores amended with Hydrocks, Profile, and Permatill^{TM}.

Packed Soil Cores				
Soil Amendment Treatments	Bulk density ($g{\cdot}cm^{-3}$)	Grav. PAW^{z}	Grav. RAW^{y}	Air filled porosity^{x}
Unamended soil	1.21 a^{w}	15% a	12% a	20% a
Hydrocks	1.19 a	13% ab	10% b	17% b
Profile	1.22 a	12% bc	10% b	16% b
Permatill^{TM}	1.23 a	11% c	9% b	15% b

^{z}PAW = θ_{fc}-θ_{wp} Field capacity at 10 kPa bars and wilting point at 1500 kPa.

^{y}RAW = $\theta_{fc} - \theta_{rwc}$ Field capacity at 10 kPa and RWC = 70 kPa

^{x}Air filled porosity = $\theta_{fc} - \theta_{s}$

^{w} Means followed by the same letter within a column are not significantly different using Fishers lsd, $p \leq 0.05$

CHAPTER 4

EFFECT OF LANDSCAPE SOIL AMENDMENTS ON SOIL NITROGEN[1]

[1] **McBee, O., T.J. Smalley,M.L. Cabrera, and D.E. Radcliffe. To be submitted to HortScience.**

Abstract:

This study was conducted to determine the effect of landscape soil amendments on soil inorganic nitrogen over time. Pine bark, peat moss, mushroom compost, and Erthfood[TM] compost (composted biosolids and peanut hulls) were mixed 25% by volume with Cecil sandy clay loam and incubated at 25.5ºC for 140 days. Subsamples were taken at 0, 7, 14, 28, 56, 84, 112, and 140 days for inorganic nitrogen (N) determinations. Soil pH for all treatments decreased below 4.7 except for mushroom compost, which contains lime. The results indicated that amending a Cecil sandy clay loam soil with mushroom compost and Erthfood[TM] compost provided immediate nitrogen and increased total soil inorganic nitrogen overtime. Peat moss-amended soil inorganic nitrogen did not differ from the control. Pine bark-amended soil immobilized nitrogen for 56 days. The results demonstrated that peat moss and pine bark do not supply nitrogen.

Introduction:

Organic amendments may reduce fertilizer requirements of landscape soils by increasing cation exchange capacity, promoting a better soil environment for root growth, and providing essential macro-and micronutrients as organic matter breaks down (Khaleel et al., 1981). Most nitrogen in the soil is found in organic forms, and organic nitrogen serves as a reservoir of nitrogen that slowly releases inorganic nitrogen as it decomposes (Sylvia et al., 1999).

The first step of inorganic nitrogen release from organic amendments is ammonification, where simple organic nitrogen compounds are converted to NH_4^+ (Haynes, 1986). In the soil, ammonium can be held on cation exchange sites, react with organic compounds, volatilize, be assimilated by plant and microbes, or be oxidized to nitrate by nitrifiers (Sylvia et al., 1999). Factors that affect the rate of ammonification are carbon to nitrogen (C:N) ratios, with immobilization of nitrogen at C:N ratios greater than 20:1 (Sylvia et al., 1999, Haynes, 1986), soil moisture potential(optimal from -10 to -50 kPa) (Haynes, 1986), and temperature (optimal from 45 to 60°C) (Haynes, 1986).

The second step of inorganic nitrogen release is nitrification. Ammonium (NH_4^+) is oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-). Factors that affect the rate of nitrification are oxygen levels, ammonium availability (Haynes, 1986 and Sylvia et al., 1999), soil moisture (optimal from -10 to -33 kPa) (Haynes, 1986, Sylvia et al., 1999), pH (optimal between 7 to 9 pH) (Haynes, 1986, Focht, 1977, Sylvia et al., 1999), and temperature (optimal from 25 to 35°C) (Haynes, 1986, Sylvia et al., 1999).

Clay content of a soil can reduce the rate of decomposition of organic matter because organic matter becomes absorbed onto the surfaces of clays or becomes entrapped in the aggregates within the soil (Haynes, 1986).

The effect of landscape organic amendments on soil inorganic nitrogen availability in a Cecil sandy clay loam has not been well documented. The objective of this study is to determine the effect on soil inorganic nitrogen of amending a Cecil sandy clay loam soil with pine bark, mushroom compost, Erthfood™ compost, and peat moss.

Materials and Methods:

Samples were collected from the upper 10 cm of an area mapped as Cecil sandy clay loam soil (clayey, kaolinitic, thermic Typic Kanhapludult) at the University of Georgia Horticulture Farm in Watkinsville, GA. The soil was air-dried, crushed, and then sieved through a 1-mm sieve to remove small rocks and plant residue. Four soil amendments, Erthfood™ compost (ERTH Products, LLC., Peachtree city, Georgia), peat moss (Kent Peat Moss, New Brunswick, Canada), pine bark (Smith Garden products, Cummings, Georgia), and mushroom compost (Black Gold Compost Co., Oxford, Florida) were mixed with the sieved soil in a 1:3 ratio amendment to soil (by vol.), which is similar to recommended rates. Application bulk density for these products before incorporation was 0.32 $g \cdot cm^{-3}$ for Erthfood™ compost, 0.18 $g \cdot cm^{-3}$ for peat moss, 0.24 $g \cdot cm^{-3}$ for pine bark, and 0.56 $g \cdot cm^{-3}$ for mushroom compost.

The mixed soils were wetted and packed into soil cores, and Tempe cells were used to obtain the water content at the soil water potential of -20 kPa (-0.2 bars). Mixed soils (280g) were wetted to the corresponding water contents for each mix and placed into plastic bags (0.168 mm x 0.149 mm, 30 x 10^{-6}mm thick) with three replicates for each treatment. To minimize soil drying in the bags, samples were placed on shelves 16 cm above the bottom of a humidity chamber (38 L glass aquarium). One centimeter of water was placed in the bottom to maintain high humidity. The aquarium was closed and humidified air was pumped into the aquarium at a rate of 1 $L \cdot min^{-1}$. The aquarium was placed in an incubator at 25.5ºC.

The samples were incubated for 140 days. To insure adequate aeration, bags were opened once every 7 days and the soil was mixed for 5 s before closing. At 0, 7, 14, 28, 56, 84, 112, and 140 day after study initiation, soil in the bags were sampled to determine the NH_4-N and NO_3-N levels and weighed to determine the water content of the sample. Water losses during the incubation were negligible. Soil pH was determined using a 1:2.5 soil to water ratio.

On each sampling date, 5 g moist soil was extracted with 40 mL of 1M KCl (Egelkraut et al, 2000), and filtered through a Glass fiber filter (0.8-8.0µm particle retention). The KCl extract was analyzed for NO_3-N with the Griess-Ilosvay technique after reduction of NO_3^- to NO_2^- with a Cd column (Keeney and Nelson, 1982) using an Autoanalyzer (300 series) (Alpkem Clackmans,OR). Ammonium was analyzed with the salicylate-hypochlorite method (Crooke and Simpson, 1971) using a Perstorp Analytical Autoanalyzer (500 series, Alpkem).

Net inorganic nitrogen was determined by subtracting the unamended total inorganic nitrogen from the treatment total inorganic nitrogen.

Net nitrogen mineralization was determined by subtracting the initial amounts of net inorganic nitrogen of Erthfood™ compost and mushroom compost from the amount present at each sampling, and the data was fit to a re-wetted single nitrogen pool model (Cabrera, 1993):

$$Nmin = N_1(1-e^{-k_1 t})$$

Nmin is net nitrogen mineralization, N_1 is the pool of mineralizable nitrogen made available after a drying and rewetting event, k_1 is the rate constant of mineralization of N_1, and t is the time.

Procedures REG, NONLIN, and Means separated by Fisher's LSD in SAS (SAS Institute, 1985).

Results and Discussion:

For all treatments except mushroom compost, pH decreased over time (Figure 4.1). The nitrification of organic matter in the soil amendments released H^+, which decreased pH. The pH of mushroom compost amended soil (7.2) was higher than the other treatments throughout the experiment because mushroom compost is limed. Shuman (1998) also found that amending soil with mushroom compost raised soil pH.

The pH of pine bark-amended soil did not decrease from day 14 to day 28 because of net immobilization of nitrogen during this time. Instead of being nitrified, ammonium, the source of H^+ as it is nitrified, was utilized by microbes to degrade the uncomposted cellulose in the pine bark. By the end of the experiment, all treatments except the mushroom compost were below 4.7 pH.

Ammonium on day 0 for Erthfood™ compost amended soil was higher than all other treatments (Table 4.1) indicating that Erthfood™ compost supplied ammonium immediately. The low ammonium content and high nitrate content of the mushroom compost on day 0 indicated that nitrifiers were actively converting ammonium to nitrate.

Ammonium for day 7 was highest for Erthfood™ compost and lowest for pine bark and mushroom compost. The low ammonium levels in the pine bark are attributed to microbial immobilization of the ammonium.

After day 28, ammonium levels remained highest for peat moss while all other treatments continued to decrease toward zero for the rest of the experiment. Because nitrifiers are reduced below pH 6 and become negligible below pH 5 (Alexander, 1977, Tyson and Cabrera, 1993), nitrification may have been occurring at a slower rate in the peat moss amended soil because the pH was never above 5.

Nitrate accumulation followed a quadratic relationship (Figure 4.2). Nitrate levels increased over time, except in the bark, which decreased until day 56 and then increased (Table 4.1). The decrease in nitrate of pine bark amended soil indicated microbial immobilization of nitrogen.

On day zero, Erthfood™ compost and mushroom compost amended soils had higher nitrate levels than the other treatments (Table 4.1). This indicated that Erthfood™

compost and mushroom compost could supply nitrate when initially incorporated. Unamended soil, pine bark and peat moss treatments did not differ inferring that pine bark and peat moss did not supply nitrate when first amended into the soil.

On all days, Erthfood™ compost and mushroom compost had higher nitrate levels than other treatments indicating that Erthfood™ compost and mushroom compost provide more nitrate than the other soil amendments (Table 4.1). Pine bark had the lowest nitrate levels because of microbial immobilization.

The total inorganic nitrogen was quadratic and resembles the results found by Cabrera (1993) for nitrogen released from broiler litter compost in rewetted soil (Figure 4.2). Total inorganic nitrogen increased for all treatments except pine bark, which decreased before increasing (Table 4.1). At the start of the experiment, Erthfood™ compost had the highest total inorganic nitrogen for 56 days indicating that Erthfood™ compost provided the most nitrogen initially. Mushroom compost had the highest total nitrogen for the remaining 84 days. Stewart (1998) determined that mushroom compost can be used as a slow release fertilizer.

Unamended soil and peat moss treatments had higher total nitrogen levels than bark treatments and did not differ from each other throughout the treatment. Hue and Sobieszczyk found peat moss increased the nitrogen levels in soil, but Durham (1967) documented nitrogen deficiency from the incorporation of peat moss. Thus amending with peat moss may not increase the nitrogen levels of soil, but this might have been caused by the low pH of the peat moss amended soil.

Pine bark had the lowest total nitrogen level for all days except day 0 for all treatments. This research indicates that pine bark may have immobilized nitrogen for 56 days or more. Dunn (1956) and Odneal and Kaps (1999) found that pine bark does not supply nutrients to plants, because of the high carbon to nitrogen ratio, and fertilizer must be supplied to compensate. Another possibility is that pine bark absorbed nitrate into the spaces of the pine bark, and this was found with nursery container media not with soil amendments (Pokorny, et al., 1977).

By day 140, mushroom compost increased nitrogen by about 233 kg per hectare (ha), and Erthfood™ compost increased nitrogen by about 178 $kg \cdot ha^{-1}$(Figure 4.3). Pine bark decreased nitrogen by 89.2 $kg \cdot ha$, and peatmoss showed no change (Figure 4.3).

Of the two soil amendments that showed net nitrogen mineralization, Mushroom compost had the highest amount of mineralizable nitrogen, but the slowest mineralization rate of organic nitrogen with 0.8% mineralized per day (Figure 4.4). Erthfood™ compost had the lowest amount of mineralizable nitrogen, but the fastest mineralization rate of organic nitrogen with 4% mineralized per day for approximately 56 days.

The results of this experiment demonstrated that amending a Cecil sandy clay loam soil with mushroom compost and Erthfood™ compost increased total inorganic nitrogen content more than the unamended soil overtime indicating that these amendments could be used as a slow release fertilizer. Peat moss did not increase total inorganic nitrogen content greater than the unamended soil indicating that peat moss does not supply nitrogen. Pine bark decreased total inorganic nitrogen suggesting that supplemental nitrogen is necessary.

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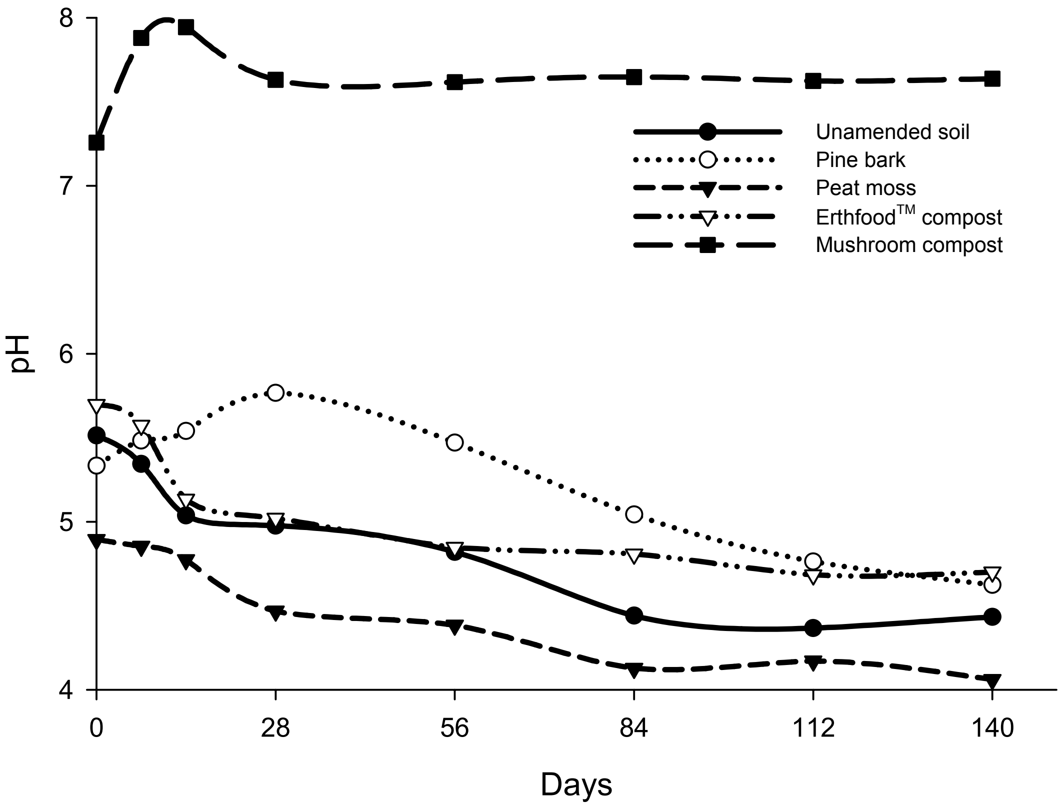

Figure 4.1: Changes in pH of a Cecil sandy loam soil after amending with pine bark, peat moss, Erthfood™ compost, and mushroom compost.

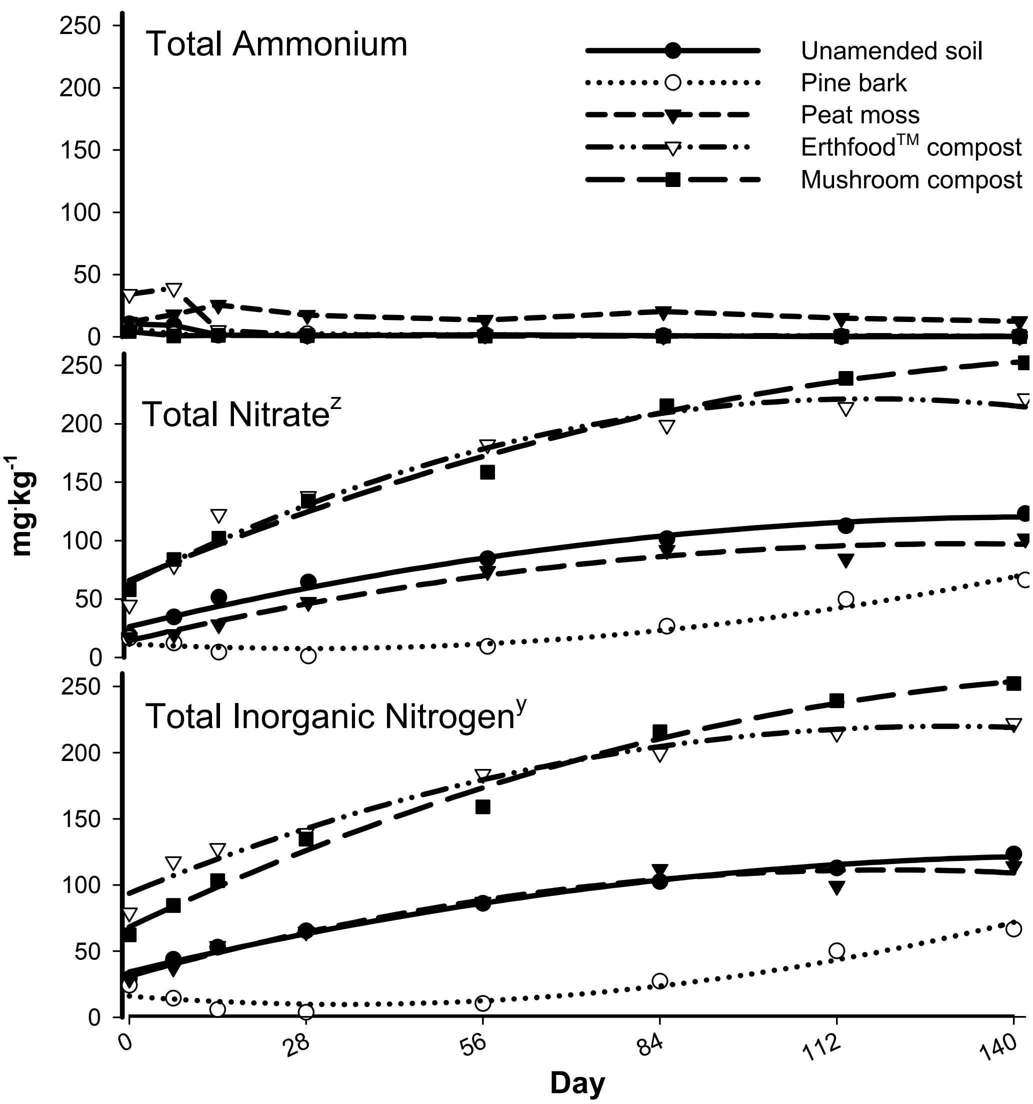

Figure 4.2: Inorganic nitrogen release in a Cecil sandy loam soil amended with pine bark, peat moss, Erthfood™ compost, and mushroom compost.

[z] Regression lines for nitrate: Control r^2 =0.98, Pine bark r^2 = 0.94, Peat moss r^2 = 0.93, Erthfood™ r^2 = 0.93, Mushroom compost r^2 = 0.95.

[y] Regression lines for total inorganic nitrogen release: Control r^2 = 0.99, Pine bark r^2 = 0.91, Peat moss r^2 = 0.90, Erthfood™ compost r^2 = 0.93, Mushroom compost r^2 = 0.95.

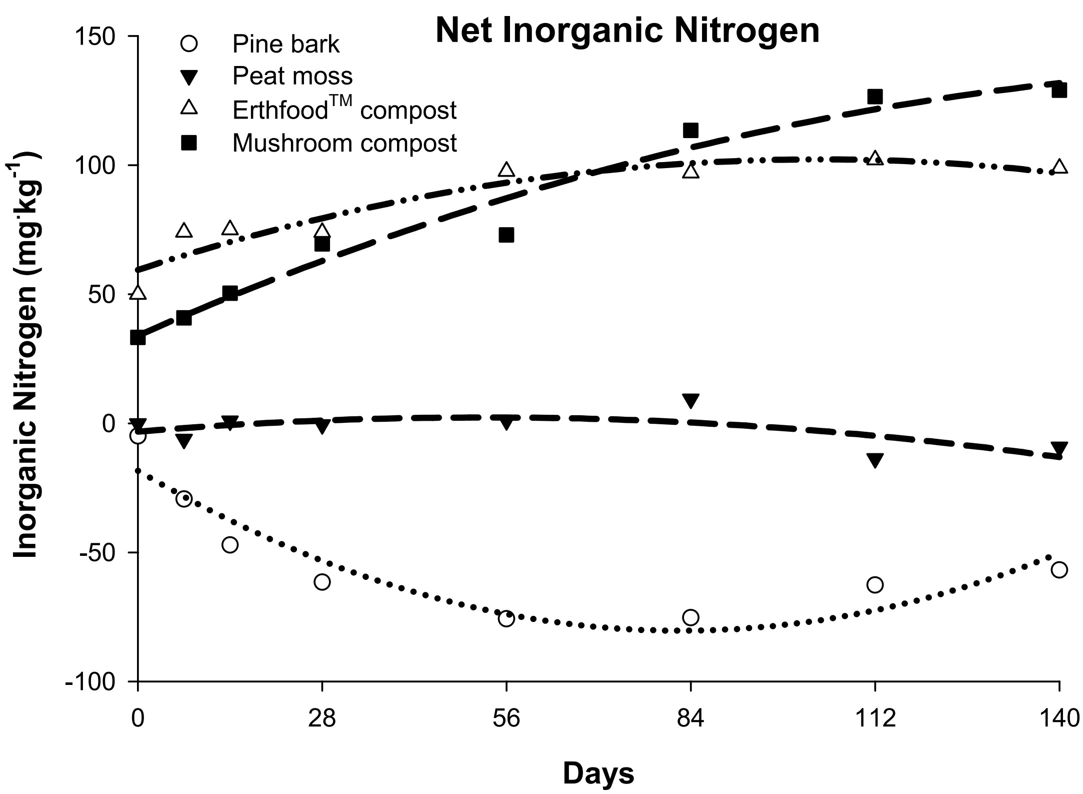

Figure 4.3: Net inorganic nitrogen released from a Cecil sandy clay loam soil amended with pine bark, peat moss, Erthfood™ compost, and mushroom compost.

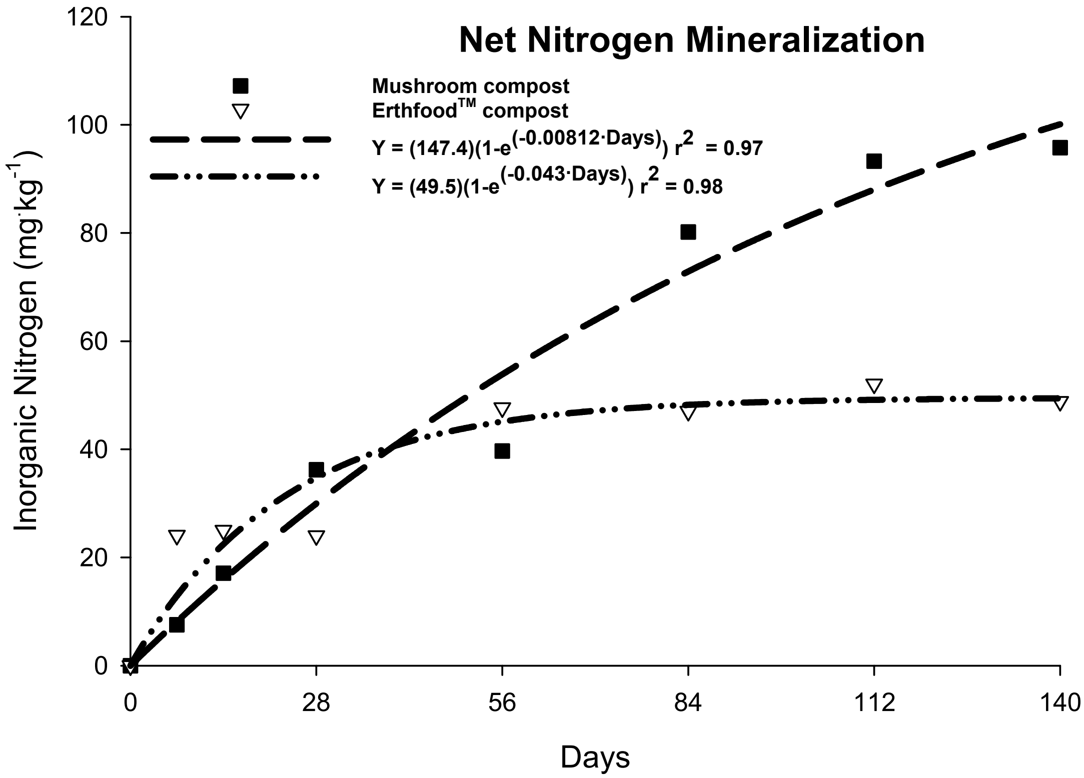

Figure 4.4: Net inorganic nitrogen mineralization from a Cecil sandy clay loam soil amended with mushroom compost and Erthfood™ compost.

Table 4.1: Ammonium, nitrate, total inorganic nitrogen levels in a Cecil sandy clay loam soil amended with pine bark, peat moss, Erthfood™ compost, and mushroom compost.

Treatments	Days after amending							
	0	7	14	28	56	84	112	140
	Ammonium (mg/kg)							
Unamended soil	10.4b[z]	9.2c	1.4c	0.7b	1.7b	0.9b	0.1b	0.2b
Pine bark	7.7bc	2.1d	1.2c	2.4b	1.0b	0.5b	0.4b	0.3b
Peat moss	11.7b	17.8b	25.6a	17.4a	13.4a	20.2a	14.8a	12.5a
Erthfood™ compost	34.1a	39.1a	5.1b	1.3b	1.5b	0.7b	0.8b	0.5b
Mushroom compost	4.2c	0.7d	1.1c	1.0b	0.6b	0.5b	0.4b	0.3b
	Nitrate (mg/kg)							
Unamended soil	18.7c	34.5b	51.4c	64.4b	84.5c	101.6c	112.7b	123.2c
Pine bark	16.5c	12.2c	4.48e	1.3d	9.5d	26.7d	49.7c	66.2d
Peat moss	17.2c	19.8c	28.2d	47.3c	73.8c	91.7c	84.3cb	101.7c
Erthfood™ compost	44.9b	78.7a	122.7a	137.9a	182.2a	198.8b	214.0a	221.7b
Mushroom compost	58.1a	83.9a	102.1b	133.7a	158.5b	215.5a	238.9a	252.1a
	Total Inorganic Nitrogen (mg/kg)							
Unamended soil	29.1c	43.7c	52.8 c	65.2b	86.2c	102.5c	112.8b	123.4c
Pine bark	24.1c	14.3d	5.7d	3.7c	10.4d	27.2d	50.2c	66.6d
Peat moss	28.9c	37.6c	53.8c	64.7b	87.2c	111.9c	99.1b	114.1c
Erthfood™ compost	79.1a	117.8a	127.8a	139.1a	183.8a	199.5b	214.8a	222.2b
Mushroom compost	62.4b	84.6b	103.2b	134.7a	159.1b	216.0a	239.3a	252.4a

[Z]Means with same letter within a column are not significantly different using Fisher's LSD, $p \leq 0.05$.

CHAPTER 5

CONCLUSION

The effect of broiler litter compost, pine bark, and Permatill^{TM} amendments on soil water was determined. Pine bark and broiler litter compost amendments increased air-filled porosity, plant available water (PAW), readily available water (RAW), and lowered bulk density. These results implied that the use of these amendments might reduce irrigation requirement for plants grown in these soils. Permatill^{TM} increased air-filled porosity and PAW, and lowered bulk density, but did not increase RAW. Pine bark and broiler litter compost must be added each year because of decomposition, but Permatill^{TM} is an expanded slate that does not decompose. Hence, Permatill^{TM}, as an amendment, may have permanent positive affects on soil properties.

The results of our research implied that packed soil cores may be of limited value when trying to determine how soil amendments affect air-filled porosity, PAW, RAW, or bulk density in the field. With intact soil cores a change in bulk density was observed while packed soil cores did not differ, which questions the applicability of this packing technique to field situations.

We assessed the effect of pine bark, peat moss, Erthfood^{TM} compost, and mushroom compost on soil inorganic nitrogen when incorporated into a Cecil sandy clay loam soil. We found that Erthfood^{TM} compost and mushroom compost contain nitrogen that is immediately available and also nitrogen that is slowly released over time. Pine bark incorporation immobilized nitrogen, which reduced nitrogen availability. Amending with peat moss had no affect on soil nitrogen.