EFFECT OF SPODIC DERIVED FILL MATERIALS ON GROWTH AND ESTABLISHMENT OF ST. AUGUSTINEGRASS

By

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To my friends and family

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Turfgrass represents a dominate component of urban landscapes and require water and fertilizer inputs to produce functioning healthy systems. *Stenotaphrum secundatum* Walt. Kuntze (st. augustinegrass, STA) is a widely used turfgrass choice in urban settings throughout Florida. Fill materials used in residential construction can have varying physical and chemical properties which have the potential to negatively impact the establishment of turfgrass in urban settings. The phosphorus (P) sorption capacity of different fill materials can affect P leaching from urban areas. Research has shown that P retention capacity and P saturation status of soils, mainly the amounts of aluminum and iron in relation to P, greatly affect the potential for soils to leach P. Research has also shown different P saturation measurements like the P saturation ratio (PSR), degree of P saturation (DPS), and soil P storage capacity (SPSC) have been able to accurately identify the P leaching potential of acidic soils in agricultural systems. Over the last 20 to 30 years, there has been an increase of fresh surface water quality issues that have been linked to excess P inputs from urban areas. In response, Florida adopted the urban turf rule which limits the amount of P allowed to be

applied to turfgrass in urban settings. It is unknown if certain chemical properties of soil fill materials that are related to P retention will effect P bioavailability to turfgrass and influence P leaching from urban settings. The objectives of this study were to: 1) determine the response and quality of STA grown on spodic (Bh horizon) derived fill materials and 2) to quantify the leaching of P from Bh and non-Bh fill soils.

We evaluated the growth and quality of STA sod establishment in PVC columns containing five soil fill materials (three Bh and two non-Bh) over a 9- and 27-week period. Phosphorus (molybdate reactive, dissolved reactive orthophosphate, and total dissolved) leaching losses from the soil columns were also evaluated. Soil physical and chemical properties, turfgrass biomass, quality, and tissue nutrient contents; and leachate volume, molybdate reactive P, dissolved reactive orthophosphate, and total dissolved P were assessed periodically throughout the study period.

Results from our study show that Bh horizon soil treatments did not negatively affect the establishment or bioavailability of P to STA. In fact, turfgrass quality ratings and shoot count measurements of STA grown on some Bh horizons were significantly higher than compared to the uncoated sands in of the E horizon soil. Results from this study indicate that turfgrass was able to effectively uptake stored P from the Bh horizons during establishment periods. Results from our study also indicate that STA is able to establish on low P soils, even without significant application of P fertilizer.

Phosphorus saturation measurements (PSR, DPS, and SPSC) were generally able to predict soil treatments with high leaching P potentials and soils with high concentrations of water soluble P. However, one Bh horizon (Myakka-Bh1) with significantly lower PSR and DPS values and positive SPSC values leached significantly higher P concentrations and contained similar soil water soluble P values to the Paola-Bw soil that had significantly higher PSR and DPS values and negative SPSC values. Data obtained from our study supports the idea that different soil types should have different PSR and DPS threshold values. Results from this study also indicate that, even with as little as 0.059 $g \cdot m^{-2}$ P fertilizer applied, some Bh horizon fill materials with PSR and DPS values well below established change points still leach P concentrations that may be of environmental concern.

CHAPTER 1
LITERATURE REVIEW AND RESEARCH OBJECTIVES

St. Augustinegrass Origin and Morphological Characteristics

Stenotaphrum secundatum Walt. Kuntze (st. augustinegrass, STA) is native to the Gulf of Mexico region, the West Indies, and parts of Western Africa (Trenholm et al., 2011). On the east coast of the United States, STA is planted from Florida to the Carolinas because it is best adapted to subtropical climates. St. augustinegrass is a stoloniferous grass species that roots at the nodes. This coarse textured turfgrass has compressed leaf sheaths, generally folded leaf blades, and rounded leaf tips (U.S. Department of Agriculture, 2010). It has moderate shade tolerance, low drought tolerance, and can be best established in soils with a pH range of 4.8 to 7.5 (Trenholm et al., 2006; U.S. Department of Agriculture, 2010). St. augustinegrass develops roots within the upper 15.2 to 30.5 cm of the soil and does not tolerate compacted or waterlogged soils (U.S. Department of Agriculture, 2010). St. augustinegrass has a green to blue-green colored dense turf and can produce a thick thatch layer under high fertilization and irrigation regimes (Trenholm et al., 2006). Like most other warm season grasses, STA goes into winter dormancy during colder months, turning a brown or tan color.

St. augustinegrass is the most popular turfgrass choice for lawns throughout the southeastern United States, covering roughly 40% of the approximately 2 million ha of home lawn turfgrass in the state of Florida (Liu et al., 2008; Trenholm et al., 2006). Haydu et al. (2005) reported that STA represented 64% of the total sod production for Florida in 2003, of which 69% was the cultivar ‘Floratam’. There are several cultivars of STA that are available for lawn use in Florida. The cultivars have a range of leaf textures, varying tolerances to environmental stresses, and different susceptibilities to pests (Trenholm et al., 2011). ‘Floratam’ STA is a popular coarse-textured cultivar that was released in 1973 by the University of Florida and Texas A & M University. Despite its poor cold and shade tolerance (relative to other STA cultivars), ‘Floratam’ STA remains the most widely produced and used STA cultivar for Florida lawns in urban settings (Trenholm et al., 2011).

Urban Topsoil Fill

Human construction activities that occur during the urbanization of rural areas often result in the disturbance and redistribution of native soils. During the development of residential communities the native vegetation and topsoil are often removed to prepare the soil for building (Lehmann and Stahr, 2007; Scharenbroch et al., 2005; Shober and Toor, 2009). After removal of vegetation and topsoil, the addition of fill material is sometimes required to achieve a level grade. This fill material usually consists of soil that was removed from nearby areas during the construction of storm water retention ponds or soil that was hauled in from other locations, such as a borrow pit. Fill material used in construction can have varying physical and chemical properties due to the mixing of different soil horizons (Pouyat et al., 2007; Scharenbroch et al., 2005; Short et al., 1986).

Occurrence of Spodosols in Florida

Spodosols are most prevalent in cool, humid or perhumid climates; however, they are widely distributed throughout the southeastern USA, occurring mainly in flatwoods ecosystems of the Coastal Plains (U.S. Department of Agriculture-Natural Resources Conservation Service, 2012). Spodosols are a dominant soil order in Florida; covering approximately 3.4 million ha (approximately 27% of soil coverage) throughout the state

(Carlise and Brown, 1982; Collins, 2010; Stone et al., 1993). In Florida, Spodosols are typically characterized by sandy soil textures, fluctuating water tables, and the presence of a subsurface spodic (Bh) horizon (Harris et al., 1995).

The main accepted theory of Bh horizon formation and Spodosol genesis, involves mobilization and complexation of metals by dissolved organic carbon (DOC) (Deconinck, 1980). Dissolved organic carbon is released into the soil profile during microbial-mediated litter decay. Once released into the soil environment, DOC molecules promote the weathering of various soil minerals and metal oxide coatings on sand grains (Harris et al., 1995). As these soil minerals and metal oxide coatings weather, they release ions [e.g., aluminum (Al), iron (Fe), etc.] into the soil solution. The DOC molecules, which possess a net negative charge, attract cations that were released when soil minerals were weathered. Larger valence cations, like Al^{3+} and Fe^{3+}, are strongly attracted to the DOC molecules and become chelated or complexed. As the DOC molecules move downward through the soil profile, they complex additional metal cations, reducing the net negative charge on the DOC molecule. When the net negative charge on the DOC molecules are reduced enough for Van der Waals forces to overcome the force of repulsion between the DOC molecules, precipitation or flocculation can occur (Deconinck, 1980). This process of eluviation leaves uncoated sand-grains exposed in a light colored E horizon, which overlays the dark-colored layer of illuvation (Bh horizon) that is enriched with organo-metal compounds. Spodic horizons in Florida are typically acidic and contain large amounts of organic carbon (C) and Al oxides as a result of podzolization processes.

Since Spodosols are one of the most widely distributed soil orders in Florida, it is likely that some of the fill material imported into construction areas will contain Bh horizon subsurface soils. Misinterpretation of the quality of this dark colored acidic soil may also lead to application of Bh horizon soil as a topsoil. It is possible that the acidic nature and accumulation of metal oxides in Florida Bh horizons may have direct affects on nutrient fate and bioavailability.

Eutrophication and Nutrient Management Strategies

Many studies link the degradation of surface water quality (e.g. harmful algal blooms, eutrophication, and dead zones) to the discharge of nutrients from point- and non-point sources (Anderson et al., 2002; Riegman, 1995; Sharpley et al., 2003; Smith, 1983). In particular, phosphorus (P) has been shown to be the main limiting nutrient for algal and aquatic weed growth in fresh surface-water bodies (Correll, 1998; Sharpley et al., 2003). Excess additions of P into freshwater bodies can result in large algal blooms that restrict recreational and drinking water usage and can cause oxygen shortages to other aquatic biota (Sharpley et al., 2003).

In Florida, the main strategies for controlling nutrient losses from lawns and landscapes are best management practices (BMPs) and controlling fertilizer applications in urban areas. In 2002, the Florida Department of Environmental Protection (FDEP) published the Florida Green Industries BMP Manual, which provided BMPs for turfgrass and landscape maintenance professionals to use statewide (Hartman et al., 2008). This manual followed the Professional Lawn Care Association of America's BMPs as a guide. Prior to 2002, only two local governments, St. Johns County and the Village of Wellington, had placed restrictions on the use of fertilizers (Hartman et al., 2008). However, both of these fertilizer restrictions were tailored to improved water quality by decreasing nutrient runoff from ranching practices and did not focus on nutrient runoff from urban areas.

In 2003, the FDEP developed a model ordinance, entitled “Guidelines for Model Ordinance Language for the Protection of Water Quality and Quantity Using Florida-Friendly Lawns and Landscapes”, to assist local governments in improving their existing land development regulations (Hartman et al., 2008). This model ordinance combined Florida-Friendly Landscaping™ concepts with BMPs that were supported by University of Florida – Institute of Food and Agricultural Sciences (UF–IFAS). This model ordinance mainly addressed site planning techniques and only briefly addressed fertilizer use. In 2007, the Florida Legislature appointed the Florida Department of Agriculture and Consumer Services (FDACS) to create the Florida Consumer Fertilizer Task Force (Hartman et al., 2008). This task force helped develop recommendations for statewide policies and programs regarding consumer fertilizer use. As state agencies worked to implement plans for the statewide protection of surface and groundwater, many local governments began to implement their own preventive measures via county and city-wide fertilizer ordinances. By the end of 2007, the city of Sanibel Island, Sarasota County, the city of Sarasota, the city of Cape Coral, the city of North Port, and the city of Naples had adopted local fertilizer ordinances (Hartman et al., 2008).

Numerous state statutes were developed that encouraged communities and local governments to adapt various Florida-Friendly ordinances. As enacted, Section 403.9337 of the Florida Statutes encouraged county and municipal governments to adopt and enforce the model ordinance for “Florida-Friendly Fertilizer Use on Urban Landscapes” (or an equivalent) as a mechanism for protecting local surface water and groundwater quality (Florida Department of Environmental Protection, 2010). Local governments are allowed to adopt more stringent standards then outlined in the model ordinance if it demonstrated that: a) additional or more stringent standards were necessary to adequately address fertilizer contributions to nutrient loading in water bodies; and b) it had considered all relevant scientific information, including input from the FDEP, FDACS, and the UF–IFAS (Florida Department of Environmental Protection, 2010). Many of these local ordinances included preventive measures that were more stringent than guidelines in the model ordinance. For example, these local ordinances contained language designating fertilizer "blackout periods", which prohibited fertilizer applications during certain months of the year (Hartman et al., 2008). Other differences in local ordinances, as compared to the model ordinance, were related to the amount of nitrogen (N) and P applied in a single application and annually, the distance from water bodies required for "no fertilizer zones", and N and P allowances for turfgrass establishment periods (Hartman et al., 2008).

In 2008, the newly appointed FDACS fertilizer task force enacted the urban turf fertilizer rule to help protect Florida's waters (Florida Department of Agriculture and Consumer Services, 2010; Trenholm, 2010). The urban turf fertilizer rule changed the labeling requirements for turf fertilizers and limited fertilizer application rates of N and P in turfgrass areas. The urban turf fertilizer rule allows for a one time starter P application within one year of planting new sod. This starter fertilizer can be applied at a P rate of 2.15 $g \cdot m^{-2}$ P. Subsequent P applications are limited to 0.54 $g \cdot m^{-2}$ P per application, with no more than 1.07 $g \cdot m^{-2}$ P applied annually (Florida Department of Agriculture and

Consumer Services, 2010; Trenholm, 2010). Additional P fertilizer is permitted provided soil testing indicates the need for P.

However, standard agronomic soil tests [e.g., Mehlich 1 (M1) or Mehlich 3 (M3)] do not account for the P retention capacity of the soils and may overestimate the pool of available P for turfgrass use. Results of a standard soil test may show “low levels” of P, allowing for fertilizer applications in excess of the urban fertilizer rules annual limit, but the soil may not have any low remaining P sorption capacity so added P could easily be lost to the surrounding environment. On the other end, a standard soil P test may show “high levels” of P indicating no fertilizer additions allowed by the urban turf rule, but the soil may have high levels of P associated with Al or Fe that is not readily available to the turfgrass, which may result in unhealthy turfgrass growth and development. Therefore, it is important to understand P retention in soils and considered adopting soil measurements that account for P retention in soils.

Phosphorus Retention in Soils

Phosphorus exists in many different chemical forms and species (i.e., H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) in the soil-solution environment (Brady and Weil, 2002). The presence of these P species can be directly related to soil pH, which in turn, has a direct effect on the amount of plant available P. In acid soils (pH < 5.5), P ions react with Fe and Al oxides to form surface complexes or react with dissolved Fe^{3+} and Al^{3+} ions to form insoluble hydroxyl phosphate precipitates (Brady and Weil, 2002). When soil pH is neutral to alkaline, P reacts with calcium and magnesium ions to form precipitates or is absorbed to surfaces of $CaCO_3$ (Havlin et al., 2005; Lindsay, 2001). This leaves a small pH range (6.5 to 7.0) for the dominance of the optimal plant available P ions, $H_2PO_4^-$ and HPO_4^{2-} (Havlin et al., 2005). Phosphorus adsorption is the process by which phosphate ions in solution react with different surfaces of soil constituents [clays; oxides of Fe and Al; organic matter (OM); and Al and Fe compound coating surfaces of sand particles] (McBride, 1994). Phosphorus is mainly adsorbed to metal oxides and clay minerals as inner-sphere complexes (Goldberg and Sposito, 1985). Since Fe- or Al-(hydr)oxide coatings were identified as major factor in a soils ability to absorb P, multiple chemical extractions that each account for different forms of Fe and Al are used as a way to asses a soils P sorption potential. Three chemical extractions that have been used in the past by many researchers to show the amount of Fe and Al in soils are the citrate-dithionite-bicarbonate extraction (crystalline and amorphous Fe; mainly amorphous Al), the pyrophosphate extraction (organically bond Al and Fe), and the oxalate extraction (amorphous and organically bond Fe and Al) (Freese et al., 1992; McKeague et al., 1971; Parfitt and Childs, 1988; Villapando and Graetz, 2001).

Some studies determined that Al plays a more dominant role than Fe in sorbing P (Ballard and Fiskell, 1974). For example, Villapando and Graetz (2001) showed a correlation of P sorption to numerous forms of Al (e.g., oxalate-extractable Al, citrate-dithionite-bicarbonate-extractable Al, and pyrophosphate-extractable Al) in Bh horizon samples using full P sorption isotherms, with the highest correlation to P sorption for $CuCl_2$-extractable Al; no positive relationship between P sorption maxima and Fe was reported. However, the lack of a positive relationship between Fe and P sorption found by Villapando and Graetz (2001) was most likely due to the fact that the soils used in the study contained a greater amount of Al than Fe. Other studies have shown that both Fe and Al play a dominant role in P sorption. For example, Yuan and Lavkulich (1994) and van der Zee and van Riemsdijk (1986) reported a strong correlation between P sorption and oxalate-extractable Al and Fe in Spodosols. Borggaard et al. (1990) showed that P sorption in a range of Danish soils was a function of both citrate-dithionite-bicarbonate and oxalate-extractable Al and Fe. This result was also supported by the findings of Nair et al. (1998), who attributed the high P sorption capacity of Florida Bh horizons to the presence of oxalate-extractable Al and Fe.

Phosphorus Retention in Florida Soils

Many of Florida's sandy soils have low P sorption capacity (Nair et al., 2004) due to low concentrations of metal oxides [namely Al- and Fe-(hydr)oxides] that are capable of forming surface bonds with orthophosphates (Harris et al., 1996). Snyder et al. (2001) showed that the P leaching potential of an acidic uncoated sand soil was much greater than a Fe- or Al-(hydr)oxide coated sandy soil. Uncoated or "clean" sand grains are typical of most A and E horizons in Florida Spodosols. However, some of Florida's subsurface horizons (e.g., Bh and Bt) have the capacity to sorb large amounts of P. In a study measuring the P retention characteristics of Spodosols and the potential for movement of P from surface (A) horizons to the underlying Bh horizon, Nair et al. (1998) reported that P sorption capacities of Bh horizon soils was 1.5 to 2 times greater than overlying uncoated E horizon soils. Zhou et al. (1997) concluded that metal-OM complexes were the primary source of P sorption capacity in Bh horizon soils from Florida. This finding was also supported by Villapando and Graetz (2001), who determined the ability of Bh horizons to adsorb P was due to low soil pH coupled with the accumulation of metals and organic C (Villapando and Graetz, 2001). Therefore, Bh horizons can generally be considered to have high P retention capacities. Many studies have developed measurements to account for the P sorption capacities of soils and are able to predict if soils will act as P sinks or P sources.

Measurements of Soil Phosphorus Retention Capacity

The degree of P saturation (DPS), the P saturation ratio (PSR), and soil P storage capacity (SPSC) are measurements that account for the P retention capacity of a acidic soil by quantifying the relationship between soil P and P retaining soil minerals (mainly Al and Fe) (Chakraborty et al., 2011a; Maguire and Sims, 2002; Nair et al., 2004). The utility of the DPS and PSR relates to the fact that they tend to have discrete threshold values, within certain ranges of soils, above which the P in solution abruptly starts to increase in a linear fashion.

The degree of P saturation (DPS) is calculated from a single extraction with acid ammonium oxalate (DPS_{ox}) and relates ammonium oxalate P (P_{ox}) to the sum of oxalate-extractable Fe (Fe_{ox}) and Al (Al_{ox}) by the following equation:

$$DPS_{ox} = [(P_{ox}) / \alpha\ (Al_{ox} + Fe_{ox})] \times 100$$

where P_{ox}, Al_{ox} , and Fe_{ox} are the concentration of oxalate extractable P, Al, and Fe expressed in mmol kg^{-1} and α is an empirical factor that compares different soils with respect to P saturation (Breeuwsa et al., 1995). An α value of 0.50 has been used in many studies (Schoumans, 2009; Sims et al., 2002), but Nair and Graetz (2002) reported that a α value of 0.55 was appropriate for Bh horizons in Florida.

Since oxalate extractions are not routinely conducted in soil testing labs, the concept of the P saturation ratio was developed (PSR) (Maguire and Sims, 2002; Nair and Graetz, 2002), which relates the amount of M3 or M1 extractable P to the sum of M3 or M1 extractable Fe and Al. Maguire and Sims (2002) suggested the following equation to determine PSR based on the M3 extraction (PSR_{M3}):

$$PSR_{M3} = P_{M3} / (Al_{M3} + Fe_{M3}),$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentrations of M3 extractable P, Al, and Fe expressed in mmol kg^{-1}. In an effort to evaluate the relationship between widely reported DPS_{ox} values of past studies to the more commonly used Mehlich soil extractant, Nair et al. (2004) developed the following equation to calculate DPS based on analysis of Mehlich 3 extracts (DPS_{M3}) was:

$$DPS_{M3} = [(P_{M3}) / \alpha (Al_{M3} + Fe_{M3})] \times 100,$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentrations of M3 extractable P, Al, and Fe expressed in mmol kg^{-1} and α is an empirical factor that compares different soils with respect to P saturation. Nair et al. (2004) showed a strong correlation between DPS_{ox} and DPS_{M3}, demonstrating that both methods were equally appropriate for DPS calculations. Since both PSR_{M3} and DPS_{M3} use results of tests that are readily available from most standard soil testing labs, these equations provide a more practical way to assess the P saturation of a soil than using equations requiring oxalate extractable values.

Maguire and Sims (2002) evaluated the potential of DPS_{ox} and PSR_{M3} as environmental soil tests by comparing P in leachate from soil cores with different DPS_{ox} and PSR_{M3} levels. The authors reported a change point of 56% and 0.23 for DPS_{ox} and PSR_{M3}, respectively, for five different Delaware soils. Phosphorus concentrations in leachate tended to increase rapidly when DPS_{ox} or PSR_{M3} levels exceeded the change point. However, the authors did note that before these change points could be extrapolated to a wide range of soil types, more research was needed to determine the effect of various chemical and physical properties of soil types on the change point values. The coefficient of determination for the relationship between leachate P and

PSR_{M3} was much greater (r^2 = 0.78) then the relationship between leachate P and DPS_{ox} (r^2 = 0.46). Thus, Maguire and Sims (2002) concluded that the PSR_{M3} showed excellent promise for identifying soils that represent an increased risk for P leaching losses.

However, neither the DPS nor the PSR equations provide information on the amount of P that can added to the soil before the soil becomes a potential environmental concern (Chakraborty et al., 2011a). The SPSC equation is used to estimate the remaining P sorption capacity of the soil. The SPSC is calculated based on oxalate, M1, or M3 extractable Al and Fe. Charakraborty et al. (2011a) reported the following equation for SPSC calculation based on Mehlich 3 extraction ($SPSC_{M3}$):

$SPSC_{M3}$= (Change point PSR_{M3} – Soil PSR_{M3}) × (Fe_{M3} + Al_{M3}) × 31,

where Al_{M3}, and Fe_{M3} are the concentrations of M3 extractable Al and Fe expressed in mmol kg^{-1} and change point PSR_{M3} is the threshold value determined for a specific range of soil. When the SPSC value is positive the soil is a P sink, while a negative SPSC value indicates that the soil is a potential P source (Chrysostome et al., 2007). The P status of a soil can affect the P leaching potential when applied as fill materials in urban settings.

Phosphorus Leaching from Turfgrass Systems

Phosphorus loss due to leaching has been considered a minor pathway in agricultural and urban systems because most soils and subsoils have relatively high P sorption capacities compared to the amount of P being applied (Sims et al., 1998). However, Soldat and Petrovic (2008) reviewed several studies that highlighted situations under which P leaching could become a major pathway for P loss in turfgrass systems, including: fertilized soils with low P sorption capacities, soils with high organic matter content, soils with large networks of macropores, and soils with elevated P levels caused by long term P fertilization regimes. Most research on P leaching from turfgrass systems was conducted on sand-based zones for golf courses and athletic fields (Soldat and Petrovic, 2008). These sand based root zones have high infiltration rates and typically very low P sorption capacities (Soldat and Petrovic, 2008) and, therefore, may be comparable to some of Florida sandy soils. Results from numerous field studies showed that annual P leaching losses of fertilized sands ranged from 0.03 to 6.1 $kg \cdot ha^{-1}$, with P concentrations in leachate observed at concentrations exceeding 13 $mg \cdot L^{-1}$ (Soldat and Petrovic, 2008). However, the golf courses and athletic fields in these studies received mainly soluble fertilizers inputs, were provided frequent irrigation, and included subsurface drainage systems, all of which may have promoted P leaching.

Most studies evaluating P leaching from fine-textured soils found lower P leaching losses (ranging from 0.2 to 0.7 $kg \cdot ha^{-1}$) than studies conducted on sandy soils (Soldat and Petrovic, 2008). However, Soldat and Petrovic (2008) noted that some studies conducted on fine-textured soils still had relatively high P losses, ranging from 0.2 to 5.4 $kg \cdot ha^{-1}$. Easton and Petrovic (2004) observed annual P leaching losses of 1.3 $kg \cdot ha^{-1}$ for unfertilized turfgrass grown on a sandy loam soils. This was slightly lower than findings by Linde and Watschke (1997) who observed P leaching losses of 1.7 to 2.2 $kg \cdot ha^{-1}$. However, many researchers did not report or consider soil P concentrations as a factor that could influence P leaching. Thus, research evaluating how P sources other than fertilizer (i.e., soil P and soil chemical properties) affect P leaching from turfgrass areas is needed. Soil properties can greatly influence nutrient fate and bioavailability and should be considered for all turfgrass management strategies.

Phosphorus Fertilizer and Soil Effects on Turfgrass Quality

Most research investigating the effect of soil physical properties on turfgrass establishment has focused on golf course management. McCoy (1998) investigated the effects of organic and sand amendments on the soil physical properties that were related to turf establishment for golf course putting greens. The results showed that increasing the OM content of the soil led to an increase in the soil water holding capacity, a decrease in soil bulk density, and improved soil cation exchange capacity (McCoy, 1998). Ntoulas et al. (2004) concluded that higher quality turf was observed in sandy soils treated with compost amendments. Improved turf quality, was mainly attributed to an increase in soil water and nutrient holding capacity. Results of the studies conducted by McCoy (1998) and Ntoulas et al. (2004) suggested that soils with higher levels of OM were effective at producing quality turf than soils with low OM levels. Brar and Palazzo (1995) investigated the effects of different soil textures on turfgrass root development. The authors concluded that roots grew significantly deeper in sandy textured soils than in sandy loam textured soils because of the coarser grain size and wider pore spaces in sandy soil, which presented less resistance to root elongation. However, greater root mass was observed in the sandy loam soil, which was attributed to the smaller pores that can better retain water and nutrients than larger pores that dominate the sandy soils.

Research relating turfgrass quality to soil nutrient content has mainly focused on fertilizer studies that determined the relationship between turfgrass quality and various fertilizer application rates (Christians et al., 1979; Colclough and Canaway, 1989; Fry et al., 1989; Liu et al., 2008; Lodge et al., 1990). Phosphorus fertilizer additions have been shown to help stimulate turfgrass root formation and early season growth in the young tissues near turfgrass root tips (Landschoot, 2003). An early symptom of P deficiency in turfgrass is the appearance of a dark-green coloration in older leave blades. As the deficiency worsens, the turfgrass develops a purplish to reddish coloration that can eventually lead to leaf tip necrosis and poor seed development (Heydari and Balestra, 2008). Another visual sign of P deficiency in turfgrass is wilting, which may be confused with water stress (Heydari and Balestra, 2008). Christians et al. (1979) found no significant clipping, root development, or quality response of *Agrostis palustris* (creeping bentgrass) to applied P in a sand media. However, Fry et al. (1989) reported a significant turf quality response to adding P fertilizer, but only for the first fertilizer rate increment from 0 to 5 $kg \cdot ha^{-1}$ P per month; no further quality response was reported with higher fertilizer rates.

Some researchers considered the effects of initial soil nutrient levels on turfgrass quality responses to different fertilizer regimes. For example, Liu et al. (2008) determined the P requirements of STA grown in sandy soils by inducing P deficiency in the turf and then applying different P fertilizer rates to determine the critical minimum P tissue level and critical minimum soil P concentration. The authors noted when STA was grown in soils with “very low” soil M1 P concentrations ($<10\ mg \cdot kg^{-1}$) and received no P fertilizer applications, that P deficiency in STA was not induced until almost one year after planting. Once P deficiency was induced, STA recovered from P deficiency status after 4 weeks of P fertilizer applications; the higher the P application rates the faster the recovery time. Turf quality ratings remained above acceptable levels (6.0 out of 9.0) for all fertilizer rate treatments, including the control (no P added), for the first 10 to 12 weeks of the study after P deficiency was induced, which suggested that quality STA could be sustained for months on soils with very low soil P concentrations (Liu et al., 2008). Liu et al. (2006) reported a critical tissue P concentration of 1.6 $g \cdot kg^{-1}$ (on a dry weight basis) for STA grown in a hydroponic study. In a follow up study, Liu et al. (2008) reported a slightly higher critical tissue P concentration of 1.9 $g \cdot kg^{-1}$ (on a dry weight basis) for STA grown on sandy soils. Liu et al. (2008) recommended no P fertilization if soil M1 P concentration was above 10 $mg \cdot kg^{-1}$ or tissue P level exceeded 1.8 $g \cdot kg^{-1}$ (on a dry weight basis). Liu et al. (2009) reported that optimal growth of STA can be obtained at "very low" soil test P levels and saw little growth response differences to increased P fertilization rates once critical tissue P levels were obtained.

Current Situation and Research Objectives

Soils in urban settings can display a wide variety of chemical and physical properties due to the mixing of soil layers during construction activities (Scharenbroch et al., 2005). Urban soils tend to have higher bulk densities, lower OM contents, lower microbial activities, and usually higher P concentrations then typical topsoils (Scharenbroch et al., 2005). Urban soils often build up very high levels of soil test P as a result of years of fertilization (Scharenbroch et al., 2005). As a result of repeated P applications and natural soil conditions, a standard soil P test (M3 or M1) may reveal P concentrations that would not allow a Florida homeowner to apply more than 1.07 $g \cdot m^{-2}$ P based on provisions in the urban turf rule (Trenholm, 2010). Bans on P fertilizer applications may further prevent the establishment of healthy turfgrass and reduce assimilation of other essential nutrients, mainly N, by turfgrass. Unhealthy turfgrass does not effectively use water and fertilizer due to inadequate root system development (Beard and Green, 1994). Since turfgrass is the dominant component of the pervious areas in urban landscapes (Milesi et al., 2005), and often times is highly managed with fertilizer and water inputs, it is important to understand the fate and cycling of nutrients in turfgrass systems. By understanding the possible fate of added P, homeowners may be able to apply appropriate amounts of P for turfgrass usage and help limit P losses (i.e., leaching and runoff) to the surrounding environments.

Since Bh horizons have unique properties that can bind P, large areas with Bh derived fill used as topsoil may limit healthy turfgrass establishment. Some studies have shown that bahiagrass and some deep rooted trees were able to remove and effectively uptake some P that is bound up in Bh horizons (Chakraborty et al., 2011b; Ibrikci et al., 1999; Obour et al., 2011). However, past research has not focused on the effects of using Bh horizons as a topsoil fill. Therefore, additional research is needed to determine if applying Bh horizons as a topsoil fills will affect the establishment and nutrient content of STA and affect the leaching of P from urban systems.

The objectives of this study were to 1) determine the response and quality of STA grown on Bh horizon fill materials, and 2) to quantify leaching of P from Bh and non-Bh fill soils.

CHAPTER 2
EFFECT OF SPODIC FILL MATERIALS ON THE GROWTH AND ESTABLISHMENT OF ST. AUGUSTINEGRASS

Introduction

Stenotaphrum secundatum Walt. Kuntze (st. augustinegrass) is the most popular turfgrass choice in Florida, covering roughly 800,000 ha of lawns in urban areas throughout the state (Liu et al., 2008; Trenholm et al., 2011). St. augustinegrass (STA) has moderate shade tolerance, low drought tolerance, and is best established in soils with a pH range of 4.8 to 7.5 (Sartain, 2012; Trenholm et al., 2006; U.S. Department of Agriculture, 2010). St. augustinegrass is a coarse-textured stoloniferous grass that roots at the nodes. Since STA and other turfgrasses represent the largest portion of pervious areas in urban landscapes (Milesi et al., 2005), and are often highly managed by applying fertilizer and water, it is important to understand the bioavailability and fate of nutrients added to the soil. Soil quality in urban areas often presents challenges when establishing turfgrass (McCoy, 1998). Native topsoil is usually altered or removed completely by heavy construction equipment during land preparation for residential development (Lehmann and Stahr, 2007). Soil fill material is often brought in during construction activities to generate a level foundation that can support a structure. These fill materials have varying physical and chemical properties that affect nutrient bioavailability and may prevent the establishment of a fully functioning, healthy turfgrass system (Pouyat et al., 2007; Scharenbroch et al., 2005; Short et al., 1986). Unhealthy turfgrass with an inadequate root system does not effectively use water and fertilizer and could ultimately result in large quantities of nutrients be lost to the surrounding environment (Beard and Green, 1994).

Many studies have linked the degradation of surface water quality (e.g. harmful algal blooms, eutrophication, and dead zones) to the discharge of nutrients mainly nitrogen (N) and phosphorus (P)] from point and non-point sources (Anderson et al., 2002; Riegman, 1995; Sharpley et al., 2003; Smith, 1983). In an effort to reduce the occurrence of algal bloom outbreaks and to help slow down the eutrophication of surface waters, Florida adopted an urban turf fertilizer rule in 2008. The urban turf fertilizer rule limits P fertilizer applications to turfgrass in urban areas (Trenholm, 2010). For example, the urban turf fertilizer rule restricts single applications of P to 0.54 $g \cdot m^{-2}$ per application and annual applications of P to 1.07 $g \cdot m^{-2}$ (Trenholm, 2010). Phosphorus fertilizer applications exceeding the annual application limit are only permitted if a soil test indicates the need for P. However, standard soil tests [i.e., Mehlich 1 (M1) and Mehlich 3 (M3)] do not account for a soils capacity to retain P and may overestimate the pool of available P for plant uptake.

The degree of P saturation (DPS) and the P saturation ratio (PSR) are measurements that account for the P retention capacity of a soil by quantifying the relationship between soil P and P retaining soil minerals [mainly aluminum (Al) and iron (Fe)] (Maguire and Sims, 2002; Nair et al., 2004). Soil tests that determine P saturation can more accurately assess soil P status and provide insight about the need for additional fertilizer to achieve adequate plant growth.

Phosphorus is a critical macronutrient for turfgrasses and has been shown to help stimulate root formation and early season growth in the young tissue near root tips (Landschoot, 2003). However, Liu et al. (2008) suggested that no P fertilization would be recommended for STA when soil M1 P concentration exceeded 10 $mg \cdot kg^{-1}$ or tissue

P level exceeded 1.8 $g \cdot kg^{-1}$ on a dry weight basis. Besides soil P status, other soil properties can greatly affect the quality and establishment of turfgrass (McCoy, 1998; Rowland et al., 2009; Sartain, 2012; Soldat et al., 2007).

Brar and Palazzo (1995) showed that mass of *Festuca arundmacea* Schreb. (tall fescues) and *Festuca ovina* Koch. (hard fescues) were significantly affected by soil texture. Brar and Palazzo (1995) observed greater root mass when tall and hard fescues was grown in the sandy loam soil because the smaller pores retained water and nutrients longer than the large pores in the sandy soils. Rowland et al. (2009) concluded that the high fertilizer and water inputs required to establish *Cynodon dactylon* (bermudagrass) on coarse textured soils was due to the soils low organic matter (OM) content. Carrow (1989) reported that there are many soil physical, chemical, and biological properties that limit root growth in turfgrass, including soil layers, soil texture, soil temperature, water deficiency, acidic soils with high Al content, soil nutrient deficiencies or excesses, soils with high salt levels, and root feeding insects. Carrow (1989) also determined that growth of new roots was dependent on carbohydrate production from turf shoots above ground, so any factors that limit shoot density or carbohydrate production will also affect root growth. Sartain (2012) reported that soil pH is a very important factor in influencing turfgrass quality because soil pH influences nutrient availability and toxicity.

Since Spodosols represent a dominant soil order in Florida (Stone et al., 1993) and exhibit morphological characteristics (mainly the dark brown color) that are similar to native topsoil, spodic (Bh) derived soils are sometimes used as topsoil fill material during residential construction. The frequency and land coverage of Bh fill materials in urban areas is currently unknown. The low pH values and high concentrations of organically complexed metals (Al and Fe) common to most Bh horizons (Villapando and Graetz, 2001) may severely limit P availability to turfgrass grown on Bh soils. Phosphorus exists in many different chemical forms and species (i.e., H_3PO_4 ,$H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) in the soil-solution environment (Brady and Weil, 2002). The presence of these P species can be directly related to soil pH, which in turn, has a direct effect on the amount of plant available P. In acid soils (pH < 5.5), P ions react with Fe and Al oxides to form surface complexes or react with dissolved Fe^{3+} and Al^{3+} ions to form insoluble hydroxyl phosphate precipitates (Brady and Weil, 2002).

Phosphorus limitations may be further accelerated due to the fertilizer laws that strictly govern the amount of P fertilizer allow to be applied to turfgrass in urban settings. However, past research showed that *Paspalum notatum* (bahiagrass) and some deep-rooted trees were able to remove and effectively take up a portion of soil P complexed within Bh horizons (Chakraborty et al., 2011b; Ibrikci et al., 1994; Ibrikci et al., 1999; Obour et al., 2011). The relatively higher OM content and elevated clay content found in Bh horizons when compared to other sandy soils (Obreza and Collins, 2008) may result in more water and nutrient retention for turfgrass establishment. However, the high Al content found in Bh horizons may limit root growth and effect turfgrass establishment (Carrow, 1989). The effects of using Bh horizon materials as soil fill on the establishment and quality of STA has not been evaluated. Therefore, the objective of this study was to determine the growth response and quality of STA planted on Bh and non-Bh derived fill materials.

Materials and Methods

Site Locations and Soil Sampling

Five subsoils were obtained from two different geographical locations in Florida. Two soil samples were collected from an active borrow pit located 20 km southeast of Jacksonville, FL. Soils were removed from the ground by backhoe operations prior to our sampling. One soil was collected from the Bw horizon of a Paola sand (Hyperthermic, uncoated Spodic Quartzipsamments) (Soil Survey Staff, 2010). The second soil was collected from a Bh horizon of a Pomello fine sand (Sandy, siliceous, hyperthermic Oxyaquic Alorthod) (Soil Survey Staff, 2010) . Soil was also collected from a new residential housing development located east of Fruit Cove, FL. Various soil horizons were exposed in a circular trench that was excavated prior to sampling. The exposed Bh and E horizons of a St. Johns sand (Sandy, siliceous, hyperthermic Typic Alaquods) (Soil Survey Staff, 2010) were collected. An additional soil sample was collected near Labelle, FL at a private cattle farm dominated by pine flatwoods vegetation. A small circular soil pit was hand dug using a shovel. Soil was excavated from the Bh1 horizon of a Myakka sand (Sandy, siliceous, hyperthermic Aeric Alaquods) (Soil Survey Staff, 2010).

Experimental Design

Forty soil columns were constructed by cutting polyvinyl chloride (PVC) pipe (15.2-cm internal diameter) into 30.5-cm long sections. Forty 15.2-cm diameter endcaps were filled with three pieces of cheesecloth that had been cut into 15.2-cm circular pieces and caulked to the bottom of each endcap. A mixture of deionized water washed sand (186 g) and pea gravel (614 g) was added to each endcap to allow for free drainage of water and to help prevent soil loss from the column. Endcaps were then attached to the bottom of each PVC column and water resistant caulk was applied to the outside and inside lips of the endcap to prevent water leakage. A 1.3-cm hole was drilled into the center of each endcap to allow for water drainage. The experiments were conducted inside a sawtooth production house at the University of Florida Institute of Food and Agricultural Sciences (UF–IFAS) Gulf Coast Research and Education Center in Wimauma, FL.

Each air-dried soil was packed into eight PVC columns; four columns were used for a 9-week turfgrass establishment study (11 May to 11 July 2011) and four columns for a 27-week turfgrass establishment study (11 May to 10 Nov. 2011). Soils were packed into the columns in 1000 g increments by alternating packing with ten taps of a hand-made tool (steel rod welded to a 10.2-cm diameter steel circle). The packing tool was moved in a circular pattern in between each tap to ensure the entire column was evenly packed. Packing was performed until the soil level was within a 1.3-cm of the top of the column to allow room for placement of sod. Circular sections of 'Floratam' STA (Council Growers, Inc., Ruskin, FL) were cut from sod pallets using a 15.2-cm cup cutter. Soil was gently washed off of the turfgrass roots using a low pressurized hose prior to the installation of sod in the columns. Sod was installed by placing the 15.2-cm turf cutouts onto the packed soil columns. Excess turfgrass extending over the edge of the 15.2-cm radius of PVC column was trimmed evenly with the side walls of the column using pruning shears.

Irrigation and Fertilizer Application

Columns were irrigated with potable well water that contained no measurable molybdate reactive P (< 0.09 $mg \cdot L^{-1}$) (Pierzynski et al., 2009), using a drip irrigation system that was regulated to 206.8 kPa and connected to a sand filtration system. Each turf column was outfitted with two drip emitter stakes (Arrow Dripper; MMXI NetaFim Irrigation, Inc., Fresno, CA) that were placed in the middle of the column; each emitter applied 0.95 $L \cdot hr^{-1}$ of water. Irrigation events were scheduled using an automated timer to ensure that the turf received adequate water for optimal growth. The amount of water applied to each column was determined by following UF–IFAS irrigation recommendations for STA in southern Florida (Trenholm et al., 2011; Trenholm et al., 2006). The irrigation schedule for the first 40 days after planting (DAP) is presented in Table 2-1. At 21 DAP, the two drip emitter stakes were removed from each column and replaced with a single, adjustable-spray emitter (Shrubbler® 360°; Antelco Corp., Longwood, FL) due to concerns of uneven wetting of the soil columns. The spray emitters were adjusted individually until an application rate of 20.8 ± 2.84 $L \cdot hr^{-1}$ of water was achieved for all emitters. From 40 DAP until 82 DAP, the turf received 0.97 cm of water twice a week (Monday and Thursday of each week at 0800HR for a 30 sec run time). From 85 DAP until the end of the experiment, the turfgrass received 1.02 cm of water twice a week (Monday and Thursday of each week at 0800HR for a 32 sec run time). The amount of water was increased from 0.97 to 1.02 cm of water because turfgrass showed signs of water stress due to increasing air temperatures in summer.

Soil columns were fertilized with a water-soluble 36N-0P-5K fertilizer mix (Miracle-Gro® Water Soluble Lawn Food; The Scotts Company, LLC, Marysville, OH) that was specifically formulated for lawns. Columns were fertilized at a nitrogen (N) rate of 2.4 $g \cdot m^{-2}$ following UF-IFAS recommendations for STA (Trenholm et al., 2011). During the first fertilizer application (applied 30 DAP), 0.059 $g \cdot m^{-2}$ P was applied as a starter application by dissolving 0.168 g NaH_2PO_4 into the water-soluble fertilizer solution.

During subsequent fertilizer applications (approximately every 30 d), no P fertilizer was applied. Fertilizer was applied to the columns by hand using pre-measured aliquots (half the volume of irrigation applied) the fertilizer solution. After the fertilizer was applied, the columns were irrigated with the remaining volume of water to help move the fertilizer into the soil and prevent foliar burn on the turfgrass blades.

Pesticide Applications

On 20 July 2011 (71 DAP), Attain® Greenhouse (Prescription Treatment® brand insecticide, St. Louis, MO) was sprayed onto the turfgrass columns at a low rate (0.26 $mL \cdot L^{-1}$ water) to help combat the outbreak of chinch bugs. Attain® was re-applied at a higher rate (1.9 $mL \cdot L^{-1}$ water) on 25 July 2011 (75 DAP) to ensure that any newly hatched chinch bugs were also treated. Attain® Greenhouse and Marathon® (Olympic horticultural products™, Mainland, PA) pesticides were both applied to turfgrass columns on 4 Aug. 2011 (85 DAP) to ensure that any remaining chinch bugs were killed. Marathon® is a granular slow release pesticide and was applied by scooping half of teaspoon of pesticide into each column, afterwards the Attain pesticide was applied to the columns by drenching the columns with predetermined aliquots at an application rate of 6.4 $L \cdot L^{-1}$ water. On 26 Aug. (106 DAP), Avid® (KORUSA pest control, INC., Duluth, GA) pesticide was sprayed at a rate of 0.32$mL \cdot L^{-1}$ water to help combat an outbreak of spider mites in turfgrass columns. The pesticide (Avid®; KORUSA pest control, Inc., Duluth, GA) was reapplied at the same rate on 1 Sept. 2011 (113 DAP) to treat any newly hatch spider mites. On 25 Oct. 2011 (167 DAP), 500 mL of a new pesticide (Judo™, Olympic horticultural products™, Mainland, PA) was sprayed onto the turfgrass columns at a application rate of 264 $mL \cdot L^{-1}$ water to kill any remaining spider mites that were resistant to the Avid® pesticide treatments.

Characterization of Soil Properties

The different soil horizon samples that were collected were air-dried at 25 ± 2°C for 10 d and sieved to pass a 2-mm screen. Initial soil bulk density of soil treatments in PVC columns were calculated by dividing the oven dried mass of soil packed into columns by the PVC columns area. Soil texture was determined using the hydrometer method (Bouyoucos, 1962). Soil pH (1:2 soil to deionized water ratio) and OM (loss on ignition) were determined by standard methods of the UF-IFAS Analytical Research Laboratory (ARL) in Gainesville, FL (Mylavarapu, 2009). Soil samples were extracted using the Mehlich 3 (M3) method (1:7 ratio of soil to 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA)(Baker et al., 2002).

Mehlich 3 extracts were analyzed for P, Calcium (Ca), Al, Fe, and Potassium (K) using inductively coupled plasma-atomic emission spectroscopy (ICP-AES) at the ARL. Water soluble phosphorus (WSP) was extracted by following method of Self-Davis et al. (2009). Soluble P in filtrate was determined on a spectrophotometer (Genesys 20; Thermo Fisher Scientific, Madison, WI) at 882 nm following the Murphy and Riley (1962) procedure. The M3 PSR (PSR_{M3}) values for the soils were calculated using the following equation:

$$PSR_{M3} = P_{M3} / (Al_{M3} + Fe_{M3}),$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentration of M3 P, Al, and Fe expressed in mmol kg^{-1} (Maguire and Sims, 2002). Degree of P saturation was calculated using the following equation:

$$DPS_{M3} = [(P_{M3}) / \alpha\ (Al_{M3} + Fe_{M3})] \times 100,$$

where P_{M3}, Al_{M3}, and Fe_{M3} the concentration of M3 P, Al, and Fe are expressed in mmol kg^{-1} and α (0.55) is an empirical factor that compares different soils with respect to P saturation (Nair and Graetz, 2002). Soil electrical conductivity (EC) and volumetric water content were obtained weekly using the Stevens® POGO portable soil sensor (Stevens Water Monitoring Systems, Inc., Portland, OR) with an EC detection limit 0.01 $S \cdot m^{-1}$.

At the end of 9 and 27 weeks after planting (WAP), the soil from each column was removed and air-dried at 25 ± 2°C for 10 d and sieved to pass a 2-mm screen. All soil samples collected at 9 and 27 WAP were analyzed for the same parameters as outline for pre-experiment parameters expect for M3 nutrients. Soil samples collected at harvest were extracted using a different M3 method (1:10 ratio of soil to 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA) (Mehlich, 1984; Sims, 2009b).

Turfgrass Quality and Chlorophyll Content (SPAD)

Turfgrass quality in each column was determined weekly using the National Turfgrass Evaluation Program (NTEP) numerical rating system. The NTEP rating system uses a scale from 1 to 9, where 1 indicates dead, brown turfgrass; 6 indicates minimally acceptable turfgrass; and 9 indicates the highest quality turfgrass (Shearman and Morris, 2011). Turfgrass blade chlorophyll content was estimated weekly, starting at 5 WAP, using a hand held Special Products Analysis Division (SPAD) meter (SPAD-502; Konica Minolta Sensing Americas, Inc., Ramsey, NJ). Tissue SPAD readings were reported as the average of three different turfgrass blades collected from each soil column.

Turfgrass Biomass

Turfgrass height was maintained at 9 cm above the soil surface. Clippings were removed using shears when turfgrass height exceeded 9 cm (approximately every 20 to 40 days). Turfgrass was harvested from 20 columns at 9 WAP and from the remaining

20 columns at 27 WAP, by sliding a knife blade around the edges of the PVC columns and inverting the column to allow the turfgrass and soil to slide out onto a tray. Soil was removed from the roots by gently shaking the turfgrass cutouts; soil was saved for further analysis. The harvested turfgrass was then separated into above-ground (pelt, thatch, and stolons) and below-ground (roots) portions. Roots were removed from the above ground portion of the turfgrass using scissors. Shoot counts were determined for each pelt by counting and recording the number of shoots on each pelt. Turfgrass roots were placed in a 2-mm sieve and any soil remaining on them was washed off under gently flowing water. The wet roots were then wrapped in a paper towel.

Tissue Nutrient Content

After collection, clippings, shoots, pelts, and roots were dried at 41 ± 2°C, weighed, and ground using a Wiley mill (Arthur H. Tomas Co., Swedesboro, NJ). Turfgrass clippings were combined to generate a single composite sample for each soil type from 0 to 9 WAP and 10 to 27 WAP. One-gram subsamples of plant tissues (root, pelt, and clippings) were then weighed into ceramic crucibles and ashed in a muffle furnace for 6 h at 500°C. Phosphorus and K were determined by dissolving the ash in 6 M HCl (Mylavarapu, 2009) and analyzed by ICP–AES at the ARL in Gainesville, FL. Tissue N was determined by following standard methods for total Kjeldahl N (TKN) plant tissue digestion (Mylavarapu, 2009) and analyzed on a flow-segmented analyzer (Astoria 2 Analyzer; Astoria Pacific International, Clackamus, OR) at the ARL in Gainesville, FL. Total nutrient content of STA pelts, roots, and clippings were calculated by multiplying nutrient concentration by dry biomass weight.

Data Analysis

The experiment was designed as a completely randomized design with soil as the only factor with five treatments. Each soil treatment was randomly assigned to the columns, with four replications for each treatment for the 9-week establishment period, and four replications for the 27-week establishment period. Soil samples with concentrations of P_{M3} and Fe_{M3} below the detection limit were assigned a value of half the detection limit. Soil treatment effects on soil properties, turfgrass biomass, and turfgrass tissue nutrients were analyzed using the PROC MIXED procedure in SAS 9.3 with soil treatment as a fixed effect and replication as a random effect (SAS Institute, 2012). Normality was checked by examining histogram and normality plots of the conditional residuals. Soil P_{M3} and Fe_{M3}, PSR_{M3}, DPS_{M3}, soil OM, and root mass were log transformed prior to statistical analysis for 9-week harvest data. Soil P_{M3} and Al_{M3}, PSR_{M3}, DPS_{M3}, soil OM, root mass, root K, and root TKN; pelt P, pelt K, and pelt TKN; were log transformed prior to statistical analysis for 27-week harvest data. Weekly turfgrass visual ratings were analyzed by week for columns harvested at 27 WAP due to an overall significant soil treatment × week interaction. Weekly SPAD readings were analyzed by week for columns harvested at 9 WAP due to an overall significant soil treatment × week interaction. All remaining parameters were analyzed using a repeated measures model with a heterogeneous variance in the covariance structure of R. Relationships between soil and turfgrass parameters were determined using a Pearson correlation analyzed by the PROC CORR procedure in SAS 9.3 (SAS Institute, 2012). All comparisons were completed using the Tukey's honestly significant difference (HSD) with a significant level of $\alpha = 0.05$. Statistical analysis was not able to be performed on turf clipping nutrient content (P, K, and TKN) due to a lack of replications of composite samples.

Results

Soil Characterization

The initial bulk density of the Paola-Bw and St. Johns-E soils were significantly higher than the other three soils. The bulk density of the Myakka-Bh1 and St. Johns-B soil were significantly lower than the other three soils (Table 2-2). All five soils had a soil texture of sand (data not shown). The pH of the initial soil samples ranged from 4.1 to 5.8 (Table 2-3). The three Bh horizon soils (Pomello, St. Johns, and Myakka) had pH values less than 4.3 while the St. Johns-E and Paola-Bw soils had pH values greater than 5.0 (Table 2-3). The three Bh soils (Myakka, Pomello, St. Johns) had significantly lower pH values than the St. Johns-E and Paola-Bw soils at the 9- and 27-week harvest; in addition the Myakka-Bh1 soil had significantly lower pH values than the other two Bh soils (Pomello and St. Johns) at the 9-week harvest (Table 2-3). The OM concentrations of the initial soils ranged from 1.6 to 67.5 $g{\cdot}kg^{-1}$ (Table 2-3). The soil OM content of the Myakka-Bh1 and Pomello-Bh soils were not statistically different, but soil OM was significantly higher than the St. Johns Bh, Paola-Bw, and St. Johns-E soil at the 9-week harvest date (Table 2-3). Similar trends in OM concentrations were determined for soils collected at the 27-week harvest date (Table 2-3). The initial M3 Ca (Ca_{M3}) concentrations of the soil were all below 29.3 $mg{\cdot}kg^{-1}$ expect for the Myakka-Bh1 soil which had a Ca_{M3} concentration of 333 $mg{\cdot}kg^{-1}$ (Table 2-3). The Myakka-Bh1 soil had significantly higher Ca_{M3} concentration then the other four soils at the 9- and 27-week harvest date (Table 2-3). The Paola-Bw soil had the highest initial Fe_{M3} concentration of all soils, while the Pomello-Bh and St. Johns-E soils had initial Fe_{M3}

concentrations below the detection limit (<5.0 mg·kg^{-1}) (Table 2-3). The Paola-Bw had significantly higher Fe_{M3} concentrations than the other four soils at the 9- and 27-week harvest dates (Table 2-3). Initial soil P_{M3} concentrations ranged from <12.5 to 193 mg·kg^{-1}, with the Pomello-Bh and Paola-Bw soils containing the highest P_{M3} concentrations of the soils while, the Myakka-Bh1, St. Johns-E, and St. Johns-Bh soils had P_{M3} concentrations below the detection limit (12.5 mg kg^{-1}) (Table 2-3). Similar trends were determined in P_{M3} concentrations of soils collected at the 9- and 27-week harvest (Table 2-3). Soil test interpretations are not available for P_{M3} concentrations, but they are available for M1 P (P_{M1}). Mylavarapu et al. (2002) provided the following equation to covert P_{M1} to P_{M3} values for comparison:

$$P_{M3}= 1.43 (P_{M1}) +18.6$$

Based on P_{M1} soil test interpretations provided by Kidder et al. (2003) and Sartain (2012), and using the M1 to M3 conversion equation provided by Mylavarapu et al. (2002), both the Pomello-Bh and Paola-Bw would have “very high” soil P concentrations (P_{M3} > 105 mg·kg^{-1}) while the remaining three soils (Myakk-Bh1, St. Johns-Bh, and St. Johns-E soil) would have “very low” soil P concentrations (P_{M3} < 33 mg·kg^{-1}). All soils had M3 K (K_{M3}) concentrations (data not shown) below the detection limit (12.5 mg kg^{-1}) and would be “very low” soil K concentrations (K_{M3} < 33 mg·kg^{-1}) (Kidder et al., 2003). The three Bh soils (Myakka, Pomello, and St. Johns) had the significantly higher Al_{M3} concentrations than the Paola-Bw and St. Johns-E soils (Table 2-3), with the Pomello-Bh soil having the highest Al_{M3} concentrations at the 9- and 27-week harvest (Table 2-3).

Initially the Pomello-Bh soil had the highest WSP concentrations of all the soils, while both St. John soils had no detectable WSP (Table 2-3). The Pomello-Bh soil had significantly higher WSP concentrations then the other four soils at both the 9- and 27-week harvest dates (Table 2-3). Initially, both the Pomello-Bh and Paola-Bw soils had PSR values over 0.1, while the remaining soils had PSR values all below 0.031 (Table 2-3). The Paola-Bw soil had significantly higher PSR_{M3} values then the other four soils at 9- and 27-week harvest (Table 2-3). Similar trends between PSR and DPS values were calculated for soils at the beginning and 9- and 27-week harvest dates (Table 2-3). When all soils where analyzed together there was no statistically difference in PSR, DPS, WSP, and P_{M3} values from the 9- to 27-week study. However, when soil parameters were analyzed by soil treatment some significant differences were determined. The Paola-Bw soil had significant decrease between soil WSP and P_{M3} concentrations from 9 to 27 WAP, which was accompanied by a significant increase in PSR_{M3} and DPS_{M3} values from 9 to 27 WAP. The St. Johns-Bh had significant increase in PSR_{M3}, $DPS_{M3,}$ and P_{M3} from 9 to 27 WAP. The Myakka-Bh1 soil had a significant decrease in WSP concentrations from 9 to 27 WAP. All other soils had no statistical differences in PSR_{M3}, DPS_{M3}, and P_{M3} values from 9 to 27 WAP.

Splitting the soils into non-Bh and Bh soil types greatly increased their *r* values for correlations between soil WSP concentrations and other soil parameters at 9 and 27 WAP. Soil WSP was highly correlated to P_{M3} (r = 0.95, P = 0.0003), PSR_{M3} (r = 0.98, P < 0.0001), and DPS_{M3} (r = 0.98, P < 0.0001) for the two non-Bh soils (Paola-Bw and St. Johns-E) harvested at 9 WAP. For the three Bh soils harvested at 9 WAP, soil WSP was highly correlated to P_{M3} (r = 0.94, P< 0.0001), PSR_{M3} (r = 0.94, P< 0.0001), and

DPS_{M3} (r =0.94, $P < 0.0001$). Soil WSP concentrations of non-Bh soils harvested at 27 WAP were highly correlated to the following soil parameters: P_{M3} ($r = 0.89$, $P = 0.003$), PSR_{M3} ($r = 0.88$, $P = 0.004$), and DPS_{M3} ($r = 0.88$, $P = 0.004$). Soil WSP concentrations of Bh soils harvested at 27 WAP were highly correlated to P_{M3} ($r = 0.98$, $P < 0.0001$), PSR_{M3} ($r = 0.98$, $P < 0.0001$), and DPS_{M3} ($r = 0.98$, $P < 0.0001$).

The mean of weekly soil EC values for the entire 9- and 27-week harvest periods were below the detection limit (<0.01 S/m) (data not shown). Therefore, salt build up related to fertilizer and irrigation applications to the turf was not evident. There was not a significant soil treatment × sampling date interaction determined for soil volumetric water content for the 9- or 27-week establishment periods. However, soil treatment (Figure 2-1) and measurement date (data not shown) effects were determined for soil volumetric water content ($P \leq 0.05$.). The soil volumetric water content of the St. Johns-Bh soil was not statistically different than the Myakka-Bh1 and Pomello-Bh soil but was significantly higher than the Paola-Bw and St. Johns-E soils during the 9-week establishment period (Figure 2-1). No statistical difference was determined between the soil volumetric content of the St. Johns-Bh and Myakka-Bh1 soils; however, the St. Johns-Bh soil had significantly higher soil volumetric content than Pomello-Bh, Paola-Bw, and St. Johns-E soils during the 27-week establishment period (Figure 2-1). In general, the soil volumetric water content of all soil treatments slightly decreased throughout the 27-week study except for the Myakka-Bh1 soil which had a slight increase in soil volumetric water content (Figure 2-1).

Turfgrass Quality Ratings and Chlorophyll Content (SPAD)

No significant soil treatment × sampling date interaction was determined for visual ratings during the 9-week establishment study; therefore, the weekly data was analyzed over the whole sampling date. No significant soil treatment effect was determined for mean visual quality ratings for STA rated during the initial 9-week establishment period ($P > 0.05$, Figure 2-2). There was a significant soil treatment × sampling date interaction noted for visual ratings during the 27-week establishment study; therefore, the data was analyzed separately for each weekly sampling date ($P \leq 0.05$). We reported a significant soil treatment effect on turfgrass quality graded at 11, 12, 15, 17, 25, and 27 WAP (Figure 2-3). In general, visual quality ratings of STA grown on the Myakka-Bh1 were not statistically different than STA grown on Pomello-Bh, St. Johns-Bh and Paola-Bw soils but were significantly higher than quality ratings of STA grown on the St. Johns-E soil. However, mean weekly quality ratings of STA grown on all soil treatments declined to below the minimally acceptable rating of 6.0 by the end of the 27-week study period (Figure 2-3).

A significant soil treatment × sampling date interaction was determined for turfgrass SPAD readings measured during the 9-week establishment study; therefore, the data was analyzed separately for each weekly sampling date. There was a significant soil treatment effect on turfgrass SPAD readings at 5, 8, and 9 WAP ($P \leq 0.05$, Figure 2-4). Although there was a soil treatment × sampling date interaction determined for SPAD readings, no clear trend of a single soil having significantly higher SPAD readings than other soils was determined, as it varied from week to week (Figure 2-4).

No significant soil treatment × sampling date interaction was determined for STA SPAD readings collected during the 27-week establishment period, therefore the mean of all weekly SPAD readings throughout the whole 27-week study were reported (Figure

2-5). However, significant soil treatment (Figure 2-5) and significant sampling date effects (data not shown) were determined for turfgrass mean weekly SPAD readings collected during the 27-week establishment period ($P \leq 0.05$). The SPAD reading of STA grown on the St. Johns-E soil were not statistically different than SPAD readings of STA grown on St. Johns-Bh soil but were significantly higher than SPAD readings of STA grown on the Myakka-Bh1, Pomello-Bh, and Paola-Bw soils during the whole 27-week establishment period ($P \leq 0.05$, Figure 2-5).

Turfgrass Biomass

No significant soil treatment × sampling date interaction was determined for STA clipping biomass during the 9- and 27-week study periods. No significant soil treatment effect was determined for STA clipping biomass collected during the 9-week study ($P >$ 0.05, Table 2-4). However, there was a significant soil treatment effect determined for STA clipping biomass collected during the 27-week establishment period ($P \leq 0.05$, Table 2-4). St. Augustinegrass grown on the Myakka-Bh1, Pomello-Bh, and St. Johns-Bh soils produced clipping biomasses that were not statistically different but were all significantly greater than clipping biomass of STA grown on the St. Johns-E soil during the 27-week establishment period (Table 2-4).

No significant soil treatment effect was determined for pelt dry biomass at the 9- and 27-week harvest (P > 0.05, Table 2-4). A significant soil treatment effect was determined for root dry biomass at the 9- and 27-week harvest ($P \leq 0.05$, Table 2-4). No statistical differences were determined for root biomass of STA grown on St. Johns-Bh, Paola-Bw, and St. Johns-E soil however, STA grown on the St. Johns-Bh soil did produced significantly higher root biomass than STA grown on the Myakka-Bh1 and Pomello-Bh soils during the 9-week establishment period (Table 2-4). St.

Augustinegrass grown on St. Johns-E soil produced significantly lower root biomass then STA grown on the other four soils during the 27-week establishment period (Table 2-4).

No significant soil treatment effect was observed on STA shoot counts collected at the 9-week harvest ($P > 0.05$, Figure 2-6). However, at the 27-week harvest, no statistical differences on shoot counts were determined for STA grown on the Myakka-Bh1, Pomello-Bh, St. Johns-Bh, and Paola-BW soils but STA grown on the Myakka-Bh1 and Paola-Bw soils did produced significant more shoots than STA grown on the St. Johns-E soil (Figure 2-6). Shoot counts were highly correlated ($r = 0.76$, $P = 0.0002$) to root biomass at 27 WAP.

Tissue Nutrient Content

Total TKN content of STA clippings collected from 0 to 9 WAP, ranged from 32.8 mg in clippings collected from the Myakka-Bh1soil to 54.3 mg for clippings collected from the Paola-Bw soil (Table 2-5). The total P content of STA clippings collected during the 9-week establishment study ranged from 4.5 mg for the Myakka-Bh1soil to 9.1 mg for the Pomello-Bh soil (Table 2-5). Total K content of STA clippings collected from 0 to 9 WAP, ranged from 38.7 mg for the Myakka-Bh1 soil to 61.2 for the Paola-Bw soil (Table 2-5). Total TKN content of STA clippings collected from 10 to 27 WAP, ranged from 71.1 mg for the St. Johns-E soil to 106 mg for the St. Johns-Bh soil (Table 2-5). Total P content of STA clippings collected from 10 to 27 WAP, ranged from 4.1 mg in clippings collected from the St. Johns-E soil to 19.7 mg in clippings collected from the Pomello-Bh soil (Table 2-5). Total K content of STA clippings ranged from 71.0 mg from the St. Johns-E soil to 105 mg from the St. Johns-Bh soil for clippings collected from 10 to 27 WAP (Table 2-5).

The P and K concentrations of STA clipping tissues (Table 2-8) were within the sufficiency ranges for N (20 to 30 g·kg^{-1}), P (1.5 to 5 g·kg^{-1}), and K (10 to 30 g·kg^{-1}) reported by Broschat and Elliot (2004), Mills and Jones Benton Jr. (1996), and Sartain (2012), with the exception of clipping P content collected at 27 WAP from STA grown on the St. Johns-E and St. Johns-Bh soils (Table 2-8), which were slightly under this range indicating possible P deficiency. Tissue TKN contents for STA grown on all soil treatments were slightly below the sufficiency range indicating possible N deficiency as well. However, TKN values do not necessarily represent the total N content of the clippings since not all forms of N are converted to the ammonium form during the procedure (Mills and Benton Jones Jr., 1996).

No significant soil treatment effect was determined for pelt tissue total TKN, P, or K contents for pelts harvested at 9 WAP (P > 0.05, Table 2-7). However, there was a significant soil treatment effect on pelt tissue total P content for pelts harvested at 27 WAP; but none for total TKN and K content harvested at 27 WAP (Table 2-7). No statistical differences were determined for pelt tissue total P contents of STA grown on the Myakka-Bh1, Pomello-Bh, and Paola-Bh soils but pelt tissue total P contents of STA gown on the Pomello-Bh soil were significantly higher than STA grown on the St. Johns-Bh and St. Johns-E soils harvested at 27 WAP (Table 2-7).

No significant soil treatment effect was determined for root tissue total P or TKN contents collected at 9 WAP (P > 0.05, Table 2-8). No statistical differences were determined for root tissue total TKN contents of STA grown on the St. Johns-Bh and Paola-Bw soils at the 9-week harvest however root tissue total TKN contents of STA grown on the St. Johns-Bh were significantly higher than root tissue total TKN content of STA grown on the Myakka-Bh1, Pomello-Bh, and St. Johns-E soils (Table 2-8).

There was a significant soil treatment effect determined for root tissue total TKN, P, and K contents collected at 27 WAP (Table 2-8). No statistical difference was determined for root tissue total TKN content of STA grown on the Myakka-Bh1, Pomello-Bh, St. Johns-Bh, and Paola-Bw soils but STA grown on the Myakka-Bh1, St. Johns-Bh, and Paola-Bw had significantly higher root tissue total TKN contents than STA grown on the St. Johns-E soil at 27 WAP (Table 2-8). The root tissue total P contents of STA grown on the Myakka-Bh1, Pomello-Bh, and Paola-Bw soils were not statistically different but the root tissue total P contents of STA grown on the Pomello-Bh and Paola-Bw soils were significantly higher than STA gown on the St. Johns-Bh and St. Johns-E soils at 27 WAP (Table 2-8). The root tissue total K content of STA grown on the Myakka-Bh soil was significantly higher than STA grown on the Pomello-Bh and St. Johns-E soils but not statistically different than the root tissue total K content of STA grown on the St. Johns-Bh and Paola-Bw soils at 27 WAP (Table 2-8).

Clipping total P content was highly correlated to soil P_{M3} (r = 0.91, P = 0.03), PSR_{M3} (r = 0.94, P = 0.02), and DPS_{M3} (r = 0.94, P = 0.02) concentrations for clippings collected during the 9-week study. Soil P_{M3}, PSR_{M3}, and DPS_{M3} values had similar linear relationships (r = 0.63, P = 0.004) to pelt tissue total P contents during the 27-week study while soil WSP was less correlated (r =0.52, P = 0.02) to pelt tissue total P contents. Root tissue total P contents of STA were highly correlated to soil P_{M3} (r = 0.72, P = 0.0005), PSR_{M3} (r = 0.76, P = 0.0002), DPS_{M3} (r = 0.75, P = 0.0002), and WSP (r = 0.65, P = 0.003) values at 27 WAP.

Discussion

The high concentrations of OM and Al_{M3} coupled with low pH values observed in the three Bh horizon soils were expected because Spodosols are characterized by accumulation of organically bound metals (i.e., Al and Fe) (Deconinck, 1980). The high OM concentrations of the three Bh samples indicate that other mass losses may be contributing to the LOI measurements (e.g., dehydroxylation). The large difference in pH values of the non-Bh horizons from the initial to the 9- and 27-week harvest dates may be contributed to the lower buffering capacity of these soils than compared to the Bh horizon soils. There was a wide range in P_{M3} concentrations between the five soil samples. Based on soil P test results, a homeowner would be required to follow P restrictions outlined in the urban fertilizer turf rule and no additional P beyond what is stated for the one time starter fertilizer application would be allowed for the first year on the Pomello-Bh and Paola-Bw soils. The significantly higher PSR_{M3} and DPS_{M3} values of the Pomello-Bh and Paola-Bw soils than of the other three soils suggest that the Pomello-Bh and Paola-Bw soils are more P saturated than the other three soils and could be potential P sources to the turfgrass.

Nair et al. (2004) reported a PSR_{M3} threshold value of 0.08 for sandy surface horizons while Chakraborty et al. (2011a) reported a PSR_{M3} threshold value of 0.09 for Bh horizons in Florida. These threshold values represent a change point value at which WSP concentrations start to rapidly increase with increasing PSR values. PSR_{M3} values above these thresholds may result in added P being lost easily from the soil through leaching (Chakraborty et al., 2011a). If we compare our PSR_{M3} values to these findings, our Pomello-Bh and Paola-Bw soil would be considered higher than the change points and the remaining three soils (Myakka-Bh1, St. Johns-Bh, and St. Johns-E) would be lower than the reported change points.

Usually higher PSR_{M3} and DPS_{M3} values correspond to higher WSP concentrations (Nair et al., 2004) and more WSP could lead to higher plant available P. However, the Paola-Bw, which had the highest DPS_{M3} value of 31.0% had similar WSP (0.89 $mg \cdot kg^{-1}$) concentrations to the Myakka-Bh1 (WSP = 0.84 $mg \cdot kg^{-1}$), which had a lower DPS_{M3} value of 0.87% at 9 WAP. The Myakka-Bh1 and St. Johns-Bh soils had similar WSP concentrations to the Paola-Bw soil despite having significantly lower soil DPS_{M3} values at 27 WAP. The comparable WSP concentrations of the lower DPS_{M3} and PSR_{M3} Myakka-Bh1 and the St. Johns-Bh soils to the higher PSR_{M3} and DPS_{M3} Paola-Bw soil may be attributed to the presence of organically complexed-P released the Bh soils. The dark color of the drainage water collected from the Myakka-Bh1 soil support the hypothesis of this soil WSP consisting of dissolved or colloidal organically complexed P. Dissolved OM is darkly-colored and contains C, N, P, and some metals (Wright and Reddy, 2012). Fox et al. (1990) indicated that dissolved organic P that was released from Bh horizons may be a significant component of plant available P in Florida Bh horizons.

In general, soils with the higher P_{M3} soil values (Paola-Bw and Pomello-Bh soils) produced STA pelt and root tissues with the highest total P contents at the 27-week harvest. However, the Myakka-Bh1 soil with significantly lower P_{M3} had comparable pelt and root tissue total P contents to the significantly higher P_{M3} Pomello-Bh and Paola-Bw soils at the 27-week harvest. McCray et al. (2012) showed M3 to be a better indicator of plant available P than WSP for Saccharum spp. (sugarcane) grown on organic soils in southern Florida. Fageria et al. (1988) reported that soil test P concentration was strongly correlated to P content in roots and shoots of rice, with" low" P soils producing shoot and roots with significantly lower P content then rice grown in "med" or "high" P soils. Liu et al. (2009) reported that both soil WSP and P_{M1} concentrations were closely correlated to tissue P concentrations in STA (P_{M3} was not tested). Our results suggest that both soil WSP and P_{M3} influenced pelt and root tissue total P contents at the 27-week harvest.

The lack of soil treatment effect on pelt and root tissue total P contents harvested at 9 WAP may be attributed to the relatively short establishment period of the turf, with initial P fertilizer inputs providing adequate nutrients over the short term. Differences in pelt tissue and root tissue total P contents determined at 27 WAP were likely due to soil chemical properties effecting P bioavailability since P was only applied during the first fertilizer application at 30 DAP. Liu et al. (2006) reported a P deficiency value, based on visual symptoms, for STA tissue as anything less than 1.0 $g \cdot kg^{-1}$ with a minimum P tissue concentration of 0.45 $g \cdot kg^{-1}$ to keep STA alive. Clipping P contents collected from all soil treatments were above 1.0 $g \cdot kg^{-1}$ for the entire 27 week study and no visual symptoms for P deficiencies were observed for turfgrass grown on any soil. This supports findings by Liu et al. (2008) who noted that with no P application to STA and very low soil P concentrations it took almost one year to induce P deficiency. Liu et al. (2008) findings coupled with our results suggest that STA could be sustained for at least 6 month to a year with very low soil P concentrations.

The lack of soil treatment effect on pelt tissue total TKN and K (at 9 and 27 WAP) and root tissue K contents harvested at 9 WAP, may be attributed to adequate nutrients obtained from fertilizer inputs throughout the whole study period. Any differences in root tissue total TKN at 9 and 27 WAP and root tissue K at 27 WAP were likely attributed to differences in biomass production, since these nutrient parameters were highly correlated with biomass weights.

The lack of soil treatment effect on STA clipping and pelt biomass and shoot counts collected during the first 9 WAP may be attributed to the relatively short establishment period of the turfgrass and the soils natural ability to provide ample nutrients and water over the short term. Differences determined in STA clipping and pelt biomasses at 27 WAP support the idea that the establishment periods may be longer for STA grown on different soil types. At 27 WAP, there were significant differences in pelt TKN and P, but no trends emerged showing a single soil treatment having significantly higher contents of all three nutrients.

Differences in root biomass between soil treatments collected at 9 and 27 WAP may be attributed to the high correlation between root biomass and root tissue total TKN contents. The significantly lower root biomass of STA grown on the St. Johns-E soil at 27 WAP may be the factor controlling the lower shoot count of turfgrass harvested from the St. Johns-E soil. Less roots biomass could result in less nutrient uptake, therefore limiting new shoot growth. Carrow (1989) showed that root growth can be affected by the amount of leaf area per unit of sod, with greater green leaf area producing more carbohydrates for root growth which support the high correlation between root mass and shoot counts reported for our study at 27 WAP.

Differences in SPAD readings can likely be attributed to turfgrass blade TKN concentrations. Higher blade TKN concentrations may have produced higher tissue chlorophyll levels resulting in higher SPAD readings. However, STA nutrient clippings concentrations represented a composite of clippings collected over the whole 9 week study period and from 10 to 27 WAP; therefore, statistical analysis could not be completed. Soil EC values were extremely low for all soil treatments across the entire 27 week study (data not shown). Camberato (2001) observed a upper salt tolerance limit of >1.0 $S \cdot m^{-1}$ for STA, while Miyamoto et al. (2004) reported the salt tolerance of STA range from 0.8 to 1 $S \cdot m^{-1}$ of soil EC. Therefore, salts had no effect on turfgrass growth or quality in our study.

The significantly higher soil moisture content of the St. Johns-Bh soil may be due to the significantly higher OM content when compared with the St. Johns-E and Paola-Bw soils. However, the St. Johns-Bh soil had lower OM content then the Myakka-Bh1 and the Pomello-Bh. The higher moisture content observed in the St. Johns-Bh soil compared to the Pomello-Bh may be attributed to the lower bulk density of the St. Johns-Bh soil. The Myakka-Bh1 had lower bulk density and higher OM content then the St. Johns-Bh soil so differences in the moisture content may be attributed to formation of preferential flow pathways in the Myakka-Bh1 soil or differences in mineral pore sizes between the two soils.

Based on our results, the chemical properties of spodic derived fill materials had little effect on the establishment STA. General trends emerging towards the end of the 27-week establishment study show overall higher quality STA growing in the Myakka-Bh1 and the Paola-Bw soils than compared to the St. Johns-E soil, but no differences in quality for STA grown on the Pomello-Bh and St. Johns-Bh soils. With the small amount of P fertilizer added to the soils during the 9- and 27-week studies, the ability of the fill materials to retain P for the turfgrass uptake was likely an important factor in producing quality turfgrass. The low quality of STA grown on the St. Johns-E soil may be attributed to the relatively inert chemical properties and low OM content of the St. Johns-E soil. The low pH and high concentrations of Al and Fe in the Bh soils did not seem to effect P bioavailability to turfgrass in the short term. In fact, the comparable WSP values of some of the lower P_{M3} Bh horizons to the higher P_{M3} non-Bh horizon supports the idea that Bh horizons may be able to provide plant available P to turfgrass by the release from organically complexed P.

Soil P status alone was not a good predictor of visual turfgrass quality ratings, as other factors may have influenced total quality. However soil P status, particularly P_{M3} and WSP, was a good predictor of turfgrass tissue P contents. In general, the two soils with the higher P_{M3} and WSP values produced turfgrass tissue with the higher clipping P content. Soil DPS_{M3} and PSR_{M3} values were not good indicators of P content in turfgrass tissue as some lower DPS_{M3} value Bh samples were able to produce comparable WSP values which may have led to higher plant available P. Phosphorus deficiency would be expected to develop in turfgrass planted on the St. Johns-Bh and St. Johns-E soils if the study time was extended. However, since these soils tested in the “very low” P soil status, they would be allowed additional P fertilization beyond what is outlined in the urban fertilizer turf rule. The two soils (Pomello-Bh and Paola-Bw) testing in the “very high” P status would be limited by the urban fertilizer turf rule on the amount of P allowed to be added. However, these soils had the highest tissue P contents of all the soil treatments and possible P deficiency would not be likely for some time. Thus, the urban fertilizer turf rule is not expected to limit newly established quality and growth of STA grown on low or high PSR_{M3} or DPS_{M3} Bh or non-Bh soils. However, this study only examined a few soil types that fell into two soil P test categories of "very low" and "very high" soil P. In addition, only 0.059 $g \cdot m^{-2}$ of water soluble P fertilizer was added at the beginning of the study which likely influenced turfgrass P tissue contents.

This study did not document any major effects of spodic derived fill materials on the establishment of STA during the 27-week study period. However, different trends may emerge if the turfgrass was grown for longer periods. The low pH found in most Bh horizons may limit P bioavailability to the turfgrass in post establishment periods and could also affect the bioavailability of other important turfgrass micronutrients not tested for in this study. Future studies need to include a wide range in soil test P status of Bh and non-Bh fill materials and look at effects of soil types on post-establishment periods conducted in field plots. Future studies should also include adequate P inputs based on soil tests recommendations throughout the study period to see if P deficiencies that arise are solely due to soil properties that limit P bioavailability and not to the lack of P fertilizer inputs.

Table 2-1. Irrigation schedule for st. augustinegrass establishment in soil columns in a production house in Wimauma, FL.

Date	DAP[z]	Depth per irrigation event (centimeter)	Number of events	Irrigation event Timing
11 May 2011	0	0.84	1	1600 HR
12-14 May 2011	1-3	0.84	2	1600 HR
15-17 May 2011	4-6	0.84	3	0900 HR/1600 HR
18-24 May 2011	7-13	0.69	3	0800 HR/1200 HR/ 1600 HR
25 May 2011	14	0.00	0	—[y]
26-31 May 2011	15-20	0.69	2	0900 HR/1600 HR
1 June 2011	21	0.69	1	0800 HR
2-8 June 2011	21-28	0.84	1	0800 HR
9 June 2011	29	0.00	0	N/A
10 June 2011	30	0.84	1	0800 HR
11 June 2011	31	0.00	0	N/A
12 June 2011	32	0.84	1	0800 HR
13 June 2011	33	0.00	0	N/A
14 June 2011	34	0.84	1	0800 HR
15 June 2011	35	0.00	0	N/A
16 June 2011	36	ND[x]	1	0800 HR
17-19 June 2011	37-39	0.00	0	N/A
20 June 2011	40	0.97	1	0800 HR

[z]DAP = Days after planting.
[y]— = Value not measured for that event.
[x]ND = Not determined due to a power outage to automatic timing system that resulted in unknown application amount of water.

Table 2-2. Mean initial bulk density of Florida fill materials used in soil columns to evaluate st. augustinegrass growth and quality response to soil properties.

Soil series and horizon	Bulk density ($g \cdot cm^{-3}$)
Myakka-Bh1	1.20 c
Pomello-Bh	1.34 b
St. Johns-Bh	1.24 c
Paola-Bw	1.56 a
St. Johns-E	1.58 a

Table 2-3. Mean selected chemical properties of Florida soil fill materials used in a column study to evaluate st. augustinegrass growth and quality response to soil properties at 0, 9, and 27 weeks after planting.

Harvest date and soil material	pH	Organic matter ($g \cdot kg^{-1}$)	Mehlich 3 Ca ($mg \cdot kg^{-1}$)	Mehlich 3 Fe ($mg \cdot kg^{-1}$)	Mehlich 3 Al ($mg \cdot kg^{-1}$)	Mehlich 3 P ($mg \cdot kg^{-1}$)	Water soluble P ($mg \cdot kg^{-1}$)	PSR[z]	DPS[y] (%)
0 weeks after planting									
Myakka-Bh1	4.1	67.5	333	27.6	988	<12.5	0.45	0.004	0.69
Pomello-Bh	4.3	60.6	14.2	<5.0[x]	1593	193	1.3	0.105	19.12
St. Johns-Bh	4.1	41.6	14.1	37.3	1481	<12.5	0.00	0.006	1.0
Paola-Bw	5.3	3.8	24.2	60.9	643	123	0.03	0.159	28.97
St. Johns-E	5.8	1.6	29.3	<5.0	145	<12.5	0.00	0.026	4.73
9 weeks after planting									
Myakka-Bh1	4.1 c[y]	67.6 a	356 a	36.6 c	1138 c	<12.5 c	0.84 bc[w]	0.004 d	0.87 d
Pomello-Bh	4.5 b	61.2 a	42.4 b	< 5.0 d	2406 a	339 a	2.8 a	0.123 b	22.3 b
St. Johns-Bh	4.5 b	39.1 b	71.0 b	68.6 b	1962 b	<12.5 c	0.13 d	0.003 e	0.50 e
Paola-Bw	6.9 a	3.0 c	51.2 b	148 a	737 d	158 b	0.89 b	0.171 a	31.0 a
St. Johns-E	6.8 a	2.2 d	62.2 b	< 5.0 d	171 e	<12.5 c	0.26 cd	0.031 c	5.7 c
27 weeks after planting									
Myakka-Bh1	4.0 b	66.1 a	330 a	32.7 c	1121 c	<12.5 d	0.24 bc	0.005 e	0.87 e
Pomello-Bh	4.5 b	69.0 a	65.7 b	<5.0 d	2172 a	313 a	2.5 a	0.126 b	22.8 b
St. Johns-Bh	4.4 b	37.8 b	94.1 b	58.8 b	1862 b	18.1 c	0.16 bc	0.009 d	1.5 d
Paola-Bw	6.8 a	3.00 c	89.7 b	73.6 a	591 d	125 b	0.59 b	0.174 a	31.6 a
St. Johns-E	6.6 a	2.30 c	87.1 b	<5.0 d	155 e	<12.5 d	0.14 c	0.036 c	6.4 c

[z]Phosphorus saturation ratio.
[y]Degree of phosphorus saturation.
[x]Less then the detection limit of inductively coupled plasma-atomic emission spectroscopy.
[w]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

Table 2-4. Mean biomass of clippings, pelts, and roots of st. augustinegrass grown on different Florida soil fill materials in a soil column study.

Harvest date and soil material	Clipping biomass (g)	Pelt biomass (g)	Root biomass (g)
9-week harvest			
Myakka-Bh1	0.10 a[z]	47.9 a	2.29 b
Pomello-Bh	0.13 a	46.3 a	2.65 b
St. Johns-Bh	0.15 a	37.1 a	4.92 a
Paola-Bw	0.14 a	41.4 a	3.32 ab
St. Johns-E	0.16 a	44.2 a	2.90 ab
27-week harvest			
Myakka-Bh1	0.25 a	61.0 a	8.58 a
Pomello-Bh	0.26 a	45.8 a	7.72 a
St. Johns-Bh	0.26 a	49.7 a	7.13 a
Paola-Bw	0.26 a	51.0 a	8.50 a
St. Johns-E	0.16 b	46.2 a	3.25 b

[z]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

Table 2-5. Mean total nutrient content of clippings from st. augustinegrass grown on five different Florida soil fill materials collected from 0 to 9 and 10 to 27 weeks after planting.

Collection period and soil material	Total TKN (mg)	Total P (mg)	Total K (mg)
0 to 9 weeks after planting			
Myakka-Bh1	32.8	4.5	38.7
Pomello-Bh	45.6	9.1	51.0
St. Johns-Bh	52.4	5.5	52.9
Paola-Bw	54.3	8.7	61.2
St. Johns-E	44.1	5.3	48.4
10 to 27 weeks after planting			
Myakka-Bh1	92.2	12.2	99.4
Pomello-Bh	95.2	19.7	88.6
St. Johns-Bh	106	6.9	105
Paola-Bw	81.6	16.6	95.4
St. Johns-E	71.1	4.1	71.0

Table 2-6. Mean nutrient concentrations of clippings from st. augustinegrass grown on five different Florida soil fill materials collected from 0 to 9 and 10 to 27 weeks after planting.

Harvest date and soil material	TKN ($g \cdot kg^{-1}$)	P ($g \cdot kg^{-1}$)	K ($g \cdot kg^{-1}$)
9-week harvest			
Myakka-Bh1	12.9	1.78	15.3
Pomello-Bh	13.9	2.79	15.6
St. Johns-Bh	13.8	1.45	13.9
Paola-Bw	15.3	2.45	17.2
St. Johns-E	13.1	1.58	14.4
27-week harvest			
Myakka-Bh1	13.2	1.75	14.2
Pomello-Bh	13.7	2.82	12.7
St. Johns-Bh	15.7	1.03	15.7
Paola-Bw	12.3	2.51	14.4
St. Johns-E	17.8	1.02	17.7

Table 2-7. Mean total nutrient content of pelts from st. augustinegrass grown on five different Florida soil fill materials collected at the 9- and 27-week harvest date.

Establishment period and soil material	Total TKN (mg)	Total P (mg)	Total K (mg)
9-week harvest			
Myakka-Bh1	303 a[z]	43.3 a	243 a
Pomello-Bh	331 a	49.6 a	258 a
St. Johns-Bh	242 a	30.7 a	191 a
Paola-Bw	290 a	43.4 a	199 a
St. Johns-E	287 a	32.5 a	192 a
27-week harvest			
Myakka-Bh1	362 a	51.0 ab	243 a
Pomello-Bh	318 a	58.2 a	223 a
St. Johns-Bh	422 a	38.5 bc	266 a
Paola-Bw	354 a	56.4 ab	253 a
St. Johns-E	387 a	34.3 c	217 a

[z]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

Table 2-8. Mean total nutrient content of roots from st. augustinegrass grown on five different Florida soil fill materials collected at the 9 and 27 weeks after planting.

Establishment period and soil material	Total TKN (mg)	Total P (mg)	Total K (mg)
9 weeks after planting			
Myakka-Bh1	16.5 b[z]	1.4 a	6.9 a
Pomello-Bh	15.7 b	2.4 a	6.3 a
St. Johns-Bh	29.1 a	2.5 a	13.0 a
Paola-Bw	19.8 ab	2.7 a	15.1 a
St. Johns-E	16.3 b	1.8 a	13.5 a
27 weeks after planting			
Myakka-Bh1	41.3 a	3.5 ab	35.1 a
Pomello-Bh	31.4 ab	4.8 a	25.0 bc
St. Johns-Bh	40.9 a	2.7 bc	26.1 abc
Paola-Bw	40.5 a	4.9 a	27.3 ab
St. Johns-E	25.7 b	1.5 c	17.8 c

[z]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

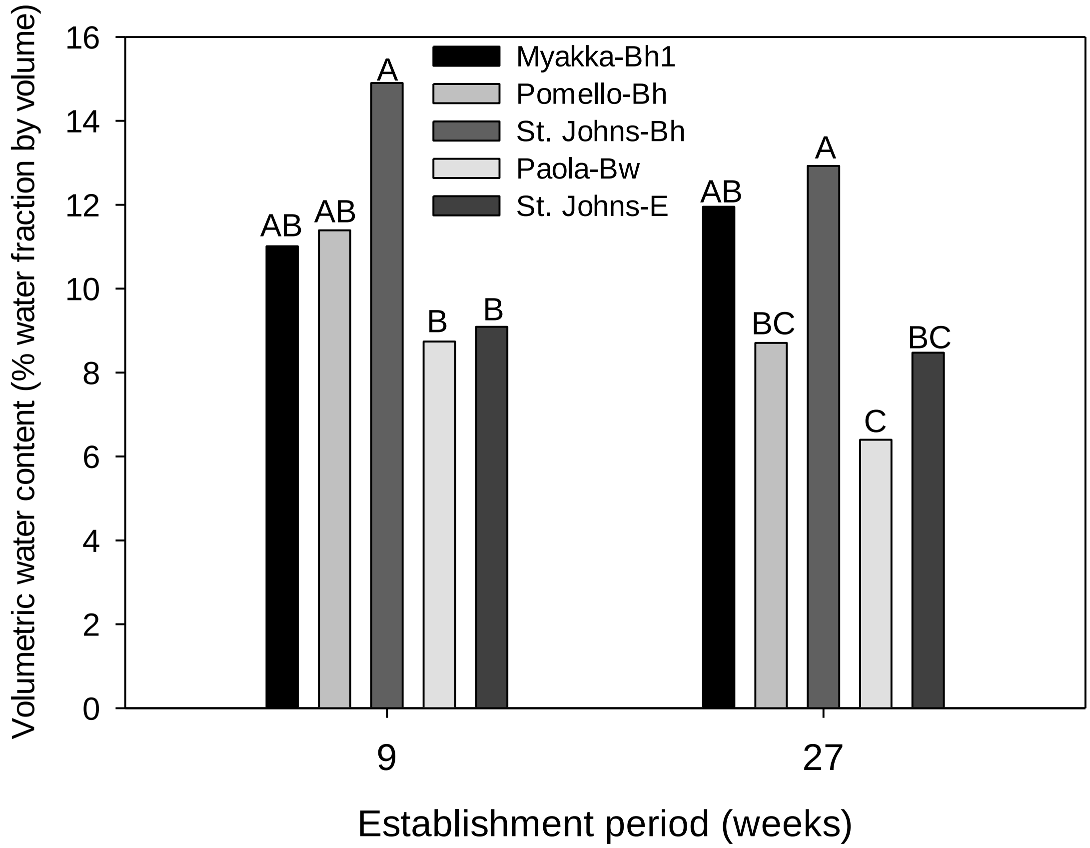

Figure 2-1. Mean weekly soil volumetric water content of Florida soil fill materials used in a column study to evaluate st. augustinegrass growth and quality response to soil properties collected over 9-and 27-week establishment study periods. Values within the establishment period with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

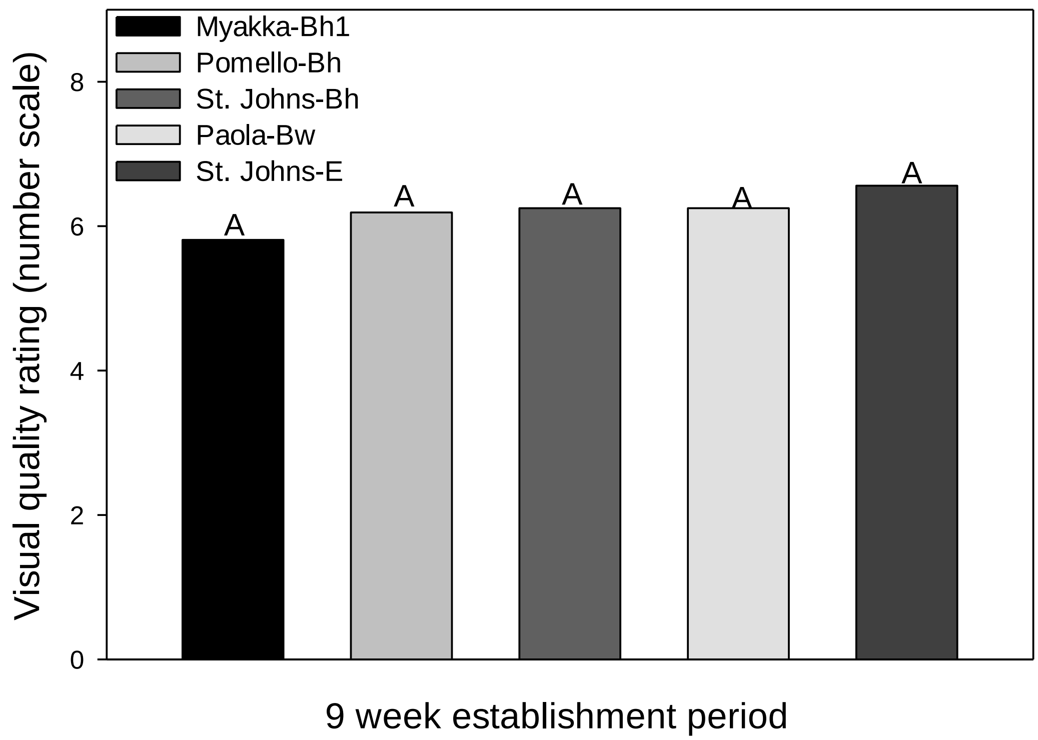

Figure 2-2. Mean weekly visual quality ratings from 0 to 9 weeks after planting of st. augustinegrass grown in Florida soil fill materials. Visual ratings use a scale from 1 to 9, with 1= dead, brown turf; 6= minimally acceptable turf; and 9= highest quality turf. No significant difference (*P* > 0.05) was observed between soil treatments during the first 9 weeks after planting.

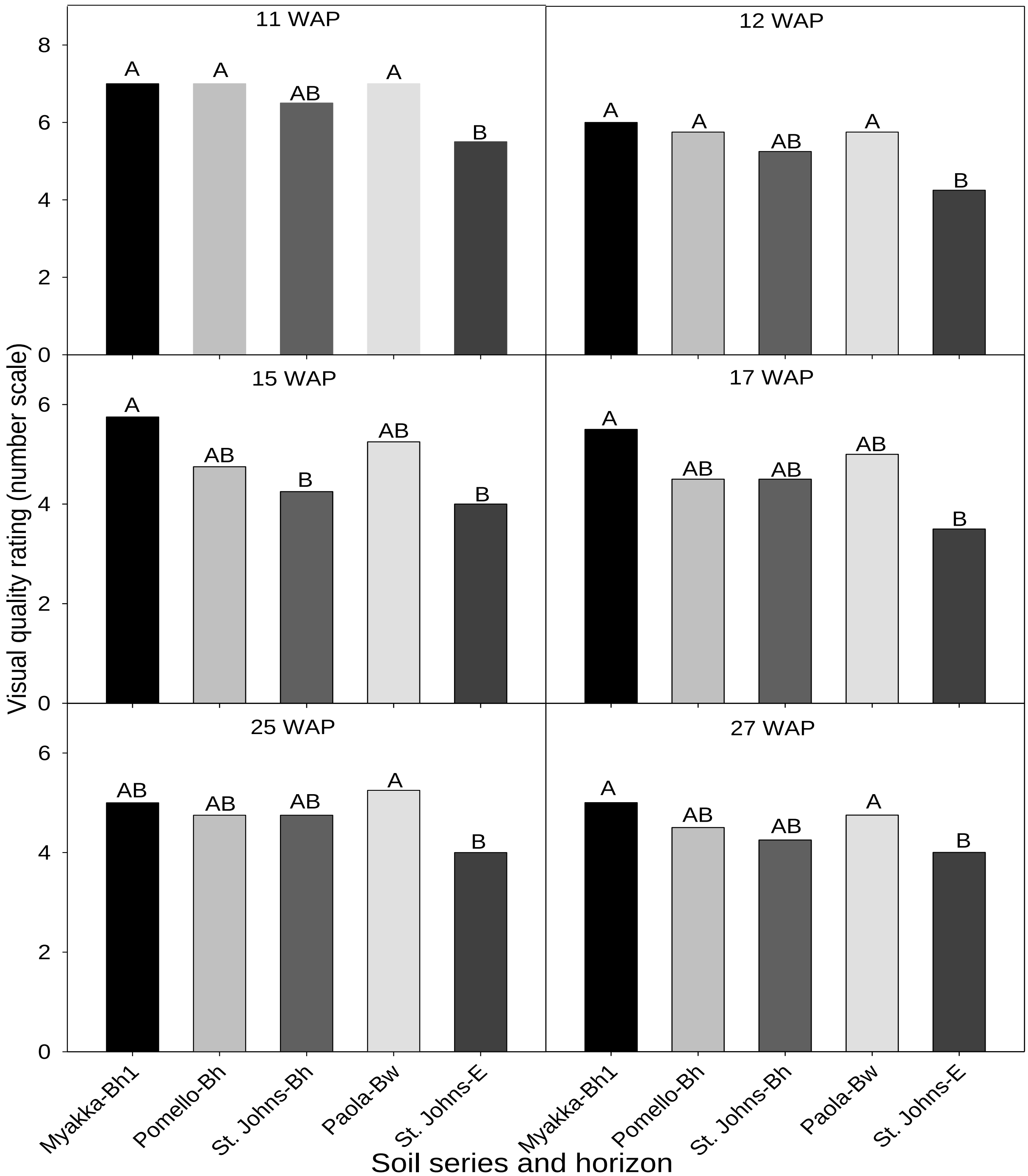

Figure 2-3. Mean visual quality ratings of st. augustinegrass grown in Florida soil fill materials at 11, 12, 15, 17, 25, and 27 weeks after planting (WAP). Visual ratings use a scale from 1 to 9, with 1= dead, brown turf; 6= minimally acceptable turf; and 9= highest quality turf. Values within the same sampling date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

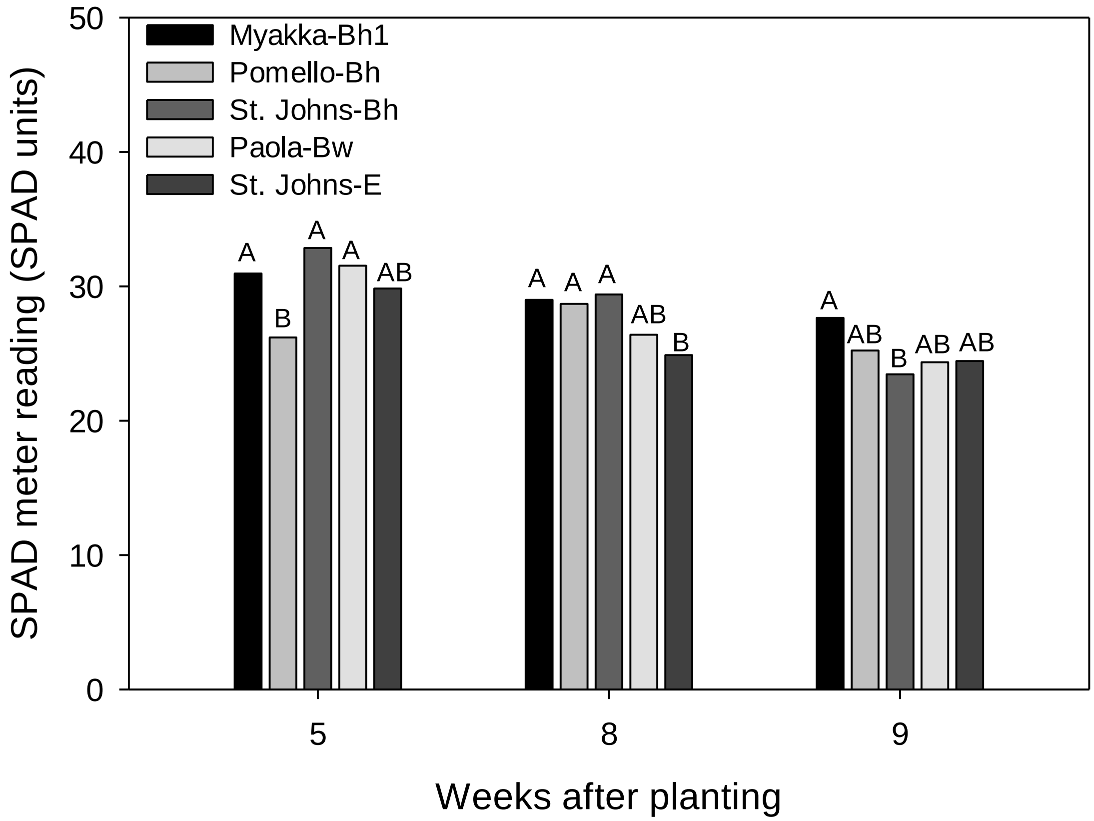

Figure 2-4. Mean SPAD meter readings for st. augustinegrass grown in Florida soil fill materials at 5, 8, and 9 weeks after planting (WAP). Values within the same sampling date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

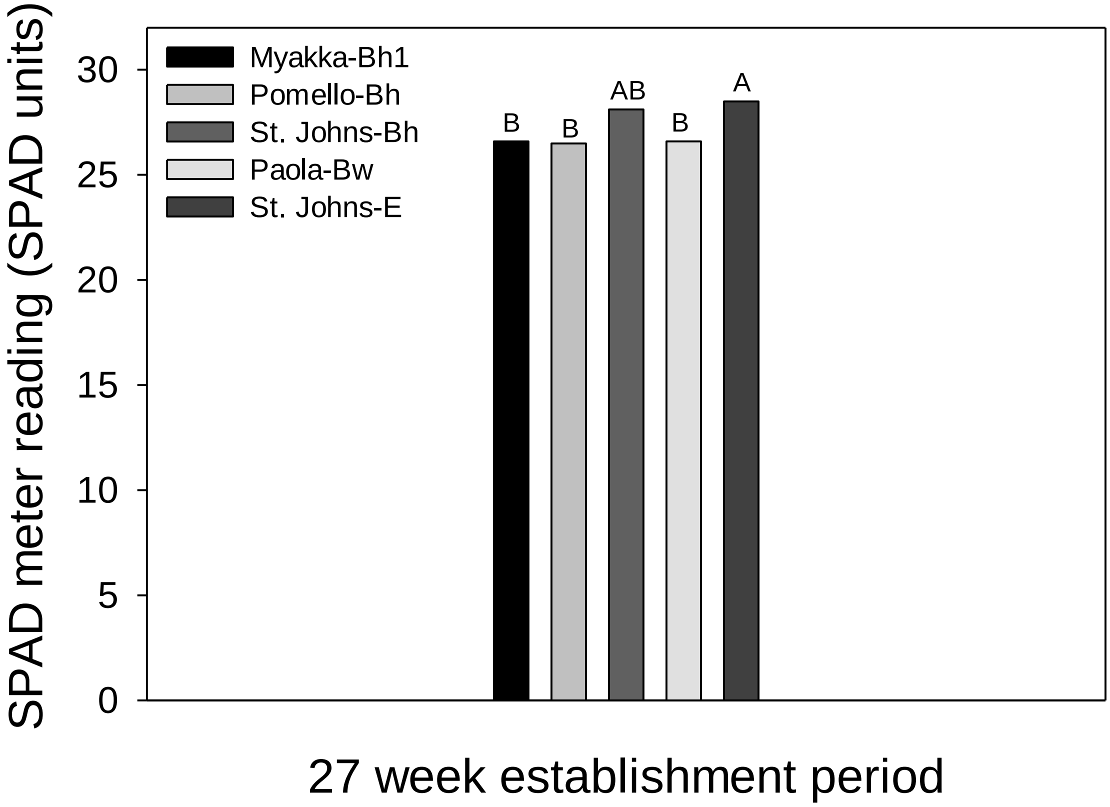

Figure 2-5. Mean SPAD meter readings st. augustinegrass grown in Florida soil fill materials during a 27-week establishment study. Values with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

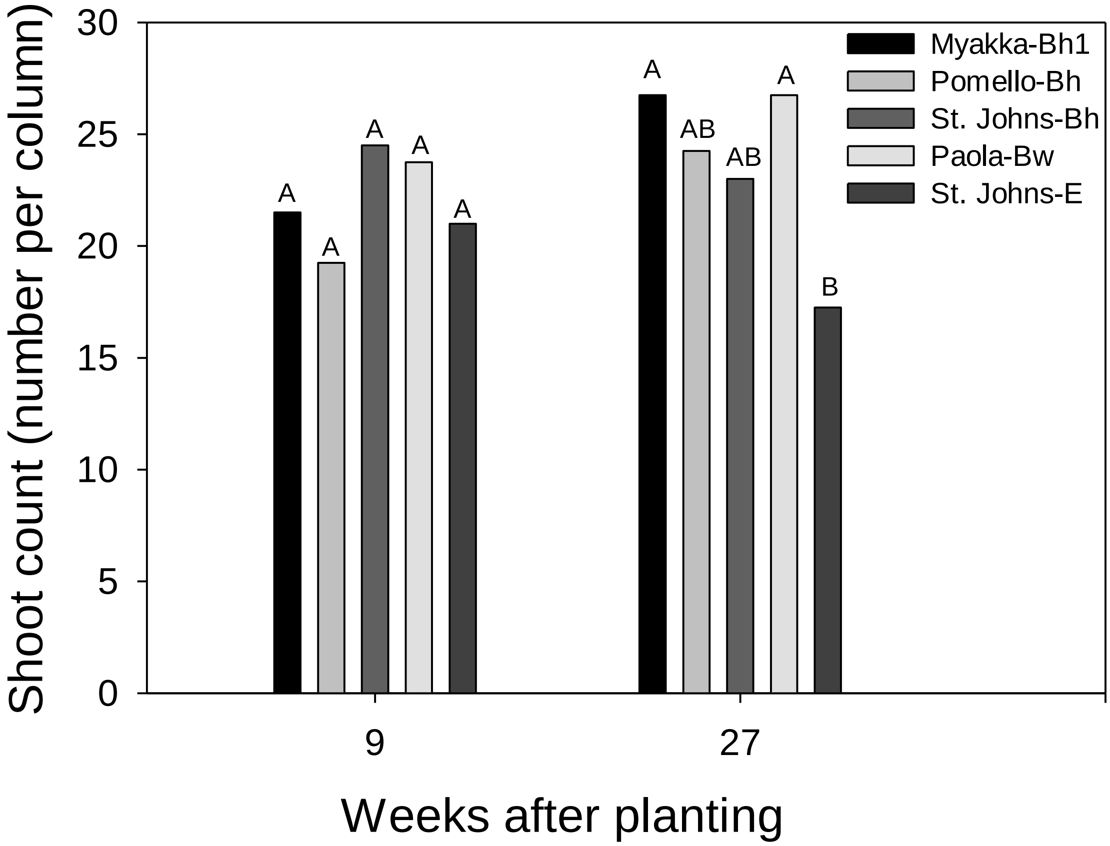

Figure 2-6. Mean shoot counts of st. augustinegrass grown in Florida soil fill materials at 9 and 27 weeks after planting. Values within the same harvest date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

CHAPTER 3
LEACHING OF PHOSPHORUS FROM ST. AUGUSTINEGRASS ESTABLISHED ON SPODIC FILL MATERIALS

Introduction

Water quality degradation is a major problem for many fresh surface-water bodies throughout the U.S. (Soldat and Petrovic, 2008). Since phosphorus (P) is often the limiting nutrient for algal and aquatic weed growth in freshwater bodies, P enrichment from point and non-point sources has been long been considered the leading cause of freshwater quality issues (e.g. harmful algal blooms, eutrophication, and dead zones) (Anderson et al., 2002; Correll, 1998; Riegman, 1995; Sharpley et al., 2003; Smith, 1983). When P concentrations in freshwater bodies become elevated beyond natural levels they can stimulate large algal blooms, which result in decreased oxygen supplies to other aquatic biota. Since P is an essential element for proper crop and plant growth, it is often included in fertilizer regimes for agricultural crops and lawns in urban areas (Chakraborty et al., 2011a; Liu et al., 2008). Both agricultural and urban areas have been identified as the two most important contributors to nonpoint-source nutrient enrichment of surface water (Carpenter et al., 1998; Hartman et al., 2008; Sharpley et al., 2003). A considerable amount of research has focused on nutrient losses from agricultural areas, with less work evaluating nutrient losses from urban areas (Soldat and Petrovic, 2008).

Phosphorus leaching has traditionally been considered a minor pathway of P losses from agricultural soils (Sims et al., 1998) because P is very reactive in the soil-solution environment and most soils have relatively high P sorption capacities. However, soils with low P sorption capacities that are fertilized and soils with elevated P levels (natural or due to repeated applications of P) have the potential to leach P below the root zone (Heckrath et al., 1995; Hongthanat et al., 2011; Schwab and Kulyingyong, 1989; Soldat and Petrovic, 2008). Many of Florida's sandy, uncoated, acidic soils are prone to leaching due to the absence of iron- (Fe) or aluminum- (Al) (hydr)oxide coatings that are capable of retaining phosphate ions by forming surface bonds (Harris et al., 1996; Liu et al., 2008; Snyder et al., 2001). Soil texture can also have an effect on P concentrations and loads in leachate (Linde and Watschke, 1997; Petrovic, 2004; Soldat and Petrovic, 2008). In a comprehensive review of turfgrass leaching studies, Soldat and Petrovic (2008) reported that P leaching from fine-textured soils was generally lower than sandy-textured soils.

Researchers often use standard agronomic soil tests (e.g., Mehlich 1, Mehlich 3, etc.) to assess the environmental risk of P loss in runoff or leachate (Nair and Harris, 2004). However, standard agronomic soil tests do not account for the P retention capacity of the soils. In contrast, measurements such as the degree of P saturation (DPS), the P saturation ratio (PSR), and the soil P storage capacity (SPSC) account for the P retention capacity of soils by quantifying the relationship between soil P and P retaining soil minerals (mainly Al and Fe) (Chakraborty et al., 2011a; Maguire and Sims, 2002; Nair et al., 2004). Linear relationships between soil WSP concentrations or leachate P concentrations and DPS and PSR values are used to determine "change point" or threshold, above which the release of P from the soil to solution abruptly increases (Chakraborty et al., 2011a; Nair et al., 2004; Sims et al., 2002). In contrast, the soil SPSC indicates how much P can be added to a soil before critical PSR or DPS thresholds are reached (Chakraborty et al., 2011a). These soil tests can more accurately assess soil P saturation status and can provide environmental P risk assessments for acidic soils. However, DPS, PSR, and SPSC measurements are not appropriate for calcareous or high pH soils, since P absorption and retention is not directly related to extractable Al and Fe in those soil types. Instead, the dominant forms of P in neutral and calcareous soils are calcium (Ca) P minerals or P adsorbed to the surfaces of clay minerals and Ca-carbonates (Havlin et al., 2005).

Urban soils and fill materials have been shown to have widely varying physical and chemical properties when compared to neighboring native soils (Pouyat et al., 2007; Scharenbroch et al., 2005; Short et al., 1986). Chakraborty et al. (2011a) showed that the P storage capacities of surface horizons are typically lower than Bh horizons and that Bh horizons generally act as potential P sinks. Spodic horizons are characterized by having large quantities of Al and Fe associated with carbon, which when coupled with low pH values give them the ability to sorb large portions of P (Chakraborty et al., 2011a; Deconinck, 1980). Spodosols represent the largest soil order in Florida for land coverage (Collins, 2010; Stone et al., 1993); therefore, it is likely that some of these Bh horizons collected from Spodosols will end up as fill materials. These Bh horizons may have large stores of P that could become a potential P source when Bh derived soils are applied as fill materials. Other fill materials may contain low concentrations of P values initially and have little capacity to assimilate additional P; these soils may quickly become potential environmental risk when applied as fill materials. In addition, turfgrass is a dominant component of pervious surfaces in urban landscapes (Milesi et al., 2005) that requires significant fertilizer and water inputs to maintain a healthy and functional turf stand. It is important to understand how the initial P statuses of different soil fill materials and their remaining P sorption capacity can affect the leaching of P form urban areas. Therefore, the objective of this study was to quantify the P leaching from Bh and non-Bh derived fill materials.

Materials and Methods

Site Locations and Soil Sampling

Five subsoils were obtained from two different geographical locations in Florida. Two soil samples were collected from an active borrow pit located 20 km southeast of Jacksonville, FL. Soils were removed from the ground by backhoe operations prior to our sampling. One soil was collected from the Bw horizon of a Paola sand (Hyperthermic, uncoated Spodic Quartzipsamments) (Soil Survey Staff, 2010). The second soil was collected from a Bh horizon of a Pomello fine sand (Sandy, siliceous, hyperthermic Oxyaquic Alorthod) (Soil Survey Staff, 2010). Soil was also collected from a new residential housing development located east of Fruit Cove, FL. Various soil horizons were exposed in a circular trench that was excavated prior to sampling. The exposed Bh and E horizons of a St. Johns sand (Sandy, siliceous, hyperthermic Typic Alaquods) (Soil Survey Staff, 2010) were collected. An additional soil sample was collected near Labelle, FL at a private cattle farm dominated by pine flatwoods vegetation. A small circular soil pit was hand dug using a shovel. Soil was excavated from the Bh1 horizon of a Myakka sand (Sandy, siliceous, hyperthermic Aeric Alaquods) (Soil Survey Staff, 2010). Soil samples were air-dried at 25 ± 2°C for 10 d and sieved to pass a 2-mm screen.

Experimental Design

The experiment was conducted inside a sawtooth production house at the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) Gulf Coast

Research and Education Center in Wimauma, FL. Forty soil columns were constructed by cutting polyvinyl chloride (PVC) pipe (15.2-cm internal diameter) into 30.5-cm long sections. Forty 15.2-cm diameter endcaps were filled with three pieces of cheesecloth that had been cut into 15.2-cm circular pieces and chalked to the bottom of each endcap. A mixture of deionized water-washed sand (186 g) and pea gravel (614 g) was added to each endcap to allow for free drainage of water and to help prevent soil loss from the column. Endcaps were then attached to the bottom of each PVC column and water resistant caulk was applied to the outside and inside lips of the endcap to prevent water leakage. A 1.3-cm hole was drilled into the center of each endcap to allow for water drainage.

The five excavated air-dried soils were packed into eight PVC columns; four columns containing each soil were used for a 9-week turf establishment study (12 May to 11 July 2011) and four columns for a 27-week turf establishment study (12 May to 10 Nov. 2011). Air-dried soils were packed into the columns in 1000 g increments by alternating packing with ten taps of a hand-made tool (steel rod welded to a 10.2-cm diameter steel circle). The packing tool was moved in a circular pattern in between each tap to ensure the whole column was evenly packed. Packing was performed until the soil level was within a 1.3-cm of the top of the column to allow room for placement of sod.

Circular sections of ‘Floratam’ st. augustinegrass (Council Growers, Inc., Ruskin, FL) were cut from sod pallets using a 15.2-cm cup cutter. Soil was gently washed off of the turfgrass roots using a low pressurized hose prior to the installation of sod in the columns. Sod was installed by placing the 6-inch turfgrass cutouts onto the packed soil columns and ensuring the top of thatch layer was even with the top of the PVC column walls. Excess turfgrass extending over the edge of the 15.2-cm PVC column was trimmed evenly with the side walls of the column using pruning shears.

Irrigation and Fertilizer Application

Columns were irrigated with potable well water that contained no measurable no measurable molybdate reactive P (MRP, < 0.09 mg·L^{-1}) (Pierzynski et al., 2009) using a drip irrigation system that was regulated to 206843 Pa and connected to a sand filtration system. Each turf column was outfitted with two drip emitter stakes (Arrow Dripper; MMXI NetaFim Irrigation, Inc., Fresno, CA) that were placed in the middle of the column; each emitter applied 0.95 L·hr^{-1} of water. Irrigation events were scheduled using an automated timer to ensure that the turf received adequate water for optimal growth. The amount of water applied to each column was determined by following UF–IFAS irrigation recommendations for STA in southern Florida (Trenholm et al., 2011; Trenholm et al., 2006). The irrigation schedule for the first 40 d after planting (DAP) is presented in Table 2-1. At 21 DAP, the two drip emitter stakes were removed from each column and replaced with a single, adjustable-spray emitter (Shrubbler® 360°; Antelco Corp., Longwood, FL) due to concerns of uneven wetting of the soil columns. The spray emitters were adjusted individually until an application rate of 20.8 ± 2.84 L·hr^{-1} of water was achieved for all emitters. From 40 through 82 DAP, the turf received 0.97 cm of water twice a week (Monday and Thursday of each week at 0800 HR for a 30 s run time). From 85 DAP until the end of the experiment, turf received 1.02 cm of water twice a week (Monday and Thursday of each week at 0800HR for a 32 s run time). The amount of water was increased from 0.97 to 1.02 cm of water because turf showed signs of water stress due to increasing air temperatures in summer.

Soil columns were fertilized with a water-soluble 36N-0P-5K fertilizer mix (Miracle-Gro® Water Soluble Lawn Food; The Scotts Company, LLC, Marysville, OH) that was specifically formulated for lawns. Columns were fertilized at an nitrogen (N) rate of 2.4 $g \cdot m^{-2}$ following UF–IFAS recommendations for STA (Trenholm et al., 2011). During the first fertilizer application (applied 30 DAP), 0.059 $g \cdot m^{-2}$ P was applied as a starter application by dissolving 0.168 g NaH_2PO_4 into the water-soluble fertilizer solution. During subsequent fertilizer applications (approximately every 30 d), no P fertilizer was applied. Fertilizer was applied to the columns by hand using pre-measured aliquots (half the volume of irrigation applied) the fertilizer solution. After the fertilizer was applied, the columns were irrigated with the reaming volume of water to help move the fertilizer into the soil and prevent foliar burn on the grass blades.

Soil Characterization

Soil samples were air-dried at 25 ± 2°C for 10 d and sieved to pass a 2-mm screen. Initial soil bulk density of soils in PVC columns were calculated by dividing the oven dried mass of soil packed into columns by the PVC columns area. Soil texture was determined using the hydrometer method (Bouyoucos, 1962). Soil organic matter (OM; loss on ignition) and pH (1:2 soil to deionized water ratio) were determined by standard methods of the UF-IFAS Analytical Research Laboratory (ARL) in Gainesville, FL (Mylavarapu, 2009). Soil samples were extracted using a modified Mehlich 3 (M3) dilution ratio method (1:7 ratio of soil to 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA) (Baker et al., 2002). Mehlich 3 extracts were analyzed for calcium (Ca_{M3}), Fe, Al, and P using inductively coupled plasma-atomic emission spectroscopy (ICP–AES) at the ARL in Gainesville, FL. Soil water soluble phosphorus (WSP) was extracted by following method of Self-Davis et al. (2009) and soluble P in filtrate was determined on a spectrophotometer (Genesys 20; Thermo Fisher Scientific, Madison, WI) at 882 nm following the Murphy and Riley (1962) procedure. The PSR values for the soils were calculated using the following equation:

$$PSR_{M3} = P_{M3} / (Al_{M3} + Fe_{M3}),$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentrations of M3 extractable P, Al, and Fe expressed in mmol kg^{-1} (Maguire and Sims, 2002). The DPS was calculated using the following equation:

$$DPS_{M3} = [(P_{M3}) / \alpha\ (Al_{M3} + Fe_{M3})] \times 100,$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentrations of M3 extractable P, Al, and Fe expressed in mmol kg^{-1} and α (0.55) is an empirical factor that compares different soils with respect to P saturation (Nair and Graetz, 2002). Soil P storage capacity was calculated using the following equation:

$$SPSC_{M3} = (\text{change point } PSR_{M3} - \text{soil } PSR_{M3}) \times (Fe_{M3} + Al_{M3}) \times 31,$$

where Fe_{M3} and Al_{M3} are the concentrations of Mehlich 3 extractable Al and Fe expressed in mmol kg^{-1} and the change point PSR_{M3} is the value at which WSP abruptly starts to increase with increasing PSR_{M3} (0.09) for 241Bh horizons collected in Florida (Chakraborty et al., 2011a).

At turfgrass harvest [9 and 27 weeks after planting (WAP)], the soil from each column was removed and air-dried at 25 ± 2°C for 10 d and sieved to pass a 2-mm screen. All soil samples collected at 9 and 27 weeks after planting (WAP) were analyzed for the same parameters as described for the initial soil parameters, with the exception of M3 nutrients. Soil samples collected at harvest were extracted using for M3 using the method of Sims (2009b) adopted from Mehlich (1984) (1:10 ratio of soil to 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA).

Leachate Collection and Analysis

One day prior to the sod installation, 2.82 L of water was applied to each column by pouring water onto the soil at a rate slow enough to avoid ponding. Water was applied to the columns to remove any air in the soil pores and to ensure uniform leaching of the columns. The amount of water that was applied to each column was determined by slowly pouring water onto the soil treatment with the lowest bulk density value until water started to drip out of the bottom of the column. The columns were allowed to drain for 24 h, at which time the total leachate from each column was measured and recorded. A 125-mL subsample of leachate was collected from each column. An unfiltered portion of the leachate subsample was stored in a 60-mL scintillation vial. The remaining portion of the leachate subsample was filtered through a 0.45-µm filter and stored in a separate 60-mL scintillation vial. Unfiltered and filtered leachate samples in scintillation vials were stored at 0 ± 2°C until analysis.

Following sod application, leachate was measured and collected 24 h after the first daily irrigation event. Leachate samples were combined to create weekly flow-weighted composite samples unless the volume of leachate was too small to allow for weekly compositing, in which case leachate samples were combined to generate multi-week flow-weighted composite samples. Filtered (0.45-µm) and unfiltered samples were stored in two separate plastic 60-mL scintillation vials at 0 ± 2°C until analysis. Drainage depths (cm) were calculated by divided leachate volumes (kL) by the area (m^2) of the column and multiplying by a factor of 100.

Unfiltered leachate samples were analyzed for MRP. Filtered leachate samples were analyzed for dissolved reactive orthophosphate (DRP) and total dissolved P (TDP) (Pierzynski et al., 2009). Unfiltered total P samples were not analyzed throughout the experiment due to limited leachate sample volume and negligible differences were found when spot checks were performed on filtered and unfiltered samples (mean difference = 0.05 $mg \cdot L^{-1}$, standard deviation of 0.06 $mg \cdot L^{-1}$). Reactive P (MRP and DRP) analysis was performed using the molybdate blue method (Murphy and Riley, 1962) on a spectrophotometer (Genesys 20; Thermo Fisher Scientific) at 882 nm. Total dissolved P was extracted from leachate samples following a modified version of EPA method 351.2 for TKN determination of surface waters; a 5 to 1 ratio of leachate sample to digestion solution was used instead of the 2.5 to 1 ratio outlined in the EPA method (U.S. Environmental Protection Agency, 1993). Total dissolved P was analyzed on a flow segmented analyzer (Astoria 2 Analyzer; Astoria Pacific International, Clackamus, OR) at the ARL in Gainesville, FL. Nutrient load calculations for MRP, DRP, and TDP composite samples were determined by multiplying P concentrations ($mg \cdot L^{-1}$) by the total volume (L) of leachate collected over the time period of the composite sample.

Turfgrass Root Biomass

Turfgrass was harvested from 20 columns at 9 WAP and from the remaining 20 columns at 27 WAP, by sliding a knife blade around the edges of the PVC columns and inverting the column to allow the turfgrass and soil to slide out onto a tray. Turfgrass roots were placed in a 2-mm sieve and any remaining soil was washed off under gently flowing water. The wet roots were then wrapped in a paper towel and dried to a constant mass at 41 ± 2°C, prior to being weighed.

Data Analysis

The experiment was designed as a completely randomized design with five soil treatments. Each soil treatment was randomly assigned to the columns, with eight replications for each treatment for the 9-week establishment period, and four replications for the 27-week establishment period for leachate analysis. Each soil treatment was randomly assigned to the columns, with four replications for each treatment for the 9-week establishment period, and four replications for the 27-week establishment period for soil analysis. Soil samples with concentrations of P_{M3} and Fe_{M3} below the detection limit were assigned a value of half the detection limit. Soil treatment effects on soil properties and root biomass were analyzed using the PROC MIXED procedure in SAS 9.3 with soil treatment as a fixed effect and replicate as a random effect (SAS Institute, 2012). Normality was checked by examining histograms and normality plots of the conditional residuals. Soil P_{M3} and Fe_{M3}, PSR_{M3}, DPS_{M3}, and soil OM (9-week harvest only) were log transformed prior to statistical analysis. Soil P_{M3} and Al_{M3}, $PSR_{M3,}$ and DPS_{M3} (27-week harvest only) were log transformed prior to statistical analysis. Relationships between soil and leachate parameters were determined using a Pearson correlation analyzed by the PROC CORR procedure in SAS 9.3 (SAS Institute, 2012). Leachate volumes, MRP, DRP, and TDP concentrations and loads were analyzed by week due to an overall significant soil treatment × week interaction. All comparisons were completed using the Tukey's honestly significant difference with a significant level of $\alpha = 0.05$.

Results

Soil Properties

The initial bulk densities of the Paola-Bw and St. Johns-E soils were significantly higher than the other three soils (Table 2-2). The soil textural class of all five soils was sand (data not shown). The initial OM contents of the three Bh soils (Pomello, St. Johns, and Myakka) were above 41.6 $g \cdot kg^{-1}$; the St. Johns-E and Paola-Bw soils had OM contents were less than 3.80 $g \cdot kg^{-1}$ (Table 3-1). The soil OM contents of the Myakka-Bh1 and Pomello-Bh soils were not statistically different, but both were significantly higher than the OM contents of the St. Johns Bh, Paola-Bw, and St. Johns-E soil at the 9- and 27-week harvest date (Table 3-1). The pH of the initial soil samples ranged from 4.1 to 5.8, with a median pH of 4.7 (Table 3-1). All soils were acidic, but the three Bh horizon soils (Pomello, St. Johns, and Myakka) had significantly lower pH than compared to the pH of the St. Johns-E and Paola-Bw soils at the 9- and 27-week harvest (Table 3-2). The initial Ca_{M3} concentrations ranged from 14.1 $mg \cdot kg^{-1}$ in the St. Johns-Bh soil to 333 $mg \cdot kg^{-1}$ in the Myakka-Bh1 soil (Table 3-1). The Maykka-Bh1 soil had significantly higher Ca_{M3} concentrations than the other four soils at the 9- and 27-week harvest date (Table 3-1). The Paola-Bw soil had the highest initial Fe_{M3} concentration of all soils, while the Pomello-Bh and St. Johns-E soils had initial Fe_{M3} concentrations below the detection limit (<5.0 $mg \cdot kg^{-1}$) for soils at the beginning of the experiment (Table 3-1). The Paola-Bw soil had significantly higher Fe_{M3} concentrations than the other four soils at the 9- and 27-week harvest dates (Table 3-1). The three Bh soils (Myakka, Pomello, and St. Johns) had significantly higher Al_{M3} concentrations than the Paola-Bw and St. Johns-E soils (Table 3-1), with the Pomello-Bh soil having the highest Al_{M3} concentrations at the 9- and 27-week harvest (Table 3-1). Initial soil P_{M3}

concentrations ranged from <12.5 to 193 $mg \cdot kg^{-1}$, with the Pomello-Bh and Paola-Bw soil treatments containing the highest P_{M3} concentrations of the soils; the Myakka-Bh1, St. Johns-E, and St. Johns-Bh soils had P_{M3} concentrations below the detection limit (12.5 $mg \cdot kg^{-1}$) (Table 3-1). Similar trends were determined for soil P_{M3} concentrations at the 9- and 27-week harvest (Table 3-1).

Initially the Pomello-Bh soil had the highest WSP concentrations of all the soils, while both St. Johns soils contained no detectable WSP (detection limit = 0.088 $mg \cdot L^{-1}$) (Table 3-1). The Pomello-Bh soil had significantly higher WSP concentrations then all other soils at both the 9- and 27-week harvest dates (Table 3-1). Initially, both the Pomello-Bh and Paola-Bw soils had PSR_{M3} values over 0.1, while the remaining soils had PSR_{M3} values all below 0.031 (Table 3-1). The Paola-Bw soil had significantly higher PSR_{M3} values then the other four soils at 9- and 27-week harvest (Table 3-1). Similar trends between PSR_{M3} and DPS_{M3} values were reported for soils at planting and at the 9- and 27-week harvest dates (Table 3-1). Nair et al. (2004) reported a PSR_{M3} threshold value of 0.08 for sandy surface horizons while Chakraborty et al. (2011b) reported a PSR_{M3} threshold value of 0.09 for Bh horizons in Florida. These threshold values represent a change point value at which soil WSP and leachate P concentrations start to rapidly increase with increasing PSR values (Chakraborty et al., 2011a; Nair et al., 2004). Soil PSR_{M3} values above these thresholds may result in added P being lost easily from the soil through leaching (Chakraborty et al., 2011b). If we compare our PSR_{M3} values to these findings, our Pomello-Bh and Paola-Bw soil would be considered higher than the change points and the remaining three soils (Myakka-Bh1, St. Johns-Bh, and St. Johns-E) would be lower than the reported change points.

When all five soils were used in correlation analysis, WSP was moderately to highly correlated to P_{M3}, Al_{M3}, PSR_{M3}, DPS_{M3}, OM, and $SPSC_{M3}$ at the 9- and 27-week harvest (*r* values not shown, all *P* values < 0.05). However, when soils were split into Bh (Myakka, Pomello, St. John) and non-Bh (Paola and St. Johns) categories before correlation analysis, their respective *r* values all increased for soil parameters mention above.

Initially, both the Pomello-Bh and Paola-Bw soils had negative $SPSC_{M3}$ values, while the remaining three soils had positive $SPSC_{M3}$ values (Table 3-1). At the 9-week harvest, the St. Johns-Bh soil had significantly higher $SPSC_{M3}$ values then all other soils, while the Pomello-Bh and Paola-Bw soils had the lowest $SPSC_{M3}$ values of the soils (Table 3-1). Similar trends in $SPSC_{M3}$ values were determined for soils at the 27-week harvest date except for the Pomello-Bh soil, which had significantly lower $SPSC_{M3}$ values then the other four soils (Table 3-1).

For the two non-Bh soils harvested at 9 WAP, soil WSP was highly correlated to P_{M3} ($r = 0.95$, $P = 0.0003$), PSR_{M3} ($r = 0.98$, $P < 0.0001$), DPS_{M3} ($r = 0.98$, $P < 0.0001$), and $SPSC_{M3}$ ($r = -0.96$, $P = 0.0002$). For the three Bh soils harvested at 9 WAP, soil WSP was highly correlated to P_{M3} ($r = 0.94$, $P < 0.001$), Fe_{M3} ($r = -0.94$, $P < 0.001$), PSR_{M3} ($r = 0.94$, $P < 0.0001$), DPS_{M3} ($r = 0.94$, $P < 0.0001$), and $SPSC_{M3}$ ($r = -0.96$, $P < 0.0001$). Water soluble P concentrations of non-Bh soils harvested at 27 WAP were highly correlated to the following soil parameters: P_{M3} ($r = 0.89$, $P = 0.003$), PSR_{M3} ($r = 0.88$, $P = 0.004$), DPS_{M3} ($r = 0.88$, $P = 0.004$), and $SPSC_{M3}$ ($r = -0.82$, $P = 0.003$). Water soluble P concentrations of Bh soils harvested at 27 WAP were highly correlated to P_{M3}

($r = 0.98$, $P < 0.0001$), Fe_{M3} ($r = -0.88$, $P = 0.0004$), PSR_{M3} ($r = 0.98$, $P < 0.0001$), DPS_{M3} ($r = 0.98$, $P < 0.0001$), and $SPSC_{M3}$ ($r = -0.96$, $P < 0.0001$).

Leachate Drainage Depths

Drainage collected from the soil columns significantly decreased with time over the 27-week study period for all soils (Figure 3-1; $P \leq 0.05$). We reported a significant soil treatment effect on drainage depth at 4, 5, 9, 12, 13, 14, 15, 17, 23, 24, 25, and 26 WAP (Figures 3-2 and 3-3). At 4 WAP, significantly more water drained from the Myakka-Bh1, Pomello-Bh, and Paola-Bw soil than compared to the two St. Johns soils (E and Bh) (Figure 3-2). By 5 WAP, significantly more water drained from the Myakka-Bh1 soil than compared to the two St. Johns soils (E and Bh) and the Paola-Bw soil; no statistical differences were determined for drainage depths collected from the Myakka-Bh1 and Pomello-Bh soil (Figure 3-2). Significantly more water drained through the Myakka-Bh1 soil than the other soils at 9 WAP (Figure 3-2). From 12 to 27 WAP, significantly more water generally drained from the St. Johns-E than the other soils (Figures 3-2 and 3-3). However, at 12 WAP, significantly more water also drained from the Myakka-Bh1 soil than compared to the Pomello-Bh, St. Johns-Bh and Paola-Bw soils (Figure 3-2). At 13 WAP, significantly more water drained from the St. Johns-E soil than compared to the Myakka-Bh, Pomello-Bh and Paola-Bw soils; no statistical differences were determined for drainage depths between the two St. Johns (Bh and E) soils (Figure 3-2). By 24 WAP, no statistical differences were determine for drainage depths between the two St. Johns soils (Bh and E), but significantly more water drained from the St. Johns-E soil then compared to the remaining three soils (Myakka-Bh1, Pomello-Bh, and Paola-Bw) (Figure 3-3). At 25 WAP, significantly more water drained from the St. Johns-E soil than compared to the Pomello-Bh and Paola-Bw soils; no statistical differences were determined for drainage depths between the two St. Johns soils and the Myakka-Bh1 soil (Figure 3-3). At 26 WAP, significantly more water drained from the St. Johns-E soil than compared to the other four soils (Figure 3-3).

Molybdate Reactive Phosphorus in Leachate

Temporal trends in MRP concentrations show a significant spike in weekly leachate concentrations collected from the Paola-Bw, St. Johns-Bh, and St. Johns-E soils for some weeks towards the end of the study; no statistical differences were determined between weekly MRP concentrations collected from the Myakka-Bh1 and Pomello-Bh soils throughout the 27-week study period (Figure 3-4). There was a significant soil treatment effect on MRP leachate concentrations collected at 2, 4, 9, 14, and 23 WAP (Figure 3-5). In general, the Myakka-Bh1 soil leached significantly higher MRP concentrations than most over soils during the first 14 WAP (Figure 3-5). At 2 WAP, the Myakka-Bh1 and Pomello-Bh soil leached significantly higher MRP concentrations than the Paola-Bw and the two St. Johns (Bh and E) soils (Figure 3-5). At 4 WAP, the Myakka-Bh1 leached significantly higher MRP concentrations than the other four soils; the Pomello-Bh soil leached significantly higher MRP concentrations than the Paola-Bw and two St. Johns (E and Bh) soils (Figure 3-5). By 9 WAP, the Myakka-Bh soil leached significantly higher MRP concentrations then all other soils (Figure 3-5). At 14 WAP, the Myakka-Bh1 soil leached significantly higher MRP concentrations than the St. Johns-Bh and Paola-Bw soils; no statistical differences were determined for MRP concentrations leached from the Pomello-Bh and St. Johns-E soil (Figure 3-5). By 23 WAP, The St. Johns-E soil leached significantly higher MRP concentrations than the other four soils (Figure 3-5).

Temporal trends in MRP loads showed a significant decrease in P loads over the 27-week study period for leachate collected from all soils (Figure 3-6). There was a significant soil treatment effect on the MRP loads in leachate collected at 2, 4, 9, 14, 21, and 23 WAP (Figure 3-7). In general, the Myakka-Bh1 soil leached significantly higher MRP loads then most all other soil treatments during the first 9 WAP (Figure 3-7). At 2 WAP, the Myakka-Bh1 and Pomello-Bh soil leached significantly higher MRP loads than the St. Johns-Bh and Paola-Bw soils, no statistical differences were determined for MRP loads collected from the St. Johns-E soil (Figure 3-7). At 4 WAP, both the Myakka-Bh1 and Pomello soils leached significantly higher MRP loads than the St. Johns-Bh soil; no statistical differences were determined for the Paola-Bw and St. Johns-E soils (Figure 3-7). By 9 WAP, The Myakka-Bh1 leached significantly higher MRP loads than the other four soils (Figure 3-7). At 14 WAP, the St. Johns-E soil leached significantly higher MRP loads than the Paola-Bw soil and at 21 WAP the St. Johns- soil leached significantly higher MRP loads than the Myakka-Bh1 and Paola-Bw soils; no statistical differences were determined for remaining soil types (Figure 3-7). By 23 WAP, the St. Johns-E soil was leaching significantly higher MRP loads then all other soil types except the St. Johns-Bh soil (Figure 3-7).

During the 9-week establishment period, cumulative MRP leachate loads collected from the Myakka-Bh1 soil and Pomello-Bh were significantly higher than cumulative MRP loads collected from the St. Johns-E soils; no statistical differences were determined between cumulative MRP leachate loads of the St. Johns-Bh, Paola-Bw, and St. Johns-E soils (Figure 3-8). During the 27-week establishment period, cumulative MRP leachate loads collected from the Myakka-Bh1 soil were not statistically different than cumulative MRP leachate loads collected from the Pomello-Bh and St. Johns-Bh soils, but were significantly higher than cumulative MRP leachate loads collected from the Paola-Bw and St. Johns-E soils which were not statistical different (Figure 3-8).

There were moderate correlations between MRP concentrations and soil OM content (r = 0.77, P = 0.003) and soil pH (r = -0.69, P = 0.01) at 9 WAP for the three Bh (Myakka, Pomello, St. Johns) horizons soils. No significant (P > 0.05) correlations were determined between MRP concentrations and soil properties at the 9- and 27-week harvest for the two non-Bh soils (Paola and St. Johns) and for the three Bh soils at the 27-week harvest. Turfgrass root biomass was moderately correlated (r = -0.47, P = 0.04) to MRP concentrations at 9 WAP.

Dissolved Reactive Orthophosphate Filtered in Leachate

Temporal trends in DRP concentrations show a significant spike in weekly leachate concentrations collected from the Paola-Bw, and St. Johns-Bh soils for some weeks towards the end of the study; no statistical differences were determined between weekly DRP concentrations collected from the Myakka-Bh1, Pomello-Bh, and St. Johns-E soils throughout the 27-week study period (Figure 3-9). We observed a significant soil treatment effect on DRP leachate concentrations (Figure 3-10) and loads (Figure 3-11) at 2, 3, 4, 5, 6, and 9 WAP. In general, the Myakka-Bh1 soil leached significantly higher DRP concentrations (Figure 3-10) and loads (Figure 3-11) then leachate collected from most other soils during the first 9 WAP. At 2 WAP, the Myakka-Bh1 and Pomello-Bh soil leached significantly higher DRP concentrations and loads than the St. Johns-Bh and Paola-Bw soils; no statistical differences were determined for DRP concentrations and loads collected from the St. Johns-E soil (Figure 3-10 and 3-11). At 3 WAP, both the Myakka-Bh1 and Pomello-Bh soils leached significantly higher DRP concentrations and loads than the Paola-Bw soil; no statistical differences were determined for DRP concentrations and loads collected from the two St. Johns (Bh and E) soils (Figures 3-10 and 3-11). At 4 and 5 WAP, the Myakka-Bh1 leached significantly higher DRP concentrations and loads than the other four soils; the Pomello-Bh1 soil leached significantly higher DRP concentrations than both St. Johns (Bh and E) and the Paola-Bw soils. At 4 and 5 WAP, the Pomello-Bh1 soil leached significantly higher DRP loads than both the St. Johns-Bh and the Paola-Bw soils while the St. Johns-E soil had statistically similar DRP loads (Figures 3-10 and 3-11). By 6 WAP, the three Bh soils (Myakka, Pomello, and St. Johns) leached significantly higher DRP concentrations than the Paola-Bw soil; no statistical differences were determined for the St. Johns-E soil (Figure 3-10). The St. Johns-Bh soil leached significantly higher DRP loads than the Paola-Bw and St. Johns-E soils while no statistical differences were determined for DRP loads collected from the Myakka-Bh1 and Pomello-Bh soils at 6 WAP (Figure 3-11). At 9 WAP, The Myakka-Bh1 soil leached significantly higher DRP concentrations and loads than the other four soils (Figure 3-10 and 3-11). Temporal trends in DRP loads showed a significant decrease in leached P over the 27-week study period for all soils (Figure 3-12). No significant correlation relationships between DRP concentrations and soil properties where determined for non-Bh soils at 9 and 27 WAP and for Bh soils at 27 WAP.

Cumulative DRP loads leached from the Myakka-Bh1 soil were statistical similar to the loads collected from the Pomello-Bh soil and significantly higher cumulative DRP loads than the St. Johns-Bh, Paola-Bw and St. Johns-E soils during the 9-week establishment study; cumulative DRP loads leached from the Paola-Bw soil were significantly lower than all soils except for the St. Johns-E soil which were statistical similar (Figure 3-13). During the 27-week study, the Myakka-Bh soil had significantly higher cumulative DRP loads than the other four soils; cumulative DRP loads leached from the Pomello-Bh soil were significantly higher than the Paola-Bw soil and statistical similar to the two St. Johns (Bh and E) soils (Figure 3-13).

High correlations were determined between DRP concentrations and the following soil parameters: pH (r = - 0.75, P = 0.005 and OM (r = 0.77, P = 0.003) for the three Bh (Myakka, Pomello, and St. Johns-E) soils collected at 9 WAP. Turfgrass root biomass was moderately correlated (r = -0.45, P = 0.04) to DRP concentrations at 9 WAP.

Total Dissolved Phosphorus Filtered in Leachate

There was a significant soil treatment effect on TDP leachate concentrations (Figure 3-14) and loads (Figure 3-15) collected at 1, 2, 3, and 4 WAP. Leachate TDP concentrations and loads were significantly higher from the Myakka-Bh1 soil than the other soils for the first 4 WAP. For the first WAP, The Pomello-Bh soil leached significantly higher TDP leachate concentrations and loads than the St. Johns-E soil and statistically similar TDP leachate concentrations and loads to the St. Johns-Bh and Paola-Bw soils (Figures 3-14 and 3-15). At 2, 3, and 4 WAP; The Pomello-Bh soil leach significantly higher TDP leachate concentrations and loads than Paola-Bw soil and statistically similar TDP leachate concentrations and loads to the two St. Johns (E and Bh) soils the for the first 4 WAP (Figures 3-14 and 3-15). High correlations between TDP leachate concentrations and the following 9-week harvest soil parameters: pH (r = -0.67, P = 0.001) and OM (r = 0.77, P < 0.0001) were determined for leachate collected at 4 WAP.

Turfgrass Root Biomass

A significant soil treatment effect was determined for root dry biomass at the 9- and 27-week harvest ($P \leq 0.05$, Table 3-2). No statistical differences were determined for root biomass of STA grown on St. Johns-Bh, Paola-Bw, and St. Johns-E soil; however, STA grown on the St. Johns-Bh soil produced significantly higher root biomass than STA grown on the Myakka-Bh1 and Pomello-Bh soils during the 9-week establishment period (Table 3-2). St. augustinegrass grown on St. Johns-E soil produced significantly lower root biomass then STA grown on the other four soils during the 27-week establishment period (Table 3-2).

Discussion

Soil P_{M3}, Fe_{M3}, and Al_{M3} concentrations where all within the reported ranges of M3 nutrient concentrations of acidic soils from Delaware used in a P leaching study by Maguire and Sims (2002) and a P storage capacity study of Florida acidic soils by Chakraborty et al. (2011b). However, some of soil M3 concentrations reported by Chakraborty et al. (2011b) and Maguire and Sims (2002) had higher maximum P_{M3} and Fe_{M3} concentrations than determined for our study. The Bh soils used in our study generally had higher OM contents and lower pH values than soils used by Maguire and Sims (2002), but comparable pH values to most Bh soils reported by Chakraborty et al. (2011b). The two non-Bh soils used in our study had comparable pH values and soil OM contents to most of the soils used in the leaching study by Maguire and Sims (2002) and comparable pH values to A and E horizons reported by Chakraborty et al. (2011b). The high OM contents determined for Bh samples in our study suggests that other mass losses (e.g., dehydroxylation) may be contributing to the LOI values.

The soil WSP concentrations of soils used in our study were comparable to some of the WSP concentrations of A, E, and Bh horizons reported by Chakraborty et al. (2011b), however the authors reported some soil horizons with higher WSP concentrations than determined for soils used in our study. Soil bulk density values in the PVC columns were all below the reported root penetration threshold value of 1.75 $g \cdot cm^{-3}$ for sandy soils (Brady and Weil, 2002) and turfgrass root lengths for all soil treatments were at the bottom of the soil columns by the end of 27-week harvest.

Usually for acid soils, higher PSR_{M3} and DPS_{M3} values correspond to higher soil WSP concentrations (Nair et al., 2004) or higher DRP concentrations in leachate (Maguire and Sims, 2002; Sims et al., 2002). When the soils in our study were separated into non-Bh and Bh horizon categories we observed high correlations between PSR_{M3} and DPS_{M3} values to soil WSP concentrations for most of our soils except the Myakka-Bh1 soil. The Paola-Bw, which had the highest DPS_{M3} value (31.0%), had similar WSP (0.89 $mg \cdot kg^{-1}$) concentrations to the WSP of the Myakka-Bh1 (0.84 $mg \cdot kg^{-1}$) soil, which had a lower DPS_{M3} value of 0.87% at 9 WAP. The Myakka-Bh1 and St. Johns-Bh soils had similar WSP concentrations to the Paola-Bw soil despite having significantly lower soil DPS_{M3} values at 27 WAP. The PSR_{M3} values of all soils used in our study were below the change point of 0.23, above which Maguire and Sims (2002) reported a rapid increase in dissolved leachate P concentrations for acidic sandy soils from Delaware. Chakraborty et al. (2011b) proposed a lower PSR_{M3} change point of 0.09 for Florida Bh horizons, which was similar to the PSR_{M3} change point of 0.08 for sandy surface horizon soils reported by Nair et al. (2004). No significant relationships between leachate P (MRP, DRP, and TDP) concentrations and DPS_{M3} and PSR_{M3} values were determined for soil used in our study.

Chrysostome et al. (2007) reported that soils act as a P sink when SPSC is positive, and as a potential P source when SPSC is negative. In our study, the Myakka-Bh1 soil had positive SPSC values indicating that the soil has the capacity to adsorb more P before reaching DPS_{M3} and PSR_{M3} change-points; however, we observed significantly higher leachate P (MRP, DRP, and TDP) concentrations and loads from the Myakka-Bh soils then soils with higher WSP and negative SPSC values throughout the 27 week study. The comparable WSP concentrations of the Myakka-Bh1 and the Paola-Bw soil and the higher leachate P collected from the Myakka-Bh1 may be attributed to the presence in and release of organically complexed-P from the Myakka-Bh1 soil. Wright and Reddy (2012) reported that water containing dissolved OM is darkly colored and can carry carbon (C), N, P, and metals with it. Dissolved OM and associated or complexed ions can readily move through the soil (Kaschl et al., 2002; Qualls and Haines, 1992). The dark color of the drainage water collected from the Myakka-Bh1 soil support the hypothesis of this soil leaching P complexed with DOM. The significant correlation between WSP and leachate concentrations to soil OM reported in our study may also support this idea that some complexed P was being leached with DOM. This hypothesis of complexed P leaching with DOM may explain why we observed higher or no statistical differences in cumulative DRP and MRP of the lower DPS_{M3} and PSR_{M3} Bh horizon (Myakka, Pomello, and St. Johns) soils compared to the Paola-Bw soil (which had significantly higher DPS_{M3} and PSR_{M3} values).

The significant decrease in drainage depths from the beginning to the end of the study can be attributed to the reduction of irrigation volumes, because irrigation was the only source of water applied to the columns. High drainage volumes during the first 9 WAP were also likely a result of the short time frame of the study, which did not allow enough time for roots to fully develop. Specifically, the higher drainage volume collected from the St. Johns-E soil starting at 12 WAP may be attributed to the significantly lower root mass collected from turfgrass grown on the St. Johns-E soils when compared with turfgrass grown on the other soil treatments at the 27-week harvest date. Scherer-Lorenzen et al. (2003) showed a negative relationship between root biomass and leaching volumes from grasslands, indicating that roots play an important role in intercepting water and nutrients and reducing leaching. Our study reported a moderately negative correlation relationship between turfgrass root biomass and leachate P (MRP and DRP) concentrations at 9 WAP. The low soil OM content of the St. Johns-E soil and the possible formation of preferential flow channels are two additional properties that may have contributed to the higher drainage volumes reported for the St. Johns-E soil.

The significant decrease in DRP, MRP, and TDP loads observed over the 27-week study period may also be attributed to the reduction of irrigation as the study progressed. The high irrigation inputs required for turfgrass establishment increase the potential for nutrients to be moved below the root zone and lost to leaching (Barton and Colmer, 2006; Erickson et al., 2005; King et al., 2006; Synder et al., 1984). For example, Erickson et al. (2005) reported that P leaching losses were severely higher earlier on in the study period than when compared to later months. The significant increase of MRP and DRP concentrations leached from some soils during the last few weeks of our study (when compared to earlier concentrations) were likely a result of the decrease in leachate volumes over the study period.

Results from our study show that MRP and DRP concentrations ranged from 0 to 0.5 $mg \cdot L^{-1}$ and 0 to 0.3 $mg \cdot L^{-1}$ respectively, for all soil treatments during the 27-week study period. Lawson and Colclough (1991) and Petrovic (2004) reported similar P leachate concentrations on MRP (0 to 0.3 $mg \cdot L^{-1}$) and DRP (maximum = 0.19 $mg \cdot L^{-1}$) from fertilized sandy soils. However, Engelsjord and Singh (1997) reported DRP concentrations ranging from 0.11 to 10.25 $mg \cdot L^{-1}$. Average across all soil treatments MRP and DRP 9-week cumulative loads were 0.24 and 0.19 $kg \cdot ha^{-1}$ respectively for our study. When averaged across all soil treatments, 27-week cumulative MRP and DRP loads were 0.28 and 0.21 $kg \cdot ha^{-1}$, respectively, which were similar to our 27-week loads; these results were expected since P fertilizer was only added at 30 DAP. Erickson et al. (2010) reported similar cumulative 2 month P loads of 0.27 $kg \cdot ha^{-1}$ 0.13 $kg \cdot ha^{-1}$ for some of their STA treatments establishing on sandy soils. Erickson et al. (2005) reported significantly higher cumulative 2 month P loads of 2.5 $kg \cdot ha^{-1}$ during the STA 2-month establishment period. However, most of these referenced studies applied P fertilizer at higher rates and frequencies then we did in our study, so it is expected that we would report lower P concentrations and loads. Results from our study did indicate that even with low P additions, fill materials can leach P loads that may still have environmental implications. Higher fertilizer and irrigation regimes than used in our study may further increase the potential for P leaching during turfgrass establishment periods.

Phosphorus saturation ratio, DPS, and SPSC have all been considered important tools for evaluating the P saturation status of soils. These P saturation measurements were shown to be effective in identifying acidic soils that may pose possible environmental risk for P losses in our study when they were separated into non-Bh and Bh categories. However, our results did show that some acidic sandy soils with low P saturation status (low PSR_{M3} and DPS_{M3} values) and high remaining P sorption capacity (positive $SPSC_{M3}$ values) still acted as a potential sources of P even when little P was added to them. Our study evaluated only a few types of soils and we found one main deviation from published study results, while other studies evaluating much larger soil sets showed positive relationships between high PSR or DPS change points and increase leachate P concentrations or soil WSP concentrations. However, our results suggest that established PSR and DPS change points along with SPSC calculations may not be able to accurately predict the leaching potential of all soils when they are removed from their natural settings and applied as fill materials.

Table 3-1. Mean selected chemical properties of Florida soil fill materials used in a column study to evaluate the effect of soil properties on phosphorus leaching from st. augustinegrass at 0, 9, and 27 weeks after planting.

Harvest date and soil material	Organic matter ($g \cdot kg^{-1}$)	pH	Mehlich 3 Ca ($mg \cdot kg^{-1}$)	Mehlich 3 Fe ($mg \cdot kg^{-1}$)	Mehlich 3 Al ($mg \cdot kg^{-1}$)	Mehlich 3 P ($mg \cdot kg^{-1}$)	Water soluble P ($mg \cdot kg^{-1}$)	PSR[z]	DPS[y] (%)	SPSC[x] ($mg \cdot kg^{-1}$)
0 weeks after planting										
Myakka-Bh1	67.5	4.1	333	27.6	988	<12.5	0.45	0.004	0.69	99.2
Pomello-Bh	60.6	4.3	14.2	<5.0[w]	1593	193	1.25	0.105	19.12	-27.8
St. Johns-Bh	41.6	4.1	14.1	37.3	1481	<12.5	0	0.006	1.04	145.2
Paola-Bw	3.8	5.3	24.2	60.9	643	123	0.03	0.159	28.97	-53.6
St. Johns-E	1.6	5.8	29.3	<5.0	145	<12.5	0	0.026	4.73	10.8
9 weeks after planting										
Myakka-Bh1	67.6 a[v]	4.1 c	356 a	36.6 c	1138 c	<12.5 c	0.84 bc	0.004 d	0.87 d	113.3 b
Pomello-Bh	61.2 a	4.5 b	42.4 b	< 5.00 e	2406 a	339 a	2.80 a	0.123 b	22.3 b	-90.3 d
St. Johns-Bh	39.1 b	4.5 b	71.0 b	68.6 b	1962 b	<12.5 c	0.13 d	0.003 e	0.50 e	200.1 a
Paola-Bw	3.00 c	6.9 a	51.2 b	148 a	737 d	158 b	0.89 b	0.171 a	31.0 a	-74.7 d
St. Johns-E	2.20 d	6.8 a	62.2 b	5.10 d	171 e	<12.5 c	0.26 cd	0.031 c	5.72 c	11.7 c
27 weeks after planting										
Myakka-Bh1	66.1 a	4.0 b	330 a	32.7 c	1121 c	<12.5 d	0.24 bc	0.005 e	0.87 e	111.3 b
Pomello-Bh	69.0 a	4.5 b	65.7 b	<5.00 d	2172 a	313 a	2.50 a	0.126 b	22.8 b	-88.1 e
St. Johns-Bh	37.8 b	4.4 b	94.1 b	58.8 b	1862 b	18.1 c	0.16 bc	0.009 d	1.51 d	177.4 a
Paola-Bw	3.00 c	6.8 a	89.7 b	73.6 a	591 d	125 b	0.59 b	0.174 a	31.6 a	-60.2 d
St. Johns-E	2.30 c	6.6 a	87.1 b	<5.00 d	155 e	<12.5 d	0.14 c	0.036 c	6.37 c	10.0 c

[z]Phosphorus saturation ratio.
[y]Degree of phosphorus saturation.
[x]Soil phosphorus saturation capacity.
[w]Less then the detection limit of inductively coupled plasma-atomic emission spectroscopy.
[v]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

Table 3-2. Mean biomass of roots of st. augustinegrass grown on different Florida soil fill materials in a soil column conducted in Wimauma, FL.

Harvest date and soil material	Root biomass (g)
9-week harvest	
Myakka-Bh1	2.29 b
Pomello-Bh	2.65 b
St. Johns-Bh	4.92 a
Paola-Bw	3.32 ab
St. Johns-E	2.90 ab
27-week harvest	
Myakka-Bh1	8.58 a
Pomello-Bh	7.72 a
St. Johns-Bh	7.13 a
Paola-Bw	8.50 a
St. Johns-E	3.25 b

[z]Mean separation for each soil by Tukey's honestly significant difference test at $P \leq 0.05$.

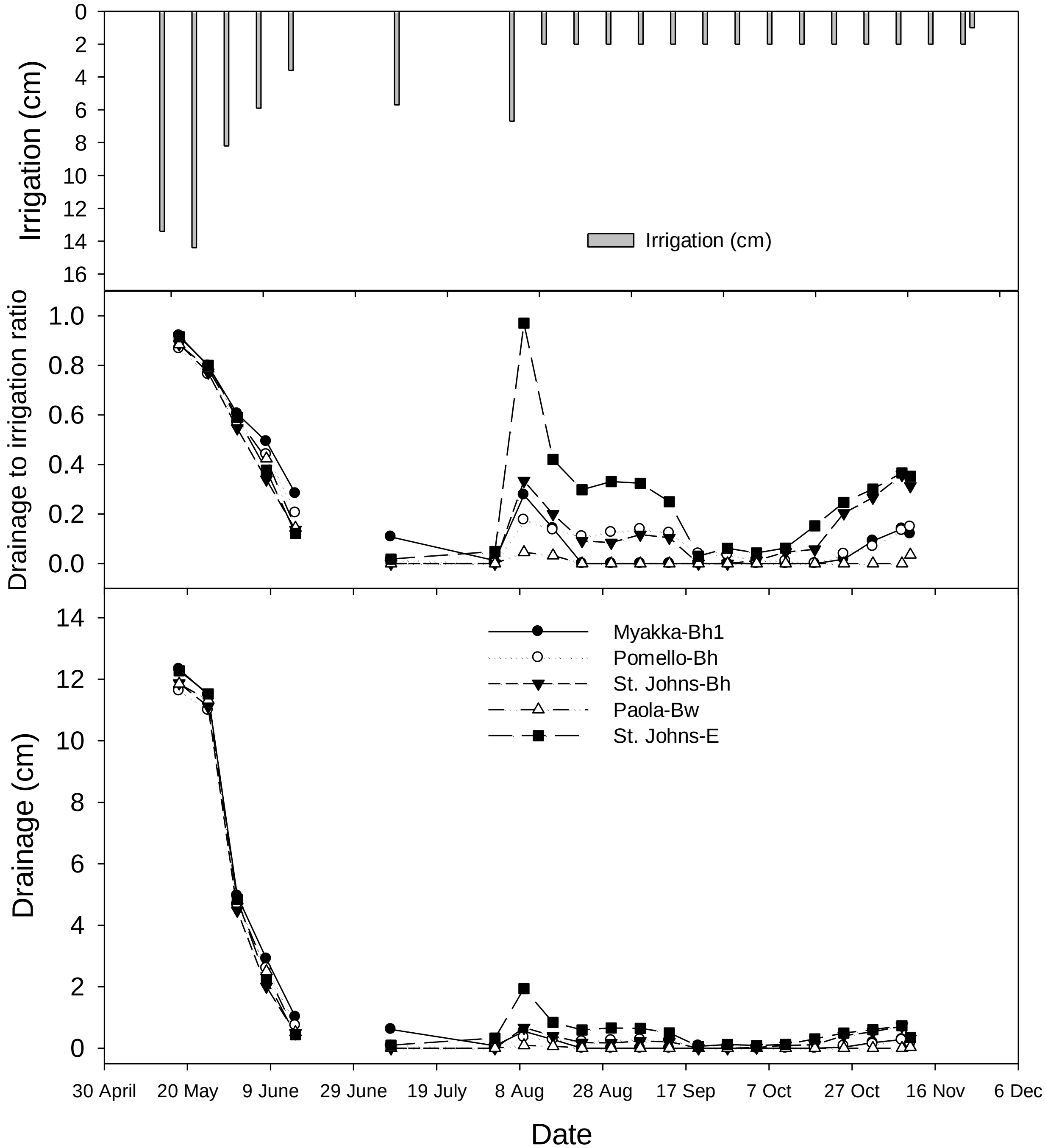

Figure 3-1. Temporal trends in mean weekly drainage collected soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials. Irrigation depths are shown on the top graph with the drainage to irrigation ratios shown in the middle graph. Irrigation depths for week six are missing due to a power outage to automatic timer that resulted in an unknown amount of water applied.

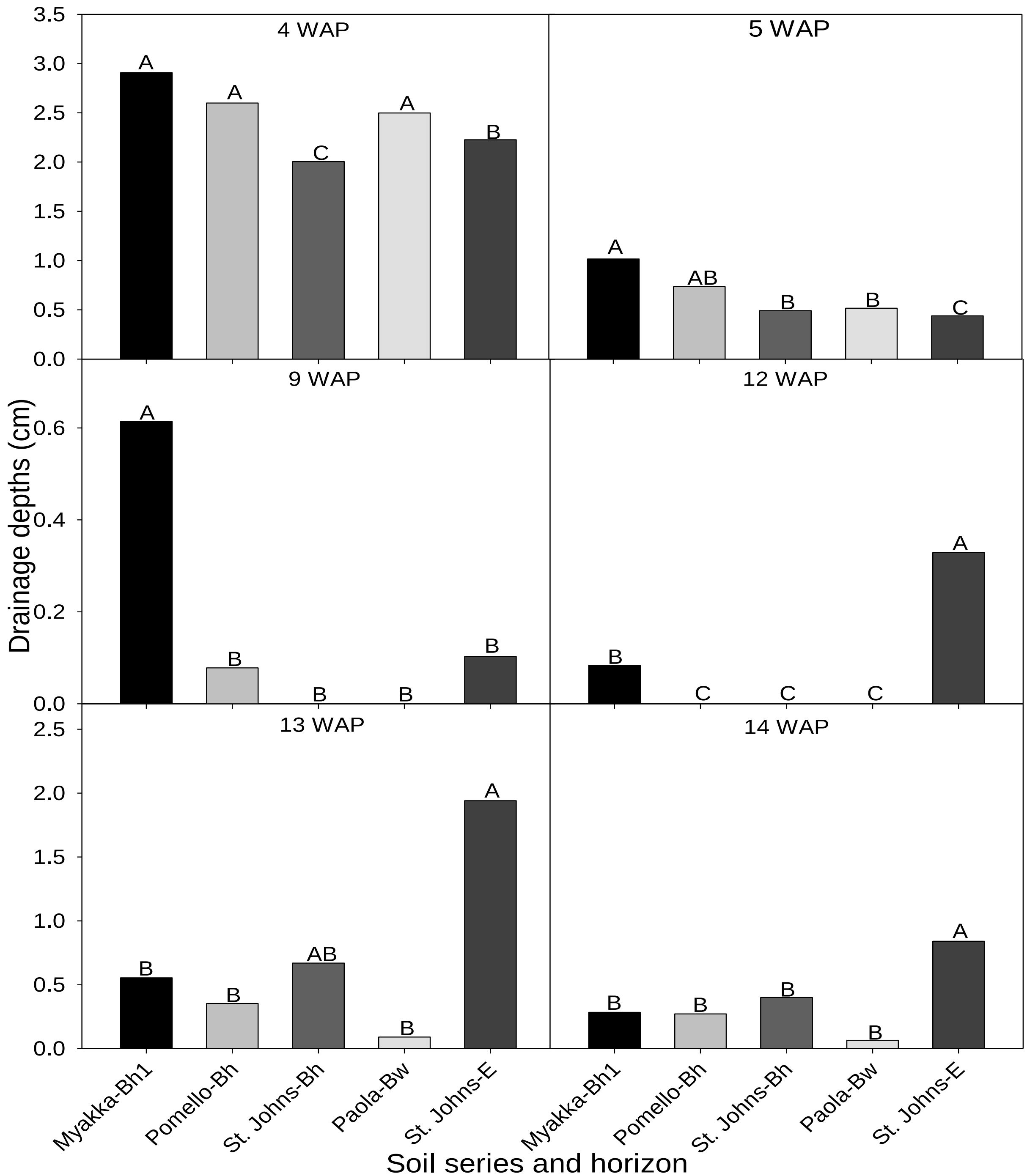

Figure 3-2. Mean drainage depths of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 4, 5, 9, 12, 13, and 14 weeks after planting (WAP). Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

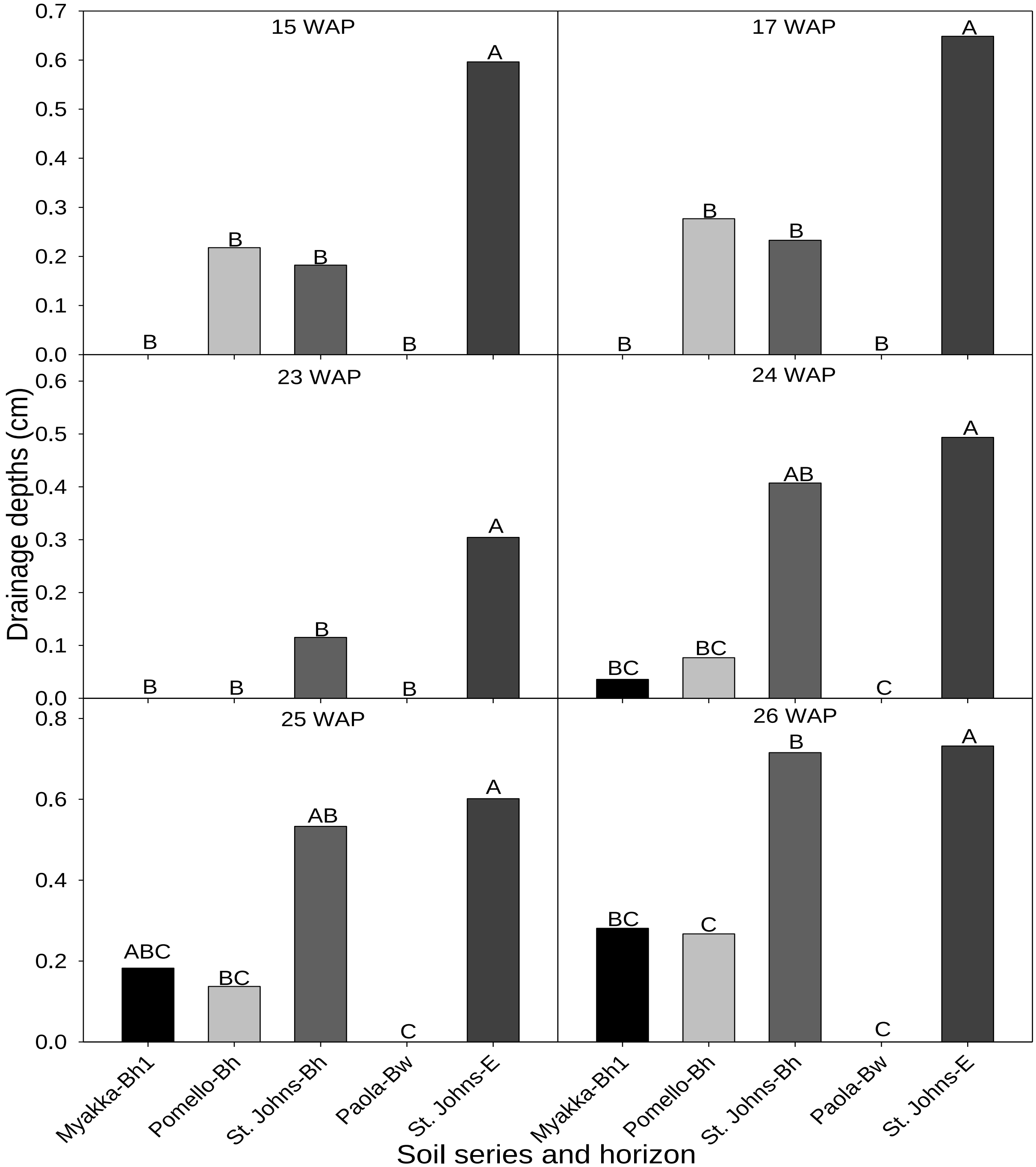

Figure 3-3. Mean drainage depths of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 15, 17, 23, 24, 25, and 26 weeks after planting (WAP). Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

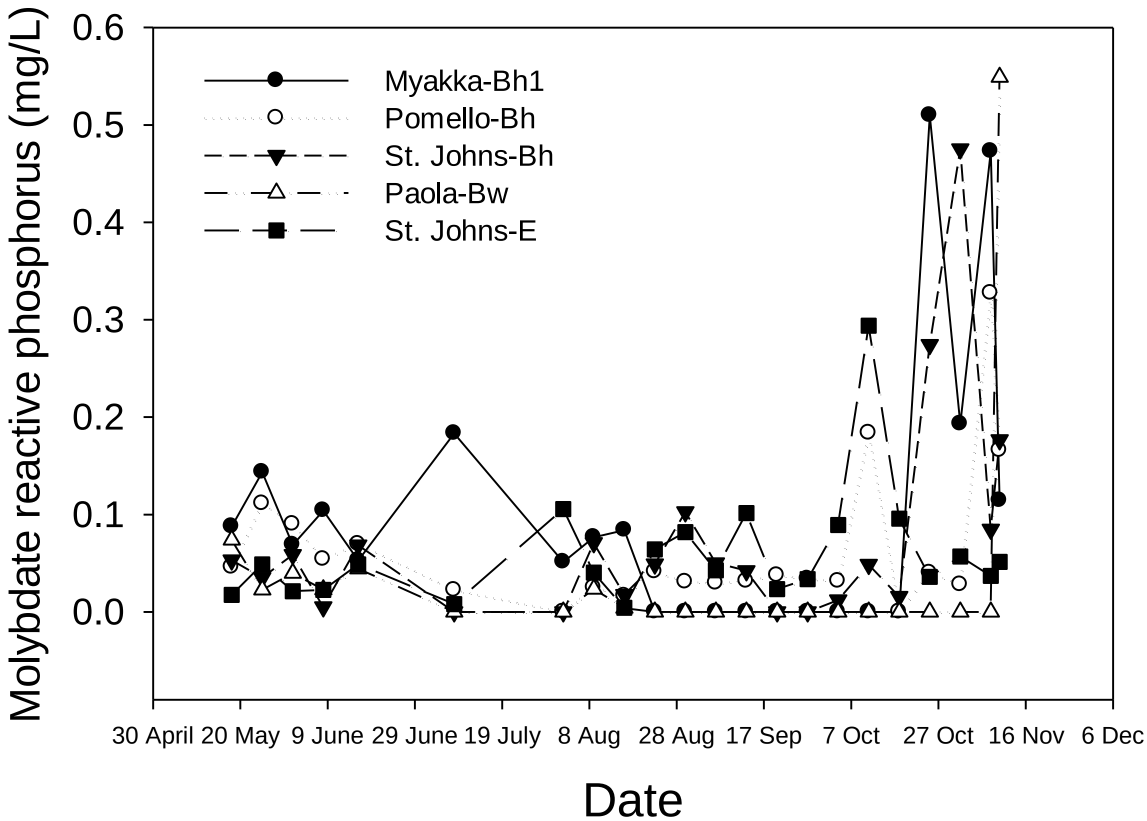

Figure 3-4. Temporal trends in mean weekly molybdate reactive phosphorus concentrations in leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials.

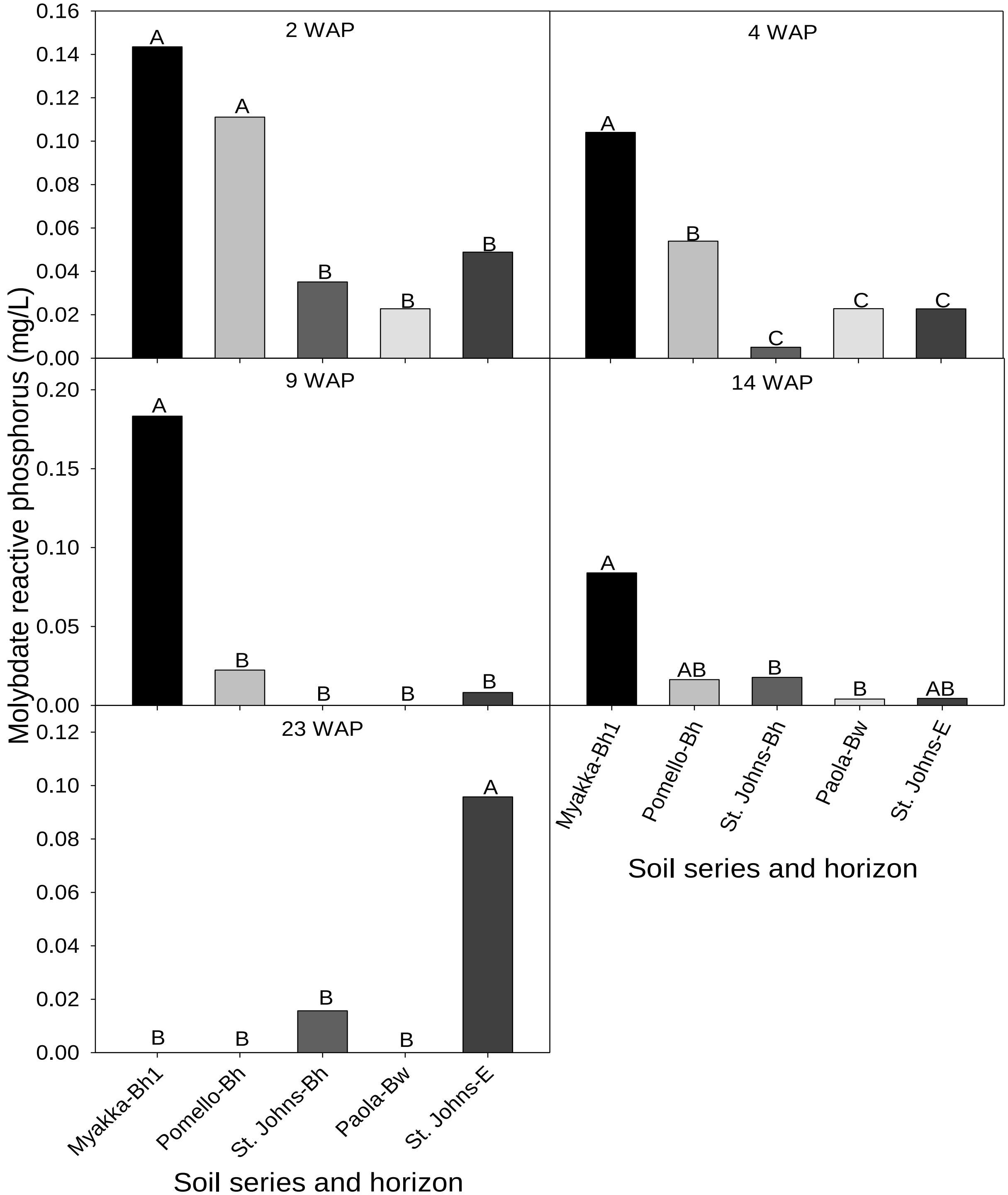

Figure 3-5. Mean molybdate reactive phosphorus concentrations of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 2, 4, 9, 14, and 23 weeks after planting (WAP). Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

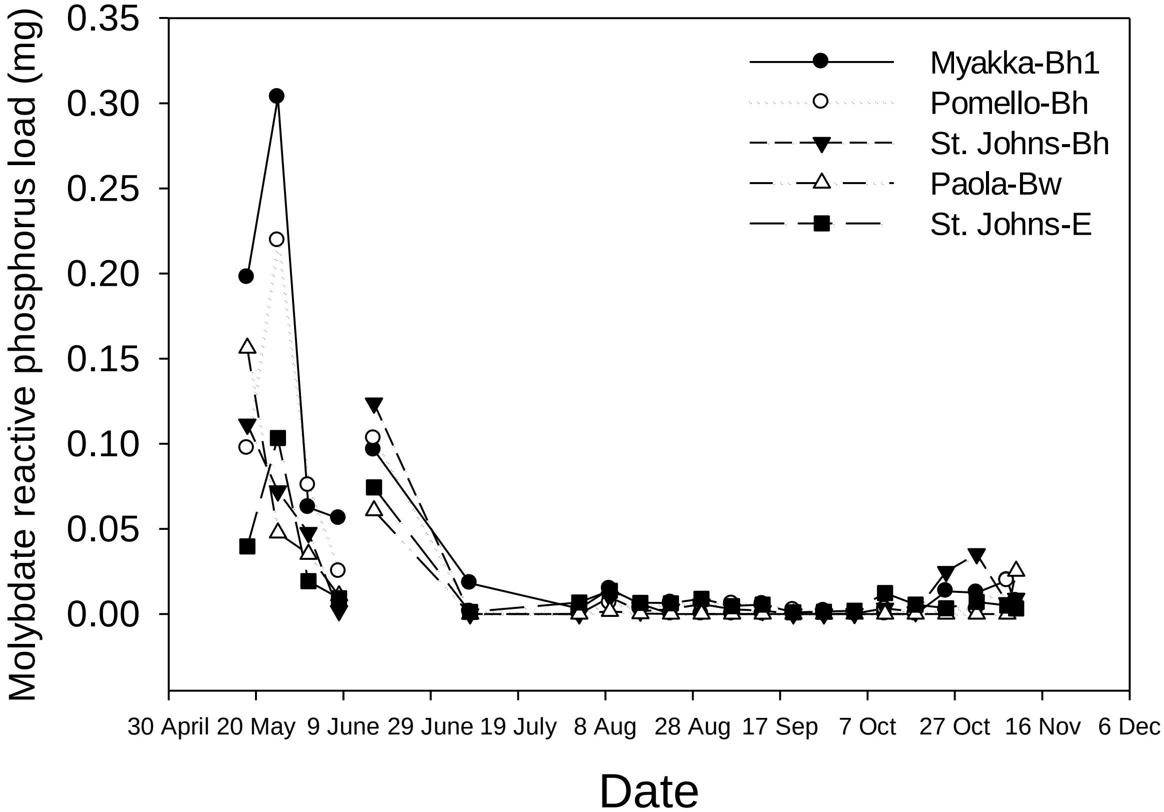

Figure 3-6. Temporal trends in mean molybdate reactive phosphorus loads in leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials.

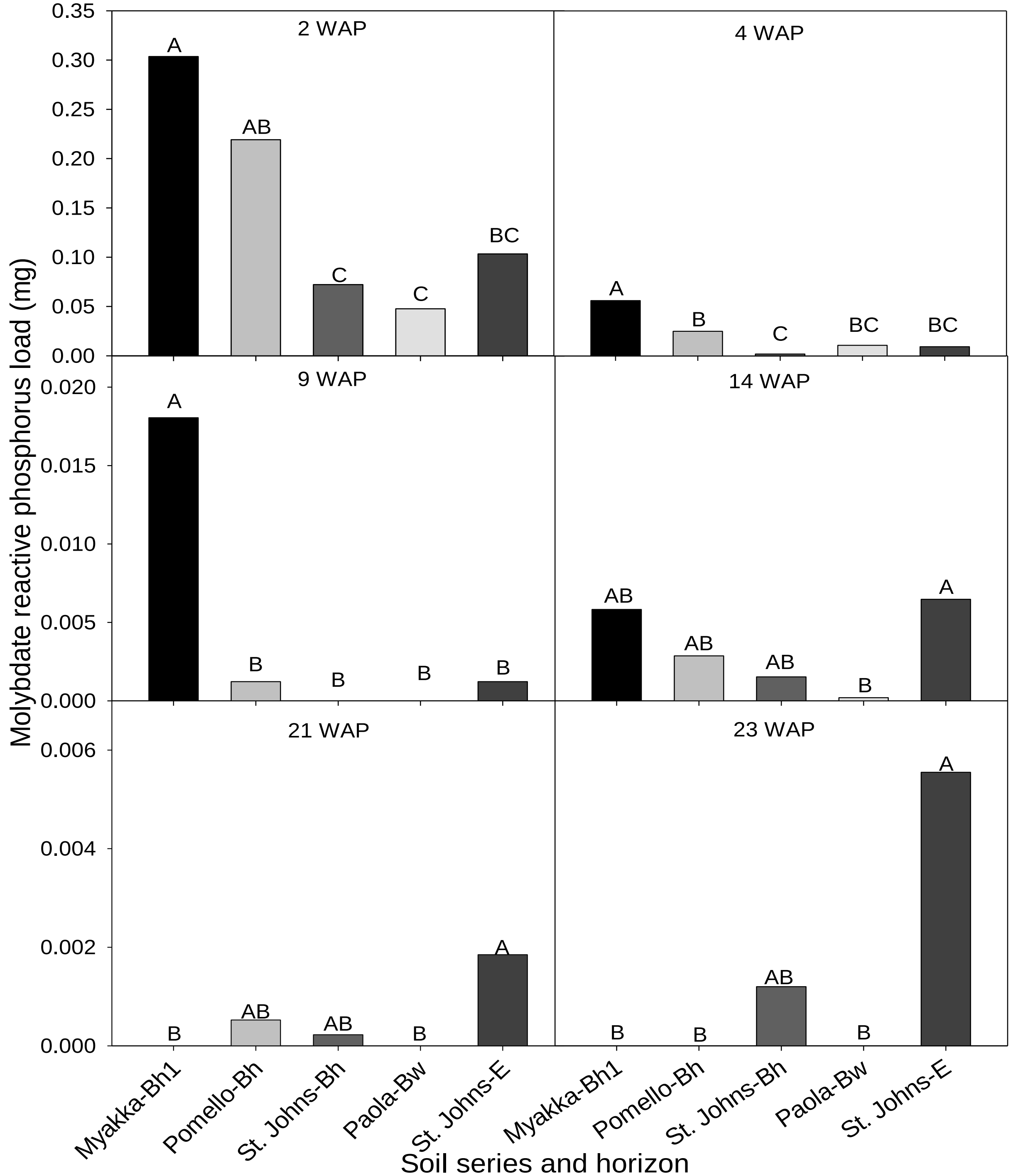

Figure 3-7. Mean molybdate reactive phosphorus loads of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 2, 4, 9, 14, 21, and 23 weeks after planting. Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

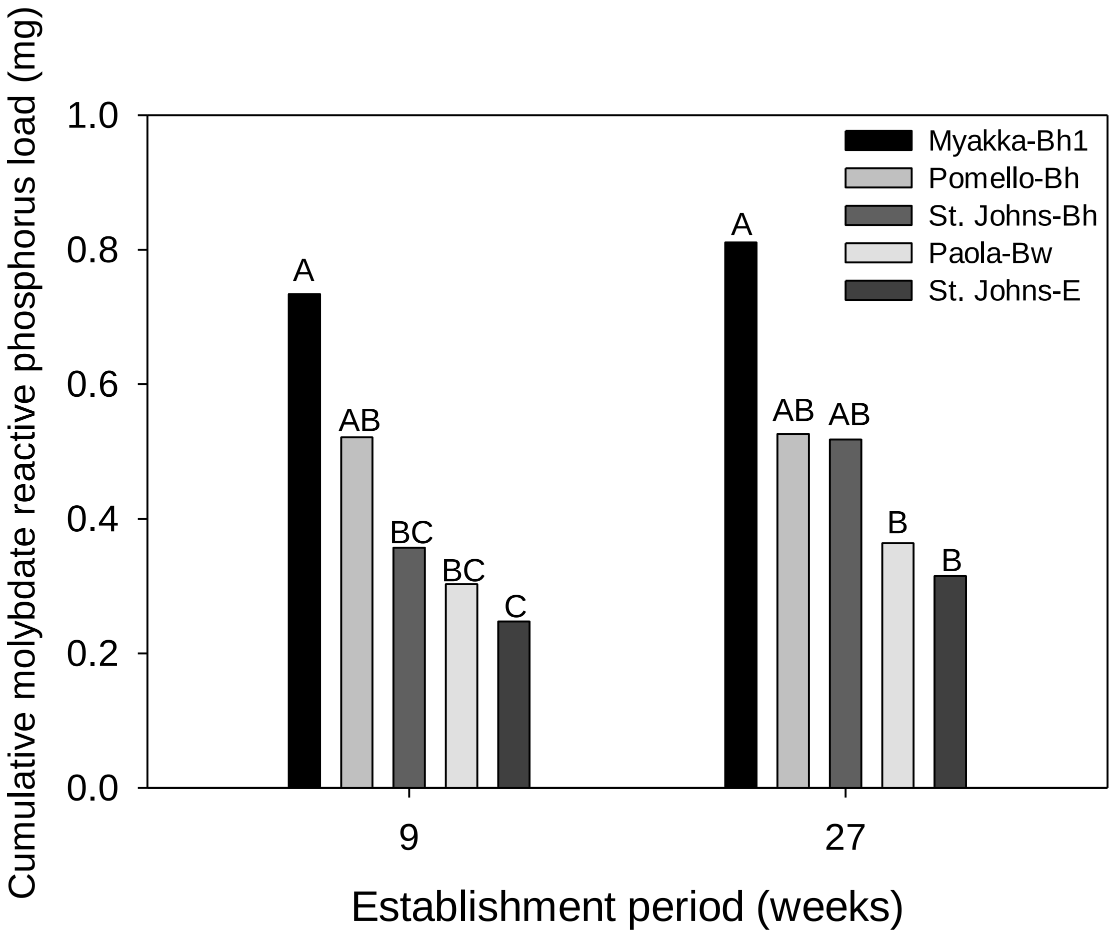

Figure 3-8. Mean cumulative molybdate reactive phosphorus loads in leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials during the 9- and 27-week establishment periods. Values within the same collection period with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

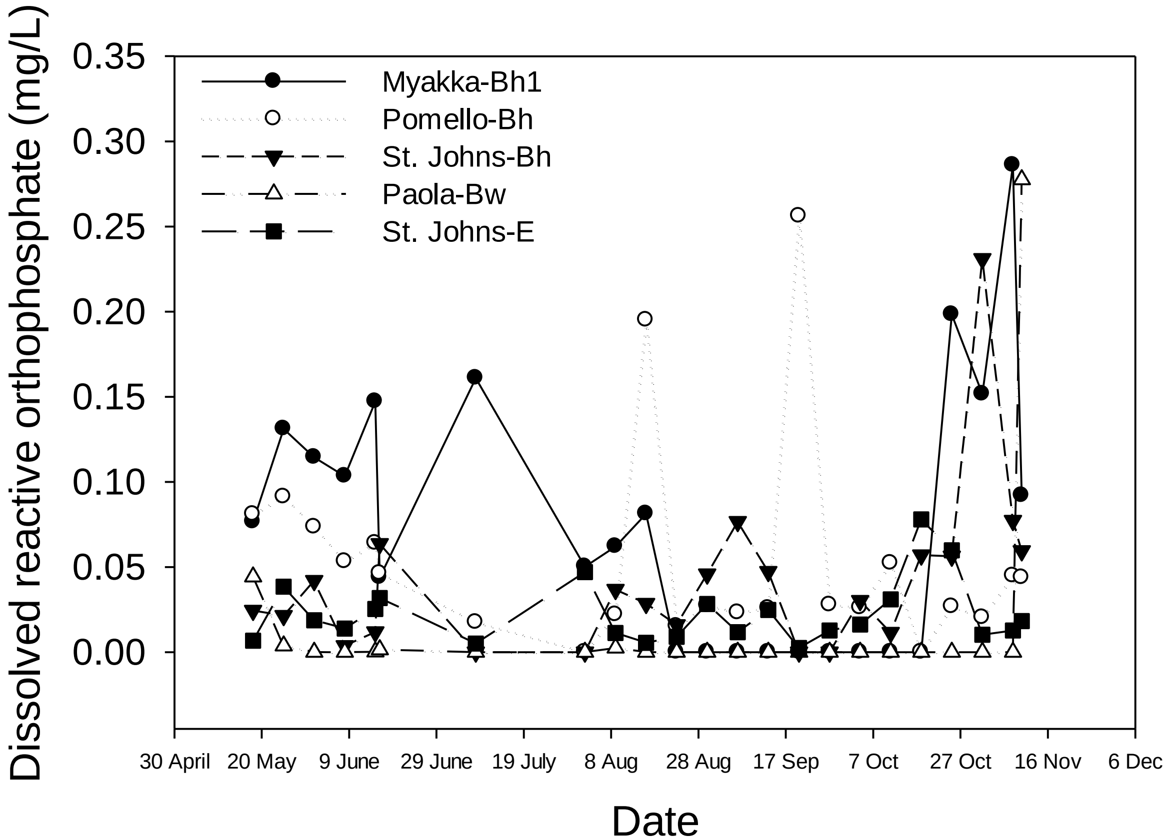

Figure 3-9. Temporal trends in mean weekly dissolved reactive orthophosphate concentrations in leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials.

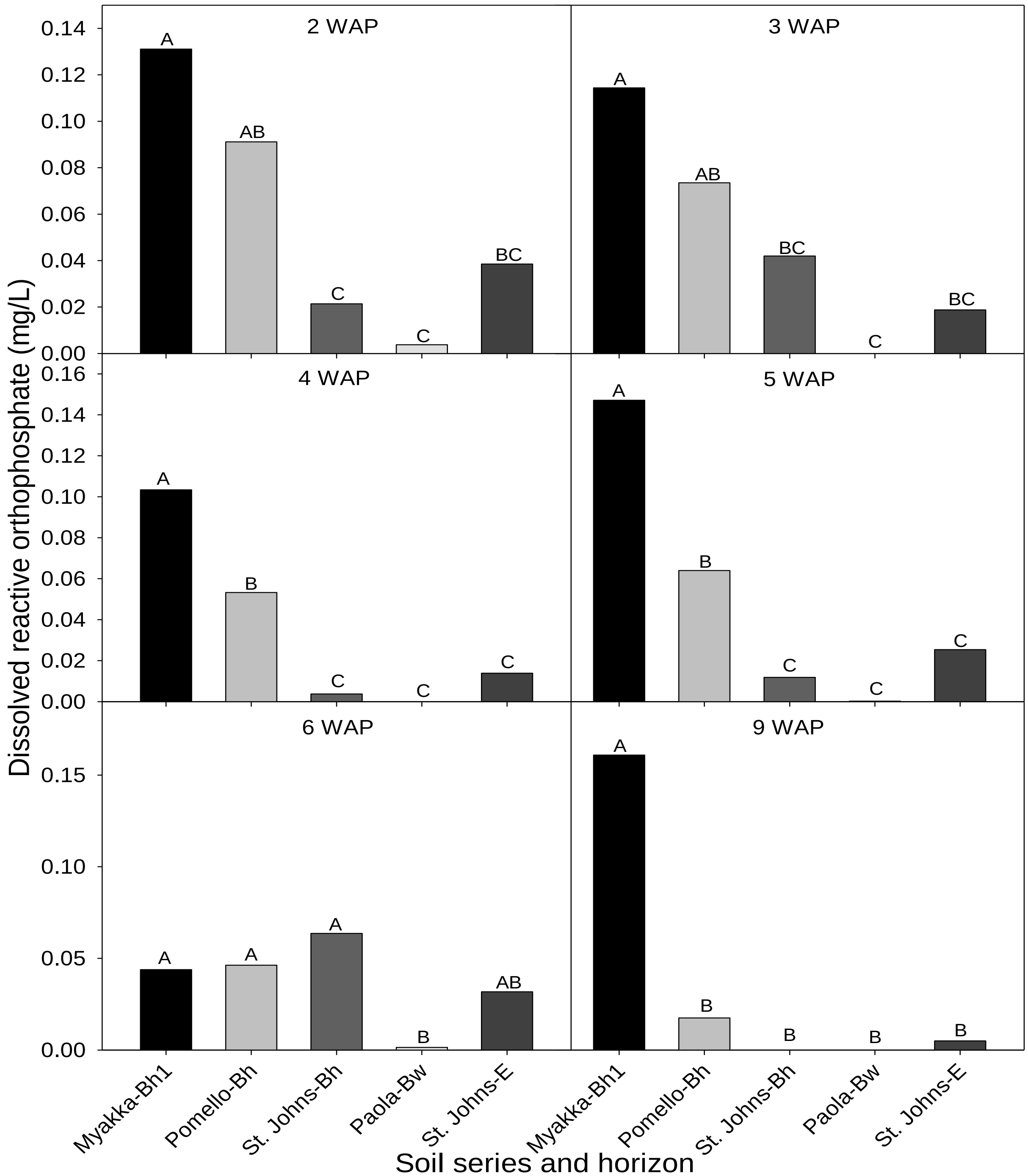

Figure 3-10. Mean dissolved reactive orthophosphate concentrations of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 2, 3, 4, 5, 6, and 9 weeks after planting (WAP). Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

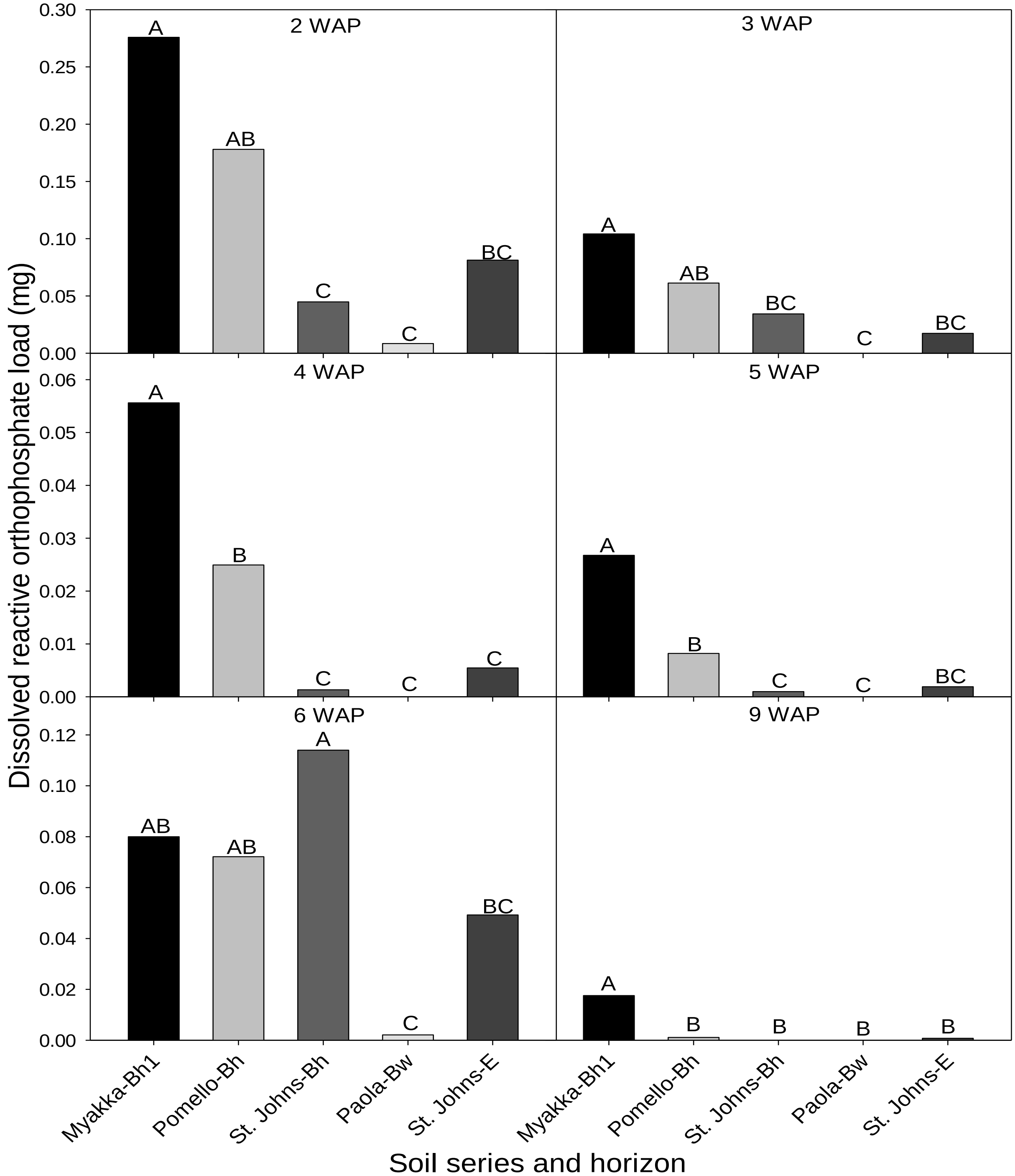

Figure 3-11. Mean dissolved reactive orthophosphate loads of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials at 2, 3, 4, 5, 6, and 9 weeks after planting. Values within the same collection date with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

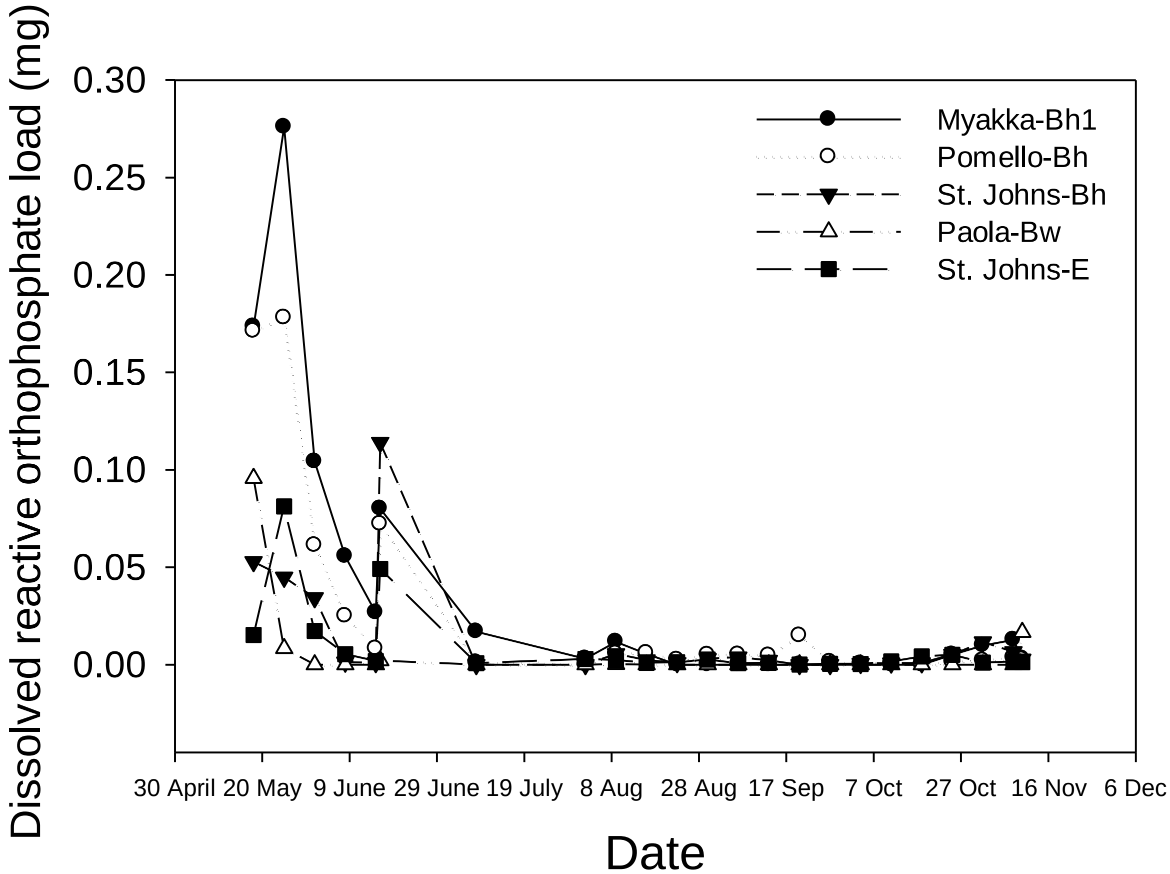

Figure 3-12. Temporal trends in mean dissolved reactive orthophosphate loads of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials.

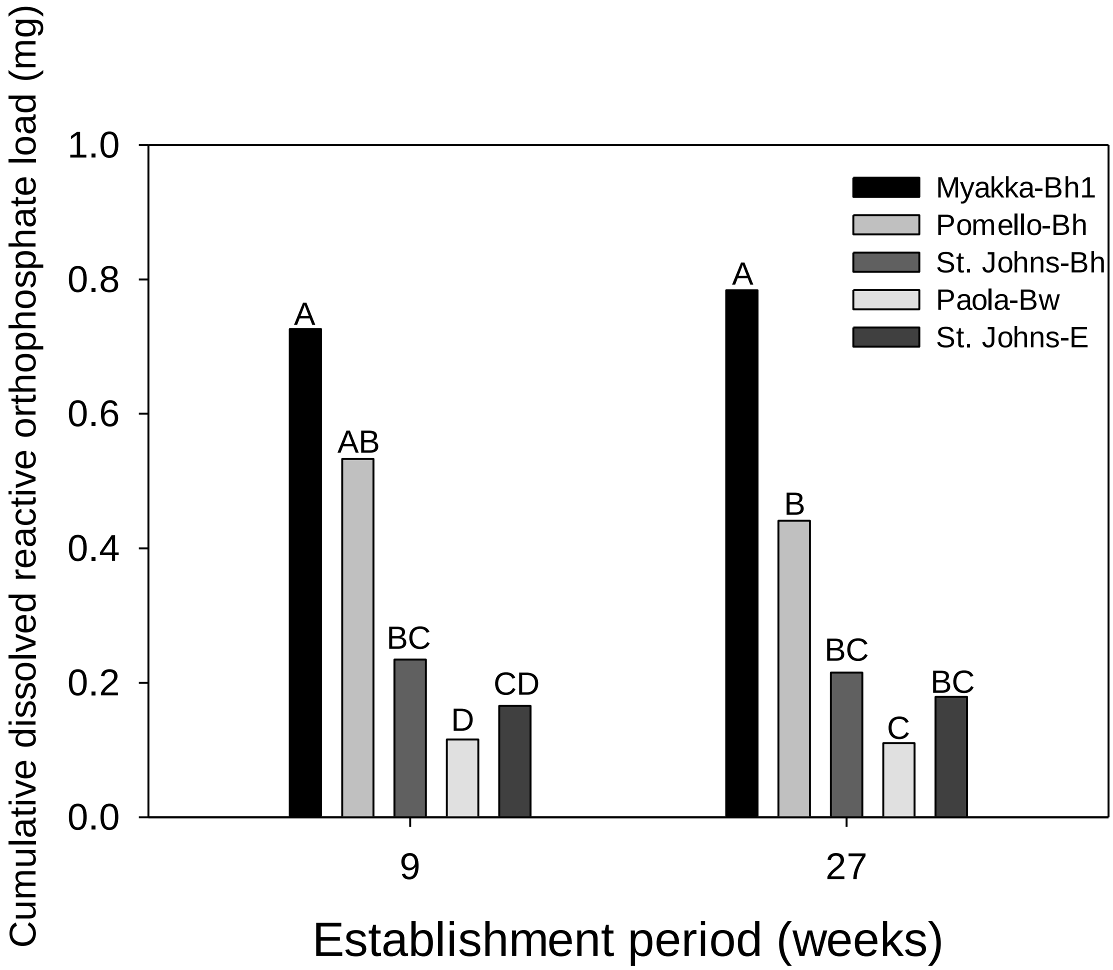

Figure 3-13. Mean cumulative dissolved reactive orthophosphate loads in leachate collected from soil coulmns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials during the 9- and 27-week establishment periods. Values within the same collection period with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

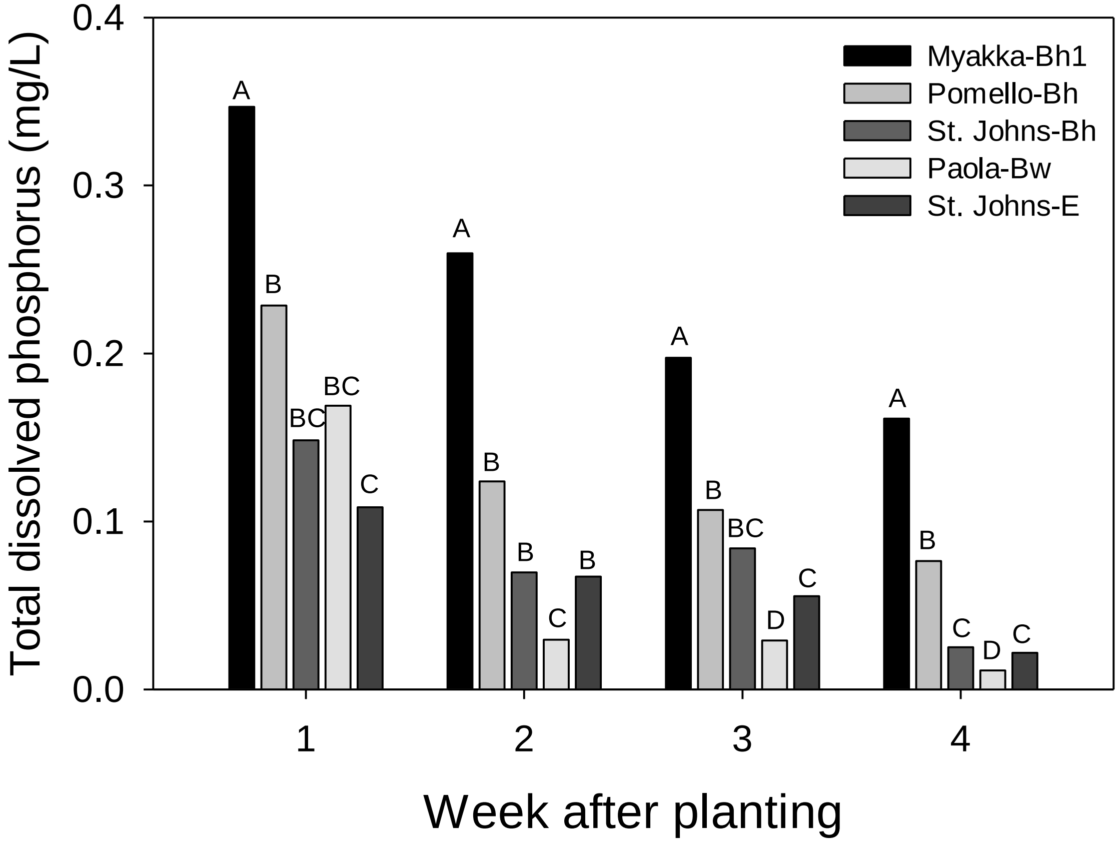

Figure 3-14. Mean total dissolved phosphorus concentrations of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials during the first four weeks after planting. Values within the same collection period with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

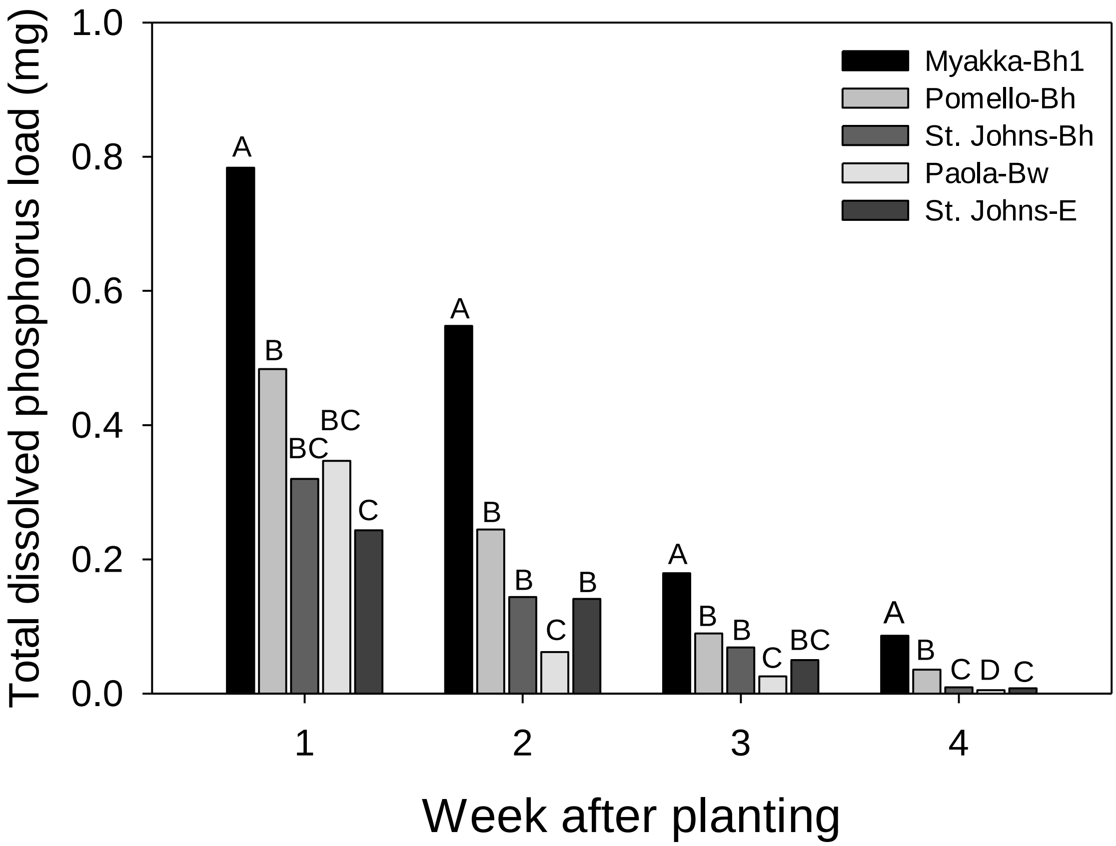

Figure 3-15. Mean total dissolved phosphorus loads of leachate collected from soil columns evaluating phosphorus leaching from st. augustinegrass establishing on different soil fill materials during the first four weeks after planting. Values within the same collection period with the same letter are not significantly different at $P < 0.05$ using Tukey's honestly significant difference test.

CHAPTER 4
CONCLUSION

Urban soils are typically disturbed due to cutting, mixing, and filling activities that occur during land development. Imported fill soil materials that are transported from various locations often contain variable amounts of sorbed phosphorus (P) and variable chemical properties that can affect their capacity to retain additional P. Over the 27-week study period, the low pH and high levels of organically complexed Al and Fe in spodic (Bh) horizons did not affect P bioavailability to and establishment of quality st. augustinegrass (STA) when used as topsoil fills. Results from this study did not dismiss the use of Bh horizons as fill materials in urban settings. However, homeowners should be aware that the potential for nutrient deficiencies to occur and production of low quality turfgrass may be elevated when growing on Bh horizon. Standard soils test (Mehlich 1 or Mehlich 3) or P saturation measurements like the P saturation ratio (PSR) and degree of P saturation (DPS) may not be enough to fully evaluate a soil's potential for establishing turfgrass as other physical and chemical properties are likely factors in turfgrass establishment.

The use of P saturation equations like the PSR, DPS, and SPSC were generally able to accurately predict P leaching loss from fill materials throughout our 27-week study. However, results from this study show that soil fill materials (mainly Bh) with low calculated P leaching loss potentials (low PSR and DPS values; positive SPSC values) can still leach high P concentrations and loads and can have comparable water soluble P concentrations to fill materials with higher calculated PSR and DPS values. This finding is important for environmental risk protection since soils with low predicted P loss potentials and little P added to them still can leached P concentrations that may impacted the quality surrounding water bodies. Results from our study also indicated that fill materials collected from different soil horizons should have different P saturation change points or threshold values.

While the results of this study did not indicate that use of a Bh horizon derived soil material will affect the establishment of STA, quality effects on STA grown on Bh horizons may be observed in STA if grown on Bh fill materials for longer periods then conducted in this study. Future field plot studies need to be performed to evaluate the long term effects on the quality of STA when using Bh horizons as fill materials. Future research should also evaluate the P leaching potential of many different soil fill materials with a wide range of initial P concentrations. Also more research needs to be conducted to confirm if other Bh and non-Bh horizon fill materials with low PSR and DPS values and positive SPSC values can act as possible P sources.

APPENDIX
CHEMICAL PROPERTIES AND PHOSPHORUS SORPTION CAPACITY OF SELECTED FLORIDA SPODIC HORIZONS

Soil Sample Collection

Soil samples from 30 spodic (Bh) horizons were obtained from five different geographical locations throughout Florida. Twelve Bh horizon samples were collected from various locations in the Austin Cary Memorial Forest (ACMF), located just northeast of Gainesville, FL (Site 1, Figure 2-1). Four of the twelve soil samples in ACMF were collected by auger from the Bh horizon of a Newnan sand (Sandy, siliceous, hyperthermic Oxyaquic Alorthod) (Soil Survey Staff, 2010). Eight of the twelve samples were collected from a Pomona sand (Sandy, siliceous, hyperhtermic Ultic Alaquod) (Soil Survey Staff, 2010). Two of the eight Pomona sand samples were collected from auger from different locations within ACMF. The remaining six of the eight Pomona sand samples were collected by shovel from a soil pit. Samples were taken from different depths and locations within the Bh horizon exposed in the soil pit.

Four Bh horizon samples were collected from two soil pits at the University of Florida – Institute of Food and Agricultural Sciences Gulf Coast Research and Education Center (GCREC) located in Wimauma, FL (Site 2, Figure 2-1). Two of the four soil samples were collected by shovel from a Bh horizon of a Myakka sand (Sandy, siliceous, hyperthermic Aeric Alaquod) (Soil Survey Staff, 2010). The remaining two soil samples were collected by shovel from a Bh horizon of a Zolfo sand (Sandy, siliceous, hyperhtermic Oxyaquic Alorthods) (Soil Survey Staff, 2010). An additional 11 samples were collected by auger from a commercial tomato farm located in Duette, FL (Site 3, Figure 2-1). Four of the 11 samples were collected from different Bh horizons of a Cassia sand (Sandy, siliceous, hyperthermic Oxyaquic Alorthods) (Soil Survey Staff, 2010). The remaining seven of the 11 samples were collected from different locations within the farm from the Bh horizons of a Myakka sand (Sandy, siliceous, hyperthermic Aeric Alaquod) (Soil Survey Staff, 2010).

The next soil sample was collected near Labelle, FL at a private cattle farm dominated by pine flatwoods vegetation (Site 5, Figure 2-1). A small circular soil pit was hand dug using a shovel. Soil was excavated from the Bh1 horizon of a Myakka sand (Sandy, siliceous, hyperthermic Aeric Alaquods) (Soil Survey Staff, 2010). An additional soil sample was collected from an active borrow pit operation located just southeast of Jacksonville, FL (Site 4, Figure 2-1). Soil was removed from the ground by backhoe operations prior to our arrival. The soil was collected from a Bh horizon of a Pomello fine sand (Sandy, siliceous, hyperthermic Oxyaquic) (Soil Survey Staff, 2010). Soil was also collected from a new residential housing development located east of Fruit Cove, FL (Site 4, Figure 2-1). Various soil horizons were exposed in a circular trench that was excavated prior to sampling. The exposed Bh horizon of a St. Johns sand (Sandy, siliceous, hyperthermic Typic Alaquods) (Soil Survey Staff, 2010) was collected.

Soil Characterization

Soil samples were air-dried at 25 ± 2°C for 12 to 14 days 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 using standard methods (Mylavarapu, 2009). Soil samples were extracted using the Mehlich 3 (M3) method (1:7 ratio of soil to 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA) (Baker et al., 2002). Mehlich 3 extracts were analyzed for phosphorus (P), calcium (Ca), aluminum (Al), and iron (Fe) using inductively coupled plasma-atomic emission spectroscopy (ICP–AES) at the Analytical

Research Laboratory (ARL) in Gainesville, FL. The M3 PSR (PSR_{M3}) values for the soils were calculated using the following equation:

$$PSR_{M3} = P_{M3} / (Al_{M3} + Fe_{M3}),$$

where P_{M3}, Al_{M3}, and Fe_{M3} are the concentration of M3 P, Al, and Fe expressed in mmol kg^{-1} (Maguire and Sims, 2002). Degree of P saturation was calculated using the following equation:

$$DPS_{M3} = [(P_{M3}) / \alpha\ (Al_{M3} + Fe_{M3})] \times 100,$$

where P_{M3}, Al_{M3}, and Fe_{M3} the concentration of M3 P, Al, and Fe are expressed in mmol kg^{-1} and α (0.55) is an empirical factor that compares different soils with respect to P saturation (Nair and Graetz, 2002). Water-soluble P (WSP) was determined by extracting soil with deionized water at a 1:10 soil to water ratio for 1 h, and determining P on the filtrate collected after passing through a 0.45-µm filter (Self-Davis et al., 2009). Phosphorus sorption index (PSI) was determined by adding 20 mL of 0.0012 M P sorption solution to 1 g of soil and shaking for 18 h. After shaking, the solution was placed in a centrifuge at 2000 rpm for 30 mins. The centrifugate was filtered through a 0.45-um filter (Sims, 2009a). Phosphorus sorption index (PSI) was calculated using the following equation (Sims, 2009a):

$$PSI\ (L \cdot kg^{-1}) = X / \log C,$$

where:

$$X = P\ sorbed\ (mg \cdot kg^{-1}) = [(75\ mg\ P / L - P_f) \times (0.020\ L)] / (0.001\ kg\ soil)$$

$$C = P\ concentration\ at\ equilibrium\ (mg \cdot L^{-1}),$$

and

$$P_f = Final\ P\ concentration\ after\ 18\ h\ equilibrium\ (mg \cdot L^{-1}).$$

Phosphorus concentration in the filtered supernatants from the WSP and PSI tests were determined on a spectrophotometer (Genesys 20; Thermo Fisher Scientific) at 880 nm using the molybdate blue method (Murphy and Riley, 1962). Soils were digested using the EPA method 3050 hot acid digestions (U.S. Environmental Protection Agency, 1986) and analyzed for total P using ICP–AES at the ARL in Gainesville, FL.

Table A-1. Selected chemical properties and phosphorus measurements of 30 Bh horizon samples collected from five locations throughout Florida.

Soil series/location and number	pH	Organic matter ($g \cdot kg^{-1}$)	Electrical conductivity ($\mu s \cdot cm^{-1}$)	P sorption index ($L \cdot kg^{-1}$)	Water soluble P ($mg \cdot kg^{-1}$)	Total P ($mg \cdot kg^{-1}$)
Newnan/ACMF[z]-1	4.8	44.7	74.5	311	0.18	61.5
Newnan/ACMF-2	4.8	37.8	67.2	211	0.51	74.4
Newnan/ACMF-3	5.1	24	65.5	135	0.25	39
Newnan/ACMF-4	4.7	25.2	67.8	210	0.03	58
Pomona/ACMF-5	5.7	7.1	47.6	81.3	0.4	38.8
Pomona/ACMF-6	5.5	21.1	79.1	183	0.47	65.5
Pomona/ACMF-7	5.1	30.5	57.1	157	3.5	154
Pomona/ACMF-8	5.4	18.6	43.3	144	5.8	172
Pomona/ACMF-9	5.3	24.5	54.3	233	3.2	149
Pomona/ACMF-10	5.2	22.2	53.4	185	3.8	156
Pomona/ACMF-11	5.5	14.4	41.9	110	5.8	160
Pomona/ACMF-12	5.6	17.5	44.2	130	6.7	180
Myakka/GCREC[y]-13	5.5	11.7	54.1	172	0.09	183
Myakka/GCREC-14	5.3	10.8	49	154	0.08	163
Zolfo/GCREC-15	5.3	17.1	76.8	256	0.11	613
Zolfo/GCREC-16	5.2	19.9	83.2	304	0.06	666
Cassia/Duette-17	6.7	30.7	77.9	257	9.8	1299
Cassia/Duette-18	5.5	31.3	74.8	216	6.6	676
Cassia/Duette-19	5.5	38.8	130	275	2.1	327
Cassia/Duette-20	5.3	40.9	105	572	0.04	1237
Myakka/Duette-21	5.9	10.5	63	143	0.29	88.4
Myakka/Duette-22	6.5	11.5	65.6	128	1.7	122
Myakka/Duette-23	5.4	30.6	274	327	0.03	108
Myakka/Duette-24	6.2	16	63	194	0.17	74.1
Myakka/Duette-25	6.8	12	57.6	203	0.19	204

Table A-1. Continued.

Soil series/location and number	pH	Organic matter ($g \cdot kg^{-1}$)	Electrical conductivity ($\mu s \cdot cm^{-1}$)	P sorption index ($L \cdot kg^{-1}$)	Water soluble P ($mg \cdot kg^{-1}$)	Total P ($mg \cdot kg^{-1}$)
Myakka/Duette-26	6.4	64.1	30.2	754	0.5	990
Myakka/Duette-27	5.9	26.7	148	347	0.18	114
Myakka/Labelle-28	4.1	67.5	—	—	0.45	—
Myakka/Fruit Cove-29	4.3	60.6	—	—	1.3	—
St. Johns/Jacksonville-30	4.1	41.6	—	—	0	—
Mean	5.4	27.7	75.8	237	1.8	303
Standard Deviation	0.7	16	47.2	143	2.6	364
Maximum	6.8	67.5	274	754	9.8	1299
Minimum	4.1	7.1	30.2	81.3	0	38.8
Range	2.7	60.4	243	673	9.8	1260

[z]Austin Cary Memorial Forest.
[y]Gulf Coast Research and Education Center.

Table A-2. Mehlich 3 nutrients and phosphorus saturation measurements of 30 Bh horizon samples collected from five locations throughout Florida.

Soil series/location and number	Mehlich 3 P ($mg \cdot kg^{-1}$)	Mehlich 3 Ca ($mg \cdot kg^{-1}$)	Mehlich 3 Fe ($mg \cdot kg^{-1}$)	Mehlich 3 Al ($mg \cdot kg^{-1}$)	PSR	DPS (%)
Newnan/ACMF-1	< 12.5	41.1	36.4	2002	0.003	0.49
Newnan/ACMF-2	30.5	12.4	16	1398	0.019	3.43
Newnan/ACMF-3	18.6	19.1	50.8	1105	0.014	2.61
Newnan/ACMF-4	30.5	12.6	12.27	1354	0.02	3.55
Pomona/ACMF-5	24.8	8.7	7.85	555	0.039	7.04
Pomona/ACMF-6	41.3	11.1	43.2	1035	0.034	6.2
Pomona/ACMF-7	133	16.6	44	1174	0.097	17.63

Table A-2. Continued.

Soil series/location and number	Mehlich 3 P ($mg\cdot kg^{-1}$)	Mehlich 3 Ca ($mg\cdot kg^{-1}$)	Mehlich 3 Fe ($mg\cdot kg^{-1}$)	Mehlich 3 Al ($mg\cdot kg^{-1}$)	PSR[z]	DPS[y] (%)
Pomona/ACMF[x]-8	166	19.9	32.8	1087	0.131	23.79
Pomona/ACMF-9	115	9.4	30.2	1425	0.07	12.64
Pomona/ACMF-10	140	7.7	23.2	1366	0.089	16.12
Pomona/ACMF-11	173	9.8	28.4	1112	0.134	24.35
Pomona/ACMF-12	198	6.9	40.9	1273	0.134	24.29
Myakka/GCREC[w]-13	74.6	41.7	48	1128	0.056	10.26
Myakka/GCREC-14	68.8	30.2	47.9	1129	0.052	9.46
Zolfo/GCREC-15	63.1	27.4	17.6	1368	0.04	7.26
Zolfo/GCREC-16	57.1	33.3	19.7	1457	0.034	6.17
Cassia/Duette-17	388	1534	13.8	1332	0.253	45.94
Cassia/Duette-18	379	131	7.9	1491	0.221	40.19
Cassia/Duette-19	135	466	54.8	1385	0.083	15.14
Cassia/Duette-20	57.5	12.4	6.8	1585	0.032	5.74
Myakka/Duette-21	25.4	252	174	718	0.028	5.02
Myakka/Duette-22	68.9	574	28.3	736	0.08	14.54
Myakka/Duette-23	< 12.5	233	5.6	1505	0.004	0.66
Myakka/Duette-24	25.5	330	33.5	1136	0.019	3.51
Myakka/Duette-25	57.3	348	11.3	1183	0.042	7.64
Myakka/Duette-26	15.6	349	< 5.0	1687	0.008	1.47
Myakka/Duette-27	15.2	203	37.5	1467	0.009	1.62
Myakka/Labelle-28	< 12.5	333	27.6	988	0.004	0.69
Myakka/Fruit Cove-29	193	14.2	< 5.0	1593	0.105	19.12
St. Johns/Jacksonville-30	< 12.5	14.1	37.3	1481	0.006	1.04
Mean	90.7	170	31.4	1275	0.062	11.25
Standard Deviation	99.2	304	31.1	300	0.063	11.38

Table A-2. Continued.

Soil series/location and number	Mehlich 3 P $(mg \cdot kg^{-1})$	Mehlich 3 Ca $(mg \cdot kg^{-1})$	Mehlich 3 Fe $(mg \cdot kg^{-1})$	Mehlich 3 Al $(mg \cdot kg^{-1})$	PSR[z]	DPS[y] (%)
Maximum	388	1534	174	2002	0.253	45.94
Minimum	12.5	6.9	5	554.8	0.003	0.49
Range	376	1527	169	1447	0.25	45.45

[z]Phosphorus saturation ratio.
[y]Degree of phosphorus saturation.
[z]Austin Cary Memorial Forest.
[y]Gulf Coast Research and Education Center.

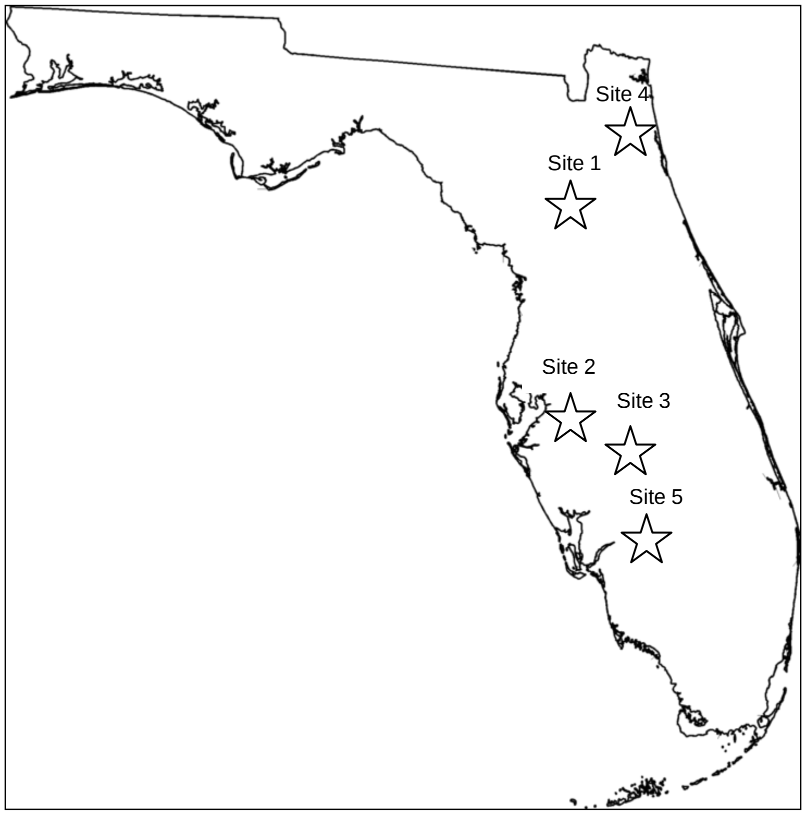

Figure A-1. Geographic locations of 30 Bh horizon samples collected for the characterization of various chemical properties.

LIST OF REFERENCES

Anderson, D.M., P.M. Glibert, and J.M. Burkholder. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25:704-726.

Baker, W.H., C.G. Herron, S.D. Carroll, M.A. Henslee, D.C. Lafex, and E.E. Evans. 2002. A comparative summary of standard Mehlich 3 soil test with a modified Mehlich 3 dilution ratio procedure. Arkansas Agricultural Expt. Sta., Univ. Arkansas, Fayetteville. <http://arkansasagnews.uark.edu/205.pdf>.

Ballard, R. and J.G.A. Fiskell. 1974. Phosphorus retention in coastal-plain forest soils: Relationship to soil properties. Soil Sci. Soc. Amer. J. 38:250-255.

Barton, L. and T.D. Colmer. 2006. Irrigation and fertiliser strategies for minimising nitrogen leaching from turfgrass. Agric. Water Mgt. 80:160-175.

Beard, J.B. and R.L. Green. 1994. The role of turfgrasses in environmental-protection and their benefits to humans. J. Environ. Qual. 23:452-460.

Borggaard, O.K., S.S. Jorgensen, J.P. Moberg, and B. Rabenlange. 1990. Influence of organic-matter on phosphate adsorption by aluminum and iron-oxides in sandy soils. J. Soil Sci. 41:443-449.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analyses of soils. Agron. J. 54:464-465.

Brady, N.C. and R.R. Weil. 2002. The nature and properties of soil. 13th ed. Prentice Hall, Upper Saddle River, NJ.

Brar, G.S. and A.J. Palazzo. 1995. Shoot and root development of tall and hard fescues in 2 different soils. J. Environ. Qual. 24:777-781.

Breeuwsa, A., J.G.A. Rijerink, and O.F. Schoumans. 1995. Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming, p. 239-249. In: K. Steele (ed.). Animal watse and the land-water interface. Lewis-CRC Press, N.Y.

Broschat, T.K. and M.L. Elliott. 2004. Nutrient distribution and sampling for leaf analysis in St. Augustinegrass. Commun. Soil Sci. Plant Analysis 35:2357-2367.

Camberato, J. 2001. Irrigation water quality. Clemson University Turfgrass Program. Clemson. 12 Apr. 2012. <http://www.scnla.com/Irrigation_Water_Quality.pdf>.

Carlise, V.W. and R.B. Brown. 1982. Florida soil identification handbook. Univ. of Florida, Inst. Food Agr. Sci., Gainesville, FL.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Applications 8:559-568.

Carrow, R.N. 1989. Managing turf for maximum root growth. Golf Course Mgt, Athens. <http://archive.lib.msu.edu/tic/gcman/article/1989jul18.pdf>.

Chakraborty, D., V.D. Nair, M. Chrysostome, and W.G. Harris. 2011a. Soil phosphorus storage capacity in manure-impacted Alaquods: Implications for water table management. Agr. Ecosystem Environ. 142:167-175.

Chakraborty, D., V.D. Nair, W.G. Harris, and R.D. Rhue. 2011b. The potential for plants to remove phosphorus from the spodic horizon. Univ. Florida-IFAS, Gainesville. 10 Feb. 2012. <http://edis.ifas.ufl.edu/ss560>.

Christians, N.E., D.P. Martin, and J.F. Wilkinson. 1979. Nitrogen, phosphorus, and potassium effects on quality and growth of Kentucky bluegrass and creeping bentgrass. Agron. J. 71:564-567.

Chrysostome, M., V.D. Nair, W.G. Harris, and R.D. Rhue. 2007. Laboratory validation of soil phosphorus storage capacity predictions for use in risk assessment. Soil Sci. Soc. Amer. J. 71:1564-1569.

Colclough, T. and P.M. Canaway. 1989. Fertilizer nutrition of sand golf greens III: Botanical composition and ground cover. J. Sports Turf Res. Inst. 65:55-63.

Collins, M.E. 2010. Key to soil orders in Florida. Univ. of Florida, Inst. Food Agr. Sci. , Gainesville. 7 May 2010. <http://edis.ifas.ufl.edu/ss113>.

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. J. Environ. Qual. 27:261-266.

Deconinck, F. 1980. Major mechanisms in formation of spodic horizons. Geoderma 24:101-128.

Easton, Z.M. and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Environ. Qual. 33:645-655.

Engelsjord, M.E. and B.R. Singh. 1997. Effects of slow-release fertilizers on growth and on uptake and leaching of nutrients in Kentucky bluegrass turfs established on sand-based root zones. Can. J. Plant Sci. 77:433-444.

Erickson, J.E., J.L. Cisar, G.H. Snyder, and J.C. Volin. 2005. Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. Crop Sci. 45:546-552.

Erickson, J.E., D.M. Park, J.L. Cisar, G.H. Snyder, and A.L. Wright. 2010. Effects of sod type, irrigation, and fertilization on nitrate-nitrogen and orthophosphate-phosphorus leaching from newly established St. Augustinegrass sod. Crop Sci. 50:1030-1036.

Fageria, N.K., R.J. Wright, and V.C. Baligar. 1988. Rice cultivar evaluation for phosphorus use efficiency. Plant Soil 111:105-109.

Florida Department of Agriculture and Consumer Services. 2010. Urban turf rule fact sheet. Florida Dept. Agri. Consumer Serv., Tallahassee. <http://www.flaes.org/pdf/urban_turf_fact_sheet.pdf>.

Florida Department of Environmental Protection. 2010. Model ordinance for the Florida-friendly fertilizer use on urban landscapes. Florida Dept. Environ. Protection, Tallahassee. 1 May 2011. <http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/dep-fert-modelord.pdf>.

Fox, T.R., N.B. Comerford, and W.W. McFee. 1990. Phosphorus and aluminum release from a spodic horizon mediated by organic-acids. Soil Sci. Soc. Amer. J. 54:1763-1767.

Freese, D., S. Vanderzee, and W.H. Vanriemsdijk. 1992. Comparison of different models for phosphate sorption as a fiunction of the iron and aluminum-oxides of soils. J. Soil Sci. 43:729-738.

Fry, J.D., M.A. Harivandi, and D.D. Minner. 1989. Creeping bentgrass response to P and K on sand medium. HortScience 24:623-624.

Goldberg, S. and G. Sposito. 1985. On the mechanism of specific phosphate-adsorption by hydroxylated mineral surfaces: A review. Commun. Soil Sci. Plant Analysis 16:801-821.

Harris, W.G., S.H. Crownover, and N.B. Comerford. 1995. Experimental formation of Aquod-like features in sandy coastal-plain soils. Soil Sci. Soc. Amer. J. 59:877-886.

Harris, W.G., R.D. Rhue, G. Kidder, R.B. Brown, and R. Littell. 1996. Phosphorus retention as related to morphology of sandy coastal plain soil materials. Soil Sci. Soc. Amer. J. 60:1513-1521.

Hartman, R., F. Alcock, and C. Pettit. 2008. The spread of fertilizer ordinances in Florida. Sea Grant Law Policy J. 1:98-114.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 2005. Soil fertility and fertilizers. 7th ed. Prentice Hall, Upper Saddle River, N.J.

Haydu, J.J., L.N. Satterhwaite, and J.L. Cisar. 2005. An economic and agronomic profile of Florida's sod industry in 2003. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 10 Jan. 2012. <http://edis.ifas.ufl.edu/pdffiles/FE/FE56100.pdf>.

Heckrath, G., P.C. Brookes, P.R. Poulton, and K.W.T. Goulding. 1995. Phosphorus leaching from soils containing different phosphorus concentrations in the broadbalk experiment. J. Environ. Qual. 24:904-910.

Heydari, A. and G.M. Balestra. 2008. Nutritional disorders of turfgrass, p. 211-223. In: M. Pessarakli (ed.). Handbook of turfgrass management and physiology. CRC Press, Boca Raton, FL.

Hongthanat, N., J.L. Kovar, and M.L. Thompson. 2011. Sorption indices to estimate risk of soil phosphorus loss in the Rathbun lake watershed, Iowa. Soil Sci. 176:237-244.

Ibrikci, H., N.B. Comerford, E.A. Hanlon, and J.E. Rechcigl. 1994. Phosphorus uptake by bahiagrass from Spodosols: Modeling of uptake from different horizons. Soil Sci. Soc. Amer. J. 58:139-143.

Ibrikci, H., E.A. Hanlon, and J.E. Rechcigl. 1999. Inorganic phosphorus and manure effects on bahiagrass production on a Spodosol. Nutrient Cycling Agroecosystems 54:259-266.

Kaschl, A., V. Romheld, and Y. Chen. 2002. The influence of soluble organic matter from municipal solid waste compost on trace metal leaching in calcareous soils. Sci. Total Environ. 291:45-57.

Kidder, G., E.A. Hanlon, T.H. Yeager, and G.L. Miller. 2003. IFAS standardized fertilization recommendations for environmental horticulture crops. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 20 Mar. 2012. <http://mrec.ifas.ufl.edu/ldspmgt/Ldsp%20Turf%20Mgmt/PDFfiles/SL141.pdf>.

King, K.W., K.L. Hughes, J.C. Balogh, N.R. Fausey, and R.D. Harmel. 2006. Nitrate-nitrogen and dissolved reactive phosphorus in subsurface drainage from managed turfgrass. J. Soil Water Conserv. 61:31-40.

Landschoot, P. 2003. Turfgrass fertilization: A basic guide for professional turfgrass managers. Pennsylvania State Univ., University Park. 6 June 2011. <http://plantscience.psu.edu/research/centers/turf/extension/factsheets/turfgrass-fertilization-professional#pit>.

Lawson, D.M. and T.W. Colclough. 1991. Fertiliser nitrogen, phosphorus and potassium leaching from fine turf growing on three different rootzone materials. J. Sports Turf Res. Inst. 67:145-152.

Lehmann, A. and K. Stahr. 2007. Nature and significance of anthropogenic urban soils. J. Soils Sediments 7:247-260.

Linde, D.T. and T.L. Watschke. 1997. Nutrients and sediment in runoff from creeping bentgrass and perennial ryegrass turfs. J. Environ. Qual. 26:1248-1254.

Lindsay, W.L. 2001. Chemical equilibria in soils. The Blackburn Press, Caldwell, N.J.

Liu, M., J.B. Sartain, L.E. Trenholm, and W.G. Harris. 2009. Comparison of soil P test procedures for St. Augustinegrass. Commun. Soil Sci. Plant Analysis 40:2234-2247.

Liu, M., J.B. Sartain, L.E. Trenholm, and G.L. Miller. 2008. Phosphorus requirements of St. Augustinegrass grown in sandy soils. Crop Sci. 48:1178-1186.

Liu, M., J.B. Sartain, L.E. Trenholm, G.L. Miller, and P. Nkedi-Kizza. 2006. St. Augustinegrass phosphorus requirement using hydroponic culture. Proc. Soil Crop Sci. Soc. Florida. 65:15-20.

Lodge, T.A., T.W. Colclough, and P.M. Canaway. 1990. Fertilizer nutrition of sand golf greens. VI. Cover and botanical composition. J. Sports Turf Res. Inst. 66:89-99.

Maguire, R.O. and J.T. Sims. 2002. Measuring agronomic and environmental soil phosphorus saturation and predicting phosphorus leaching with Mehlich 3. Soil Sci. Soc. Amer. J. 66:2033-2039.

McBride, M.B. 1994. Environmental chemistry of soils. Oxford Univ. Press, New York, N.Y.

McCoy, E.L. 1998. Sand and organic amendment influences on soil physical properties related to turf establishment. Agron. J. 90:411-419.

McCray, J.M., A.L. Wright, Y.G. Luo, and S.N. Ji. 2012. Soil phosphorus forms related to extractable phosphorus in the everglades agricultural area. Soil Sci. 177:31-38.

McKeague, J.A., J.E. Brydon, and N.M. Miles. 1971. Differentiation of forms of extractable iron and aluminum in soils. Proc. Soil Sci. Soc. Amer. 35:33-42.

Mehlich, A. 1984. Mehlich-3 soil test extractant- A modification of Mehlich-2 extractant. Commun. Soil Sci. Plant Analysis 15:1409-1416.

Milesi, C., S.W. Running, C.D. Elvidge, J.B. Dietz, B.T. Tuttle, and R.R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environmental Mgt. 36:426-438.

Mills, H.A. and J. Benton Jones Jr. 1996. Plant analysis handbook II: A practical sampling, preparation, analysis, and interpretation guide. MicroMacro, Athens, G.A.

Miyamoto, S., I. Martinez, M. Padilla, A. Portillio, and D. Ornelas. 2004. Landscape plant list for salt tolerance assessment. Texas A&M Univ. Res. Ext. Ctr. , El Paso. 10 Apr. 2012. <http://aggie-

horticulture.tamu.edu/galveston/recovery/Landscape%20Plant%20Lists%20for%20Salt%20Tolerance%20Assessment.pdf>.

Murphy, J. and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 26:31-37.

Mylavarapu, R.S. 2009. UF/IFAS extension soil testing laboratory analytical procedures and training manual. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 20 Mar. 2011. <http://edis.ifas.ufl.edu/pdffiles/SS/SS31200.pdf>.

Mylavarapu, R.S., J.F. Sanchez, J.H. Nguyen, and J.M. Bartos. 2002. Evaluation of Mehlich-1 and Mehlich-3 extraction procedures for plant nutrients in acid mineral soils of Florida. Commun. Soil Sci. Plant Analysis 33:807-820.

Nair, V.D. and D.A. Graetz. 2002. Phosphorus saturation in Spodosols impacted by manure. J. Environ. Qual. 31:1279-1285.

Nair, V.D., D.A. Graetz, and K.R. Reddy. 1998. Dairy manure influences on phosphorus retention capacity of Spodosols. J. Environ. Qual. 27:522-527.

Nair, V.D. and W.G. Harris. 2004. A capacity factor as an alternative to soil test phosphorus in phosphorus risk assessment. N. Z. J. Agric. Res. 47:491-497.

Nair, V.D., K.M. Portier, D.A. Graetz, and M.L. Walker. 2004. An environmental threshold for degree of phosphorus saturation in sandy soils. J. Environ. Qual. 33:107-113.

Ntoulas, N., P. Tsiotsiopoulou, P.A. Nektarios, M. Papafotiou, and I. Chronopoulos. 2004. Olive mill waste compost evaluation as a soil amendment for turfgrass culture. Acta Hort. 661:71-76.

Obour, A.K., M.L. Silveira, J.M.B. Vendramini, J. Jawitz, G.A. O'Connor, and L.E. Sollenberger. 2011. A phosphorus budget for bahiagrass pastures growing on a typical Florida Spodosol. Agron. J. 103:611-616.

Obreza, T.A. and M.E. Collins. 2008. Common soils used for citrus production in Florida. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 12 Jan. 2012. <http://edis.ifas.ufl.edu/ss403>.

Parfitt, R.L. and C.W. Childs. 1988. Estimation of forms of Fe and Al: A review, and analysis of contrasting soils by dissolution and mossbauer methods. Aust. J. Soil Res. 26:121-144.

Petrovic, A.M. 2004. Impact of soil texture on nutrient fate. Acta Hort. 661:93-98.

Pierzynski, G.M., A.N. Sharpley, and J.L. Kovar. 2009. Methods of phosphorus analysis for soil, sediments, residuals, and waters: Introduction, p. 1-4. In: J. L. Kovar and G. M. Pierzynski (eds.). Methods of phosphorus analysis for soils, sediments, residuals, and water. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG 17), Virginia Tech Univ., Blacksburg, VA.

Pouyat, R.V., I.D. Yesilonis, J. Russell-Anelli, and N.K. Neerchal. 2007. Soil chemical and physical properties that differentiate urban land-use and cover types. Soil Sci. Soc. Amer. J. 71:1010-1019.

Qualls, R.G. and B.L. Haines. 1992. Biodegradability of dissolved organic-matter in forest throughfall, soil solution, and stream water. Soil Sci. Soc. Amer. J. 56:578-586.

Riegman, R. 1995. Nutrient-related selection mechanisms in marine phytoplankton communities and the impact of eutrophication on the planktonic food web. Water Sci. Technol. 32:63-75.

Rowland, J.H., J.L. Cisar, G.H. Snyder, J.B. Sartain, and A.L. Wright. 2009. USGA ultradwarf bermudagrass putting green properties as affected by cultural practices. Agron. J. 101:1565-1572.

Sartain, J.B. 2012. Soil and tissue testing and interpretation for Florida turfgrasses. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 20 Mar. 2012. <http://edis.ifas.ufl.edu/ss317>.

SAS Institute. 2012. SAS/STAT 9.3 users guide. SAS Institute, Cary, NC. >.

Scharenbroch, B.C., J.E. Lloyd, and J.L. Johnson-Maynard. 2005. Distinguishing urban soils with physical, chemical, and biological properties. Pedobiologia 49:283-296.

Scherer-Lorenzen, M., C. Palmborg, A. Prinz, and E.D. Schulze. 2003. The role of plant diversity and composition for nitrate leaching in grasslands. Ecology 84:1539-1552.

Schoumans, O.F. 2009. Determination of the degree of phosphorus saturation in non-calcareous soils, p. 29-32. In: J. L. Kovar and G. M. Pierzynski (eds.). Methods of phosphorus analysis for soils, sediments, residuals, and waters. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG 17), Virginia Tech Univ., Blacksburg, VA.

Schwab, A.P. and S. Kulyingyong. 1989. Changes in phosphate activities and availability indexes with depth after 40 years of fertilization. Soil Sci. 147:179-186.

Self-Davis, M.L., P.A. Moore Jr., and B.C. Joern. 2009. Water-or dilute salt extractable phosphorus in soil, p. 22-24. In: J. L. Kovar and G. M. Pierzynski (eds.). Methods of phosphorus analysis for soils, sediments, residuals, and water. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG 17), Virginia Tech Univ., Blacksburg, VA.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural phosphorus and eutrophication. 2nd ed. U.S. Dept. Agr. Agricultural Res. Serv., Springfield, V.A.

Shearman, R.C. and K.N. Morris. 2011. NTEP turfgrass evaluation guidelines. Natl. Turfgrass Evaluation Program, Beltsville. 5 Mar. 2012. <http://www.ntep.org/pdf/ratings.pdf>.

Shober, A.L. and G.S. Toor. 2009. Soils & fertilizers for master gardener: Urban soils and their management issues. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 22 May 2010. <http://edis.ifas.ufl.edu/mg456>.

Short, J.R., D.S. Fanning, M.S. McIntosh, J.E. Foss, and J.C. Patterson. 1986. Soils of the mall in Washington, DC. 1. Statistical summary of properties. Soil Sci. Soc. Amer. J. 50:699-705.

Sims, J.T. 2009a. A Phosphorus sorption index, p. 20-21. In: J. L. Kovar and G. M. Pierzynski (eds.). Methods of phosphorus analysis for soils, sediments, residuals, and water. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG 17), Virginia Tech Univ., Blacksburg, VA.

Sims, J.T. 2009b. Soil test phosphorus: principles and methods, p. 9-19. In: J. L. Kovar and G. M. Pierzynski (eds.). Methods of phosphorus analysis for soils, sediments, residuals, and water. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG 17), Virginia Tech Univ., Blacksburg, VA.

Sims, J.T., R.O. Maguire, A.B. Leytem, K.L. Gartley, and M.C. Pautler. 2002. Evaluation of Mehlich 3 as an agri-environmental soil phosphorus test for the Mid-Atlantic United States of America. Soil Sci. Soc. Amer. J. 66:2016-2032.

Sims, J.T., R.R. Simard, and B.C. Joern. 1998. Phosphorus loss in agricultural drainage: Historical perspective and current research. J. Environ. Qual. 27:277-293.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green-algae in lake phytoplankton. Science 221:669-671.

Snyder, R.H., J.B. Sartain, J.L. Cisar, P. Nkedi-Kizza, W.G. Harris, and M.A. Brown. 2001. Investaigation of coated sands for use in putting green construction. Proc. Soil Crop Sci. Soc. Florida 60:72-78.

Soil Survey Staff. 2010. Official soil series descriptions. Natural Resources Conservation Serv., U.S. Dept. Agri. 25 June 2011. <http://soils.usda.gov/technical/classification/osd/index.html>.

Soldat, D., A.M. Petrovic, R. Rao, and T.W. Bruulsema. 2007. Testing turf grass soils. Better Crops Plant Food 91:26-27.

Soldat, D.J. and A.M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Sci. 48:2051-2065.

Stone, E.L., W.G. Harris, R.B. Brown, and R.J. Kuehl. 1993. Carbon storage in Florida Spodosols. Soil Sci. Soc. Amer. J. 57:179-182.

Synder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing nitrogen leaching in bermudagrass cynodon-dactylon-x-cynodon-transvaalensis turf. Agron. J. 76:964-969.

Trenholm, L.E. 2010. Urban turf fertilizer rule for home lawn fertilization. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 23 May 2010. <http://indian.ifas.ufl.edu/PDF/2009/MG/New_Fert_Rules.pdf>.

Trenholm, L.E., J.L. Cisar, and J.B. Unruh. 2011. St. Augustinegrass for Florida lawns. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 24 May 2010. <http://edis.ifas.ufl.edu/LH010>.

Trenholm, L.E., J.B. Unruh, and J.L. Cisar. 2006. Watering your Florida lawns. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 24 May 2010. <http://edis.ifas.ufl.edu/lh025>.

U.S. Department of Agriculture. 2010. Conservation plant characteristics. U.S. Dept. Agr., Washington. 8 May 2010. <http://plants.usda.gov/java/charProfile?symbol=STSE>.

U.S. Department of Agriculture-Natural Resources Conservation Service. 2012. Spodosols. U.S. Dept. Agr. Natural Resources Conservation Serv., Washington. 2 May 2011. <http://soils.usda.gov/technical/classification/orders/spodosols.html>.

U.S. Environmental Protection Agency. 1986. Acid digestion of sediments, sludges, and soils. section A, part I, chapter three-metallic analytes, 3.2 sample preparation methods, method 3050. U.S. Environ. Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1993. Method 351.2. Determination of total Kjeldahl nitrogen by semi-automatedcolorimetry Environ. Monitoring Systems Lab., U.S. Environ. Protection Agency, Cincinnati. 22 May 2011. <http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_351_2.pdf>.

Van Der Zee, S.E.A.T.M. and W.H. Van Riemsdijk. 1986. Sorption kinetics and transport of phosphate in sandy soil. Geoderma 38:293-310.

Villapando, R.R. and D.A. Graetz. 2001. Phosphorus sorption and desorption properties of the spodic horizon from selected Florida Spodosols. Soil Sci. Soc. Amer. J. 65:331-339.

Wright, A.L. and K.R. Reddy. 2012. Dissolved organic matter in wetlands. Univ. of Florida, Inst. Food Agr. Sci., Gainesville. 15 Mar. 2012. <http://edis.ifas.ufl.edu/ss507>.

Yuan, G. and L.M. Lavkulich. 1994. Phosphate sorption in relation to extractable iron and aluminum in Spodosols. Soil Sci. Soc. Amer. J. 58:343-346.

Zhou, M., R.D. Rhue, and W.G. Harris. 1997. Phosphorus sorption characteristics of Bh and Bt horizons horn sandy coastal plain soils. Soil Sci. Soc. Amer. J. 61:1364-1369.

BIOGRAPHICAL SKETCH

Drew McLean was born in Stuart, FL located on the south east coast of the state. Drew received a BS in Soil and Water Science from the University of Florida. While working on his BS degree Drew work as an OPS employee at the Analytical Research Laboratory located at the University of Florida, where his job duties included soil, water, plant tissue, and livestock waste sample digestions and prep work for further analysis. After earning his BS degree, he then obtained a laboratory technician position for TKN analysis at the Analytical Research Laboratory. After working as a laboratory technician for some time he decided to go back to school to get his MS degree. He then joined the Soil and Water Science mater's program at the University of Florida under Dr. Amy Shober and Rex Ellis, where he investigated the use of spodic derived fill materials on the establishment on st. augustinegrass. After earning his degree, Drew would like to apply what he has learned in the environmental job field.