Evaluation of Water Use & Water Quality Effects of Amending Soils & Lawns

Final Report

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EXECUTIVE SUMMARY

The purpose of this study was to evaluate the water conservation potential of amending new landscapes with currently recommended rates of compost within a residential setting. In addition, the study also sought to evaluate the potential environmental water quantity and quality effects of amending soils with compost. For this two-year study, 24 lots were included from the northeast section of South West Florida Water Management District, located within On Top of the World Communities within Marion County. Lots were tilled, tilled with compost, or left compacted (control) prior to installation of irrigation and landscaping. Homeowners were not informed of the soil treatment but were asked to reduce their irrigation run times 25% from the typical irrigation schedules in the area, with the ability to change their irrigation schedule as they saw fit. Monthly total water use data was provided by the local utility and irrigation data was available for a portion of the study period for a subset of 13 homes. During home construction, lysimeters were also installed within the lawn areas of each lot to collect leachate draining through the root zone. Leachate volumes were collected and analyzed for nutrient concentrations and to evaluate loadings. Runoff monitoring was also conducted by instrumenting storm inlets with weir boxes, water level loggers, and autosamplers. Stormwater runoff samples were also analyzed for nutrient concentrations and to evaluate nutrient loadings. Lastly, soil moisture sensors were installed in the rear lawns of each home to collect volumetric water content data.

Results of this study found that lots amended with compost applied the smallest irrigation depth during 2020 and a higher proportion of these lot homeowners either reduced their irrigation run times further (55% reduction) than tilled or control lots. Topdressing had no observable effect on water quality. Amending with compost or topdressing had no significant effect on runoff concentrations or loadings. However amending with compost reduced runoff quantities relative to tilled and control lots. Neither practice significantly affected total phosphorus concentrations or loadings in leachate. While compost incorporation significantly increased nitrogen leachate loadings due to increased leachate volumes, nitrogen concentrations in leachate were not significantly affected. Further, soil moisture sensor data indicated that amended lawns maintained higher water content than tilled or compacted soils. This suggests the potential for reducing irrigation beyond only 25% reduction in runtime without affecting turf quality, while also reducing leachate volumes and nitrogen loadings. Future research should investigate the limits of water conservation within a field plot study while also evaluating potential for reducing amendment rates and comparing amendment types. The transferability of amending with compost should also be investigated within different hydrogeological settings that have varying soil types and differing drainage conditions.

1 INTRODUCTION

As of July 2018, the population of Florida was 21.3 million and the average population growth rate between 2010 and 2018 was 1.63% (U.S. Census Bureau, 2018). In the Florida 2070 report, the population for 2070 is expected to double that of the baseline 2010 population from 18.8 million to 33.7 million (Carr and Zwick, 2016). With the increase in population, the amount of developed land is also project to double.

1.1.1 Current and Future Water Demand

The primary source of freshwater for the majority of Florida is groundwater (Mylavarapu, 2014; Borisova and Wade, 2008). Over 90% of people in the North and Central regions of Florida rely on groundwater for their water supply (SJRWMD, n.d). The Floridan aquifer lies beneath all of Florida, and parts of Georgia, Alabama, and South Carolina, covering about 260,000 km^2 (Spechler, 1994; Ryder, 1985; Williams and Kuniansky, 2016; Mylavarapu, 2014). Karst aquifers, like the Floridan aquifer, are known for their porosity and high transmissivity (Ravbar and Goldscheider, 2009), but infiltration into and recharge of the aquifer also depends on the type and texture of soil that sits above the aquifer system (SJRWMD, n.d). Though exact amounts vary by region, Florida receives about 50 in. (127 cm) of rain annually (SJRWMD, n.d.; Borisova and Wade, 2008).

Recharge of the Floridan aquifer occurs from rainfall that infiltrates the soil and the water that plants do not transpire can percolate through permeable materials until it enters the aquifer (Borisova and Wade, 2008). Rainfall is not constant throughout the year, however, and neither are withdrawals, which can cause aquifer water levels to rise and fall. Typically, water use increases during dry spells, even though during that time, there would be very little recharge occurring. Maintaining aquifer levels and surface water flows at sustainable levels is also important for the health of the ecosystem.

Public supply is the largest water use in Florida, and residential water use makes up 61% of the public supply (Baum et al., 2003). In the Central Florida region, public supply is where the majority of water is allocated to and agriculture is second (CFWI, 2015). This water goes toward residential, landscape, and industrial needs within the Central Florida area.

With nearly 1,000 people per day moving to Florida, the demand for water continues to increase. Demands on our water supplies include water for development, agriculture, mining, power generation, and for natural systems such as keeping freshwater flowing into estuaries and marine environments (Carr and Zwick, 2016). Statewide, total water demand is projected to increase by at least 50% by 2070 from the baseline 2010 demand, from 5.27 billion gallons per day (bpd) to 8.09 bpd (Carr and Zwick, 2016). Of the four regions in Florida, the Central Region is projected to have the largest increase in water demand of 62% (CFWI, 2015). By 2035, there will be a 250 million gallon per day (mgd) deficit, with most of the stress in Central and North Central Florida (CFWI, 2015).

Out of the panhandle, northeast, central, and south regions of Florida, the central region is expected to have the greatest increase in developed land areas. Specifically, Orange, Osceola, Seminole, Polk, and Lake County alone with the City of Cocoa are expected to experience a 51% increase in population from 2010 to 2035 (CFWI, 2015). Due to increases in population and additional developed area, there will be a 40% increase from 2010 to 2070 to all water use categories, with public supply accounting for 70% of that increase (CFWI, 2015).

The Central Florida Water Initiative (CFWI), a collaborative between St. Johns River Water Management District, Southwest Florida Water Management District, and South Florida Water Management District found that in some parts of the CFWI area, withdrawals are approaching or have already exceeded sustainable limits, leading to negative impacts on water resources and natural systems (CFWI, 2015). Previous work done in parts of the Central Florida area has shown that water withdrawal is quickly approaching or has already surpassed the limits of what would be considered sustainable or not harming water resources and natural systems (CFWI, 2015). The modeling done by the CFWI (2015) has estimated that the sustainable water withdrawal limit is 850 mgd. The CFWI estimates that the current total water demands are about 800 million gallons per day (mgd) and by 2035 the demand will increase to almost 1,100 mgd, resulting in a 250 mgd deficit (CFWI, 2015).

The CFWI estimates an 80% increase in demand of water for landscape, recreation, and aesthetics (CFWI, 2015) which includes irrigation of parks, medians, right of ways, common areas in residential areas, and recreation fields (CFWI, 2015). However, this does not include the irrigation of private residential areas.

1.1.2 Landscape Irrigation

Turfgrass is a common landscape cover in residential areas as it is the least cost option per unit area. As of 2013, about 10% of the land area in Florida is considered maintained turfgrass (U.S. Census Bureau, 2012; Kenworthy, 2013). Florida's climate along with low soil quality in most urban areas requires supplemental irrigation for turfgrass (Baum et al., 2003; Haley et al. 2007). To prevent stress and keep the soil moisture within the PAW range, irrigation is scheduled to keep the soil moisture above maximum allowable depletion (MAD). Supplemental irrigation is used almost all year round, however, during the dry spring months is when Floridians typically use supplementary irrigation most frequently for their landscapes (Borisova and Wade, 2008). During this time, there is little rainfall and most turfgrass species come out of dormancy. Supplemental irrigation also is used if there is insufficient rainfall and or if soil has a low water holding capacity (Haley et al. 2007). Irrigation frequency is based on the type of grass, soil, geography, soil compaction, and season (Trenholm et al., 1991). However, research studies have shown that regular irrigation schedules tend to provide excess water turfgrass in Florida (Haley et al., 2007). Soils throughout much of Florida hold about 1 in. (2.54 cm) of water in the top 12 in. (30.5 cm) and turfgrass roots are primarily within the top 12 in. (30.5 cm), so between ½ and ¾ of an inch of irrigation per application provides sufficient water to the plant roots (Trenholm et al., 1991).

Southwest Florida Water Management District (SWFWMD) estimates that more than half of all potable water goes towards residential irrigation, and the Florida 2070 report suggests that a way to reduce the water stress is to reduce the amount of water needed for irrigation (SWFWMD, 2018). In a Central Florida study, it was found that 71% of total household water was allocated to irrigating the landscape in residential areas (Baum et al., 2003). In 2015, agriculture was the largest water user in Florida, however, since then, public supply, which includes residential water uses such as indoor and irrigation, has exceeded agricultural water use and it is projected to continue through 2070 (CFWI, 2015; FDEP, 2019).

1.1.2.1 Establishment Irrigation

Unruh et al. (2016) suggests that after sodding a landscape, 1.30 cm (0.50 in) of irrigation be applied daily until a root system has established, which takes about two to three weeks, while others may apply 1.55 cm (0.61 in) of irrigation daily for 30 days in newly constructed residential areas in Ocala, Florida (P. Hisey, personal communication, 2018). This frequent, shallow irrigation helps prevent the shallow rootzone from drying out while deeper roots that develop which will eventually decrease its need for frequent supplemental irrigation (Wherley et al. 2011). However, during this establishment period, not all of the irrigation may be transpired by the turfgrass or retained in the root zone. An increase in water retention in the soil can occur when there is an increase in organic matter, thus an increase in the number of smaller pores. In urban residential areas, however, soil quality is often low.

1.2 Landscape Soil Quality

Conventional residential development practices in Florida clear and regrade large sections of the landscape to promote drainage of stormwater runoff to collection areas and away from lots. As construction begins, topsoil is either removed and replaced by or buried under low quality fill material during the grading process (Cogger, 2005; Chen et al., 2014; Hamilton and Waddington, 1999; Toor et al., 2018a). The remaining surficial soil is often fill material that was previously located well below the land surface either in the existing location or more from an offsite location.

1.2.1 Fill Soil Quality

Soils provide a variety of physical and chemical processes, such as water movement and nutrient cycling (Toor et al., 2018b). Soil structure is defined as the "size, shape, and arrangement of solids and voids, and forces that affect these characteristics" (Lal, 1991). Generally, the mineral and organic matter in undisturbed natural soils makes up about 45% and 5%, respectively, of the volume and voids or pore spaces make up the remaining 50% (Toor et al, 2018b). Pores provide the space for the movement of nutrients, water, and air between the surface and plants (Lal, 1991).

During the land development process, organics within surficial soil layers are removed or buried during the master grading phase, part of the overall cut and fill process across the broader developing landscape. Fill material is commonly imported from cut areas elsewhere on site or imported from an offsite mine or other supply. One of the primary functions of the fill material is to provide a stable base for the building foundation that will not settle over time. The fill material should ideally drain well to avoid water and moisture issues around the home. Based on these criteria and availability, sandy soils tend to be the preferred lot fill material.Therefore, the conventional site development process leaves behind low-quality soils in new residential landscapes (Chen et al. 2014; Hamilton and Waddington, 1999; Jim, 1998; Toor et al., 2018a).

In sandy soils, the particle sizes are large, which creates large voids, or macropores, between the particles (Magdoff and van Es, 2000). While water and air can travel freely through macropores, matric forces within macropores are not sufficient to overcome gravitational forces during drainage, and thus de-water before micropores. As a result, while water may infiltrate into sandy soils due to macropores, water drains from the root zone too quickly to be available for vegetation.

Plant available water (PAW) range falls between field capacity (FC) and the permanent wilting point (PWP) and is dependent on soil texture and structure (Zotarelli et al. 2010). Below the PWP, the water remaining in the soil is held so tightly that the plant cannot extract it. Plants go through water stress well before the PWP. If soil is saturated above FC, excess water drains relatively quickly, especially in coarse, sandy soils, through soil macropores to where it is not available for the plant to absorb (Zotarelli et al., 2010).

Low organic content in fill material also limits water holding capacity in landscape soils post-development (Toor et al., 2018a). After an irrigation or rain event, the water is temporarily available to plants but may not be later, as the water drains from the macropores and leaves the root zone. When irrigation events occur on sandy soils, the water percolates mainly through the macropores and little water is retained in the micropores when compared to finer textured soils or soils with organic matter. For example, in Candler soils, the volumetric water content (VWC) at field capacity is about 5.7 – 6.2% in the top 12 in. (15 cm) (Zekri and Parsons, 1999).

Organic matter facilitates aggregate formation in soil, which increases the amount of micropores, along with the soil surface area, which in turn increase the soil's water holding capacity (WHC) and nutrient cycling (Cogger, 2005). WHC is the amount of water that can be held in a soil at field capacity (FC), which is the total amount of water stored in a soil after it has been saturated and allowed to drain (NRCS, 2008). WHC depends on both porosity and surface area, which affect WHC in wetter and drier soils, respectively. A soil's permanent wilting point is the moisture content at which a plant cannot take up any more water from the soil (Zotarelli et al., 2010). The quantity of volume available to plants is called the plant available water (PAW) and is the volume between FC and PWP. Soil organic matter and plant available water have a positive relationship, as soil organic matter increases field capacity (Huntington, 2007).

Without sufficient organic matter, soils do not form as many aggregates resulting in fewer micropores (Magdoff and van Es, 2000). Due to the lack of organic matter and relatively few micropores, low quality soils tend to require more frequent irrigation to support turfgrass compared to higher quality soils. In turn, frequent but short irrigation events tend to encourage shallow root growth when compared to infrequent but longer irrigation events (Trenholm et al., 1991). This is because during the former, the root zone is saturated for a longer duration and does not encourage roots to grow deeper to locate water.

1.2.2 Construction and Soil Compaction

Not only does the grading process result in a lower organic matter at the surface, but the soil also experiences a loss in structure as well because of the disturbances during construction (Cogger, 2005; Toor et al., 2018a; Bhadha et al. 2017). Chen et al. (2014) reported a 29% reduction in macroaggregates in the surface soils from just topsoil removal and filling. Vehicles and heavy machinery used during construction of homes leaves the upper layer of soil on many lots compacted, increasing bulk density and reducing infiltration rates (Gregory et al., 2006; Pitt et al., 1999). Soil compaction from traffic results from vehicle weight, wheel slippage, and engine vibrations, with maximum compaction occurring in the top 30 cm of soil (Kozlowski, 1999; Gill and Vanden Berg, 1968). Some of the compaction that occurs is necessary to provide structural strength, such as increase the load-bearing capacity, prevent soil settling post development, and reduce water seepage, swelling, and contraction (Multiquip, 2011). Heavy equipment compacts soil up to 3 ft. (1 m) deep, but most of the effects typically occur in the top 12 in. (30 cm), where roots are mainly for the majority of landscape plants (Kozlowski, 1999). Soils also experience compaction during wetting and drying cycles, which cause shrinkage and swelling and weakens soil aggregates which allows for soil to be packed tighter (Kozlowski, 1999; Multiquip, 2011).

Soil compaction affects soil structure by increasing bulk density, decreasing infiltration rates, plant available water, and water holding capacity (Cogger, 2005; Gregory et al., 2006, Kozlowski, 1999, Chen et al., 2014) and affects the way air, water, and roots infiltrate the soil (Gregory et al., 2006). Bulk density increases due to the reorientation of soil particles that reduces pore space and pack tighter. An ongoing study has found that soils in a Central Florida development were dominated by sand sized particles and very compacted with average bulk densities greater than 1.7 g/cm^3 in the top 6 in. cm and greater than 2.0 g/cm^3 down to 12 in. (unpublished data by Bean et al.). In post-development conditions compared to natural areas and pre-development, infiltration rates usually decrease by a factor of two (Olson, et al. 2013; SJRWMD, n.d.).This decreases the infiltration rate due to the reduced size and overall lack of pore space that water would move through and fill, and thus decreases plant available water (Kozlowski, 1999).The issue occurs when future landscape areas are compacted to the point of being detrimental to vegetation survival limiting water and nutrient inputs and availability.

1.2.3 Nutrient Loadings to Water Resources

Soil compaction decreases infiltration rates and porosity, increasing runoff volumes and loadings to surface waters (Bean and Dukes, 2014; Pitt et al., 1999). Not only does an increase in stormwater runoff increase the risk of flooding and time to peak (Leopold, 1968), it also allows for the opportunity for nutrients to be carried off into nearby lakes and rivers, which ultimately may lead to degraded surface waters (Leopold 1968, Paul and Meyer, 2001). Because less water infiltrates soils during a rain events, more stormwater runoff is produced, which can decrease aquifer recharge quantities (Gregory et al., 2006; Paul and Meyer, 2001). Nutrient exports from residential developments can contribute to impairment of surface waters and springs via urban stormwater runoff and leachate into aquifers (FDEP, 2015; FDEP 2014).

Leaching of nutrients can be an issue in certain parts of Florida where the soil between the surface and the aquifer system is very conductive so water quickly moves through the macropores and into the groundwater without effectively removing pollutants, such as nitrate, ammonium, phosphate, and others, that are typically found in urban settings. The Floridan aquifer is the main source of drinking water for the state and the upper part of the aquifer is the portion that retains most of the fresh water (Mylavarapu, 2014). The karst geology is porous and allows for rapid movement of water into the aquifer, which may allow pollutants to enter. Precipitation is the main source of groundwater recharge, and Florida receives about 127 cm (50 in) of rainfall a year (Borisova and Wade, 2008). Of these 127 cm, about 75% is lost due to evapotranspiration or runoff, and only about 25% of the total annual rainfall recharges the aquifer (SJRWMD, n.d).

While the Floridan aquifer's rapid infiltration ability is beneficial for recharge, it also provides an opportunity for pollutant transport into the aquifer due to limited residence time for soil treatment processes to occur. Because Florida's sandy soils have a coarse texture and large macropores and the karst properties of the aquifer below, water is able to transport contaminants quickly through the pores and into the groundwater, potentially impairing it (Badruzzaman et al., 2012). Sandy soils in Florida generally have a low potential to remove and hold nutrients like nitrogen and phosphorus which can leach through the soil, into the aquifer (Mylavarapu, 2014).

A study by Trenholm et al. (2012) evaluated total nitrate leaching from two irrigation scenarios in established Floratam St. Augustinegrass and Empire zoysiagrass to see if urban turf establishment was potentially contributing to impairment of surface and groundwater. They found that many factors affect nitrate loading, such as the nitrogen application, the source of nitrogen, irrigation rates, and maturity of the grass (Trenholm et al., 2012). Easton and Petrovic (2004) found that nitrate leaching was highest in the first year following establishment of a mix of Kentucky bluegrass and perennial ryegrass and that the potential for increased nitrate losses is highest during the establishment period. Trenholm et al. (2012) found that irrigation rates had a limited effect on nitrate loading for St. Augustinegrass, but there were times when increased irrigation rates showed higher nitrate loss for zoysiagrass.

Tucker et al. (2014) conducted a study to examine if groundwater nitrate concentrations in residential areas, where fertilizer was likely the source, were higher than in nearby non-residential areas. This assumption was fulfilled by narrowing the sampled wells only to ones that would have inputs from residential areas, and not impacted by citrus production, sewer treatment, or usage of reclaimed water. They found that NO_3-N concentrations were significantly higher in residential areas compared to reference areas but found that TKN and TP were not significantly different. They also found that residential areas had lower NH_3-N concentrations than reference areas.

Morton et al. (1998) and Brown et al. (1977) both reported that nitrogen leaching is closely related to high irrigation rates and high rates of nitrogen applied, and that leachate loading could be minimized if irrigation rates are matched with evapotranspiration rates. Morton et al. (1998) found that nitrate leaching was high when irrigation was applied in excess of a rate of 3.75 cm (1.5 in) per week. Erickson et al. (2010) also found that nitrate leaching losses were highly correlated with precipitation rates.

In a South Florida vegetable farm setting, Pandey (2005) found that phosphorus leaching was higher in the control lots than in compost-amended lots. However, he did not find a difference in nitrogen leaching between the control and the amended lots. The differences in findings in these studies may be due to the differences in location and type of experiment. For example, the study done by Erickson et al. (2010) was on an experimental block design, while the Brown et al. (1977) study was done on Burmudagrass golf greens, and the study by Pandey (2005) was done in a vegetable farm setting.

1.3 Compaction Mitigation and Soil Enhancement

1.3.1 Water Conservation

As stated previously, a study done by Baum et al. (2003) found that over 70% of total household water usage goes towards landscape irrigation in Central Florida. They determined that this is due to improper scheduling and poor uniformity of irrigation heads. Water use was also affected by properly functioning rain sensors, and the differences in seasons since the same rates are not appropriate for all seasons (Baum et al. 2003).

Research conducted to evaluate water saving methods focusing on maximizing irrigation efficiency on the site-specific soil include a study done by Cardenas-Lailhacar et al. (2005). Results showed that water savings were possible with the use of irrigation systems that address available soil water compared to systems that do not. Three of four of these sensors ranged from 45% to 88% water savings. Haley et al. (2007) also conducted a study on the Central Florida ridge in Marion, Lake, and Orange Counties. Flow meters were installed on each of the 27 homes in the study to determine irrigation water use independent of total water use. Overall, it was found that 63% of total home water is allocated for irrigation and that decreases in this amount come from the use of historical ET rates when scheduling, along with designing a landscape for water savings. Haley et al. (2007) states that further reductions could come from the use of weather data from nearby weather stations, instead of historical ET, and the use of soil moisture sensors for irrigation control.

1.3.1.1 Soil Moisture Sensors

The issue of overwatering has been addressed in previous studies with the use of smart irrigator gauges and soil moisture sensors. Soil moisture sensors and rain gauges can provide the irrigation system with supplemental information on when the turfgrass needs to be irrigated. These studies have shown great reductions in the amount of water used in irrigation (Cardenas-Lailhacar et al., 2005; Baum et al. 2005, Haley et al., 2007). Haley et al. (2007) showed that based on local evapotranspiration and precipitation rates, homeowners are overirrigating, and when irrigation controllers are set with respect to historical turfgrass water needs, there is a 30% reduction in the amount of irrigation applied. A study done by Cardenas-Lailhacar et al. (2005) found that the incorporation of rain sensors alone can reduce the amount of water used for irrigation, when compared to systems that do not have a working rain shut-off device. In agricultural settings, Dukes and Scholberg (2004) and Dukes et al. (2003) found that there was 11% and 50% in water savings, respectively, when using Time Domain Reflectometry probes, which are more popular with agricultural irrigation. Cardenas-Lailhacar et al. (2005) tested four different soil moisture sensor brands and they all resulted in water savings, ranging from 46% to 82%. These studies have focused on lowering the quantity of water needed for irrigation with technology, which focuses on that specific soil type and its irrigation needs. They were also tested under controlled conditions, and it is suggested that the use of sensors in urban areas be examined with homeowners to get a sense of actual irrigation habits and real-world water savings. Historically, there has been a lack of focus on improving the soil quality in urban residential areas to decrease the quantity of water required for irrigation. However, as the rate of urban development increases, more water saving methods beyond sensor controlled irrigation and should be investigated since a large portion of residential water is allocated towards irrigation.

1.3.2 Soil Amending

Soil compaction can be mitigated via tillage, which reduces bulk density and runoff, and increases soil porosity and infiltration (Pitt et al., 1999; Bean and Dukes, 2014). Soil amendments, such as compost, have been commonly used in agricultural settings to enhance soil quality and to a lesser extent in urban settings (Pitt et al, 1999; Landschoot and McNitt, 1994). Compost has been shown to increase the soil water holding capacity and provide a source of macro- and micro-nutrients in soil (Landschoot and McNitt, 1994; Sharma and Campbell 2003). Specifically, compost amending soils has shown to increase phosphorus and micro-nutrient availability on Bermudagrass and St. Augustine (Provin et al., 2007; Wright et al., 2005; Wright et al, 2008). Compost incorporation has also been shown to suppress soil-borne plant disease (Noble and Coventry, 2005). Previous studies have shown benefits of compost being incorporated into compacted Florida soils in lysimeter (Bean & Dukes, 2014) and plot studies (Loper et al., 2010). However, studies have not looked at the potential for irrigation reduction on turfgrass when tillage and soil amendments have been used to mitigate soil compaction.

Incorporating soil amendments to increase the soil quality, should increase water holding capacity and plant available water, thus decreasing the quantity of water needed for irrigation. There is little research done on soil amendment use in urban residential development areas, since most research with soil amendment use have been mainly focused on agricultural settings to improve soil quality (Cogger, 2005). The use of organic soil amendments in agricultural areas have shown to decrease bulk densities, increase infiltration rates, and increase porosity, especially when being incorporated in sandy soils (Curtis et al. 2007; Pandey, 2005; Cogger, 2005; Loper, 2009).

Pitt et al. (1999) studied the effects of urbanization and compaction on soil structure and the infiltration of rainwater, as well as using compost as a soil amendment to increase infiltration and reduce runoff. Infiltration rates were tested on ten urban sites that were chosen had varying land uses, age, and compaction levels, which included test beds and sites at new constructions. Testing the effects of compost incorporation on infiltration rates in urban areas was done in both test beds at a demonstration site but also at two sites at a new construction, which was considered representative of the problem with infiltration in that area. The sites at the new construction was representative of the infiltration problem in that area. Soil textures were either clayey or sandy. Pitt et al. utilized tipping buckets to measure surface runoff and found that at two of the sites, the runoff coefficient was very similar in the compost amended soils and the control, but at two other sites, the compost amended soil has a significant reduction in runoff coefficient.

Bean and Dukes (2014) looked at the effects of tilling soil with and without compost or fly ash on two types of soils. The two types of soil were Arredondo fine sand and Orangeburg loamy fine sand and the amendments were incorporated to depths of 4 and 8 in. They found that tilling with amendment produced significantly lower bulk densities than compacted soils, and more specifically, that tilling with compost resulted in lower bulk densities than with fly ash. This was most likely due to the increase in number and size of pores that organic matter can provide, compared to finer sized particles like fly ash. Similar results occurred with infiltration rates, where tilling with and without compost produced higher infiltration rates than tilling with fly ash. This also has to do with the increases in pore number and size with compost when compared to fly ash. Bean and Dukes (2014) found that tilling with and without compost resulted in significant decreases in runoff compared to a control soil. However, there were no significant differences between soils that were tilled and tilled with compost.

A study done by Chen et al. (2014) in Montgomery County, Virginia, looked at urban development impacts on soil characteristics, to determine if post-development mitigation efforts can rehabilitate soils, and the relationship between changes in soil structure and hydraulic conductivity. The bulk density results showed that the treatment that included post-development soil rehabilitation by adding compost and tilling, had significantly lower bulk density results than the other treatments. They found that urban land development crushed macroaggregates, which decreased hydraulic conductivity.

Olson et al. (2013) also investigated the effects of tilling with and without compost incorporations on soil infiltration and runoff quantity. The three sites used were all parks in urban areas and they each had low infiltration to begin with. To determine if the use of compost could effectively manage runoff, they performed a simulation analysis. With the simulation, they found that soil remediation can reduce the amount of runoff generated by 17% and 33% compared to a control and tilled plot, respectively.

A study done by Loper et al. (2010) looked at if compost addition with and without tillage and aeration would improve soil physical and chemical properties in simulated residential landscapes. The five treatments were tillage only, compost with tillage, compost only, compost and aeration, and aeration only. A control was the sixth treatment. Within the turfgrass covered plots, compost with tillage produced significantly lower bulk densities than the control, tillage only, and aeration only treatments. They also found that the addition of compost did significantly increase the soil field moisture capacity compared to the control, thus also increase plant available water.

Somerville et al. (2018) investigated if tilling at two depths with and without organic matter, as municipal green waste compost, incorporation could improve soil properties that are disturbed during the urban development process, as well as determine if there are any tree growth benefits from the different treatments. At the 3-month sampling event, they found that at all three sites, bulk densities of tilled with amendment plots were significantly lower than the tilled only and control. However, at one of the sites, they found that the tilled only bulk density had reverted to the bulk density pre-treatment. Saturated hydraulic conductivity was recorded three months after establishment, and they found that the tilled with compost rates were significantly different from the control in all three sites and found no significant differences between tilling alone and the control. Saturated hydraulic conductivity was measured again 15 months after treatment establishment and tilling with compost was significantly different than the control at all three sites. However, at two of the three sites, there were no significant differences between tilling with and without compost.

Incorporating organic matter into the root zone could reduce the rate of water movement by increasing micropores and potentially making more nutrients and water available to plant roots. In an agricultural study done by Mylavarapu and Zinati (2009), results showed that in sandy soils, the addition of compost significantly reduced soil bulk density compared to non-amended soils. PAW was also greater in composted plots compared to the control.

Topdressing may be another means for increasing soil organic matter and providing a source of nutrients to turfgrass. Topdressing with compost was shown to improve turf quality and soil water content on Kentucky Bluegrass (Johnson et al., 2009). Thus, it would be expected that topdressing could also reduce irrigation necessary to sustain a similar quality of turfgrass. However, limited research has been conducted on the effects of topdressing turfgrass with compost on residential lawns and at this time, the effects are unknown.

While compost application and incorporation may improve soil characteristics, it raises a concern about the potential of leaching nutrients from the residential landscapes, which has yet to be thoroughly evaluated. Compost typically has nutrient contents of up to 2% Nitrogen and up to 0.8% Phosphorus (Bean et al., 2020). With recommended incorporation rates of 4 $yd^3/1{,}000\ ft^2$ and topdressing of up to 0.5 $yd^3/1{,}000\ ft^2$ twice per year, there is a notable introduction of nutrients into the landscape with these practices that are non-negligible and for which water resource impacts should be considered.

1.4 Goals and Objectives

Studies have shown that organic amendments have positive effects on soil structure and characteristics such as bulk density, porosity, soil structure, infiltration rates, and plant available water. While organic soil amendment incorporation in urban settings has not been studied as much as in agricultural settings, it still provides the opportunity to remedy similar issues that soils face. The overall goal of this study was to better understand the effects of mitigating soil compaction on water consumption and water quality within new residential landscapes. While previous research has been successful in water conservation in residential areas, this study sought to determine if the incorporation of soil amendments on urban residential landscapes would decrease landscape irrigation. To better understand the environmental effects of amending urban residential soils with compost, the objectives of this study were to determine if there is a difference in stormwater runoff quantity (Curve Numbers and runoff volumes), leachate quantity, and runoff and leachate quality (Nitrogen and Phosphorus concentrations and nutrient loadings) between treatment types (control (null), tilled, (tilled with) compost) and the use of or absence of topdressing.

The specific objectives of this study are:

1) Compare the relative effects of tilling compacted residential soils with and without compost incorporation on irrigation use, runoff quantity, runoff quality and leachate quality.

2) Evaluate the effect of top-dressing residential turfgrass with compost on runoff quantity and quality, and leachate quality.
3) Assess the relationships between homeowner knowledge and behavior that translate into water conservation in real-world settings

2 METHODS

2.1 SITE CHARACTERISTICS

This research project will evaluate the effects of compost and tillage applications on irrigation reductions and nutrient loadings over a period of approximately two years, from July 2018 to October 2020.

2.1.1 Site Location

This research study was conducted in North Central Florida at On Top of the World (OTOW) Communities in Ocala, Florida. OTOW is an energy and water efficient community, using water saving appliances and smart irrigation controllers. The dominant soil in this community is a Candler sand (Hyperthermic, uncoated Lamellic Quartzipsamments; 95% sand, 4% silt, 1% clay) characterized very deep, excessively drained, and very (rapid) permeable (NRCS, 2013).

Construction of homes in the research site (Candler Hills neighborhood) began in 2018 and was complete by mid-2019. Data collection began in July of 2018. Landscaping in lots conformed to Florida Water Star with only 60% turfgrass, in this case Empire Zoysia. The irrigation for each home was controlled by a Hunter Hydrawise controller (Hunter Industries, Inc., San Marcos, California). The 24 homes were split up into three treatments: tilled (8 lots), compost (7 lots) and null (9 lots) (Figure 2-1; Table 2-1). Treatments were applied to compacted soil after construction was complete, prior to the installation of sod, which was Empire zoysiagrass. The tilled lots were tilled to an approximate depth of 6 in. (15 cm), and the composted lots had a compost incorporation of 4 $yd^3/1000\ ft^2$ (3.3 $m^3/$ 100 m^2), which was also tilled to a depth of 6 in. (15 cm). The compost product was Comand Natural Soil Builder provided by LifeSoils (Sumterville, Florida) and screened to 0.5 in. (1.27 cm). This amendment was made from a blend of composted vegetative debris and equine manure and had a bulk density of 0.37 g/cm^3.

Additionally, about half of the homes received topdressing twice per year throughout the study. The 11 homes were distributed across the three treatments: five in the null treatment, three in the tilled, and three in the compost. The topdressing was Comand also provided by LifeSoils and was screened to 0.5 in. (1.3 cm) and applied at a rate of 0.50 $yd^3/1{,}000\ ft^2$ (0.41 $m^3/100\ m^2$). Homes were top-dressed twice during the study period in mid-May and late September 2019 as well as June and September 2020.

A constraint in the study was that the homes in each treatment that are receiving the topdressing must be clustered and could not randomly be scattered so that when collecting runoff samples, each drain is only receiving runoff from one treatment.

Table 2-1. Soil and topdressing treatments combinations for study with number of lots in parentheses.

Soil Treatment	Topdressed?	
	N(o)	Y(es)
Null: N	N-N (4)	N-T (5)
Tillage: T	T-N (5)	T-T (3)
Compost: C	C-N (4)	C-T (3)

Figure 2-1. Aerial view of research area including three treatments and two sub-treatments on 24 lots at On Top of the World Communities in Ocala, Florida.

2.2 Rainfall Monitoring

Daily rainfall data was collected from July 2018 to December 2019 from the Wunderground website with data coming from a weather station located at the maintenance facility at On Top of the World Communities (KFLOCALA35), as well as CoCoRaHs (US1FLMR0056, US1FLMR0059, and US1FLMR0071). An RG3 Onset rain gauge with a tipping bucket was added in May 2019 in the research area, along with a manual rain gauge to replace a previous on-site weather station (model homes area) that had ceased functioning (Spring 2018) and ensure data reliability through redundancy with other rainfall data sources. This data was downloaded and collected monthly to get more accurate rainfall data and to cross reference the weather station referenced for Wunderground and CoCoRaHs. Incremental rainfall records were summed to determine storm event depths. Storm events were separated if more than 6 hours transpired without rainfall.

2.3 Runoff Monitoring

2.3.1 Drainage Areas

Drainage areas were manually delineate using the area measurement tool within the Marion County Property Appraiser website. Areas were compared to surveyed drainage areas and drainage divides were visually confirmed in the field. The same tool was also used to measure impervious area on each lot. Impervious area within a drainage area was summed and divided by the total area to calculate the impervious fraction.

Drainage areas for each inlet were delineated using the GIS tool from Marion County Property Appraiser website (https://www.pa.marion.fl.us/) and topographic surveys provided by OTOW, to convert runoff volumes to depths. Drainage area divides were validated in the field. Each lot's impervious area was also delineated using the GIS tool from the Marion County site. This was considered when calculating the runoff volume from each treatment area in the study. Lot size information was gathered from the Marion County Property Appraiser site.

Table 2-2. Drainage area information for storm drain inlets.

Storm Drain ID	Treatment	Drainage Area (ac.)	Impervious Fraction
627	N-N	1.73	0.46
619	N-T	0.63	0.50
623	N-T	0.98	0.55
608	T-N	1.03	0.55
612	T-T	1.29	0.53
607	C-N	1.03	0.52
610	C-N	0.52	0.53
618	C-T	0.88	0.57

2.3.2 Runoff Flow Monitoring

Of the six treatment areas, a top-dressed null drainage area and non-topdressed composted drainage area drained into two inlets each, compared to the other treatments each only draining into one inlet. The storm drains were equipped with a 60° weir box containing an Onset HOBOware water level logger. The 24 homes included in the study were split up into separate drainage areas so that each drain only received runoff from one treatment area (tilled, tilled with topdressing, compost, compost with topdressing, null, or null with topdressing) and the correct runoff volumes per treatment could be calculated. To make sure that all runoff to a storm drain was directed into and through the weir box for accurate flow measurement, a visqueen plastic sheet was secured around the opening of the storm drain, and a plastic barrier was put in place to prevent water from bypassing the visqueen (Figure 2-3). Data from the water level logger was downloaded monthly and the water level was later converted to flow using standard weir equations. Data was analyzed by treatment and topdressing by compiling multiple data sets from the same treatment into one.

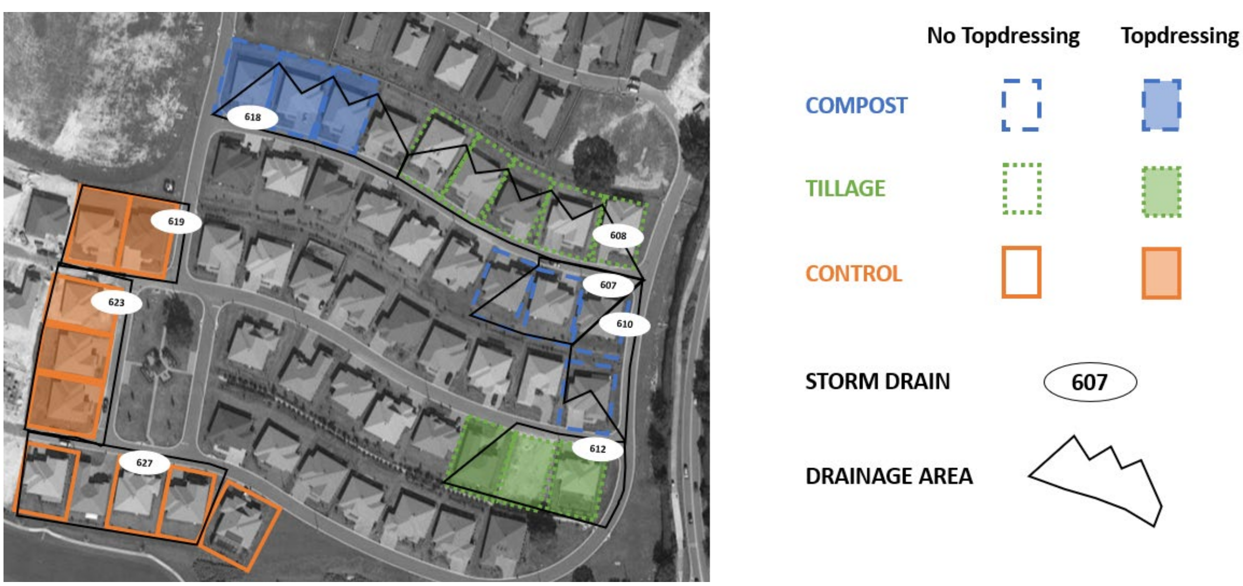

Figure 2-2. Aerial view of research area including three treatments across 24 homes at On Top of the World Communities in Ocala, Florida.

Figure 2-3. Weir box with 60° weir plate and Visqueen covering the sides to direct all water into and through the weir box for flow measurement.

2.3.3 Flow Analysis

Each weir box was instrumented with an Onset Hobo U-20 pressure logger. Raw data from the loggers was downloaded monthly and corrected for atmospheric pressure fluctuations with a separate logger. Water depths were calculated automatically within the HOBOware software using temperature dependent water density. Data were then exported to Microsoft Excel where data checks and screening were performed on timeseries. This was done on a regular basis to provide consistent readings on water level, as there was an occasional build-up of sand in the weir boxes. Water level measurements were converted to flow using the Kindsvater-Shen equation (USBR, 1997) (Equation 2-1), where C = discharge coefficient (ft^3/s), θ = notch angle, h = head (ft), and k = correction factor (ft) (Figure 2-4). The head above of the weir invert was calculated and converted to flow and later to volume (liters) and runoff depth (cm) per storm event during the monitoring period. Flow data was screened and filtered to reduce noise from water level fluctuations from sources other than precipitation (e.g. irrigation events).

$$Q = 4.28\, C \tan\left(\frac{\theta}{2}\right)(h + k)^{5/2} \quad (2\text{-}1)$$

Rainfall depths and runoff depths were used to estimate NRCS (1986) Curve Numbers (CN) for each storm event (Hawkins, 1993) (Equation 2-2, 2-3, 2-4) (Figure 2-5). Storm events that produced less than 0.50 in. (1.25 cm) of rainfall were filtered out and not used for this analysis.

$$C = \frac{Q}{P} \quad (2\text{-}2)$$

$$S = 5\left[P + 2Q - \sqrt{(4Q^2 + 5PQ)}\right] \quad (2\text{-}3)$$

$$CN = \frac{25{,}400}{254 + S} \quad (2\text{-}4)$$

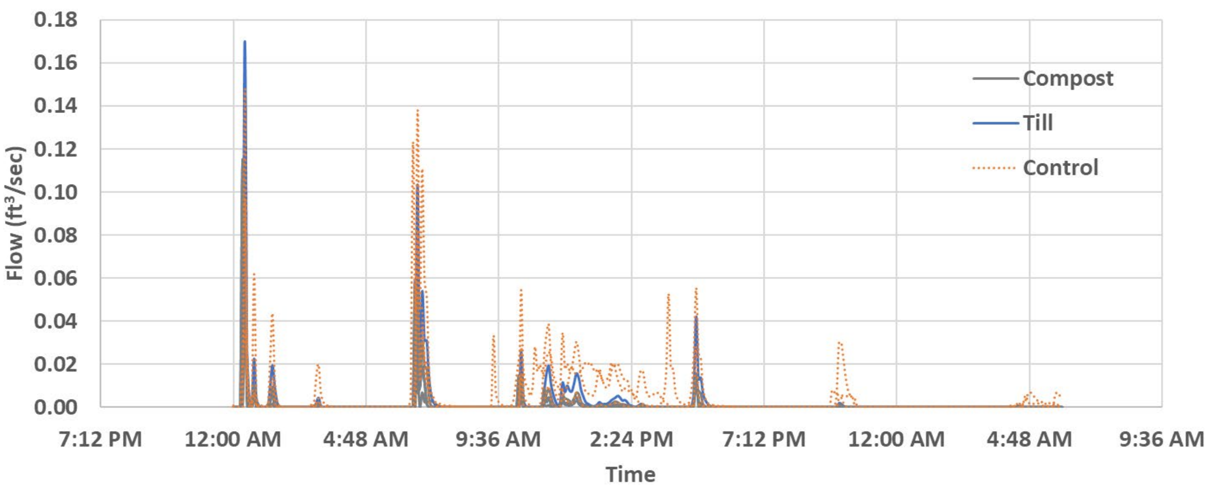

Figure 2-4. Storm flow (ft^3/sec) responses from three drains in three different treatment areas from an event on July 24-25, 2019.

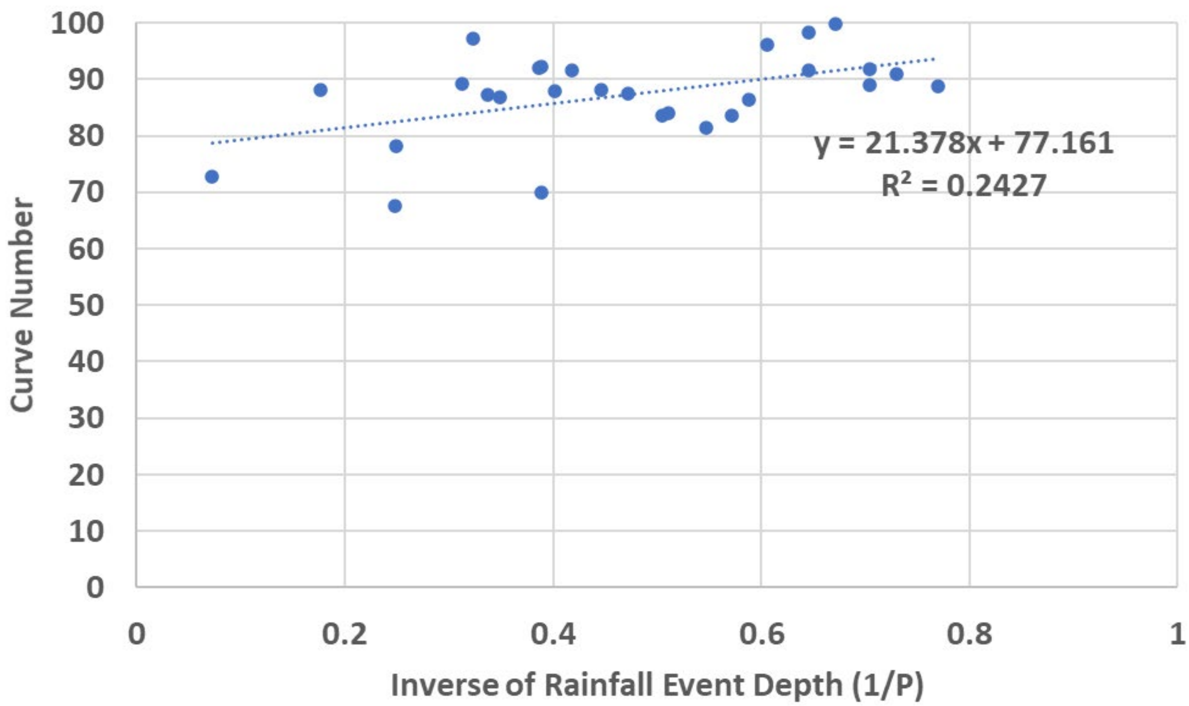

Figure 2-5. Example regression of event curve numbers on the y-axis versus inverse of rainfall depths (1/P) on the x-axis.

2.3.4 Stormwater Sampling

Approximately monthly runoff samples were collected via seven ISCO 6712 and one ISCO 3700 autosamplers during rainfall events for each of the eight storm drains (Figure 2-6). The sample tube that collected the runoff was secured to the inner side of the weir box at the same elevation as the weir invert (notch). Autosamplers were programmed to collect runoff 200 mL of runoff every 5 minutes. All of the samples taken during a storm event were composited in a 10 L carboy, which was subsampled in two 20 mL vials from each autosampler, with one duplicate collected from a random autosampler per storm event, and iced while transported to the UF/IFAS Environmental Water Quality Lab. Subsamples were collected within two to three hours after the storm event ceased, and if it was an overnight storm event, the samples were collected the next morning.

Figure 2-6. ISCO 3712 autosampler and battery positioned next to a storm drain that is equipped with a Visqueen sheet, plastic barrier to direct runoff into the weir box, and collection tube, prepared for sample collection.

2.4 Soil Moisture Sensors

Teros-12 soil moisture sensors (MeterGroup, Pullman, Washington) were installed in 12 of the 24 lawns, two in each treatment (Figures 2-7, 2-8) in the rear lawn area. They were installed 3 in. (7.6 cm) below the soil surface within an area that was representative of the rear lawn, away from rooflines and low spots. Volumetric Water Content (VWC) data was downloaded once a month from Em50 data loggers that collected soil moisture readings every 15 minutes (MeterGroup, Pullman, Washington).

2.5 Home Water Use

Monthly home water use during the study was provided by the local utility, Bay Laurel Center Community Development District (BLCCDD)for each of the 24 homes included in the study. In addition, monthly home water use data was also provided for 28 homes during the study within the same vicinity but not involved in the study. This provides a true baseline of water usage to evaluate water conservation for homes in the study against.

2.5.1 Irrigation Use

Homeowners were not informed of what treatment their lawn received, other than being topdressed. To evaluate irrigation reduction potential, homeowners were asked to reduce their irrigation run times by 25%, with the option to return their irrigation to full run times at any point. Their original irrigation schedules were set to irrigate on a cycle-soak schedule, where it irrigates for 90 minutes total, running through each zone once (45 minutes) and again a second time (45 minutes). Each home's in-ground irrigation system was controlled by a Hunter Hydrawise Irrigation Controller. This change was suggested to the homeowners during an initial meeting and made on the Hydrawise irrigation controllers (Hunter

Industries, Inc., San Marcos, California) that were already installed in their homes. Homeowners were educated on how they could make these changes in the Hydrawise application and how to revert to 100% run time if necessary. Permission to view the Hydrawise accounts was requested from the homeowners for the duration of the study so that run times could be tracked and changes to irrigation settings could be noted. Hydrawise controllers log water usage via a flowmeter, irrigation events, and sensor states through an online portal that allows for downloading of data. Irrigation volumes were be normalized by irrigable areas to determine irrigated depths. The cumulative depths were analyzed to evaluate the effect of different treatments on irrigation usage.

Figure 2-7. Installation of a Teros-12 soil moisture sensor with the cable housed in pvc pipe (left) and after installation connected to an Em50 data logger (right).

Figure 2-8. Aerial view of research area including three treatments across 24 homes at On Top of the World Communities in Ocala, Florida.

2.6 Leachate Collection

To determine if soil treatments impacted leachate quantity and quality, lysimeters were installed in all 24 lots. They served to collect leachate for estimating quantity and quality of water that exited the root zone, which would eventually enter groundwater.

2.6.1 Lysimeter Design and Installation

Lysimeters were constructed to have two main chambers: a collection chamber (3 in. (7.5 cm) diameter and 6 in. (15 cm) length) and a reservoir (2 in. (5 cm) diameter and 24 in. (61 cm) length) (Figure 2-9). The collection chamber consisted of 2 in. (5.1 cm) of washed 1/2 in. (1.3 cm) stone overlaid by the reconstructed soil profile. The collection chamber had a capacity of about 73 in.^{3} (1.2 L). A mesh screen separated the two chambers to minimize migration of soil particles into the leachate reservoir, and a sample collection tube with a diameter of 0.25 in. (6.5 mm) was installed through the side of the coupler to the bottom of the reservoir for sample collection.

Figure 2-9. Fully constructed lysimeter showing the collection chamber as well as the leachate reservoir and the positioning of the sample collection tube.

Lysimeters were installed in areas that were deemed representative of the backyard and avoided concentrated runoff from roof lines. They were installed 12 in. (30 cm) below the soil surface at the time of installation, so they would not be disturbed during tillage or other site activities. During lysimeter installation, an auger with a diameter of 10 cm (4 in) was used to remove the soil to a depth of 50 cm (20 in). After every excavation, the soil lift was separated from other lifts, ordered, and the depth of the cavity was recorded, later used to rebuild the soil profile to resemble the non-disturbed profile. After reaching the depth of 20 in. (50 cm) with the 4 in. (10 cm) diameter auger, a smaller auger with a 2 in. (5 cm) diameter was used to reach a depth of 45 in. (114 cm). These lifts were discarded, as they were not used in the profile rebuilding (Figure 2-10). Rebuilding the soil profile in the top portion of the lysimeter consisted of returning each lift of soil to the same profile position and depth that it was excavated from, while making sure that the soil was not overly compacted. The sample collection tube was buried 12 in. (30 cm) below the soil surface adjacent to the lysimeter underneath a plastic disc to protect it from any surface activities. After tilling completed, a small housing was installed flush with the ground surface adjacent to the lysimeter to store and access the purge tubing for sample collection.

Figure 2-10. Excavated soil cavity (lower center) for installation of lysimeter (upper right). Lifts were separated and ordered (1-5) to reconstruct soil profile after installation.

2.6.2 Leachate Volumes

Lysimeters were purged monthly via MP-V400 peristaltic pump and volumes purged were measured in a graduated cylinder. Both the pump and the graduated cylinder were rinsed with deionized water after purging each lysimeter. Volumes were recorded and subsamples were collected in 200 ml vials. Samples were preserved by storing them on ice and transported to the UF/IFAS Environmental Water Quality Lab for analyses.

2.7 Establishment Irrigation Column Study

To examine the potential leachability of nutrients from compost amended soils during establishment period, a column study was designed to simulate leachate resulting from daily irrigation during the 30-day establishment period.

OToW Communities (Ocala, FL) provided 0.15 yd^3 (0.11 m^3) of Candler sand (Hyperthermic, uncoated Lamellic Quartzipsamments; 95% sand, 4% silt, 1% clay) (Soil Survey Staff NRCS, 2013) from a stockpile used for onsite grading activities. This was the same stockpile used to build up fill lots at OToW within the study area. The soil was transported to the Agricultural and Biological Engineering Department's Water Resources Lab on the UF campus in Gainesville, FL, where the experiment was conducted. Small rocks and other debris were removed via sieving through a No. 10 sieve (Figure 2-11).

Figure 2-11. Debris removed from soil after passing through No. 10 sieve.

The soil collected from OToW was very dry and not representative of typical field conditions. The Candler soil field capacity was estimated to be 5-10% (v/v) (Zekri and Parsons, 1999), and during incorporation the soil was drier than field capacity. Therefore, soil was moistened by adding water approximately equal to 5% of the soil volume.

Comand Natural Soil Builder, manufactured by LifeSoils, 0.5 in. (1.3 cm) screened material was used as the compost. Five compost:soil ratios (volumetric ratios: 0:1 (control), 1:20, 1:10, 1:5, and 1:2) were simulated across three replicates of each ratio (15 columns). For comparison, the typical incorporation rate of approximately 1 in. (2.5 cm), or 4 yd^3/1,000 ft^2, of amendment incorporated into 6 in. (15 cm) of soil, is a 1:6 ratio.

Columns (6 in. (15 cm) diameter x 20 in. (50 cm) deep) were constructed of PVC pipe (Figure 2-12). Pea gravel was washed with muriatic acid and rinsed with deionized water before being placed in the bottom of the column (2 in. deep layer), intended to choke the overlying soil and limit washout (Figure 2-13). Next, 6 in. (15 cm) of Candler sand was added to each column, followed by 6 in. (15 cm) of the amended soil mixture. The control had only Candler sand in both the top and bottom 6 in. (15 cm) layers. A base soil layer of 6 in. (15 cm) was laid below 6 in. (15 cm) depth of compost and soil mixture, leaving 6 in. (15 cm) of space above the surface. A 3/8 in. (0.95 cm) hole was drilled into each cap where a small plastic coupler was screwed in to connect a collection tube to direct leachate into collection containers (Figures 2-14 & 2-15).

Figure 2-12. Soil columns arranged five across and three deep on rack with amendment/soil ratios labeled on the columns.

Figure 2-13. Adding 2 in. (5 cm) of washed pea gravel to the bottom of each column to limit soil washout.

Figure 2-14. Columns showing the 3/8 in. (0.95 cm) hole drilled into the bottom to allow for drainage.

Figure 2-15. Coupler attached to a collection tube which is taped to the inside of a catch can.

Deionized water was used for irrigation to maximize potential leaching of nutrients. A simulated irrigation volume of 282 mL, or 0.61 in. over 28 in^2 (1.50 cm over an area of 180 cm^2), was applied daily for 30 days (October 16 - November 14, 2019) to simulate the establishment irrigation period at OToW. The irrigation volume was measured in a graduated cylinder and added via a distribution device (Figure

2-16) to limit disturbing the soil surface. Irrigation volumes were added in the morning and leachate was allowed to drain until the late afternoon.

The volume of leachate in each collection can was recorded each day and emptied before the next irrigation event. Leachate samples were collected for water quality analysis on the first day leachate was produced (day 4), followed by days 10, 20, and 30.

Figure 2-16. Small holes drilled into a 15 cm (6 in) PVC cap to distribute irrigation evenly over the column and minimize disturbance.

To estimate overall loadings, concentrations were interpolated between sampled days for non-sampled days (Equations 2-5, 2-6, and 2-7). Daily nitrogen and phosphorus loadings were calculated by multiplying the leachate volume (mL) by the concentrations (mg/L or µg/L) and converting to lbs. The surface area of the columns was calculated and converted to acres, and the loading (lbs.) was divided by area to get lbs./ac.

$$(day\ \# - 4) \times \left(\frac{day\ 10\ conc - day\ 4\ conc}{10 - 4}\right) + day\ 4\ conc \quad (2\text{-}5)$$

$$(day\ \# - 10) \times \left(\frac{day\ 20\ conc - day\ 10\ conc}{20 - 10}\right) + day\ 10\ conc \quad (2\text{-}6)$$

$$(day\ \# - 20) \times \left(\frac{day\ 30\ conc - day\ 20\ conc}{30 - 20}\right) + day\ 20\ conc \quad (2\text{-}7)$$

2.8 Water Quality Analysis

2.8.1 Sample Analyses

Runoff, leachate, and column samples were analyzed by the UF/IFAS Environmental Water Quality Lab, for Nitrate (NO_3-N) (EPA methods 353.2), Ammonium (NH_4-N) (EPA method 350.1), Total Kjeldahl Nitrogen (TKN) (EPA method 351.2), and Total Phosphorus (TP) (EPA method 365.1). Total Nitrogen (TN) was calculated as the sum of TKN and NO_3-N concentrations. Organic nitrogen (Org N) was calculated as the difference between TKN and NH_4-N concentrations for column and runoff samples.

2.8.2 Nutrient Loading Calculations

Incremental TN loadings were calculated by taking the concentration (mg/L) and multiplying it by the volume collected, which was converted to liters, and the resulting mass converted from mg to lbs. The loading was then divided by the area of the collection chamber, in acre units, to get TN loading in lbs./acre. TP loading was calculated by multiplying the concentration (µg/L) by the volume collected, which was converted to liters, and the mass converted from µg to lbs. Loading was then divided by area of the collection chamber in acres to get TP loading in lbs./ac.

The cumulative total nutrient loadings were calculated by summing each lot's monthly nutrient loading over the course of the monitoring period. Annual estimated nutrient loadings were calculated by multiplying the cumulative total nitrogen loadings by the ratio of months since monitoring began to 12 months in a year.

Nutrient loadings per event (or per sample collected) were calculated by taking the concentrations per event (mg/L), multiplying it by the volume of runoff or leachate and converting to mass in lbs. To estimate nutrient runoff loadings for the entire monitoring period, mean event concentrations were calculated from sampled storm event nutrient concentrations and then multiplied by the total runoff volume measured during the monitoring period, then dividing by the delineated drainage area and converted to lbs./ac./yr.

2.9 Homeowner Surveys

UF/IFAS faculty or staff informed the residents of each home included in this study about the project and educated them on how to operate their irrigation controller within one month of occupying their home. These informational meetings took place at each residence and lasted approximately 30 minutes, and allowed time for homeowner questions. Homeowners were provided a logbook to note any changes made to their irrigation system, problems with their landscaping, or applications of fertilizers or other products. Homeowners were sent surveys with stamped return envelopes at 6-, 12-, and 18- months into the study to assess their knowledge and perceptions.

2.10 Statistical Analyses

The following parameters were analyzed by running a linear mixed-effects model (*lmer* test from *lme4* package) and Tukey's post hoc analysis to determine significant differences ($p < 0.05$) based on treatment type (compost, tilled, null) or if they had topdressing applied (yes, no): NH_4-N, NO_3-N, TKN, Org. N, TN, and TP concentrations, NH_4-N loading, NO_3-N loading, TKN loading, Org. N loading, TN loading, and TP loading in both lbs./ac. and TN and TP loading in lbs./ac./yr. Since CNs, total runoff depths and total runoff volumes did not have enough replicates for statistical analyses, the ranges and means were examined.

Soil VWC was analyzed using an ANOVA and Tukey's post hoc analysis in R to evaluate significant differences based on treatment type (compost, tilled, null) or if topdressing was applied (yes, no). The MATLAB codes from Bean et al. (2018) were used to automate and analyze VWC cycles, including peaks and field capacity.

Nutrient leachate concentrations and loadings were either square root (SR) transformed or log-transformed to normalize the data, and then the lmer test and Tukey's post hoc analysis were run. The following leachate parameters were analyzed by running the lmer test and Tukey's post hoc analysis to determine if differences were statistically significant based on treatment type (compost, tilled, null) or if they had top-dressing applied (yes, no): log-transformed TN concentrations, log-transformed TP concentrations, volume of leachate collected, square root (SR)-transformed monthly TN loading, log-transformed monthly TP loading, SR-transformed annual TN loading estimates, log-transformed annual

TP loading estimates. For the column study, the following parameters were analyzed using lmer and Tukey's post hoc analysis to determine if they were significantly different based on incorporation rate (1:2, 1:5, 1:10, 1:20, control [0:1]): concentrations of NH_4-N, NO_3-N, TKN, Org N, TN and TP, and loadings of TN and TP.

3 RESULTS & DISCUSSION

3.1 RAINFALL

Average annual rainfall for Ocala, FL is 50.8 in. and over the period of July 2018 to October 2020, would be expected to total 121 in. (Figure 3-1) Daily and cumulative rainfall data shown in Figure 3-2. was collected from and on-site tipping bucket rain gauge (Davis) from July 2018 through January 2019, at which point on-site construction interfered with communications between the rain gauge and receiver. For the remainder of the study period, daily rainfall data was collected from the National Climatic Data Center for station Ocala SW 11.2, located 1.9 miles SSE from the study site. The total rainfall during this monitoring period was 133 in. (Figure 3-1, 3-2), 12 in. (~9%) above normal. The largest deviation from normal occurred during December 2018 and January 2019, when cumulative rainfall was 29 in. above normal. During this period, there were 15 days with at least 1 in. of rainfall, five days with at least 3 in. of rainfall, and maximum daily total of 5.43 in. From February 2019 onward through the remainder of the study period, rainfall was slightly below normal with the deviation from long-term normal decreasing from 26 in. in January 2019 to 12 in. in September 2020 (Figures 3-1, 3-2).

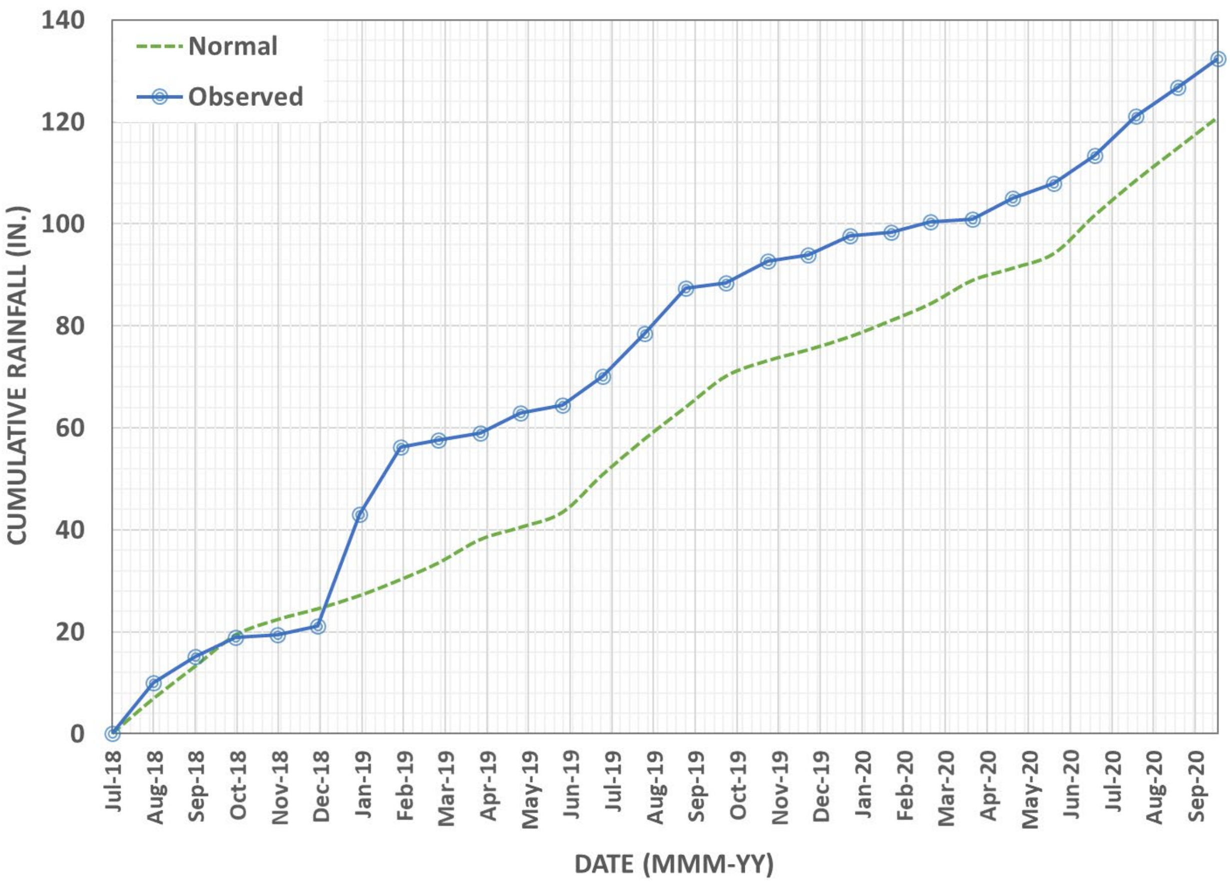

Figure 3-1. Cumulative normal and observed rainfall totals for study site location during the study period.

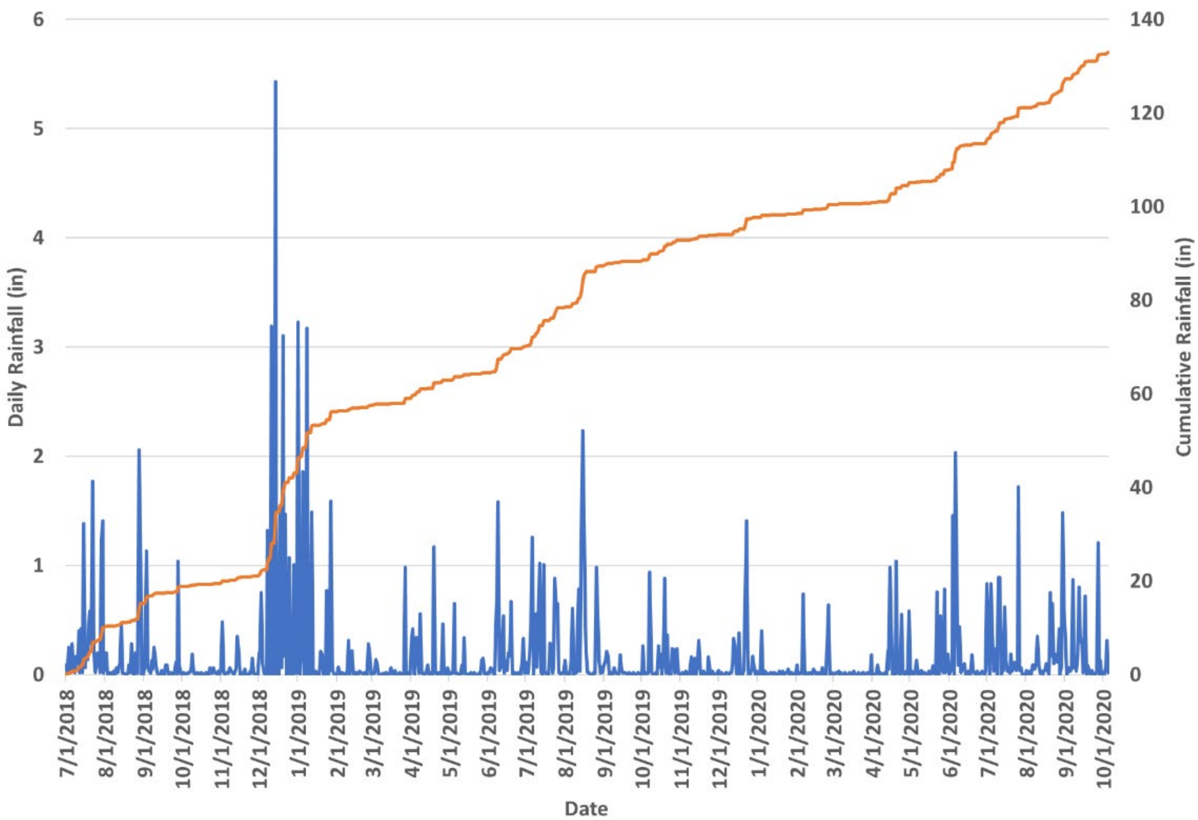

Figure 3-2. Daily rainfall and cumulative rainfall from 7/1/2018 to 10/5/2020.

3.2 Water Use

3.2.1 Home Water Use

Monthly home water use for homes included in this study was provided by Bay Laurel Community Development District (BLCCDD) for October 2017 to October 2020 and are shown in Figure 3-3. It is important to note that these data were not normalized for any variability in lot or home metrics. Home water usage tended to range from lows during the winter months of December (2018) and January (2020) of <1,000 – 7,600 gallons per home (average: 4,700 gallons), and peaking typically in March or May around 16,000 to 61,000 (October 2018, not shown) gallons per home (average: 29,000 gallons). Note that many of the homes were not completed until late 2018 or early 2019. Any water usage prior to the home being sold was excluded from the data, which generally eliminated high water usage due to landscape establishment.

Water use for each month was averaged across years and these twelve volumes summed to determine the average annual water use for each home. This normalized water use for homes that were constructed at different times and with varying lengths of water use records.

These water use data were summarized into box plots for all homes included in the study in Figure 3-4 as well as across soil treatments and whether lots received top-dressing or not. Additionally, monthly water use data was provided by BLCCDD for the remaining homes within the neighborhood that were not included in the study. These are also summarized in Figure 3-4 for comparison and labeled as “External”.

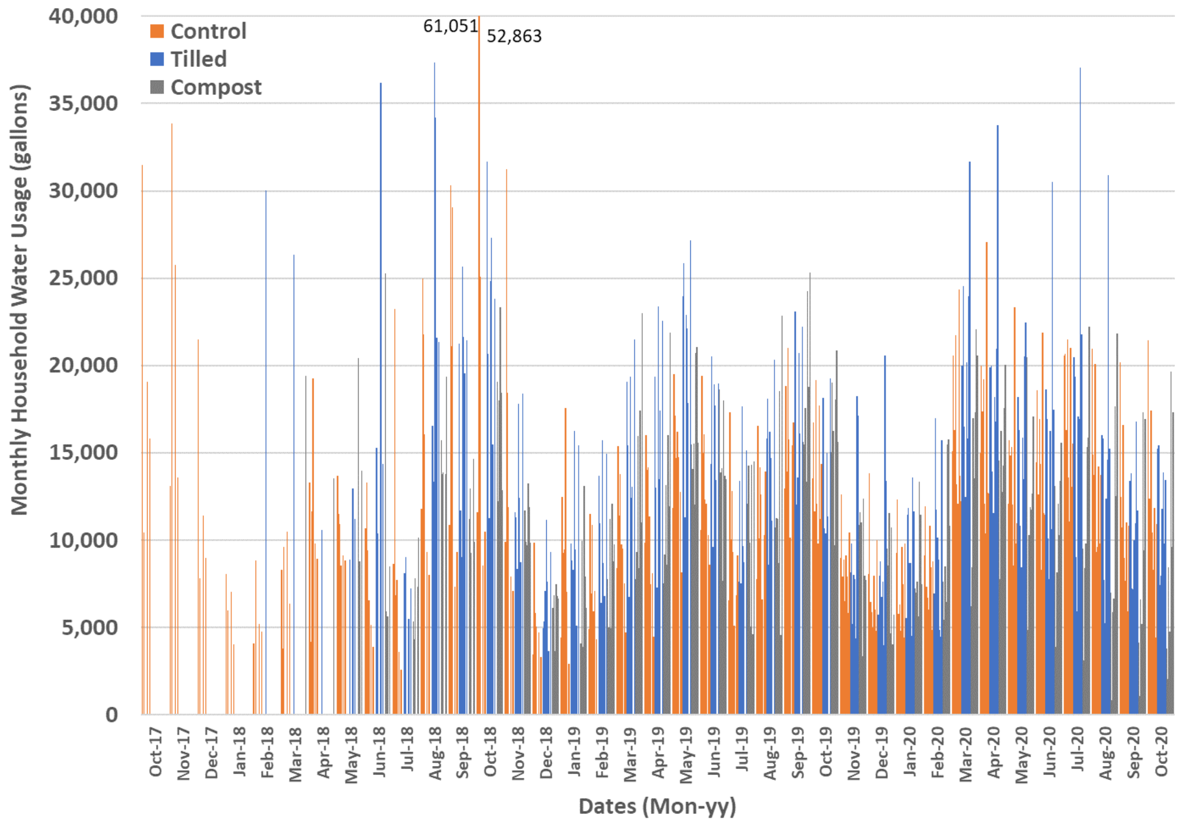

Figure 3-3. Monthly water usage for each home in this study based on soil treatment from October 2017 to October 2020.

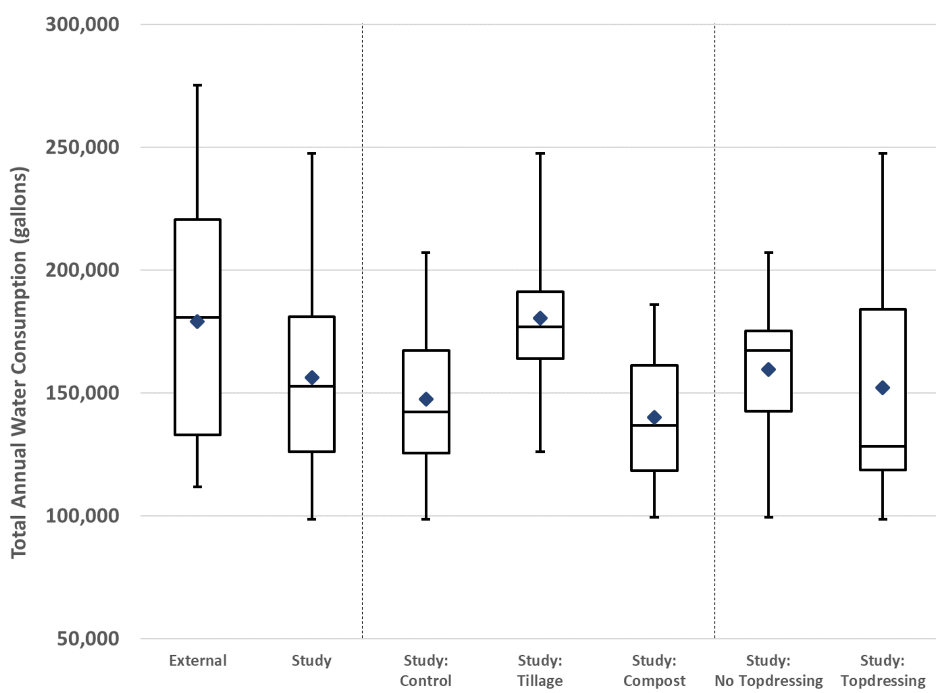

Figure 3-4. Box and whisker plots with means of total annual water consumption for homes outside and within the study, along with the distribution of water usage by soil treatment type and top-dressing status.

External homes used, on average, approximately 23,000 gallons (+13%) per year more than Study homes, which may reflect a conservation effect from reduced irrigation run times by homes within the study. Among soil treatments though, control and compost lots had similar distributions with compost mean water use ~7,000 gallons per year (5%) lower than control lots. Tillage lots overall had the highest water usage among soil treatments, averaging 33,000 gallons per year more than control lots. When looking at water usage based on whether they were topdressed or not, average usage was similar, but both distributions were noticeably skewed. The median water usage for topdressed lots was 39,000 gallons per year lower than those that were not topdressed.

3.2.2 Irrigation Water Use

Access to view irrigation data was initially granted by 23 of 24 homeowners. However, due to limited data storage by the Hydrawise system, loss of access due to system resets, and limited support from Hydrawise systems, data was only available from 13 systems for January through September 2020 (Figure 3-5). Five of the homes had metric flow meters (m^3), rather than standard flow meters (x100 gallons), even though Hydrawise systems were setup for flow meters in gallons. Therefore, the metric meter data was converted by multiplying raw data by 246 gallons/m^3. Overall, the tilled lots consumed the greatest volumes of water. In the beginning of 2020, compost and control lots consumed about the same volumes of water, but later in the year, the consumption in composted lots decreases greatly. This reflects similar total water consumption patterns shown in Figure 3-4.

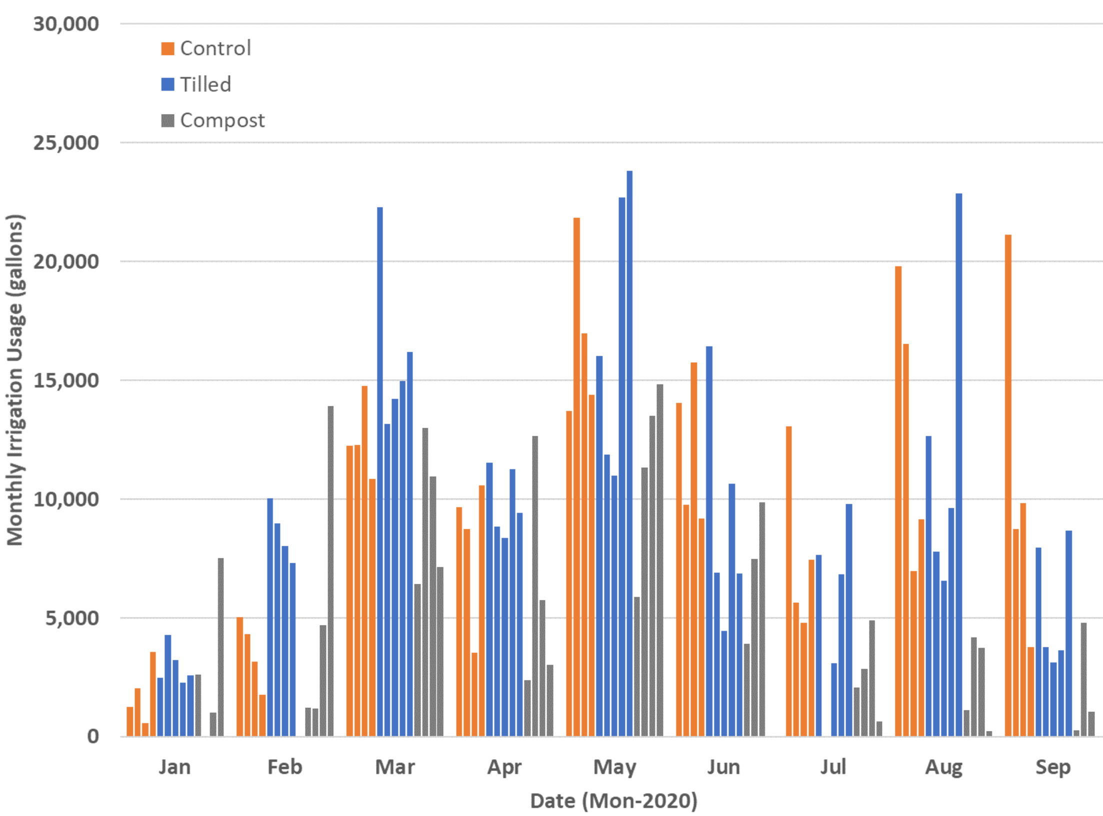

Figure 3-5. Irrigation usage from accessible Hunter Hydrawise systems from January to October 2020.

Cumulative irrigation volume was summed and divided by the total landscape area based on lot area listed on the Marion County Property Appraiser website and manually delineated impervious cover from aerial imagery (Figure 3-6). As lawns receive the majority of irrigation volume and all homes had approximately 60% of landscaped area as turfgrass, the volumes were also converted to effective depths applied only to lawn area (Figure 3-6). Based on these data, control and tilled lots had similar irrigation depths over the landscaped area ranging from 12 to 24 in., or 20 to 40 in. if applied only to lawns. By comparison, all compost lots had lower irrigation depths for total landscape (<12 in.) or lawns areas (<20 in.) than the lowest control or tilled lot, with a minimum of 6 in. over total area or 10 in. over lawn area. Though these are limited data, the irrigation depths for compost lots were essentially half of the depths applied by control or tilled lots.

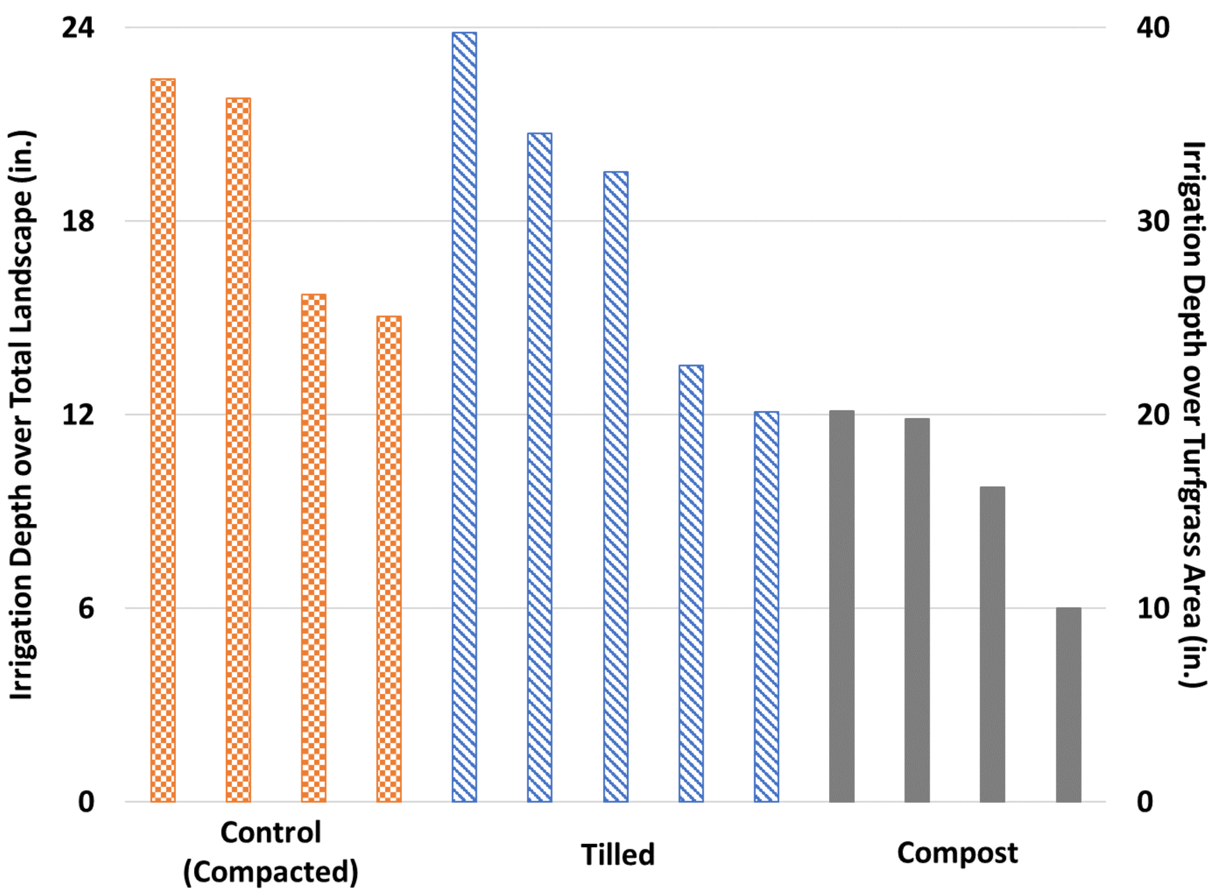

Figure 3-6. Irrigation volumes as irrigation depth over total landscaped area (left axis) or turfgrass area (right axis).

Unadjusted average annual home water use and the portion equal to January-October 2020 home water use are shown for all homes in Figure 3-7, grouped by soil treatments, whether they received topdressing or not, and sorted from greatest to least water users. The amount of 2020 water usage used for irrigation is also shown for homes this data was available as solid portions of bars. The greatest water users were tilled lots with topdressing, however, this was the only group of homes with no irrigation data available. Additionally, irrigation data was only available for the two lowest irrigation users in control not-topdressed, and compost not-topdressed, and two of the lowest three for compost topdressed. The proportion of home water use for irrigation from January to October 2020 for control and tilled lots ranged from 67% to 88%, while the range for compost lots was 35% to 66%. Overall, the average percent of home water use for irrigation for control, tilled, and compost lots was 80%, 75%, and 54%, respectively.

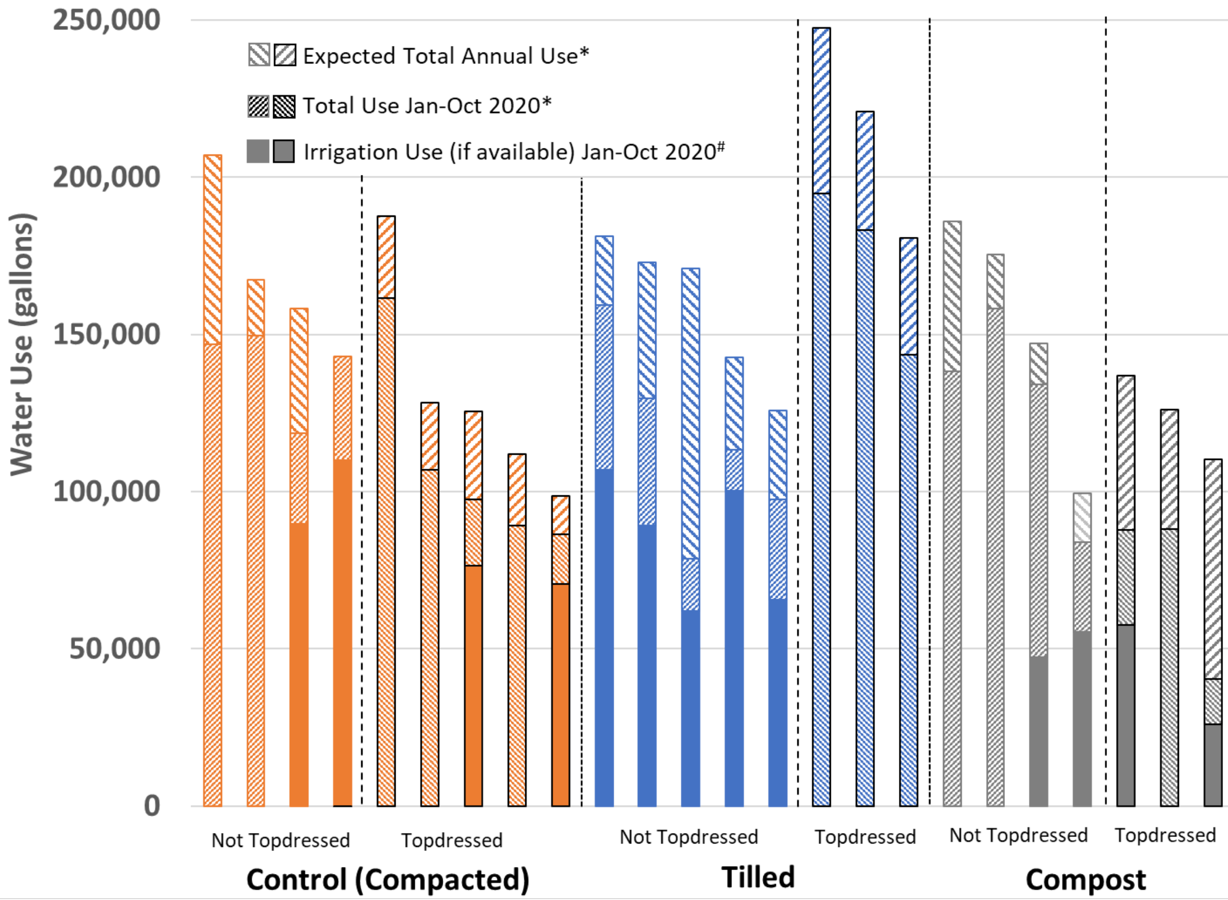

Figure 3-7. Water usage for each home in study showing annual use, total home use from Jan-Oct 2020, and Irrigation use from Jan-Oct 2020. *From Bay Laurel Center Community Development District. # Data (if available) from Hydrawise irrigation controllers on these homes.

3.2.3 Irrigation Run Times

The original total run time was 90 minutes scheduled as two "cycle and soak" 45-minute periods. During initial conversations, homeowners were asked to reduce their irrigation run cycle times by 25%, from 45 minutes to 34 minutes for a total of 68 minutes, with the option to adjust their irrigation schedules at any time. Subsequent adjustments are summarized in Table 3-1. By the end of the monitoring period, of the 16 lots that granted irrigation schedule viewing access, 10 stayed at the reduced rate or reduced it further, while five reverted to 100% run times (45 min. per cycle) or increased it further. Of the seven accessible control lots, none made further reductions to their run times beyond the 25% reduction, two lots stayed at the reduced irrigation times (25% reduction or 75% of initial duration), three lots returned their run time to 100%, and two lot increased their run time past the full run time (>100%). No access was available to tilled lots receiving topdressing. Of tilled lots not receiving topdressing, one lot decreased their run time further beyond the 25% reduction (62% of recommended run times), three lots remained between 67% and 75% run times, and one returned to the full (100%) run time. Of the composted lots, three lots decreased their run time by 56% (46% of initial run time), none stayed at the 75% run time, one returned to the full run time, and none have increased past the original run time. The mode for compost, tilled, and control lots, were reduce below 75%, remain at 75%, and return to 100%, respectively.

Based on available data, composted lots were more likely to maintain or decrease their run times below 34 minutes, had a lower proportion of home water use as irrigation, and overall applied a smaller depth of irrigation, compared to tilled or control homes. Notably, tilled lots had a higher proportion of homes remain at the 34 minute run times than controls, which had the only homes to increase their run times over the recommended 45 minute durations.

Table 3-1. Summary of irrigation run times on Hydrawise from 16 lots that granted viewing access.

Treatment	Decreased Run Time (<75%)	Unchanged Run Time (75%)	Returned Run Time (100%)	Increased Run Time (>100%)
N-N#	0	1	2	1
N-Y#	0	1	1	1
T-N	1	3	1	0
T-Y*	0	0	0	0
C-N	1	0	1	0
C-Y	2	0	0	0

*No access to T-Y lot irrigation data. #Irrigation data for two control no-topdressing (N-N) lots and one topdressing lot (N-Y) was not available beyond irrigation run times.

Overall, metered home water use was similar between control and compost amended lots, even though hydrawise data indicated that compost homeowners were irrigating less. This could be due to several factors, including that hydrawise data was for a subset of homes only during 2020 while metered water use was for all homes or greater indoor water use for compost lots than control lots. These issues are exacerbated by the limited sample size in this study.

3.3 Runoff Data

3.3.1 Runoff Monitoring

Runoff was collected from eight drop inlets during the monitoring period (July 1, 2018 – October 5, 2020). Two inlets (612 and 623) had instrumentation removed for runoff measurement and sampling due to excess sedimentation in weir boxes during on-going construction in nearby lots through the end of April 2019. Flow monitoring data from one inlet (627) was not collected due to sensor malfunctions from July to October, 2020. Total volume and runoff depth were scaled up to reflect the entire monitoring period for drains 612 and 623 due to them being out while construction was occurring for a few months. Drain 627 was also scaled up due to logger errors towards the end of the monitoring period (Table 3-3).

3.3.2 Runoff Volumes

The total runoff volumes for the monitoring period (July 2019 to January 2020) ranged from 1.1×10^6 L to 2.8×10^6 L (Table 2-1). The runoff ratios were lowest for composted lots (21%) compared to tilled (26%) and null (25%) (Table 3-3). Cumulative runoff volumes, normalized by drainage areas to depths, for all monitored inlets are shown in Table 3-3 and plotted in Figure 3-8.

Table 3-2. Treatment (C for compost, T for till, N for null) and top-dressing present (Y for top-dressed, N for not top-dressed), drainage area (hectare), rainfall depth (cm), total runoff volume (liters), runoff depth (cm), and runoff ratio for each drain.

Drain	Treatment	Drainage Area (acres)	Rainfall Depth (in.)	Runoff Volume (gal)	Runoff Depth (in.)	Runoff (%)
607	C-N	0.56	133.1	530,296	35.0	26
608	T-N	0.97	133.1	921,617	35.0	26
610	C-N	0.52	133.1	462,517	32.7	25
612	T-Y	0.81	85.4	593,694	27.2	32
618	C-Y	0.68	133.1	430,866	23.2	17
619	N-Y	0.63	133.1	666,449	39.0	29
623	N-Y	0.98	92.5	722,418	27.2	29
627	N-N	1.13	114.6	751,573	24.4	21

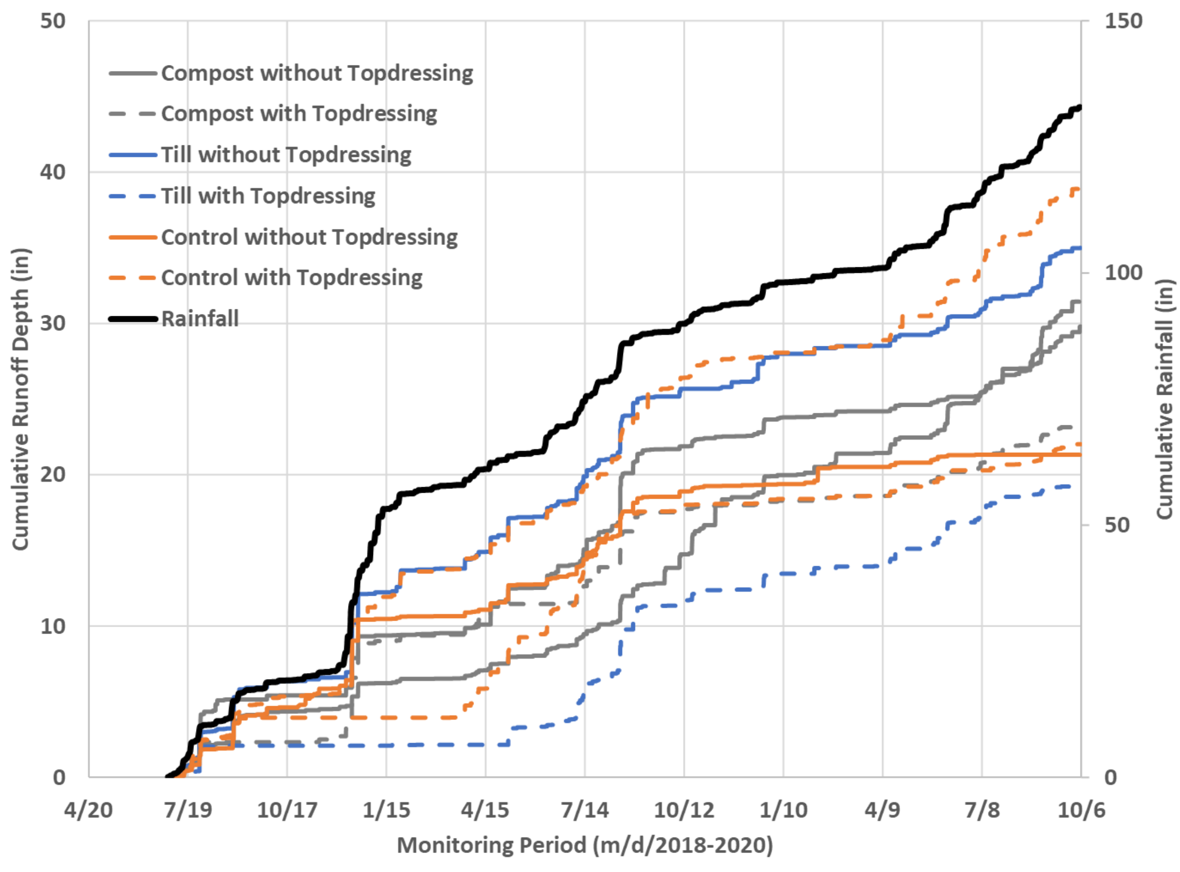

Figure 3-8. Runoff and rainfall depths for the monitoring period of 7/3/2018 to 10/5/2020.

3.3.3 Curve Numbers

This is the first research study to evaluate soil amendment effects on urban landscape runoff in a field study setting. Prior research has been limited to plots, lysimeters, or lab studies. The mean compost curve numbers, 74, was lower than the tilled and null treatments, 87 and 84 respectively, indicating relatively lower runoff production. Bean and Dukes (2014) and Olson et al. (2013) reported CNs and percent runoff produced from composted soils were lower than tilled and control treatments. In the Bean and Dukes (2014) study, the control lots had the highest CN, 75 and 87 for two different soil types, while in this study, the tilled lots had the greatest CN, 87. While Olson et al. (2013) saw a 53% increase in runoff in control plots compared to composted, this study had an average of 4% increase in runoff produced in control plots compared to composted lots. This study also had a 12% greater runoff percentage from the composted lots than the Olson et al. study observed. Pitt et al. (1999) also observed that two of the four compost amended test plots had significantly less runoff than the control plots while the other two were not significantly different.

There was also more runoff produced from top-dressed lots than lots that were not top-dressed, 88 and 74, respectively (Table 2-2).

Tilled lots produced about 12 cm more runoff than composted lots, a 25% increase, and null lots produced about 9 cm more than composted lots, a 9% increase. Drains that received runoff from top-dressed lots had a greater CN than drains that received runoff from lots that were not top-dressed.

Table 3-3. Maximum, median, minimum, mean, and standard deviation for CNs for all storm events from 2018-2020.

	Compost	Till	Null	Top-dressing	No Top-dressing
Maximum	85	91	91	91	84
Median	71	88	83	88	74
Minimum	66	84	77	83	66
Mean	74	88	84	88	74
Std. Deviation	10	6	7	4	8

Significant differences based on treatment (compost, till, and null) were analyzed separately from significant differences based on topdressing presence (top-dressing, no top-dressing).

3.3.4 Runoff Concentrations

Runoff samples were collected from the eight instrumented storm inlets for a total of 23 storms sampled from 12/9/2018-10/4/2020. In some instances, system malfunctions occurred with the autosamplers and a sample was not collected for one or a few autosamplers. Samples were analyzed for nitrogen species of NO_3-N, NH_4-N, and Total Kjeldahl Nitrogen (TKN), along with Total Phosphorus (TP). Organic Nitrogen (Org. N) was calculated as the difference between TKN and NH_4-N and Total Nitrogen (TN) is the sum of NO_3-N, NH_4-N, and Organic N. Bar graphs of TN (and Nitrogen species) and TP concentrations are included in Appendix A.1. Only one storm sample was removed from analyses after being determined an outlier. This was the tilled and topdressed sample collected on 10/20/19, which has a TN concentration of approximately 19 mg/L (Appendix Figure A-2), three times the next highest concentration sampled, and a TP concentration of 10,000 µg/l (Appendix Figure A-7), nearly five times the next highest concentration sampled.

3.3.4.1 Nitrogen Runoff Concentrations

Runoff concentrations of TN ranged from 0.16 to 10.9 mg/L (Table 3-4; Figure 3-9) and were generally dominated by Org. N, followed by NO_3-N (Table 3-5; Figures A-1 – A-5). Overall, TN concentrations were not significantly different between treatments or topdressing (Figures 3-9). Results of statistical analysis of log-transformed TN concentrations are shown in Table 3-6. The p-values were 0.795 and 0.946 for treatment and topdressing effects, respectively. Notably, no clear increases in runoff concentrations were observed following compost topdressing of lawns (2019: late April/May, September; 2020: May and September). However, date was significant ($p < 0.001$), indicating that storm to storm differences were more responsible for varying concentrations than soil treatments or topdressing. To determine if the nitrogen species varied across treatment or topdressing, they were log-transformed as well before running statistical analyses. There were no significant differences across NH_4-N, NO_3-N, TKN, or Org N for treatment or topdressing

Table 3-4. Maximum, median, minimum, arithmetic mean, and standard deviation for TN concentrations from the runoff of 23 sampled storm events in Ocala, Florida.

	Compost	Till	Control (Null)	Top-dressing	No Top-dressing
Maximum	7.52	4.10	10.90	10.90	7.52
Median	1.09	1.11	0.95	1.03	1.01
Minimum	0.31	0.16	0.22	0.16	0.25
Arithmetic Mean	1.39	1.14	1.19	1.26	1.23
Std. Deviation (Range)	-0.9 - 2.7	-1.2 - 2.5	-1.1 - 2.7	-1.2 - 2.7	-1.0 - 2.7

Significant differences are based on Tukey's post hoc analysis of log-transformed values and are denoted by different letters as superscript. Significant differences based on soil treatment (compost, till, and null) were analyzed separately from significant differences based on topdressing presence (top-dressing, no top-dressing).

Harper and Baker (2007) estimated the typical TN concentration in runoff from single-family residential areas as 2.02 mg/L. By comparison, this was greater than 79%, 87%, and 91%, of compost, tilled, and control, respectively, runoff TN concentrations. Median concentrations for TN from this study ranged from 0.95 to 1.11 mg/L. This was lower than what Lusk et al. (2020) found in their study, which had a mean event concentration of 1.61 mg/L, and 2.07 mg/L from the Harper and Baker (2007) report. Yang and Toor, (2016) however, had a monthly mean concentration of 1.04 mg/L, closer to what this study showed. Similarly, to Lusk et al., Org N was the dominant nitrogen form, making up about half or slightly more than half of TN concentrations

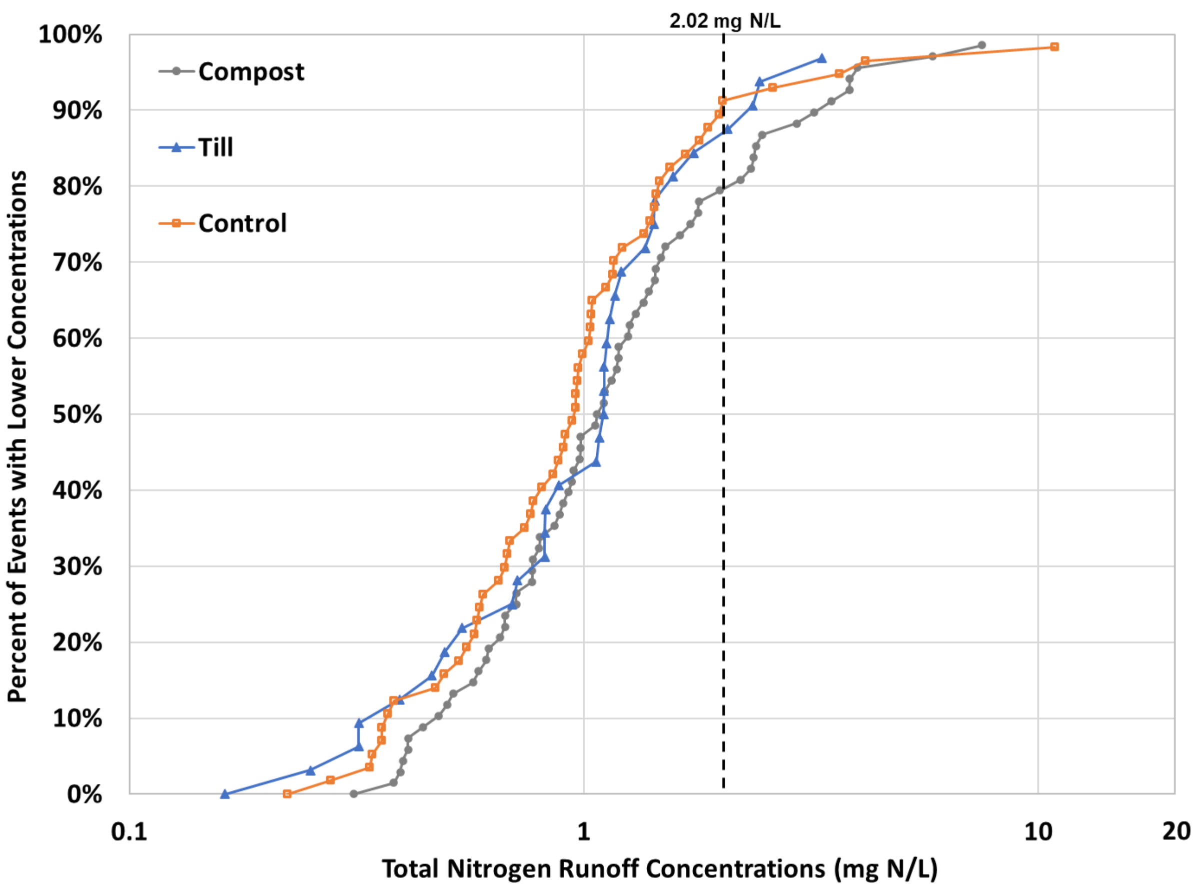

Figure 3-9. Probability of exceedance for TN concentrations in runoff for composted, tilled, and control lots.

Table 3-5. Breakdown of overall geometric means for log-transformed nitrogen species concentrations from 23 sampled storms.

	Compost	Till	Control (Null)	Top-dressing	No Top-dressing
NO_3-N (mg N/L)	0.25[a]	0.19[a]	0.20[a]	0.21[a]	0.22[a]
NH_4-N (mg N/L)	0.10[a]	0.07[a]	0.09[a]	0.09[a]	0.08[a]
Org N (mg/L)	0.72[a]	0.68[a]	0.61[a]	0.70[a]	0.64[a]
TN (mg/L)	1.09[a]	0.92[a]	0.91[a]	0.96[a]	0.97[a]

Significant differences are based on Tukey's post hoc analysis and are denoted by different letters as superscript. Significant differences based on soil treatment were analyzed separately from topdressing.

3.3.4.2 Phosphorus Runoff Concentrations

Runoff concentrations of TP ranged from 2 to 2,188 mg P/L (Table 3-7; Figure 3-10). Overall, TP concentrations were not significantly different between treatments (Figures 3-10) or topdressing (Table 3-7 & 3-8). Results of statistical analysis of log-transformed TN concentrations are shown in Table 3-6. The p-values were 0.795 and 0.946 for treatment and topdressing effects, respectively. Notably, no clear increases in runoff concentrations were observed following compost topdressing of lawns (2019: late April/May, September; 2020: May and September). However, date was significant ($p < 0.001$), indicating that storm to storm differences were more responsible for varying concentrations than soil treatments or topdressing (Table 3-8).

Table 3-6. ANOVA table for log-transformed TN concentrations looking at treatment and topdressing effects on concentrations.

	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P Value
Treatment	2	0.164	0.082	0.255	0.795
Topdressing	1	0.002	0.002	0.006	0.946
Date	22	40.165	1.826	5.694	**<0.001**
Treatment*Topdressing	2	0.061	0.031	0.096	0.912
Treatment*Date	44	7.484	0.170	0.531	0.977
Topdressing*Date	22	1.703	0.077	0.241	1.000

Harper and Baker (2007) estimated the typical TP concentration in runoff from single-family residential area as 327 µg/L. This was greater than 47%, 71%, and 74% of runoff TP concentrations from compost, tilled, and control lots, respectively (Figure 3-10). Although not significantly different, the distribution of TP concentrations in runoff from compost lots generally exceeded tilled and control lot concentrations.

Table 3-7. Maximum, median, minimum, mean, and standard deviation for SR-transformed TP concentrations from the runoff of 23 sampled storm events in Ocala, Florida.

	Compost	Till	Control (Null)	Top-dressing	No Top-dressing
Maximum	2,188	894	1,326	1,326	2,188
Median	326	202	164	232	219
Minimum	2	28	3	7	2
Mean	390[a]	272[a]	209[a]	212[a]	268[a]
Std. Deviation (Range)	244-378	166-206	114-208	177-275	144-264

Significant differences are based on Tukey's post hoc analysis of square-root-transformed values and are denoted by different letters as superscript. Significant differences based on soil treatment (compost, till, and null) were analyzed separately from significant differences based on topdressing presence (top-dressing, no top-dressing).

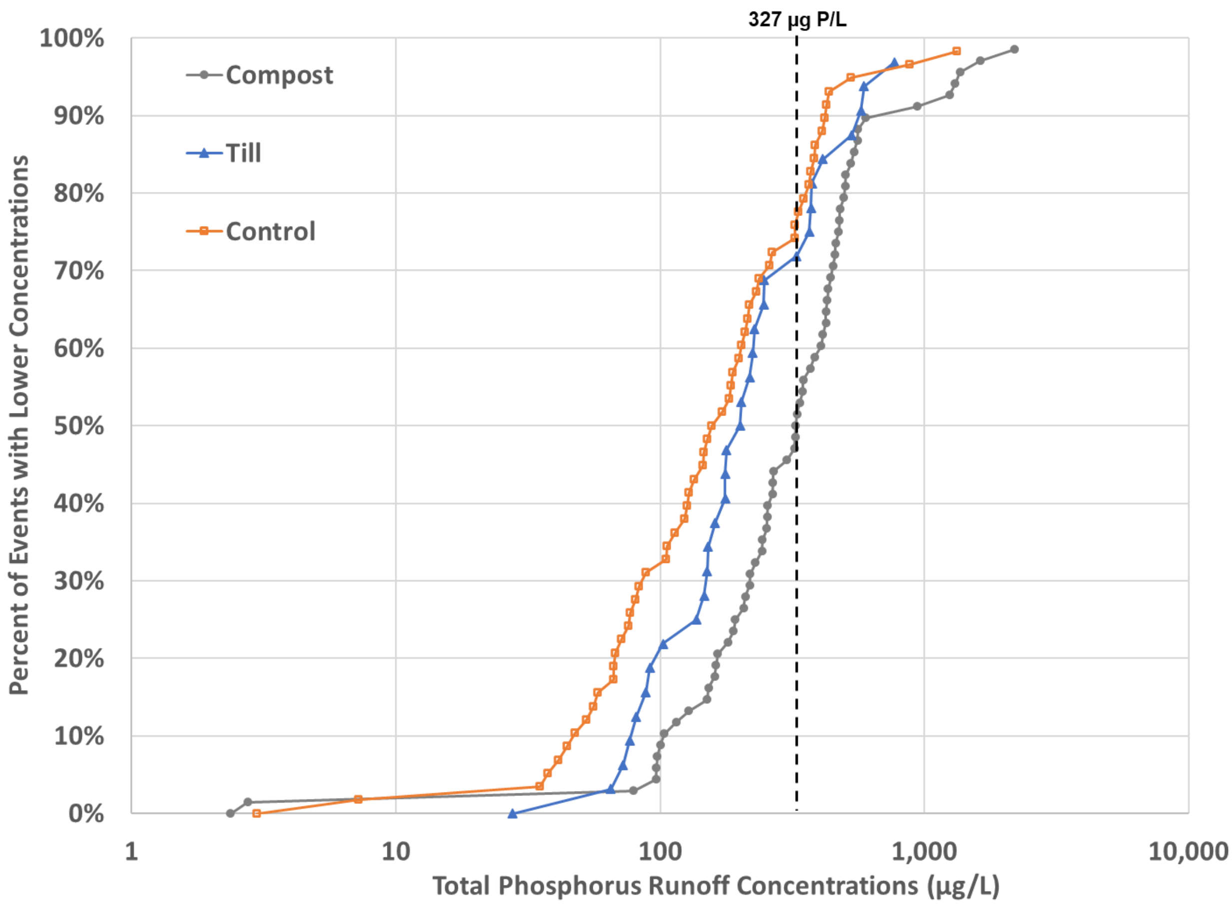

Figure 3-10. Showing the probability of exceedance for raw TP concentrations for composted, tilled, and control lots.

Table 3-8. ANOVA table for SR-transformed TP concentrations looking at treatment and topdressing effects on concentrations.

	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P Value
Treatment	2	98.52	49.26	1.415	0.404
Topdressing	1	28.74	28.74	0.826	0.447
Date	22	2634.72	119.76	3.440	**<0.001**
Treatment*Topdressing	2	32.54	16.27	0.467	0.674
Treatment*Date	44	1343.76	30.54	0.877	0.662
Topdressing*Date	22	387.73	17.62	0.506	0.952

3.3.5 Runoff Loadings

Runoff loadings (lbs./ac.) were calculated by multiplying the runoff volume for sampled events by the concentrations of TN and TP for the respective events, covered in section 2.8.2.

To determine yearly nutrient loadings (lbs./ac./yr) and account for loadings from storms not sampled, mean event concentrations were calculated by weighting the average runoff concentrations, for both TN and TP from sampled storm events by the runoff volumes. Mean event concentrations are listed in Table 3-9 and while TN concentrations were all less than 2.02 mg N/l, all TP concentrations exceeded 327 µg

P/L (Table 3-9). The mass loading was than divided by each treatment's drainage area, and then again by the total rainfall for each drain and multiplied by the average annual rainfall.

Table 3-9. Mean event runoff concentrations for Total Nitrogen and total Phosphorus.

	Compost	Till	Null	Top-dress	No Top-dress
Total Nitrogen (mg N/l)	1.35	1.38	1.68	1.63	1.22
Total Phosphorus (mg P/l)	0.47	0.61	0.69	0.72	0.40

3.3.5.1 Nitrogen Runoff Loadings

Event loadings are included in Appendix A.2. For runoff loading, TN typically did not exceed 0.01 lbs/1,000 ft^2, except for on two occasions 12/14/2018 and 3/27/2019. Based on the concentrations above, the 12/15/2018 spike in loading was most likely due to the volume of the storm, since it was the largest event of the monitoring period, while the 3/27/2019 spike was due to the slightly higher-than-average concentration in TN (6 mg/L).

Similar to runoff TN concentrations, neither soil treatment nor topdressing significantly affected runoff loadings (Table 3-10). However, date was a significant factor ($p < 0.001$), further indicating that storm to storm variability was a more significant driver of runoff water quality than soil treatments or topdressing.

Table 3-10. ANOVA summary of log-transformed TN runoff loadings (lbs. N/ac.).

	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P Value
Treatment	2	0.29	0.14	0.076	0.929
Topdressing	1	0.89	0.89	0.467	0.549
Date	22	498.58	22.66	11.96	**<0.001**
Treatment*Topdressing	2	5.26	2.63	1.389	0.380
Treatment*Date	44	73.34	1.67	0.880	0.658
Topdressing*Date	21	41.50	1.98	1.043	0.446

The yearly TN loadings (lbs./ac./yr) ranged from 2.6 lbs./ac./yr for composted lots with topdressing to 5.6 lbs./ac./yr for tilled lots with topdressing (Figure 3-11). Runoff TN loadings were dominated by Org. N, making up 63% to 73% of TN loadings, followed by NO^3-N making up 19% to 26% of TN loadings. As indicated by prior statistical analyses of concentrations and loadings, and reflected in Figure 3-11, there was no clear trend from topdressing on runoff TN loadings.

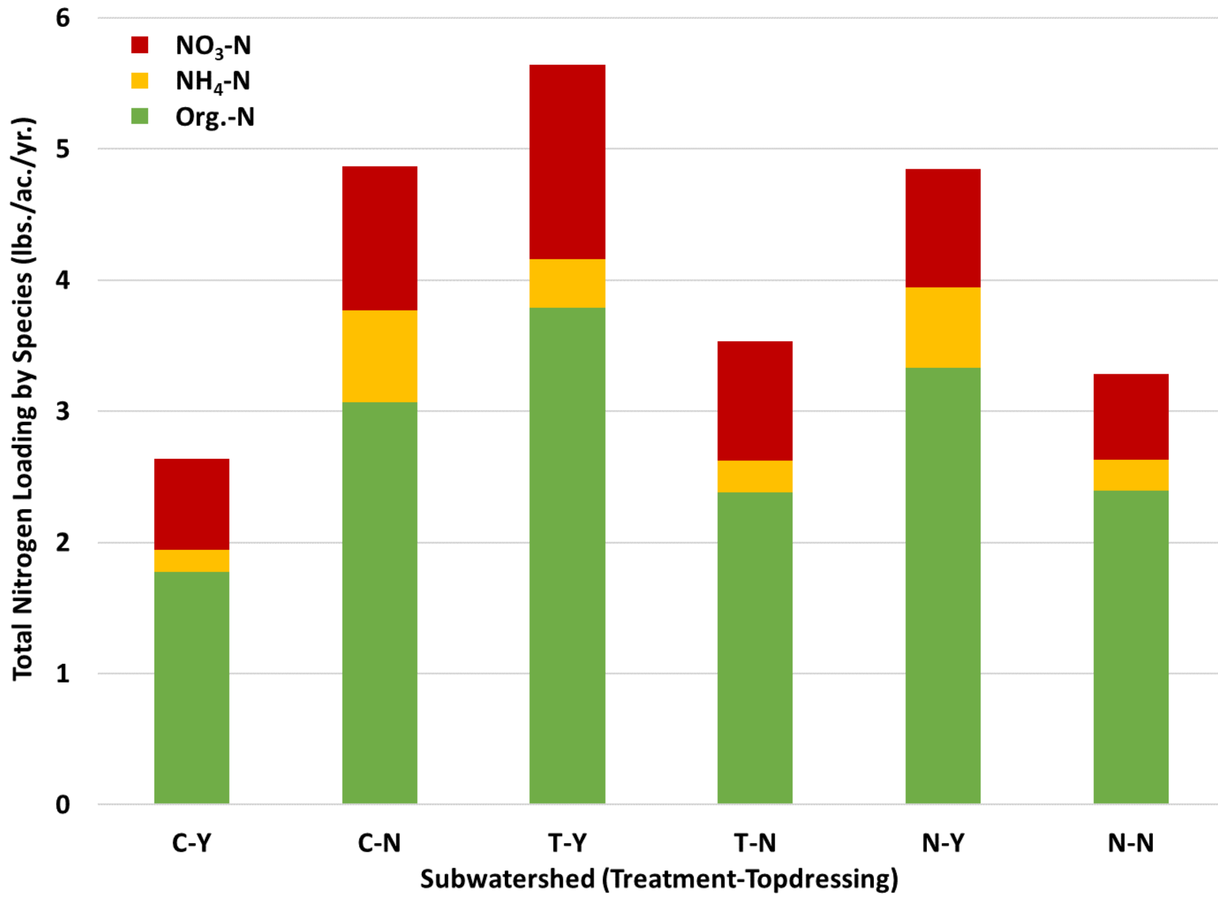

Figure 3-11. Stacked bar graph showing TN loading (lbs./ac./yr) between different soil treatments (C for compost, T for tilled, N for control) and topdressing application (Y for topdressing, N for no topdressing).

3.3.5.2 Phosphorus Runoff Loadings

Event loadings are included in Appendix A.2. For runoff loading, TP typically did not exceed 0.005 lbs./1,000 ft^2, except for the 12/14/2018 event, which was driven by high runoff volume. Again, we did not observe clear increases in runoff loadings following compost top dressing of lawns (2019: late April/May, September; 2020: May and September).

Similar to runoff TP concentrations, neither soil treatment nor topdressing significantly affected runoff TP loadings (Table 3-11). However, date was a significant factor ($p < 0.001$), further indicating that storm to storm variability was a more significant driver of runoff water quality than soil treatments or topdressing. Notably, the interaction between Date and Treatment and Date and Topdressing were both significant. While neither treatment nor topdressing were significant alone, topdressing was nearly significant ($p = 0.078$), and may reflect a minor increase. However, based on the annualized loadings (Figure 3-12) there was no consistent effect of topdressing on soil treatments. While topdressed lots had a higher loading for control and tilled lots, not topdressed lots had higher loadings than topdressed compost lots.

Table 3-11. ANOVA summary of log-transformed event runoff TP loadings (lbs./ac.).

	Degrees of Freedom	Sum of Squares	Mean of Squares	F Value	P Value
Treatment	2	0.004	0.002	0.435	0.670
Topdressing	1	0.020	0.020	4.073	0.078
Date	**22**	**1.546**	**0.070**	**13.99**	**<0.001**
Treatment*Topdressing	2	0.031	0.015	3.070	0.118
*Treatment*Date*	*44*	*0.412*	*0.009*	*1.865*	*0.014*
*Topdressing*Date*	*21*	*0.262*	*0.124*	*2.486*	*0.004*

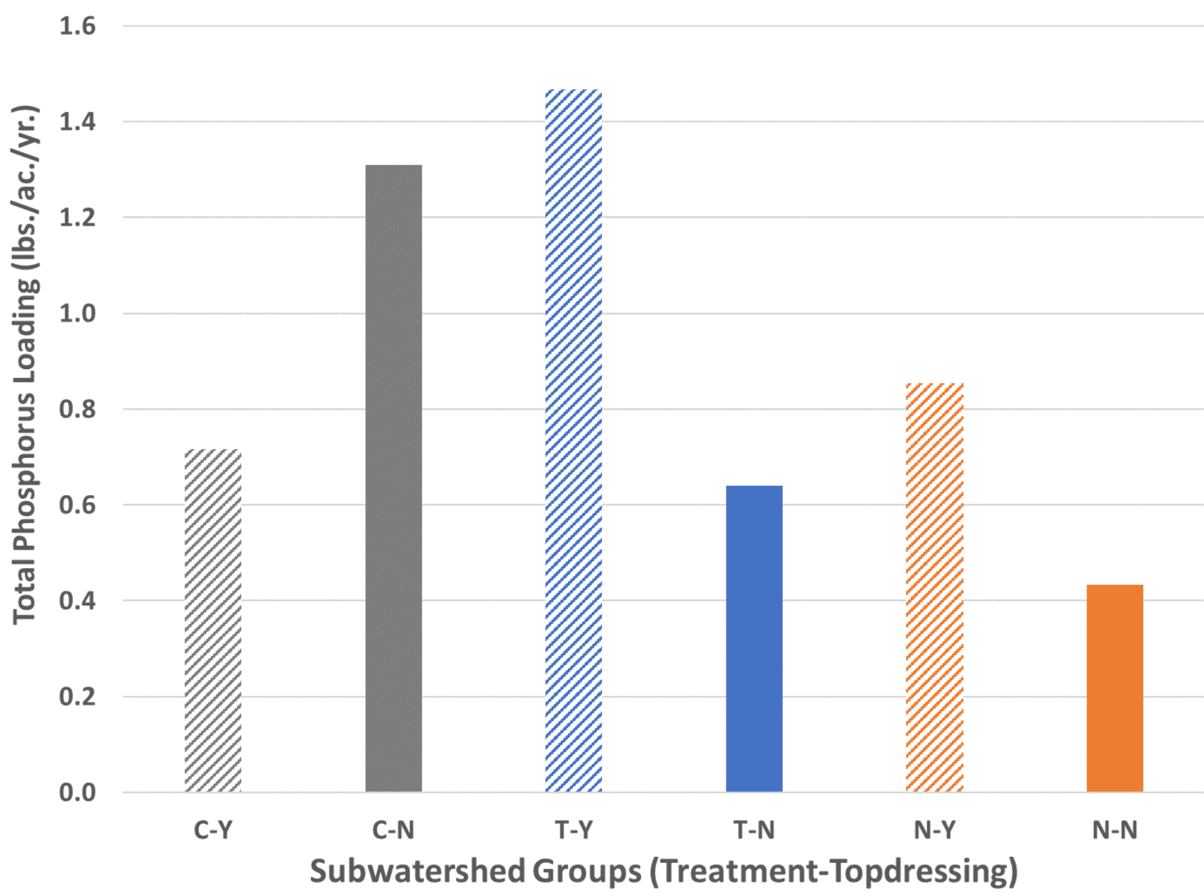

Figure 3-12. Bar graph showing TP loading (lbs./ac./yr.) between different treatments (C for compost, T for tilled, N for control) and topdressing application (Y for top-dressing, N for no top-dressing) without the 10/20/19 storm.

Annualized loadings for soil treatments and topdressing are presented in Table 3-12. Due to a lack of replicates (storm inlets) statistical analyses were not feasible to evaluate significant differences. However, in general the annualized runoff loadings were around 4.1 - 4.6 lbs. N/ac./yr and 0.7 - 1.1 lbs. P/ac./yr.

Table 3-12. Yearly estimates of total Nitrogen and total phosphorus runoff loadings.

	Compost	Till	Null	Top-dress	No Top-dress
Total Nitrogen (lbs/ac/yr)	4.12	4.59	4.33	4.49	4.14
Total Phosphorus (lbs/ac/yr)	1.12	1.05	0.71	0.97	0.92

A weakness in the study was the low sample size (eight storm drains) and low replicates in each treatment area (1-2 storm drains per treatment). To improve the study, there could have been a greater replication of treatments. There were also challenges coordinating with the construction and landscaping crews within the development process. Mainly communication and scheduling, but also the constraints of fitting research timeline within a development timeline, which may not correspond to each other.

3.4 Soil Moisture

Soil moisture sensors were installed in 12 of the 24 homes, two in each of the six treatment types. Data were downloaded monthly. The OTOW field study was conducted to determine if treatment or topdressing had significant effects on VWC (Figures 3-13). Plots of each sensor over the full duration of the study are included in Appendix A.3. Throughout the monitoring period, the compost amended lots had the highest VWC values, while the control lots had the lowest VWC values. One tilled lot tended to have a VWC higher than the rest of the tilled lots due to a large tree providing shade for the entire backyard, shown as tilled without topdressing. Shading reduces evapotranspiration thus increasing the VWC.

In response to a rain event (e.g. July 11, 2020; Figure 3-15) or irrigation event (e.g. July 8 & 15, 2020; Figure 3-15), VWC increased proportional in each treatment. However, after the irrigation or rain event concludes, the VWC response varies between treatments. In the composted lots, the VWC remained elevated for longer than control lots, while the tilled and null lot VWC values decreased more quickly to pre-event levels. This likely reflects limited infiltration depth, a sharp wetting front, and low field capacity of the soil.

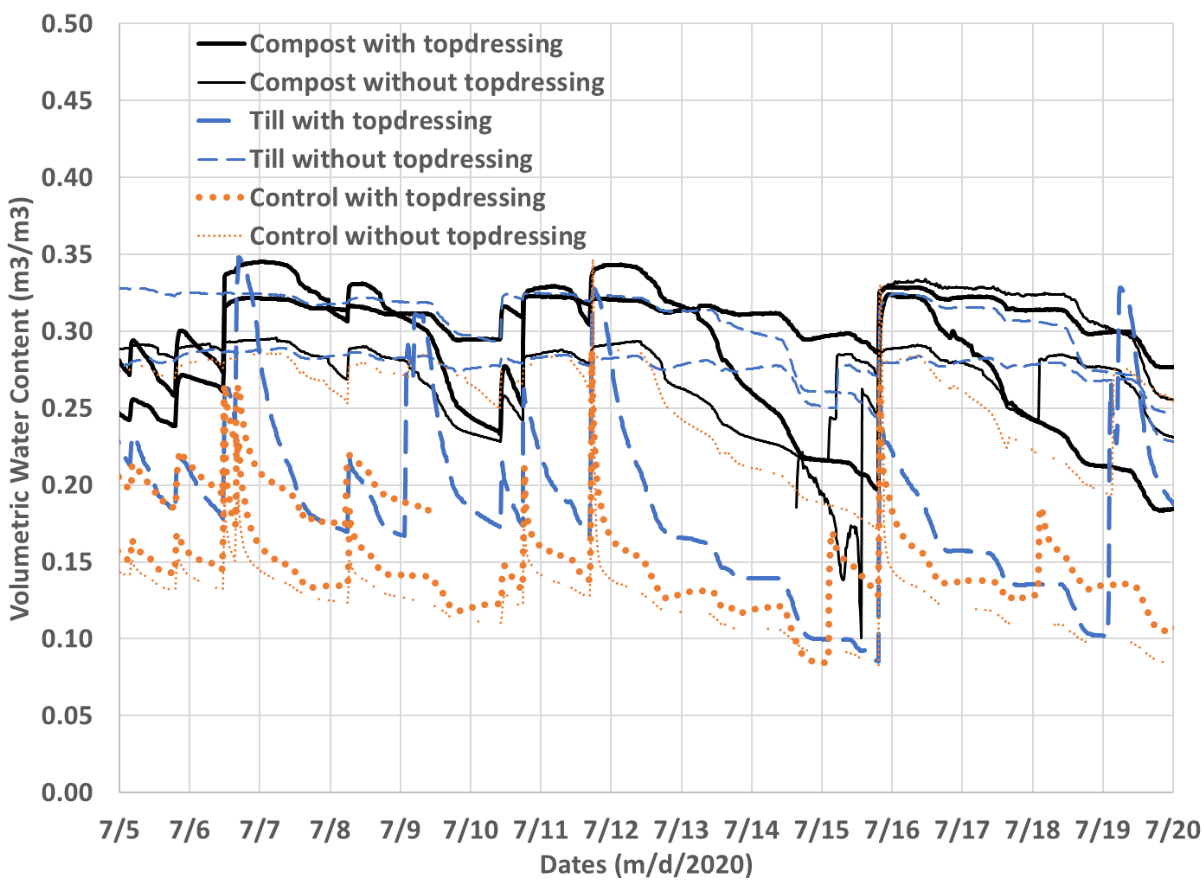

Figure 3-13. Volumetric water content values from 7/5/2020 to 7/20/2020.

Statistical analyses of the VWC time series from soil moisture sensors show that both treatment and topdressing had significant effects on VWC, as well as the interaction term (Table 3-13). The compost amended lots were significantly higher than tilled and null lots, an 8% and a 36% increase, respectively, and tilled lots were significantly higher than null lots, a 31% increase (Tables 3-14). The extended elevated VWC for compost and tilled lots likely indicate excess irrigation amounts. Surprisingly though, topdressed lots had significantly lower (~4%) VWC than lots that were not topdressed. Topdressing decreased the mean VWC of compost and control (null) lots by 1.4% and 2.0%, respectively, but mean VWC decreased by 9% for tilled lots that were topdressed (Figure 3-14). One other possible explanation is that topdressing may have improved the plant health and increased plant ET, further depleting the VWC. Although, it is not clear why this effect would have been so much greater on tilled lots than others. Analysis of the VWC before and after topdressing applications did not show an abrupt change in behavior, so the effect may have developed over a longer period as a result of cumulative applications or been the result of localized soil characteristics. The significant interaction term may be due to components not directly tied to treatments but rather homeowner behavior, such as landscaping habits or environmental conditions that were not controlled for.

The extended elevated VWC may also be a result of drainage being limited by underlying restrictive layers. Tillage only extended 6 in. below the soil surface, not nearly sufficient to alleviate the full depth of compaction. In agriculture, tillage is also known to develop a hardpan, a compacted layer just below the depth of tillage that tines push off on to lift soil during the process. Either of these could restrict drainage, effectively creating perched water table locally. This also suggests that irrigation may be reduced further without stressing turfgrass.

Table 3-13. ANOVA results for incorporation rates and amendment type effects on field VWC (%). An asterisk denotes significant effects.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	1075.8	537.9	207289	**<0.0001**
Topdressing	1	306.4	306.4	118061	**<0.0001**
Treatment:Topdressing	2	235.3	117.7	45346	**<0.0001**
Residuals	748307	1941.7	0.002		

Table 3-14. Post hoc comparison of means using Tukey's HSD on raw volumetric water content data. Significant differences are denoted by superscript letters.

	Compost	Till	Control	No Topdress	Topdress
VWC (%)	25.28^{a}	23.63^{b}	16.52^{c}	23.93^{a}	19.70^{b}

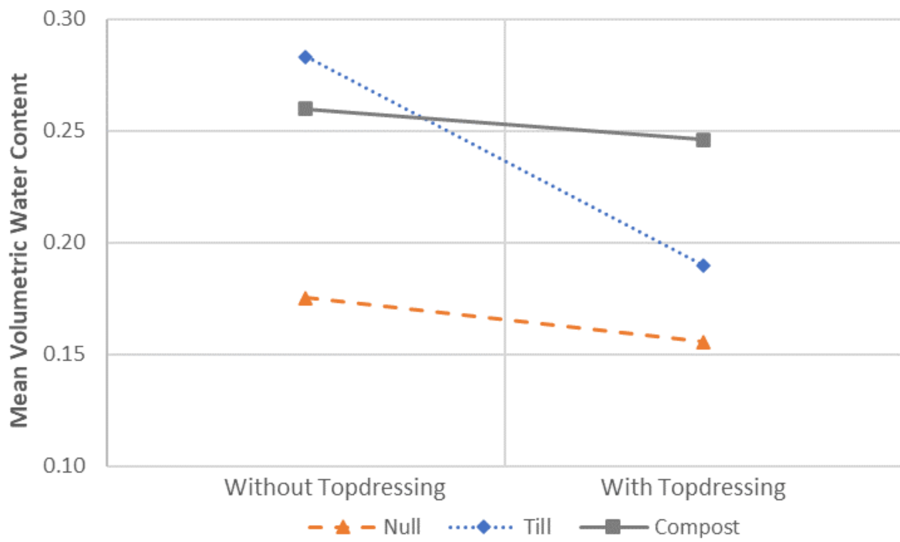

Figure 3-14. Interaction plot of soil treatment and topdressing effects on VWC.

Field capacity values were estimated using methods described in Bean et al. (2018), specifically using the MATLAB code. data was used to compare differences in field capacity and range of VWC between different treatments and sub-treatments (Figure 3-15). The box and whisker plots represent the range that FC falls within, while the maximum and minimum VWC during the monitoring period indicate the range of VWC values. FC values within the compost treatment were the most consistent and varied the least, even between lots that were topdressed and those that were not. There was more variance among the tilled and control treatments than the compost treatments, and the control varied the most.

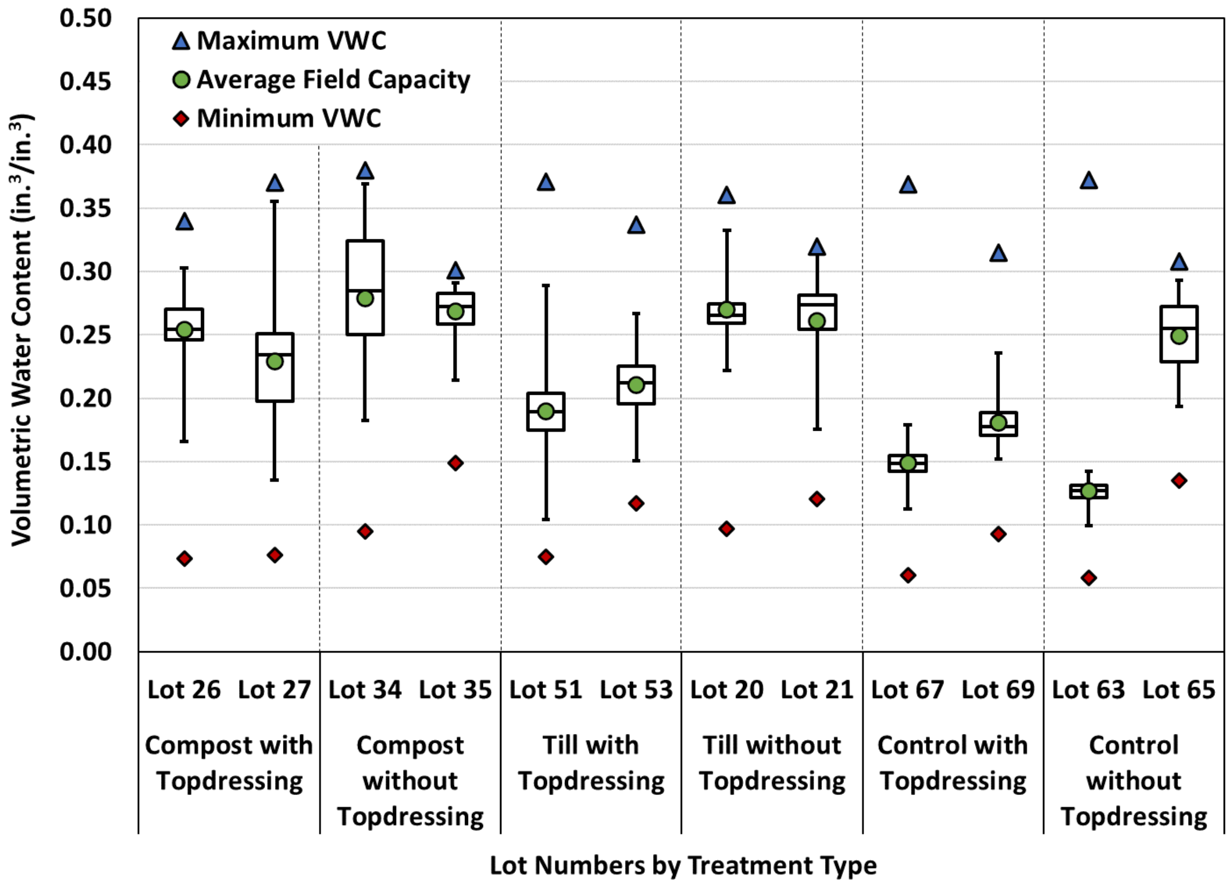

Figure 3-15. Field capacity values between different soil and topdressing treatments during the monitoring period.

The initial irrigation scheduling for turfgrass areas was set as two cycles of 45 minutes. The 25% reduction in runtimes reduced each duration to 34 minutes, but homeowners were permitted to adjust their irrigation at will, which may have influenced the field capacity results. For example, lot 65, a control lot, had irrigation cycles three times longer (60 min) than lots 26, 27, 34 (20 min), which were composted lots, yet they achieved similar ranges of FC, from about 24% to 28% (Figure 3-15). Lot 20 also had an unusually high range of FC, similar to that of a composted lot (27% to 30%), which may be related to the presence of a large tree just outside of the backyard line, which creates shade for the majority of the day in the backyard of lot 20. The presence of shade would reduce evapotranspiration rates of turfgrass compared to elsewhere on the project site, since this is the only lot with shading coming from a large pre-existing tree. Therefore, the differences may have come from factors related to irrigation schedules, as was the case with lot 65. Having access to view the schedules of more than just 15 of the study homes may have better aided our understanding of these differences.

Based on the voluntary reductions for three of four compost amended lots in Figure 3-15 (26, 27, and 34) and their corresponding FC ranges, it is reasonable to conclude there is a potential to further reduce irrigation cycle run times without negative impacts on turfgrass.

3.5 Leachate

Leachate collection was separated into two experiments. The first was a laboratory column study to investigate leaching during the establishment irrigation period while the second experiment was an in-situ lysimeter study to assess long-term leaching under residential lawns.

3.5.1 Establishment Irrigation Column Study

Columns (15) were constructed as previously described in section 2.7. Daily applications of deionized water were sprinkled on top of the columns equivalent to a depth of 0.61 in. (1.5 cm). No leachate was produced in any of the columns until day four of irrigation, and leachate volumes were consistent throughout the 30 days, ranging between 0.50 in. (1.3 cm) and 0.62 in. (1.6 cm) per day. Leachate volumes were not significantly different across columns with different amendment/soil ratios. The cumulative leachate depths over the 30 days ranged from 14 to 15 in. (36 to 39 cm).

Day four TN leachate concentrations were not significantly different between treatments (Table 3-27), with all samples ranging from 19.5 to 26.9 mg/l. Elevated TN was primarily due to relatively high NO_3-N concentrations (17.0 to 25.4 mg/l) from an unknown source. These concentrations could not be attributed to the amendment, as the control columns had similar concentrations and no trend related amendment ratio was evident. It was concluded that the initial flushing of NO_3-N was germane to the column elements and independent of treatments. A spike in TN concentrations was seen on day 10 and was mainly due to increases in concentrations of NH_4-N and Org. N from day four (Figure 3-16). On day 10, TN concentrations were significantly higher for 1:2 and 1:5 than control concentrations. Days 20 and 30 showed a decreasing trend for NO_3-N, NH_4-N, and Org. N (Figure 3-16). For all treatments, TN concentrations were below 20 mg/L on day 20 and below 10 mg/L for day 30. On day 30, the total nitrogen concentrations for 1:2 were significantly higher than all other incorporation ratios (Table 3-15). The trend of increasing concentrations with increasing amendment ratio was still visible during days 10, 20, and 30. Trenholm et al. (2011), Morton et al. (1998), and Brown et al. (1977) concluded that in addition to irrigation rates, the rate of nitrogen application is also closely related to nitrogen leaching. These conclusions are in line with the results of the column study, as it was found that although the irrigation rate was constant across all treatments, there was still variability in concentrations of nitrogen across the incorporation rates. As incorporation rates increased, concentrations tended to increase as well. Pandey (2005) also found that nitrogen leaching in amended soils was not significantly different from the control, while in this column study, the 1:2 incorporation rate was significantly different from the control and 1:20 and 1:10, but not the 1:5 incorporation rate. Statistical analyses of each nitrogen species are included in Appendix A.4.

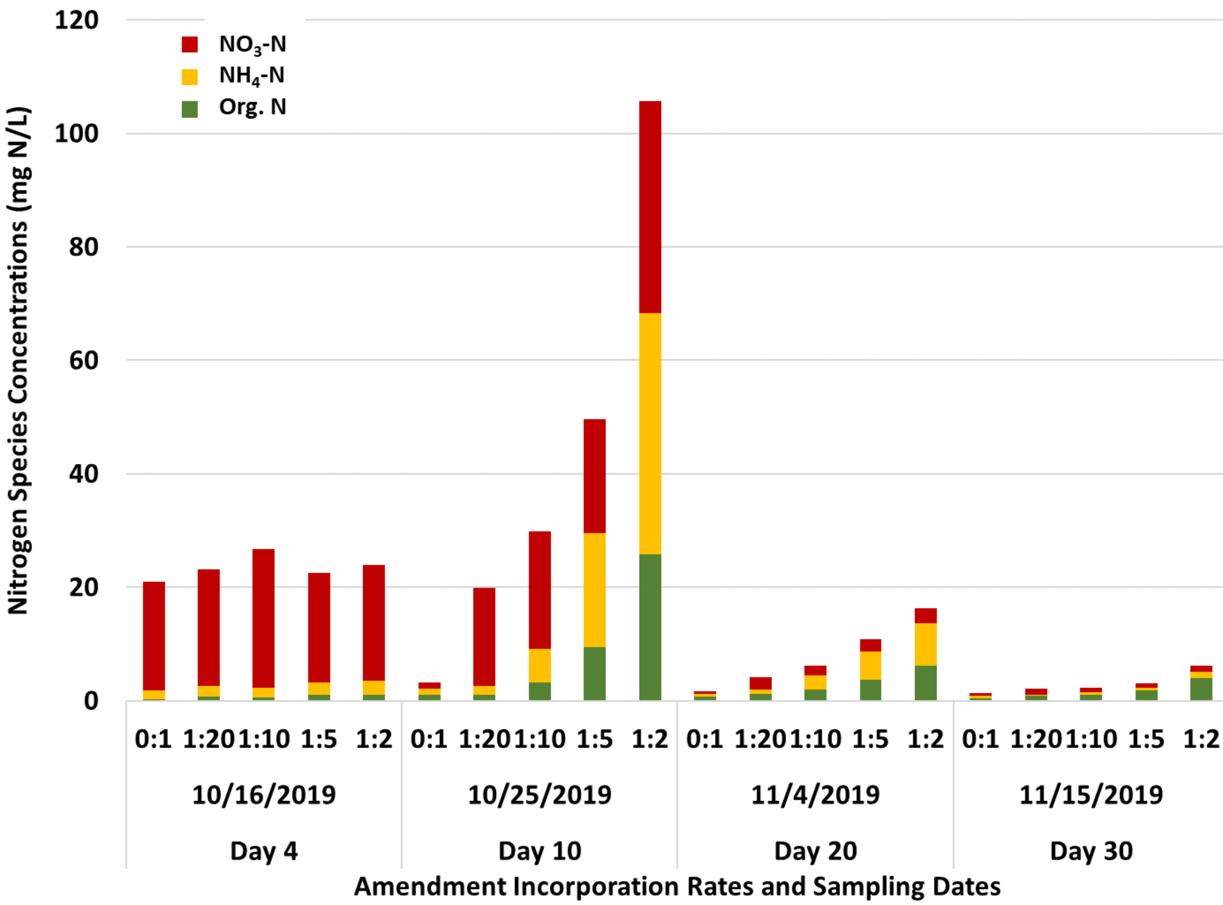

Figure 3-16. Average nitrogen species concentrations for the column study broken up by species on collection days four, 10, 20, and 30.

Table 3-15. TN concentration (mg/L) averages from various incorporation ratios on days four, 10, 20, and 30.

Incorporation Ratio (Compost:Soil)	Days after Irrigation Began			
	4 (first leachate)	10	20	30
1:2	24.1^{a*}	16.6^{a}	13.9^{a}	7.0^{a}
1:5	22.1^{a}	8.4^{b}	11.6^{ab}	3.2^{b}
1:10	26.0^{a}	4.7^{bc}	6.7^{bc}	2.4^{b}
1:20	22.4^{a}	3.5^{bc}	4.6^{c}	2.1^{b}
0:1 (control)	21.0^{a}	0.5^{c}	1.8^{c}	1.5^{b}

*Significant differences denoted by different superscripts letters as superscripts are by day and from Tukey's post hoc analysis.

Day four TP concentrations (Figure 3-17) ranged from 146 ug/L to 1,788 ug/L, with no significant differences among amendment rates (Table 3-16). The spike seen in TN concentrations on day 10 was also observed in TP on day 10. However, it was most evident at the 1:2 incorporation ratio, 2,063 µg P/L, while the 1:5, 1:10, 1:20 incorporation ratios and the control were below 600 µg P/L (Table 3-16). For days 10, 20, and 30, the 0:1, 1:20, 1:10, and 1:5 incorporation ratio TP leachate concentrations changed very little. However, TP concentrations for 1:2 decreased from day 10 to 20 and day 20 to 30 decrease over the course of the collection dates. In addition, the concentrations from the 1:2 columns were greater than any other concentrations collected on days 10, 20, and 30. Pandey (2005) found that phosphorus leaching was significantly different in amended soils, which in the column study was only the case for the 1:2 incorporation rate.

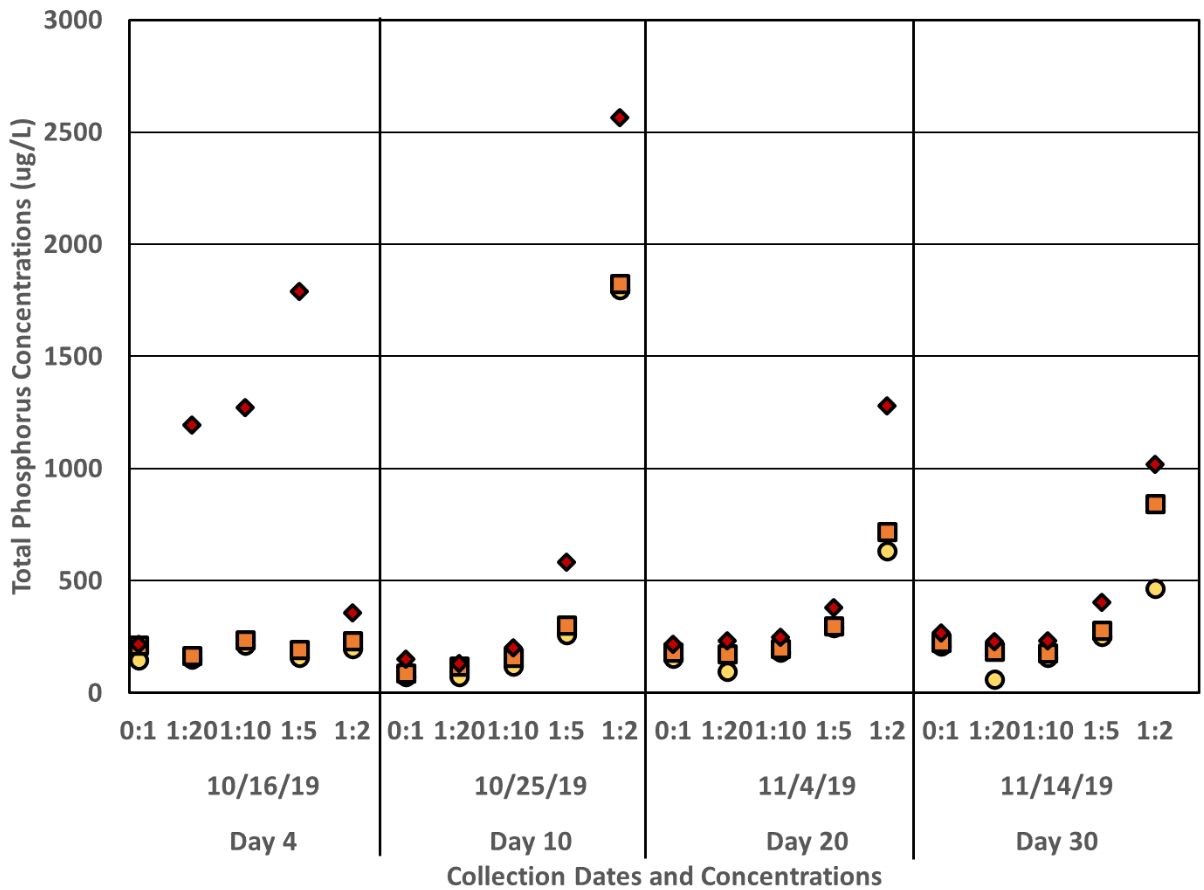

Figure 3-17. Column study maximum, median, and minimum TP concentrations for amendment incorporation ratios on days four, 10, 20 and 30.

Table 3-16. Average TP concentrations (µg/L) for days four, 10, 20, and 30 for each incorporation ratio.

Incorporation Ratio (Compost:Soil)	Days after Irrigation Began 4 (first leachate)	10	20	30
1:2	263.0[a*]	2063.3[a]	877.9[a]	777.2[a]
1:5	713.1[a]	381.0[b]	324.0[b]	312.5[b]
1:10	573.7[a]	160.0[b]	207.3[b]	189.2[b]
1:20	502.6[a]	107.6[b]	167.5[b]	158.8[b]
0:1 (control)	191.7[a]	104.3[b]	185.5[b]	233.4[b]

*Significant differences by day are based on Tukey's post hoc analysis and are denoted by different letters as superscript.

Since the volumes of leachate were not significantly different across all treatments and the control, the nutrient loadings followed the concentration trends very closely (Figures 3-18, 3-19) and incorporation ratio significantly increased the leachate TN loadings (Table 3-17).

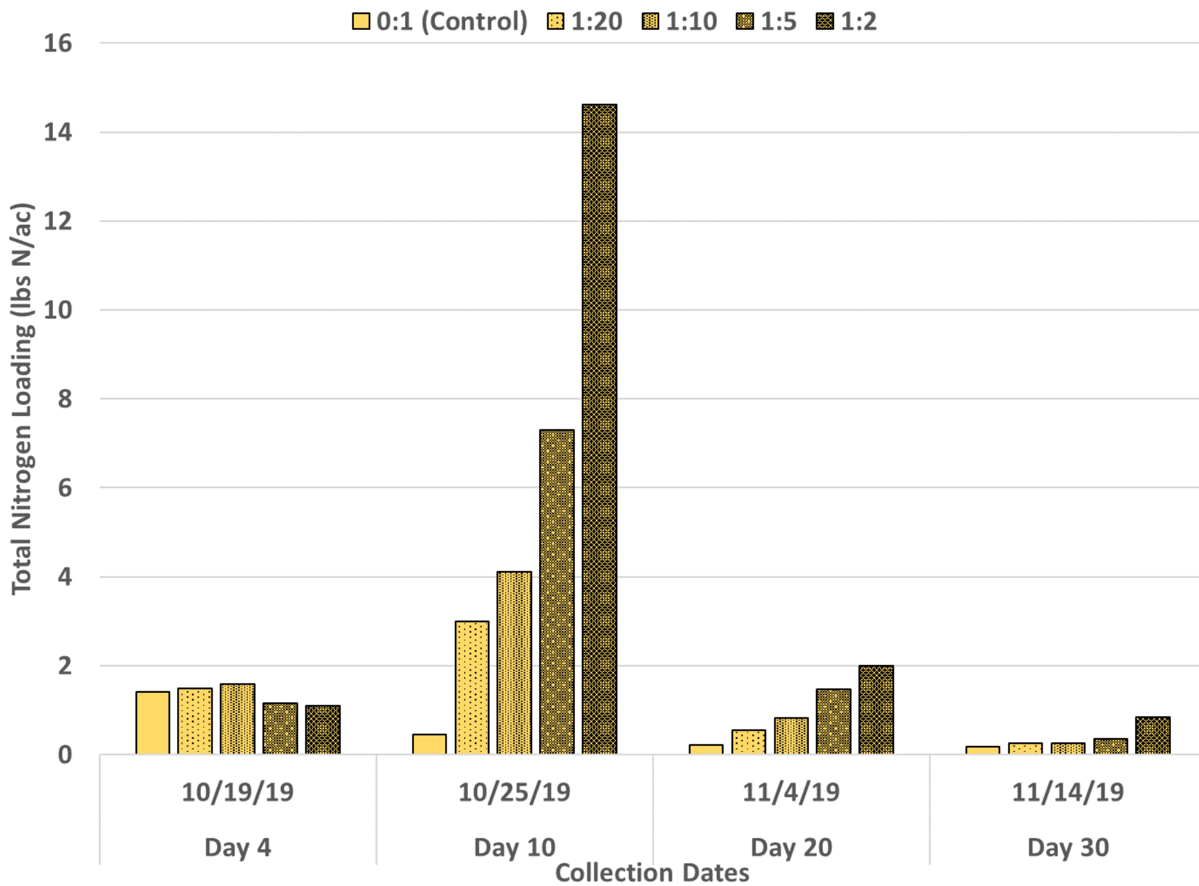

Figure 3-18. Daily averages of TN loading from column study leachate on days four, 10, 20, and 30 for each incorporation ratio.

Table 3-17. ANOVA results looking at the relationship between incorporation rate and interpolated cumulative total nitrogen loading.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	4	38185	9546	73.53	**$2.24*10^{-7}$**
Residuals	10	1298	130		

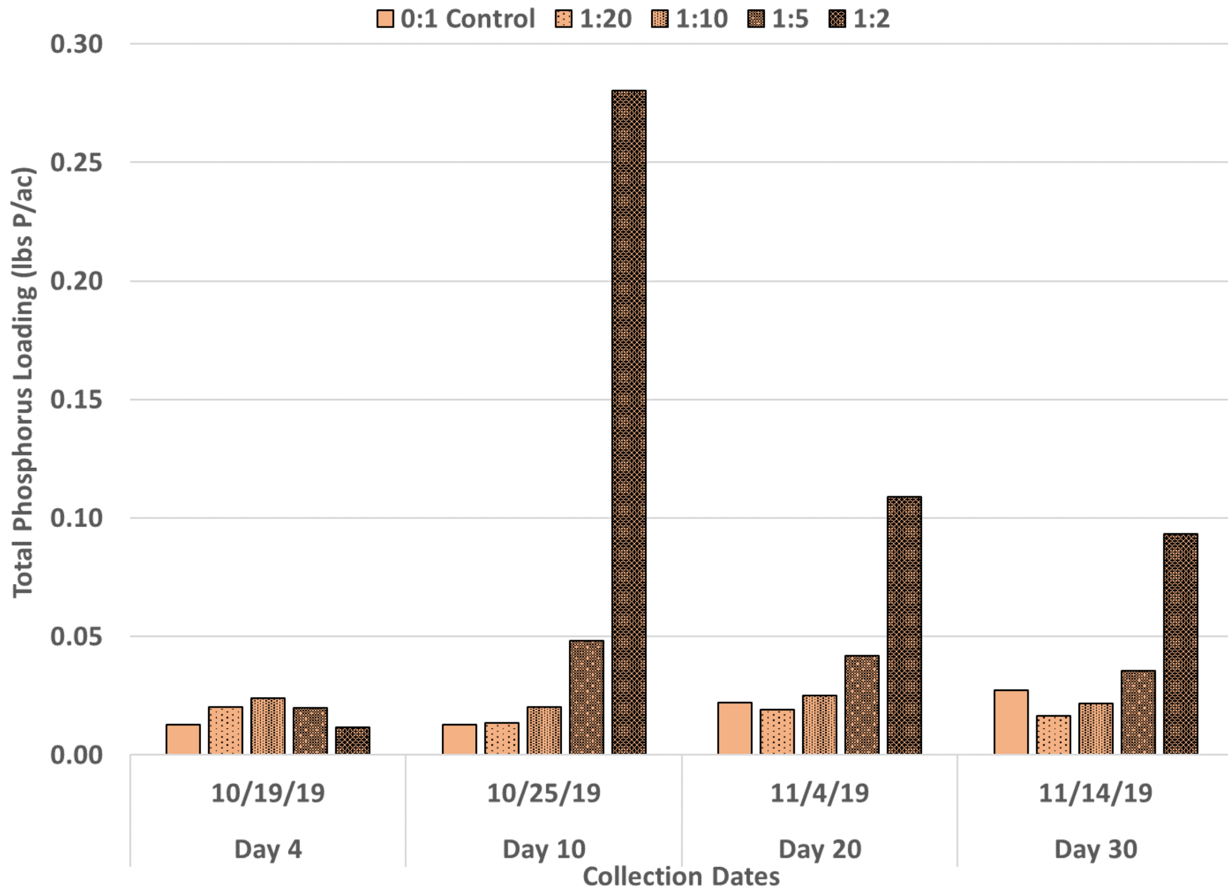

Figure 3-19. Daily averages of TP loadings from lysimeter leachate on days four, 10, 20, and 30 for each incorporation ratio.

To estimate cumulative loadings, concentrations were linearly interpolated for each day between sampling concentrations for each column. Nutrient concentrations were then multiplied by the respective daily measured leachate volume for each column and summed over the study period. Cumulative loadings for TN (Figure 3-20) and TP (Figure 3-21) were both proportional to amendment rates. The interpolated cumulative nitrogen loading (Figure 3-20; Table 3-18) for the 1:2 incorporation ratio was significantly higher than the 1:5 rate, while the 1:5 ratio was significantly higher than the 1:20 and the control, but not for the 1:10. The control, 1:20, and 1:10 rates were not significantly different from each other. For TP, cumulative loadings from amendment rates of 1:5 or less were not significantly different (Table 3-18), but were all significantly less than TP loadings from 1:2 (Table 3-18).

Table 3-18. Mean interpolated cumulative TN and TP loadings (lbs./ac.) for the 30-day column study experiment.

	Volumetric Ratio (Amendment:Soil)				
	0:1 (control)	1:20	1:10	1:5	1:2
Total Nitrogen loading (lbs. N/ac.)	15^{a*}	40^{ab}	51^{bc}	82^{c}	146^{d}
Total Phosphorus loading (lbs. P/ac.)	0.58^{a}	0.63^{a}	0.76^{a}	1.3^{a}	4.0^{b}

*Significant differences are based on Tukey's post hoc analysis and are denoted as different superscript letters.

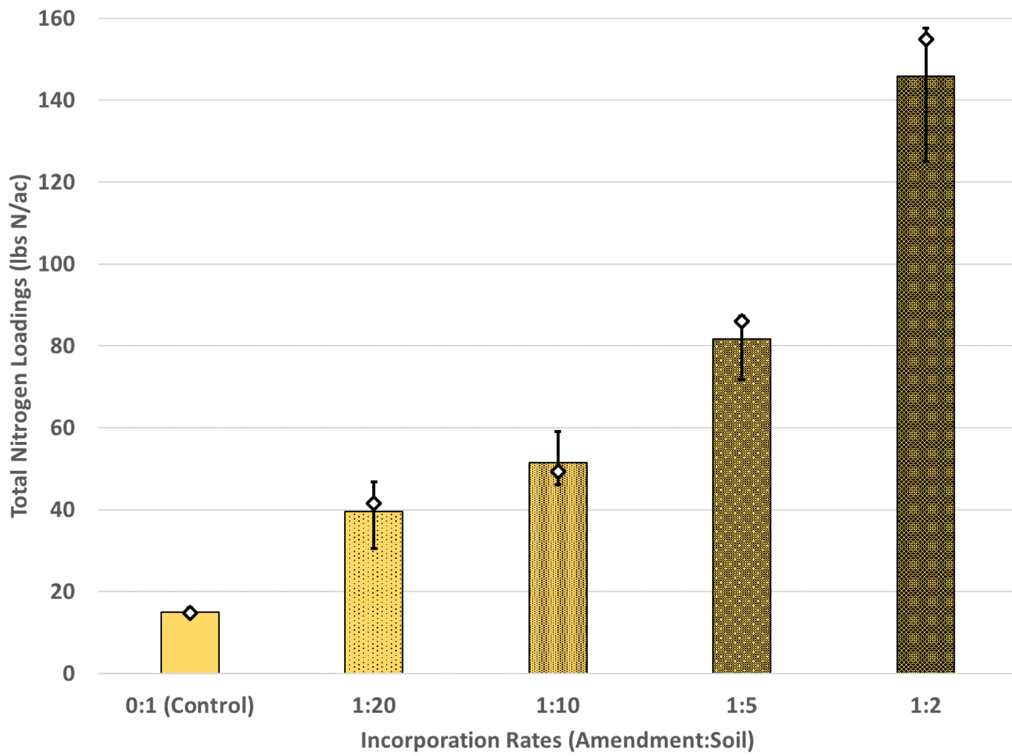

Figure 3-20. Average of cumulative TN loadings from replicated soil amendment columns with medians overlaid and minimum and maximum shown as error bars.

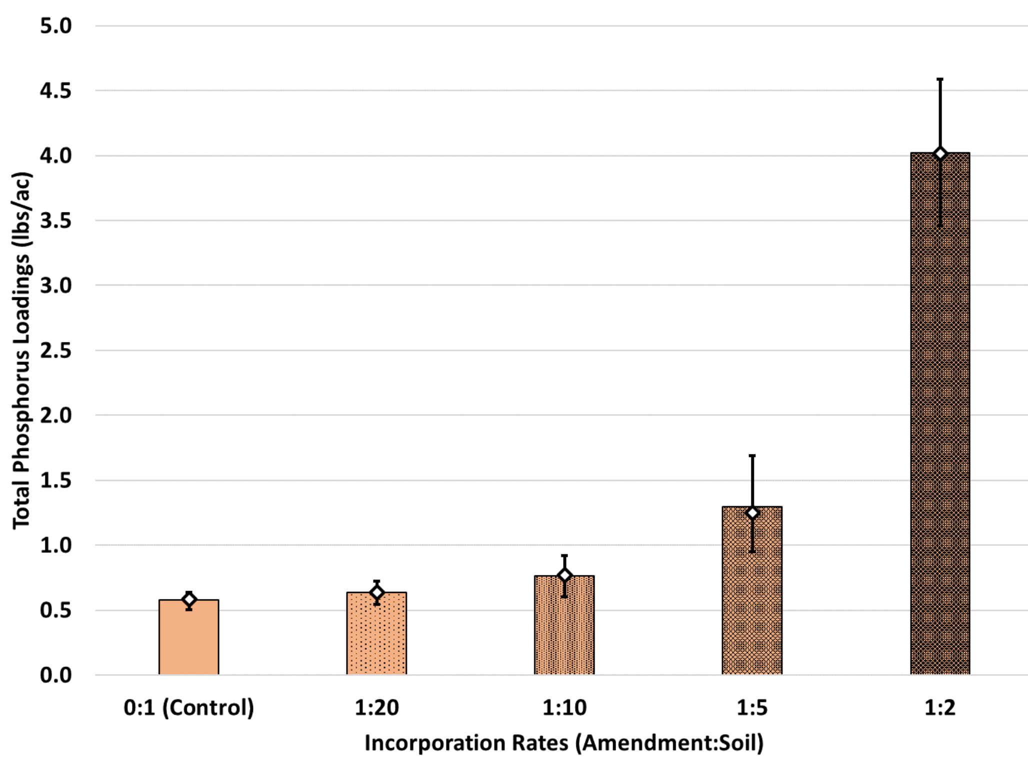

Figure 3-21. Average of cumulative TP loadings from replicated soil amendment columns with medians overlaid and minimum and maximum shown as error bars.

More frequent sampling and analysis would have allowed for a better understanding of when the nutrient spikes occurred during the leaching experiment and would eliminate the need to estimate concentrations between days 4, 10, 20, and 30. The conditions under which this column study were conducted likely resulted in greater leachate concentrations of nitrogen and phosphorus for multiple reasons. Vegetation was absent, and the study was conducted in an indoor controlled environment, which negated any transpiration and limited evaporation, thus allowing greater leachate volumes. Additionally, the lack of vegetation eliminated nutrient uptake a means of reducing nutrient loadings. Greater water content due to limited evaporation and no transpiration may have also affected the availability of nutrients to be leached from the amended soil. Finally, use of deionized water for irrigation likely leached more nutrients from the amended soil than if potable or reclaimed water had been applied. The combination of these factors likely resulted in over-estimating the initial leaching of nutrients under establishment irrigation. However, these factors had the benefit of controlling for variability due to vegetation health and growth, variable atmospheric conditions, and variable irrigation water quality.

Interpolating between 1:10 and 1:5 results, typical application rates of 4 cy/1000 ft^2 incorporated into the top 6 inches of soil (1:6 ratio), we would expect a maximum nitrogen loading of 76 lbs. N/ac and phosphorus loading of 1.2 lbs. P/ac under sod. Assuming turfgrass makes up 60% of pervious area and drainage areas are 52% impervious (Table 2-1; ~¼ acre lots), compost amended turfgrass areas would make up 29% of the surface area. This would translate to 22 lbs. N and 0.34 lbs. P per acre of residential development or 5.4 lbs. N and 0.09 lbs. P per average ¼ acre residential lot. By comparison, under these aggressive conditions, an unamended residential lot would be expected to leach 1.1 lbs. N and 0.04 lbs. P.

3.5.2 Lawn Lysimeters

Lysimeters were purged approximately monthly of accumulated leachate since the previous purging, except for March and April 2020, due to COVID-19 travel restrictions by the University of Florida.

3.5.2.1 Lysimeter Leachate Volumes

Leachate volumes were recorded for each collection and converted to a depth based on the lysimeter opening diameter (Figure 3-22). An ANOVA analysis determined that leachate depths were significantly affected by soil treatments but not whether lots were top-dressed or not (Tables 3-19). As a result, cumulative leachate depths are shown based solely on soil treatments in Figure 3-22. Control lots tended to have the least amount of leachate collected, while composted lots had the most. Notably, six (two tilled, four compost amended) had greater leachate depth than rainfall occurred, which could indicate excess irrigation, greater contributing area to the lysimeter than the opening of the lysimeter, or another anomaly.

Monthly average leachate volumes and depths are summarized in Table 3-20. As noted previously, there was no statistical difference based on whether lots were top-dressed or not. However, compost incorporation significantly increased average monthly leachate depths over control lots by 4.2 in./month. While average leachate from tilled lots was less than compost lots and greater than control lots, these differences were not significant.

Table 3-19. ANOVA results showing if treatment and top-dressing have significant effects on square root transformed volume collected from lysimeter study.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	875.5	437.7	5.9	**0.011**
Topdress	1	4.1	4.1	0.1	0.817
Treatment:Topdress	2	68.4	34.2	0.5	0.638
Residuals	18	1335.0	74.17		

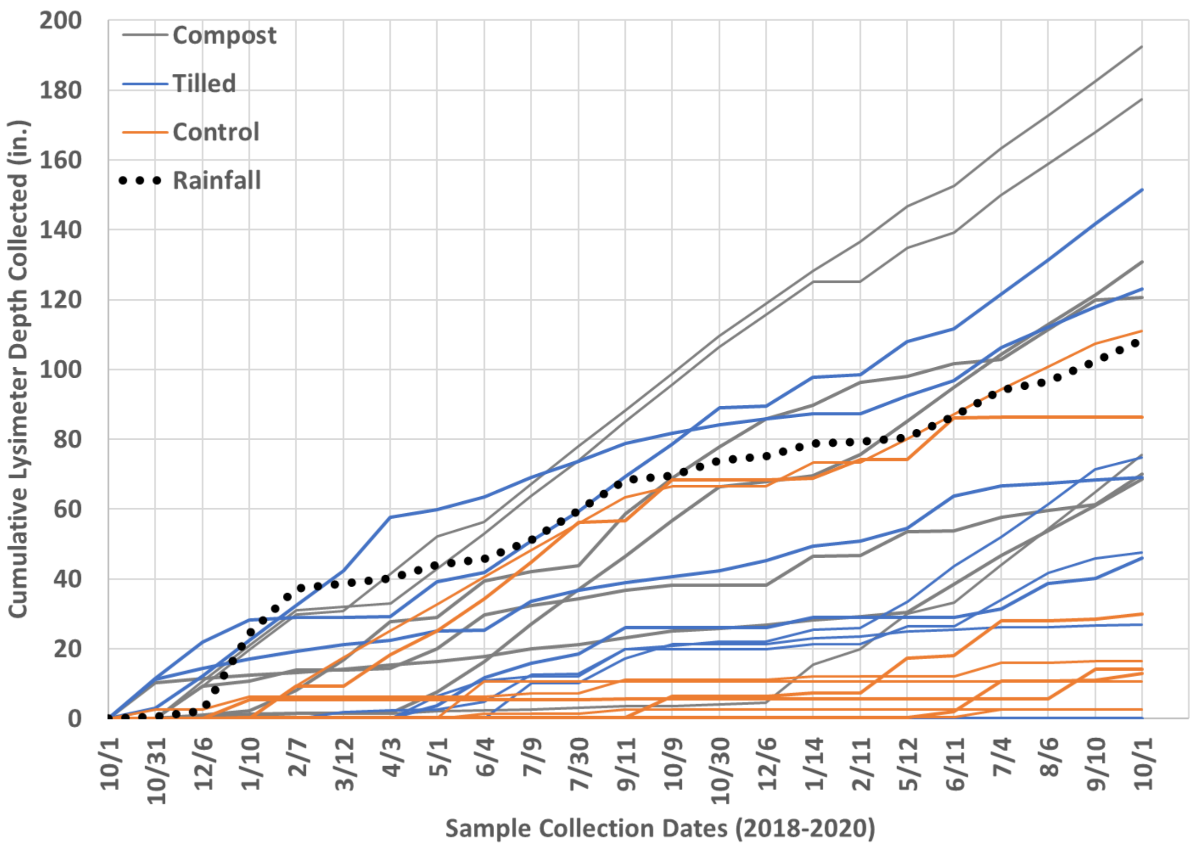

Figure 3-22. Cumulative leachate depths collected from October 2018 to October 2020 along with total rainfall for that period.

Table 3-20. Average monthly leached volumes and depths for lot treatments.

	Compost	Till	Null	Top-dress	No Top-dress
Volume Collected ($in.^3$)	47.4^{a*}	20.9^{ab}	9.6^{b}	24.8^{a}	22.3^{a}
Leachate Depth (in.)	5.3^{a}	2.3^{ab}	1.1^{b}	2.8^{a}	2.5^{a}

*Statistical differences between treatment type (compost, till, null) were analyzed separately from statistical differences between topdressing (Top-dress vs. No Top-dress).

3.5.2.2 Leachate Concentrations

Leachate concentrations for TN were below 25 mg/L for the entire monitoring period other than on three occasions (Figure 3-23). Lot 53, a tilled lot, produced TN concentrations of 76.4 and 71.3 mg/L for two consecutive months. The third occasion was from lot 23, also a tilled lot, which had a TN concentration of 31.6 mg/L and produced among the highest TN concentrations every month. We did not observe clear increases in leachate concentrations following compost topdressing of lawns (2019: late April/May, September; 2020: May and September).

Concentrations of TN were normalized by taking the square root of values prior to performing ANOVA and post-hoc Tukey's HSD analysis. Neither treatment nor topdressing had a significant effect on leachate TN concentrations (Table 3-21). The median concentration for tilled lots (5.1 mg/L) was approximately 50% greater than for compost (2.7 mg/L) and control (2.5 mg/L) lots (Table 3-22). The compost and control median concentrations were similar to the Day 30 leached concentrations from the column study, for rates below 1:2 of 1.5 to 3.2 mg N/L. Notably, the percentage of samples with TN concentrations below 10 mg N/L was 93%, 71%, and 86% for control tilled, and composted lots, respectively (Figure 3-24), Though fewer leachate samples were collected for analysis from control lots than compost lots, the distribution of TN concentrations were very similar (Figure 3-24).

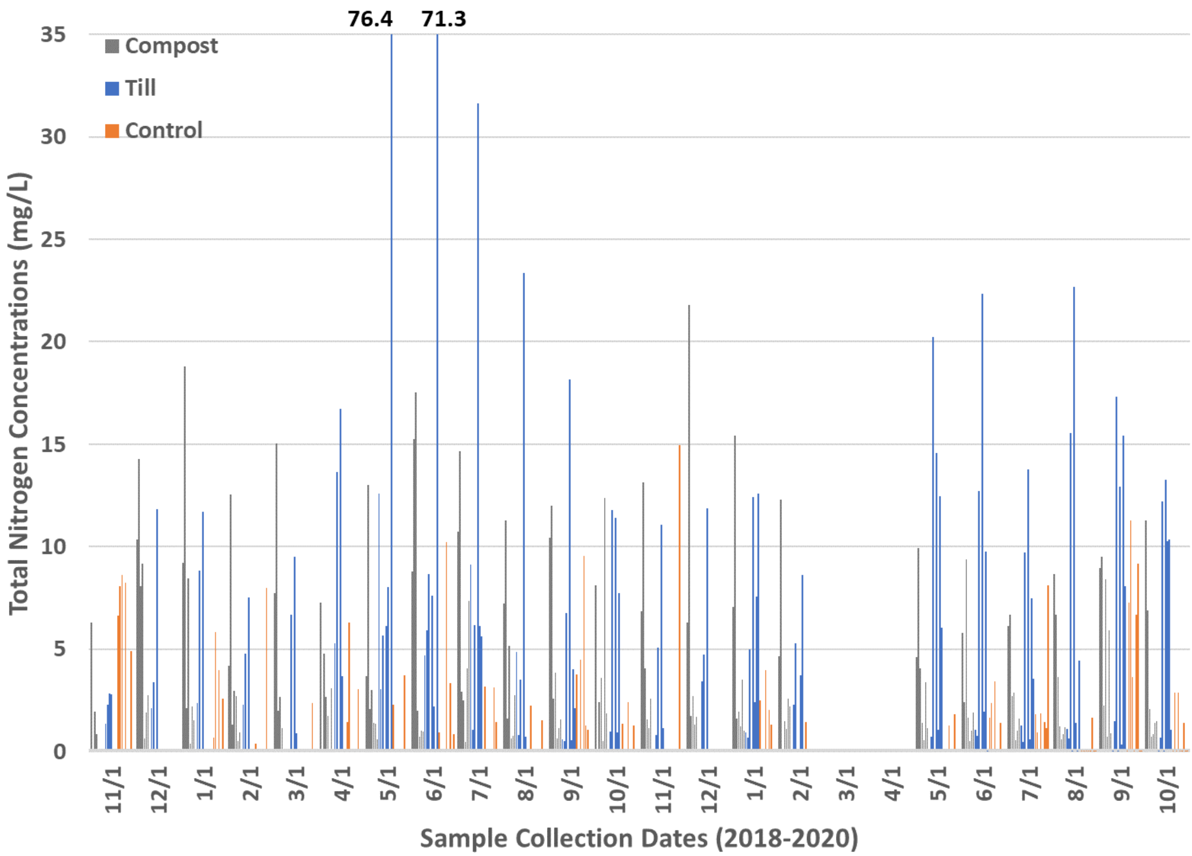

Figure 3-23. Total Nitrogen Concentrations from leachate samples collected from November 2018 to October 2020.

Table 3-21. ANOVA results looking at effects of treatment and top-dressing on square root-transformed TN concentrations.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	2.07	1.04	1.55	0.240
Topdress	1	1.03	1.03	1.54	0.232
Treatment:Topdress	2	3.33	1.66	2.48	0.112
Residuals	18	12.06	0.67		

Table 3-22. Summary of leachate TN concentrations from soil and top-dressing treatments.

	Compost	Till	Null	Top-dress	No Top-dress
Maximum	21.8	76.4	15.0	76.4	31.6
Median	2.7	5.3	2.5	5.3	4.5
Minimum	0.4	0.3	0.4	0.4	0.4
Geometric Mean	2.8[a]	4.3[a]	2.7[a]	4.5[a]	3.9[a]

Significant differences are based on Tukey's post hoc analysis and are denoted by different letters as superscript. Statistical differences between treatment type (compost, till, null) were analyzed separately from statistical differences between topdressing.

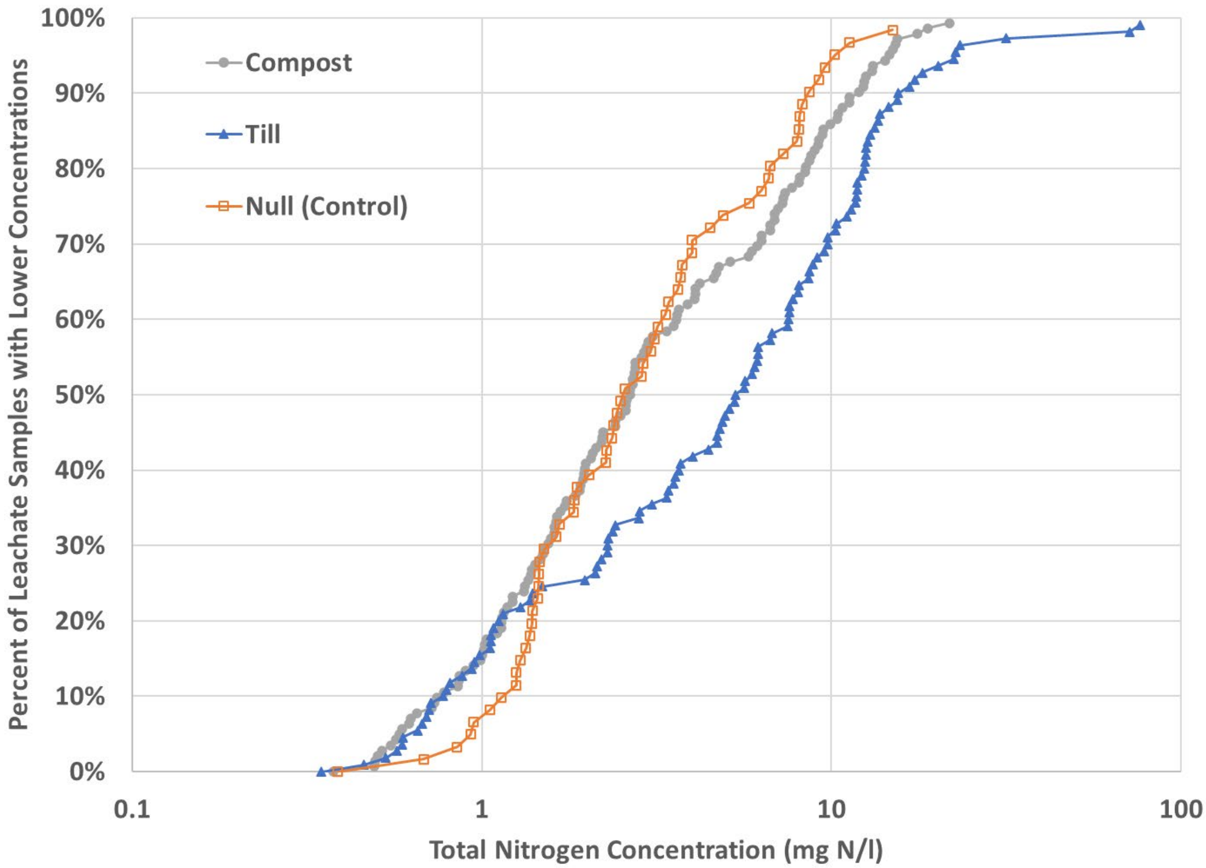

Figure 3-24. Probability exceedance plot of lysimeter total Nitrogen concentrations by soil treatments.

TP concentrations were typically below 6,000 µg/L for the majority of the monitoring period with a few exceptions from lots 21 (tilled), 23 (tilled), 68 (control), and 36 (compost) (Figure 3-25). High TP concentrations were often observed corresponding with sediment presence in leachate samples. Similar to TN, no clear increases in leachate TP concentrations were observed following compost topdressing of lawns (2019: late April/May, September; 2020: May and September).

Concentrations of TP were normalized by taking the square root of values prior to performing ANOVA and post-hoc Tukey's HSD analysis. Neither amendment nor topdressing had a significant effect on leachate TP concentrations (Table 3-23). The median concentrations were 344 µg P/L, 308 µg P/L, and 405 µg P/L for compost, tilled, and control lots (Table 3-24). Median concentrations were slightly higher than the Day 30 mean concentrations from the column study for amendment rates below 1.2: 159 to 313 µg P/L. The percentage of samples with TP concentrations below 1,000 µg P/L was 81%, 70%, and 85% for control tilled, and composted lots, respectively (Figure 3-26), Though fewer leachate samples were collected for analysis from control lots than compost lots, the distribution of TP concentrations were very similar (Figure 3-26).

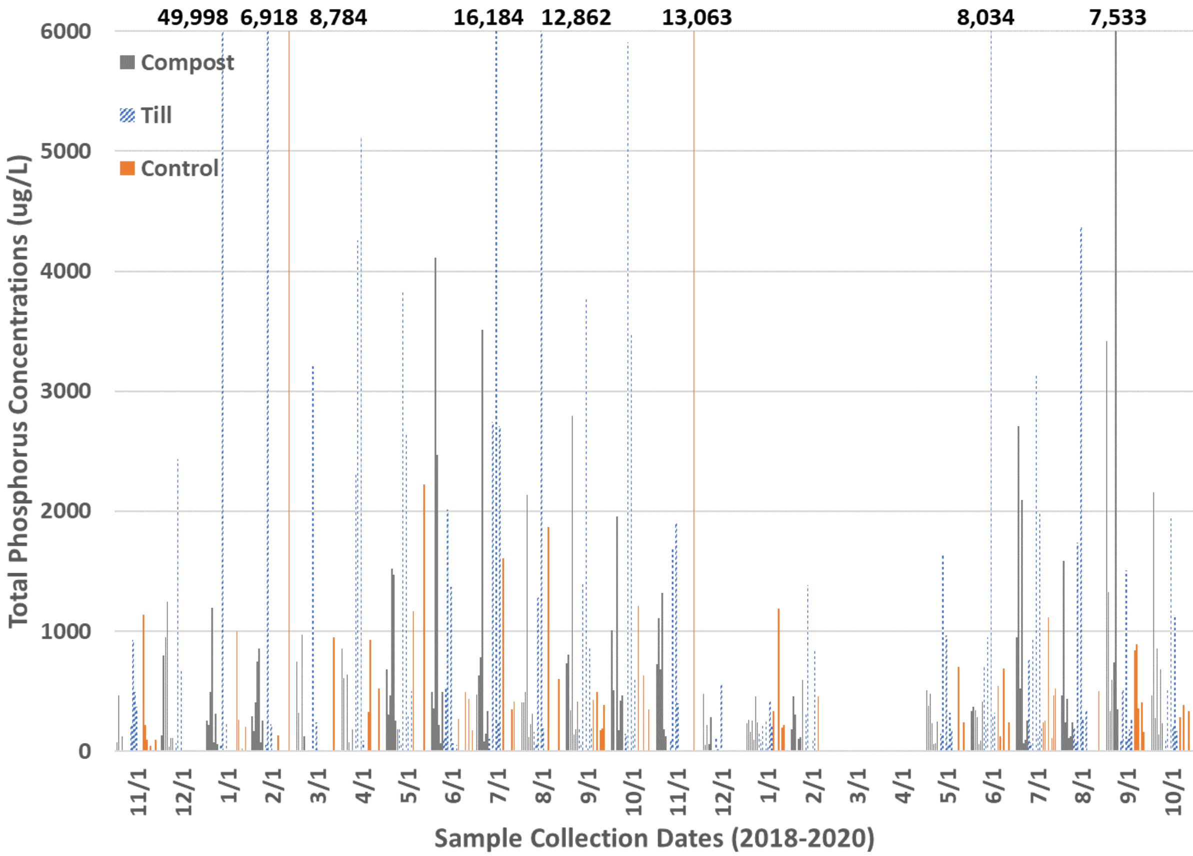

Figure 3-25. Total Phosphorus concentrations of leachate samples collected from November 2018 to October 2020.

Table 3-23. ANOVA results looking at treatment and top-dressing effects on square root-transformed TP concentrations (µg/L).

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	233.5	116.7	0.6	0.539
Topdress	1	56.3	56.3	0.3	0.585
Treatment:Topdress	2	558.0	279.0	1.53	0.243
Residuals	18	3283.0	182.4		

Table 3-24. Summary of TP concentrations (µg/L) from lysimeter samples for soil and top-dressing treatments.

	Compost	Till	Null	Top-dress	No Top-dress
Maximum	7,533	49,998[#]	13,063	13,063	49,998*
Median	344	308	405	378	538
Minimum	7	11	20	18	11
Geometric Mean	346[a]	415[a]	420[a]	394[a]	548[a]

Significant differences are based on Tukey's post hoc analysis and are denoted by different letters as superscript. Statistical differences between treatment type (compost, till, null) were analyzed separately from statistical differences between topdressing. #: concentration is the upper limit of measurement range.

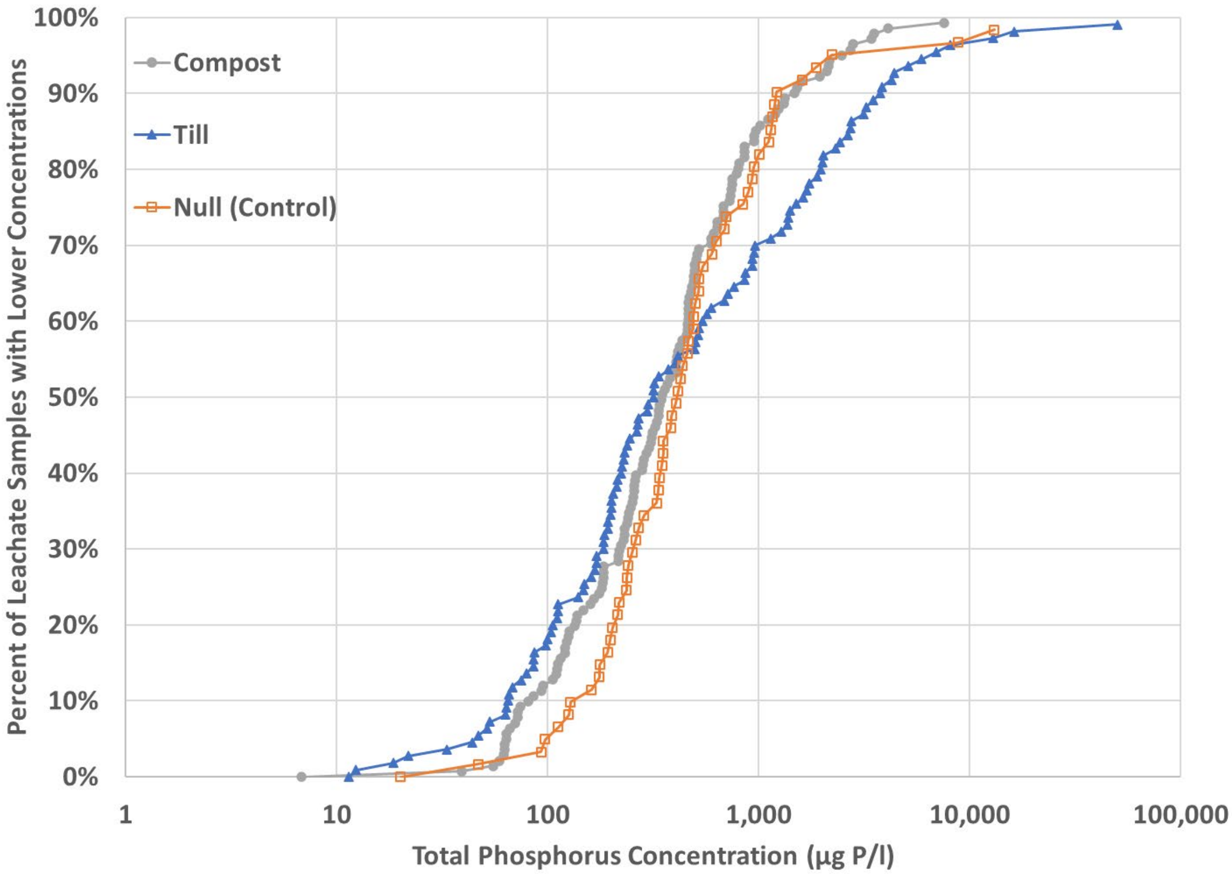

Figure 3-26. Probability exceedance plot of lysimeter total Phosphorus concentrations by soil treatments.

3.5.2.3 Leachate Loadings

Monthly nutrient loadings were calculated for each monthly sample collection by multiplying the sample nutrient concentration by the volume collected and converted to a mass per unit area. Unless specified otherwise, the results represent loadings per area of lawn. Cumulative loadings were then determined by summing the monthly loading since beginning of the study. To calculate the annualized leachate masses, total loadings were scaled from the duration accumulated to a 12-month period.

Monthly and annualized TN loadings were normalized by taking the square-root of values before performing an ANOVA analysis (Table 3-25). While soil treatment had the largest effect ($p = 0.076$, neither treatment nor topdressing were significant. However, when analyzing annual loadings, soil treatment was significant ($p = 0.029$), while topdressing was not (Table 3-26). Furthermore, no clear increases in leachate loadings followed topdressings of lawns (2019: late April/May, September; 2020: May and September).

Cumulative TN loadings are shown in Figure 3-27 by soil treatments, as topdressing was not a significant factor. Notably, the highest cumulative loadings were from compost and tilled lots, similar to the leachate volume results. All TN loadings for compost lots were greater than all control loadings. The four greatest TN loadings came from the four lots with the greatest leachate volumes. Other than a few spikes, the cumulative TN loadings for each lysimeter followed a generally consistent trajectory over the duration of the study, reflecting consistent loading rates.

Table 3-25. ANOVA results showing if treatment or top-dressing have significant effects on SR-transformed TN monthly loading values (lbs. N/ac.).

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	7.06	3.53	2.98	0.076
Topdress	1	2.46	2.46	2.08	0.167
Treatment:Topdress	2	3.61	1.81	1.53	0.244
Residuals	18	21.30	1.18		

Table 3-26. ANOVA results showing if treatment and top-dressing have significant effects on SR-transformed estimated annual TN loading in lbs. N/ac/yr.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	152.00	75.00	4.32	**0.029**
Topdress	1	27.32	27.32	1.55	0.229
Treatment:Topdress	2	67.03	33.52	1.91	0.178
Residuals	18	316.69	17.59		

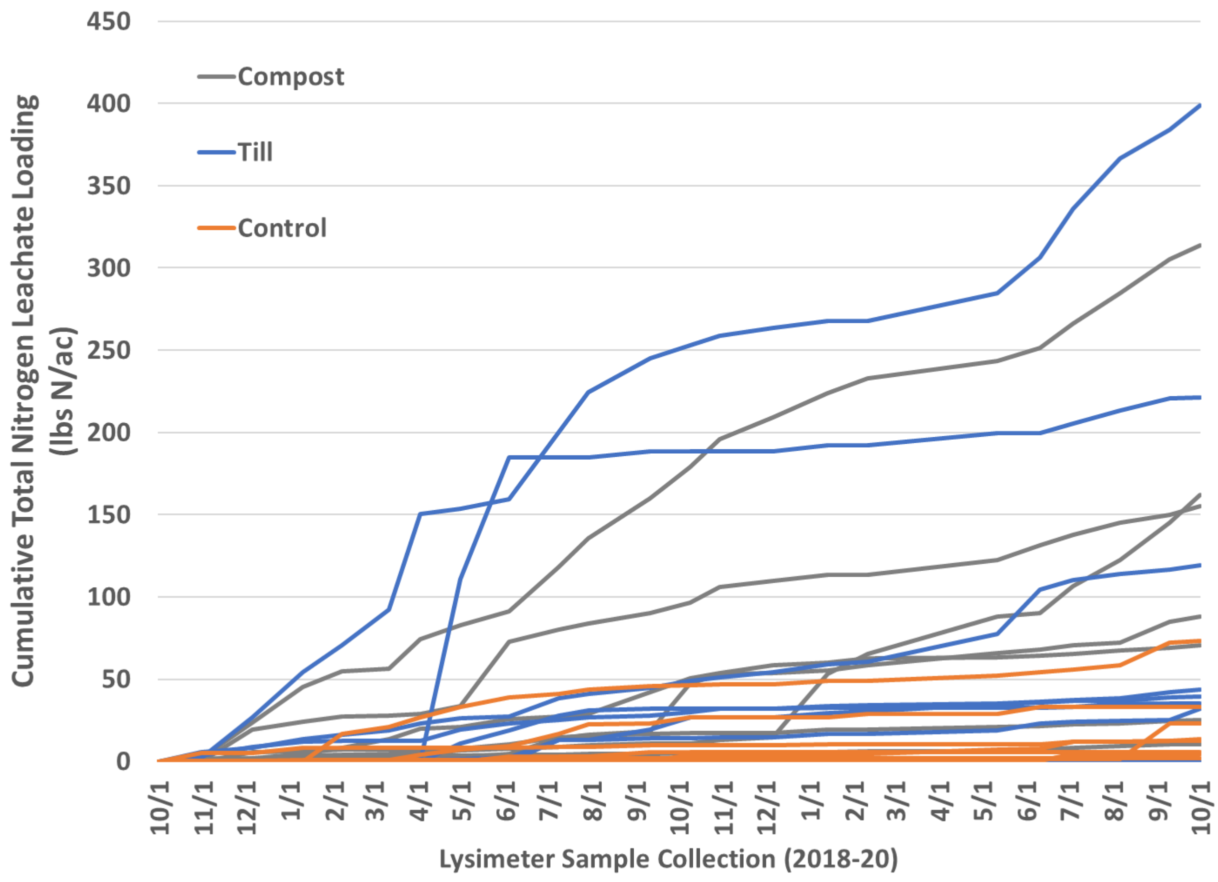

Figure 3-27. Cumulative TN loading from leachate from October 2018 to October 2020.

For statistical analysis, monthly and annualized TP loadings were also normalized by taking the square root of values before performing ANOVA analyses (Tables 3-27 and 3-28). Neither soil treatment nor topdressing were found to be significant factors for TP leachate loadings. Additionally, no clear increases in leachate loadings followed topdressings of lawns (2019: late April/May, September; 2020: May and September).

Cumulative TP loadings are shown in Figure 3-28 by soil treatments. Loading rates were consistent for each lysimeter other than occasional spikes, which corresponded to extremely high TP concentrations noted previously in Figure 3-27, which were attributed to sediment accumulation. Loadings were mostly below 10 lbs. P/ac. The lysimeters that exceeded this were a mixture of all three soil treatments. Again, no clear increase in leached TP loadings followed topdressing lawns (2019: late April/May, September; 2020: May and September).

Table 3-27. ANOVA results showing if treatment or top-dressing have significant effects on square root-transformed TP monthly incremental loading (lbs. P/ac.).

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	233.5	116.7	0.64	0.539
Topdress	1	56.3	56.3	0.31	0.585
Treatment:Topdress	2	558.0	279.0	1.53	0.243
Residuals	18	3283.0	182.4		

Table 3-28. ANOVA results showing if treatment and topdressing have significant effects on SR-transformed estimated annual TP loading in lbs. P/ac./yr.

	Degrees of Freedom	Sum of Square	Mean of Squares	F Value	P Value
Treatment	2	17.04	8.52	1.43	0.265
Topdress	1	0.02	0.02	0.004	0.952
Treatment:Topdress	2	14.16	7.08	1.19	0.328
Residuals	18	107.30	5.96		

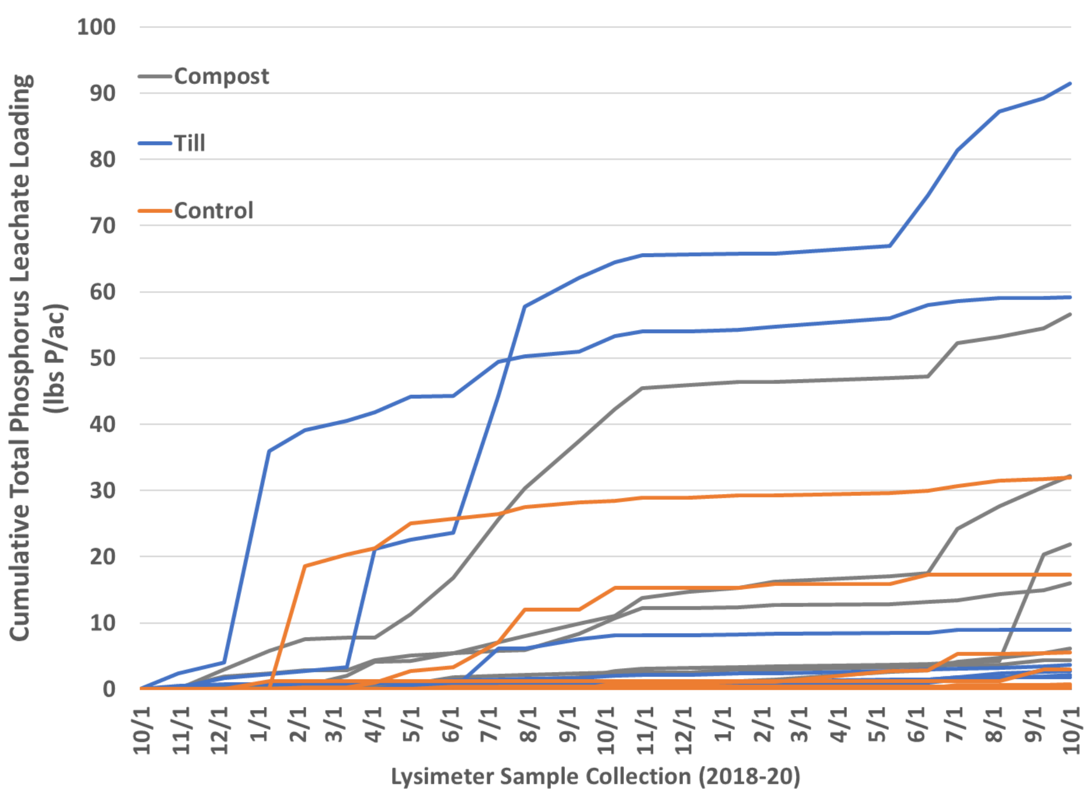

Figure 3-28. Cumulative TP loading of leachate from October 2018 to October 2020.

Treatment type had a significant effect on incremental loadings for TN but not for TP, and topdressing did not have a significant effect on either TN or TP (Table 3-29). For TN incremental loading, compost was significantly higher than null, but tilled lots were not significantly different from compost or null. For annual loading estimates, summarized in Table 3-29, soil treatment had a significant effect on TN loading, with compost being significantly greater than null, but tilled was not significantly different from compost or null. Topdressing did not have a significant effect on annual TN loadings, while annual TP loading estimates were not significantly affected by soil treatment or topdressing.

Table 3-29. Geometric mean TN and TP estimated yearly loading in lbs./ac./yr. by treatment and top-dressing application.

	Compost	Till	Null	Top-dress	No Top-dress
Total Nitrogen (lbs. N/ac./yr.)	38.1[a]	18.4[ab]	6.0[b]	20.3[a]	11.6[a]
Total Phosphorus (lbs. P/ac./yr.)	6.4[a]	1.9[a]	0.9[a]	1.7[a]	2.3[a]

Statistical differences between treatment type (compost, till, null) were analyzed separately from statistical differences between topdressing.

Scaling to the lot level and assuming an imperviousness of 52% and 60% of pervious as lawn, the resulting annual loadings are shown in Table 3-30. In a simulated model of TN loading to groundwater, Obreza (2004) stated that the range for low to medium density residential areas was 19 – 66 lbs N/ac./yr (21 – 74 kg N/ha/yr) while various agricultural land uses had a range of 16 – 54 lbs. N/ac./yr. (18 – 61 kg N/ha/yr). Lower leachate loading estimates in this study may be likely due to lower estimated lawn area within residential developments. Scaled annual loadings to the individual lot scale are listed in Table 3-31.

Table 3-30. Annualized nutrient loading rates adjusted to lawn areas within developed residential watershed (28%).

	Compost	Till	Null	Top-dress	No Top-dress
Total Nitrogen (lbs. N/ac./yr.)	11	5.3	1.7	5.8	3.3
Total Phosphorus (lbs. P/ac./yr.)	1.8	0.56	0.25	0.50	0.67

Table 3-31. Annualized nutrient loading rate estimates for ¼ acre residential lots.

	Compost	Till	Null	Top-dress	No Top-dress
Total Nitrogen (lbs. N/ac./yr.)	2.7	1.3	0.43	1.5	0.83
Total Phosphorus (lbs. P/ac./yr.)	0.46	0.14	0.063	0.13	0.17

Not all the homes in this study had uniform irrigation rates. This is potentially a source of variance in volumes collected within each treatment type, as it was often found that increased nitrogen leaching is highly correlated to increased irrigation or precipitation rates (Trenholm et al. 2011; Easton and Petrovic, 2004; Morton et al. 1998; Brown et al. 1977; Erickson et al. 2010). The field study had similar findings to Pandey (2005), where he found that nitrogen concentrations were not significantly different in amended soils compared to non-amended. However, Pandey (2005) found that phosphorus concentrations were significantly higher in control lots than in amended lots, while in the field study, it was not significantly different between treatments.

Given that the study was conducted within a residential neighborhood with homeowners present, many factors may have contributed to the occasional spike in concentration. Most homeowners (20 of 24) hired a landscaping company that cut and fertilized their lawn for them, while the others maintained their lawn themselves. In an attempt to account for this variability ahead of time, at the beginning of the monitoring period, homeowners were given a journal to make note of when they fertilized or if they had any pets.

However, upon collection of the journals, it was found that homeowners did not keep up with the specifics of their landscape maintenance, as they relied on the companies they hired to do so. Attempts to obtain records from landscape maintenance companies were not successful.

Since neither TN nor TP concentrations were significant different based on treatment or topdressing, the significant differences in loadings are driven more by leachate volumes rather than concentration. Therefor limiting the leaching volume would be expected to reduce nutrient loadings. The most direct way to achieve this is through reducing excess irrigation that leads to leaching. As noted in the Soil Moisture Sensor results, there is evidence to suggest that irrigation run times could be reduced beyond 25% on compost amended lots without impacting turf quality. This would likely reduce nutrient leaching from this study.

3.6 Homeowner Surveys

Surveys were administered 6, 12, and 18 months after data collection began. The 6- and 18-month surveys were taken during the spring and the 12-month surveys were taken during the fall. The number of survey response are summarized in Table 3-32. Overall, 20 of 24 homes sent at least one survey response back, and 10 of 24 sent responses to all three surveys.

Table 3-32. Summary of responses from 6-, 12-, and 18-month surveys.

	6-month	12-month	18-month	Combined
Date Range	May 2019	November 2019	June 2020	Anytime
Responses (of 24)	14 (58%)	17 (71%)	18* (75%)	20 (83%)
Control	5	7	6	8
Till	4	5	6	7
Compost	5	5	5	5
Not Topdressed	9	8	10	11
Topdressed	5	9	8	9

*One returned survey could not be determined what lot or treatment it corresponded.

Due to the small sample size for each soil and topdressing treatment, data were only analyzed at either the soil or topdressing treatment level. Due to a limited number of lots with multiple survey responses, and consistent responses, inferences of change over time were limited. To evaluate the effect of soil or topdressing treatments, responses for each lot were averaged across the number of surveys received and composited. Within each soil or topdressing treatment, responses were converted to percentages for each option. In general, responses were consistent across treatments. Where treatments had either different leading responses or resulted in notable differences in responses, response summaries for these questions are included and discussed in the following section.

3.6.1 Lawn Watering (Q 1-4)

Q1: Most homeowners stated that they watered their lawns once a week or less during the winter months (Table 3-33). By the 18-month survey, some homeowners (6%) watered their lawn when they thought it was necessary, and others (6%) stated that they never watered it.

Table 3-33. Responses to how often homeowners irrigate their lawns during the winter months.

	6-month	12-month	18-month
1x a Week	71%	65%	59%
2x a Week	14%	29%	29%
2x a Month	7%	0%	0%
1x a Month	7%	0%	0%
Not Sure	0%	6%	0%
When Necessary	0%	0%	6%
Never	0%	0%	6%

Q2: During the summer months, the majority said they irrigate twice a week (Table 3-34). In the 6-month survey, 7% said that they never irrigate during the summer months, and in the 18-month survey, 6% said they were not sure how often they irrigated during the summer months.

Table 3-34. Responses to how often homeowners irrigate their lawns during the winter months.

	6-month	12-month	18-month
2x a Week	93%	100%	94%
Not Sure	0%	0%	6%
Never	7%	0%	0%

Q3: When asked during what time of day homeowners irrigate their lawns, the majority for all three surveys said they irrigate during the early morning (Table 3-35). By the 18-month survey, 6% were also stating that they irrigate in the mid-morning.

Table 3-35. Responses to what time of day homeowners irrigate their lawns.

	6-month	12-month	18-month
Early Morning	71%	65%	76%
Evening	29%	35%	18%
Mid-Morning	0%	0%	6%

Q4: Homeowners were asked what determines how often they water their lawns. For all three surveys, the majority said that they water their lawn based on their watering day (Table 3-36). Other important factors were when a professional recommends it, that the community rules require watering, If the grass looks like it needs it, and that the system turns on and they do not want to change it. In the 6-month survey, 7% stated that the system turns on and they did not know how to change it. For the 12- and 18-month surveys, there were no responses of this type.

Table 3-36. Responses to what determines how often homeowners irrigate their lawns.

	6-month	12-month	18-month
It Is My Watering Day	36%	53%	35%
Professional Recommends It	21%	24%	18%
Grass Looks Like It Needs It	21%	18%	24%
Community Rules Require Watering	21%	6%	24%
System Turns on And I Don’t Want to Change It	14%	18%	24%
System Turns on And I Don’t Know How to Change It	7%	0%	0%

3.6.2 Perceptions of Own Lawn (Q 5)

The next question asked homeowners how satisfied they were with the health, look, and overall quality of their lawn.

In the 6-month survey, the majority were satisfied with the health of their lawn (Table 3-37). For the 12- and 18-month surveys, the majority was split equally between satisfied and dissatisfied (35% each).

When asked their opinion on how their lawn looks, for the 6-month survey the majority was split evenly between satisfied, neutral, and dissatisfied (31% each), while 8% was very satisfied. Similarly, for the 12-month survey, the majority was 29% each for satisfied, neutral, and dissatisfied, while 12% was very satisfied. For the 18-month survey, the majority was dissatisfied with how their lawn looks (35%) and 18% was very satisfied.

Table 3-37. Homeowner responses to their opinion on the health of their lawns.

	6-month	12-month	18-month
Very Satisfied	8%	12%	12%
Satisfied	46%	35%	35%
Neutral	15%	18%	18%
Dissatisfied	31%	35%	35%
Very Dissatisfied	0%	0%	0%

Control lots were mostly satisfied (52%), while till and compost lots were less satisfied (49% and 40% dissatisfied, respectively; Table 3-38). However, till and compost lots had some very satisfied responses (15% and 20%, respectively), while control had none. Of note, topdressed lots were more satisfied (50% at least satisfied) with the health of their lawn than lots than were not topdressed lots (39% at least satisfied and 50% dissatisfied).

Table 3-38. Homeowner responses by treatments for satisfaction with health of lawn.

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Control	0%	52%	23%	25%	0%
Till	15%	36%	0%	49%	0%
Compost	20%	7%	33%	40%	0%
Not Topdressed	9%	30%	6%	50%	0%
Topdressed	11%	39%	31%	19%	0%

When asked their opinion on how their lawn looks, for the 6-month survey the majority was split evenly between satisfied, neutral, and dissatisfied (31% each), while 8% was very satisfied (Table 3-39). Similarly, for the 12-month survey, the majority was 29% each for satisfied, neutral, and dissatisfied, while 12% was very satisfied. For the 18-month survey, the majority was dissatisfied with how their lawn looks (35%) and 18% was very satisfied.

Table 3-39. Homeowner responses to their opinion of the way their lawn looks.

	6-month	12-month	18-month
Very Satisfied	8%	12%	18%
Satisfied	31%	29%	18%
Neutral	31%	29%	24%
Dissatisfied	31%	29%	35%
Very Dissatisfied	0%	0%	0%

Control lots were mostly neutral or satisfied (76%) with the look of their lawn, while till and compost lots were less satisfied (44% and 43% dissatisfied, respectively; Table 3-40). Of note, topdressed lots were less dissatisfied than not topdressed lots (20% and 42%, respectively). However, responses for satisfied and very satisfied were similar.

Table 3-40. Homeowner responses by treatment to their opinion of the way their lawn looks.

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Control	6%	38%	38%	19%	0%
Till	15%	31%	10%	44%	0%
Compost	20%	0%	37%	43%	0%
Not Topdressed	9%	27%	17%	42%	0%
Topdressed	17%	22%	41%	20%	0%

Homeowners were also asked about the overall quality of their lawns (Table 3-41). For the 6-month survey, the majority was neutral (46%) and 8% was very satisfied, while for both 12- and 18-month surveys, the majority was dissatisfied (35%) and 12% was very satisfied.

Table 3-41. Homeowner responses to their opinion of the overall quality of their lawn.

	6-month	12-month	18-month
Very Satisfied	8%	12%	12%
Satisfied	15%	29%	29%
Neutral	46%	24%	24%
Dissatisfied	31%	35%	35%
Very Dissatisfied	0%	0%	0%

The most common response for control and compost lots was neutral, while dissatisfied was most common for till lots (Table 3-42). Similar to responses for the look of their lawns, topdressed lots were less dissatisfied than not topdressed lots (22% and 45%, respectively). However, responses for satisfied and very satisfied were similar.

Table 3-42. Homeowner responses by treatment to their opinion of the overall quality of their lawn.

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Control	6%	31%	38%	25%	0%
Till	15%	26%	10%	49%	0%
Compost	20%	0%	43%	37%	0%
Not Topdressed	9%	23%	18%	45%	0%
Topdressed	17%	19%	43%	22%	0%

3.6.3 Perceptions of Neighbors' Lawn (Q 6-8)

For all three surveys, the majority stated that their lawn looked about the same as their neighbor's lawn.

Q6: The number of homeowners that thought their lawn looked much better compared to their neighbor's lawn grew from 8% in the 6-month survey, to 12% in the 12-month survey, to 18% in the 18-month survey (Table 3-43). More homeowners also thought their lawns looked much worse compared to their neighbor's lawn, from 8% in the 6-month survey to 12% in the 18-month survey.

Table 3-43. Responses when homeowners were asked how their lawn looks compared to their neighbor's lawn.

	6-month	12-month	18-month
Much More	8%	12%	18%
Slightly More	15%	18%	12%
About the Same	54%	53%	35%
Slightly Less	15%	18%	24%
Much Less	8%	0%	12%

Q7: When asked about the health of their lawn compared to their neighbor's lawn, the majority said it was about the same as their neighbor's lawn for all three surveys (Table 3-44).

Table 3-44. Responses when homeowners were asked how healthy their lawn is compared to their neighbor's lawn.

	6-month	12-month	18-month
Much More	8%	6%	6%
Slightly More	8%	24%	18%
About the Same	69%	52%	41%
Slightly Less	8%	18%	29%
Much Less	8%	0%	6%

While "About the Same" had the highest percent of responses for all treatments, control lots had an equally high response rate for "Slightly Less" (42%), and the proportion of responses that were at least "Slightly More" was notably higher for till and compost (36% and 27%, respectively) than compost (17%; Table 3-45). This suggests that control lot homeowners viewed their lawns as less healthy than their neighbors' lawns. A higher proportion of topdressed lots were thought to be less healthy than their neighbors' than not topdressed (37% and 17%, respectively).

Table 3-45. Responses by treatment when homeowners were asked how healthy their lawn is compared to their neighbor's lawn.

	Much More	Slightly More	About the Same	Slightly Less	Much Less
Control	0%	17%	42%	42%	0%
Till	21%	15%	44%	15%	5%
Compost	20%	7%	43%	17%	13%
Not Topdressed	12%	12%	48%	17%	6%
Topdressed	11%	15%	33%	37%	4%

Q8: Similarly, for overall quality, most homeowners said their lawns were about the same quality as their neighbor's lawns for all three surveys (Table 3-46).

Table 3-46. Responses when homeowners were asked about the overall quality of their lawn compared to their neighbor's lawn.

	6-month	12-month	18-month
Much More	8%	13%	13%
Slightly More	8%	6%	19%
About the Same	77%	56%	44%
Slightly Less	8%	25%	19%
Much Less	0%	0%	6%

3.6.4 Landscape and Water Resources (Q 9-12)

Q9: Most homeowners stated that their irrigation water comes from a water supply utility (Table 3-47). During the 12-month survey, 6% said their water is reclaimed water that is provided by a municipality, and during the 18-month survey, that number rose to 18%.

Table 3-47. Responses when homeowners were asked where the water used to irrigate their lawns comes from.

	6-month	12-month	18-month
Water Supply Utility	92%	76%	82%
Reclaimed Water Provided by a Municipality	0%	6%	18%
Not Sure	8%	18%	0%

Q10: The next question asked homeowners if they knew they lived in an area with lawn watering restrictions. In the 6-month survey, all homeowners were aware of this (Table 3-48). In the 12- and 18-month surveys, 88% were aware, 6% were not, and 6% were not sure.

Table 3-48. Responses when homeowners were asked if they were aware of lawn watering restrictions.

	6-month	12-month	18-month
Yes	100%	88%	88%
No	0%	6%	6%
Not Sure	0%	6%	6%

Q11: A follow up question asked homeowners how they were made aware of the fact that they live in an area with lawn watering restrictions. The majority for all three surveys was the water management district, though this declined over time (Table 3-49). The next few popular responses were city/county government and the water bill and may indicate effectiveness of messaging from these entities.

Table 3-49. Responses to how homeowners were made aware of the lawn watering restrictions.

	6-month	12-month	18-month
Water Management District	83%	44%	59%
City or County Government	8%	19%	24%
Local News	8%	0%	0%
Water Bill	17%	6%	29%
Social Media	8%	6%	0%
Friends and Neighbors	8%	13%	6%
Homeowners Association	0%	6%	0%
Not Aware of Restrictions	0%	13%	12%

Q12: When homeowners were asked to describe the current conditions of water resources in their area, most homeowners said it was normal (58%), with “drier than normal” having 42% of responses for the 6-month survey (Table 3-50). For the 12-month survey, normal was the majority (72%), while 19% of homeowners were not sure. For the 18-month survey, the majority (47%) stated it was drier than normal in their area. Some homeowners (6%) believed they were in a drought, while others (6%) said it was wetter than normal.

Table 3-50. Responses when homeowners were asked about the current water resource conditions.

	6-month	12-month	18-month
Wetter Than Normal	0%	0%	6%
Normal	58%	75%	29%
Drier Than Normal	42%	13%	47%
In A Drought	0%	0%	6%
Not Sure	8%	19%	12%

Interestingly, most responses for soil and topdressing treatments were "Normal", except for compost lots which had slightly more responses for "Drier than Normal" (Table 3-51). Excluding "Not Sure" responses, the two most common responses were "Normal" or "Drier than Normal" across all treatments, accounting for 65 to 88% of responses.

Table 3-51. Responses by treatment when homeowners were asked about the current water resource conditions.

	In A Drought	Drier Than Normal	Normal	Wetter Than Normal	Not Sure
Control	0%	15%	50%	6%	29%
Till	5%	33%	55%	0%	0%
Compost	0%	47%	40%	0%	13%
Not Topdressed	0%	35%	52%	0%	9%
Topdressed	4%	22%	46%	6%	22%

3.6.5 Irrigation Controllers (Q 13-18)

All homeowners for all three surveys said that they do use their irrigation controller (Q13), so they were asked about the performance of the controller (Q14) and their skill level in operating it (Q15).

Q14: Over 74% of respondents for each survey stated they were either satisfied or very satisfied with the performance of their irrigation controller (Table 3-52).

Table 3-52. Responses when asked how satisfied homeowners are with their irrigation controller.

	6-month	12-month	18-month
Very Satisfied	14%	29%	27%
Satisfied	64%	59%	47%
Neutral	0%	6%	20%
Dissatisfied	7%	0%	7%
Very Dissatisfied	14%	6%	0%

However, 90% of compost lots were at least satisfied, with 81% and 64% of till and control being at least satisfied (Table 3-53). Similarly, 12% and 13% of till and control lots, respectively, were either dissatisfied or very dissatisfied with their irrigation controller while no homeowners from compost lots were dissatisfied. The distributions of responses were similar for topdressed and not, the only exception being that 17% of not topdressed were dissatisfied, while no homeowners at topdressed lawns were dissatisfied. Homeowners responses towards their controller may indicate their overall feelings towards the ease of managing their lawn, as most homeowners felt they were at least fairly skilled in using their controller (See Q15).

Table 3-53. Responses by treatment when asked how satisfied homeowners are with their irrigation controller.

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Control	10%	54%	19%	0%	13%
Till	33%	48%	0%	7%	5%
Compost	13%	77%	10%	0%	0%
Not Topdressed	12%	62%	5%	5%	12%
Topdressed	28%	52%	17%	0%	0%

Q15: When asked about their skill level when using the irrigation controller, the majority said fairly skilled for all three surveys (Table 3-54). However, the percent of homeowners saying they were highly skilled or very highly skilled increased as well and may indicate homeowers becoming more comfortable with the system.

Table 3-54. Responses when asked to rate their skill level in operating the irrigation controller.

	6-month	12-month	18-month
Very Highly Skilled	0%	6%	7%
Highly Skilled	14%	12%	33%
Fairly Skilled	71%	53%	47%
Low Skill	14%	24%	13%
Landscaper Controls It	0%	6%	0%

Q16: When asked what factors their irrigation controller used to adjust irrigation run times, nearly all responded that rainfall was a factor, followed by temperature (Table 3-55). A small portion responded that smart features were bypassed or someone else monitors the system. Only between 8 and 13% responded that seasonality was a factor.

Table 3-55. Responses when asked what factors affect irrigation controller run times.

	6-month	12-month	18-month
Rainfall	92%	94%	93%
Temperature	54%	71%	60%
Seasonality	8%	12%	13%
Soil Type	8%	0%	0%
Last Mow Occurred	8%	0%	0%
Bypassed Smart Features	15%	0%	13%
Someone Else Monitors the System	8%	6%	0%

Q17 & Q18: When asked about the appropriateness of how frequently the irrigation runs, 76 to 87% of respondents said, “As Often as Needed”, with 12 to 20% responding with “Slightly Less Often” than needed (Table 3-56). However, nearly all responded that the run times were “About as Long as Needed” (Table 3-57).

Table 3-56. Responses when asked how often the irrigation controller ran the irrigation system relative to needs of lawn.

	6-month	12-month	18-month
As Often as Needed	79%	76%	87%
Slightly Less Often	14%	12%	20%
Less Often	7%	6%	0%
Landscaper Controls It	0%	6%	0%

Table 3-57. Responses when asked how long irrigation runs.

	6-month	12-month	18-month
About as Long as Needed	100%	88%	100%
Slightly Shorter Period Than Needed	0%	6%	0%
Much Shorter Period Than Needed	0%	6%	0%

3.6.6 Neighbor Discussions of Lawns (Q 19-22)

In general, most responses noted that they did not speak to their neighbors about watering their lawns (Q19 & Q21; Table 3-58 and 60). For those that did speak to their neighbors (Q20 & Q22; Table 3-59 and 61), the most common tone was neutral, as opposed to positive or negative.

Table 3-58. Responses when asked how many times in the past month they spoke to their neighbors about watering their lawn.

	6-month	12-month	18-month
0	79%	56%	69%
1	14%	31%	19%
2	7%	6%	13%
3	0%	6%	0%

Table 3-59. Responses when asked what was mostly said when speaking with neighbor about watering their lawn.

	6-month	12-month	18-month
Did Not Speak with Neighbor	71%	53%	69%
Positive	0%	12%	6%
Neutral	21%	35%	13%
Negative	7%	0%	13%

Table 3-60. Responses when asked how many times in the past month their neighbor spoke to them about watering the neighbor's lawn.

	6-month	12-month	18-month
0	71%	69%	69%
1	21%	13%	13%
2	7%	13%	19%
3	0%	6%	6%

Table 3-61. Responses when asked what was mostly said when speaking with neighbor about watering the neighbor's lawn.

	6-month	12-month	18-month
Did Not Speak with Neighbor	71%	65%	69%
Positive	7%	12%	13%
Neutral	14%	24%	19%
Negative	7%	0%	6%

The tone of conversations about watering the neighbor's lawn did vary slightly based on treatments (Table 3-62). Conversations were mostly neutral for control and compost lots, while till lots were more positive, while also more negative than the others. Similarly, while conversations for not topdressed lots were more positive than topdressed (56% vs. 0%), they were also more negative (24% vs. 13%).

Table 3-62. Responses by treatment when asked what was mostly said when speaking with neighbor about watering the neighbor's lawn for homeowners that spoke with neighbors.

	Positive	Neutral	Negative
Control	22%	**78%**	0%
Till	**56%**	11%	33%
Compost	15%	**69%**	15%
Not Topdressed	**56%**	20%	24%
Topdressed	0%	**87%**	13%

3.6.7 Florida Residency (Q 23-24)

Q23: Between 82 and 94% of responses indicated that they had grown up outside of Florida, with 44 to 50% having moved to Florida within the past 5 years (Table 3-63). The remaining portion of responses indicated that they were native Floridians but lived outside of Florida sometime in their life.

Table 3-63. Responses when asked to describe their Florida residency.

	6-month	12-month	18-month
Haven't Lived in FL Whole Life but Am FL Native	14%	19%	6%
Grew Up Elsewhere and Moved to FL in Last 5 Years	50%	44%	50%
Grew Up Elsewhere and Moved to FL More Than 5 Years Ago	36%	38%	44%
FL Native, Lived Here Entire Life	0%	0%	6%

Q24: The duration that respondents have lived in Florida primarily fell into two groups, with ~44% having lived in Florida for five years or less, and 29 to 44% having lived in Florida for at least 20 years (Table 3-64).

Table 3-64. Responses when asked how many years they have lived in Florida.

	6-month	12-month	18-month
<1 year	7%	0%	0%
1-5 years	36%	44%	44%
6-10 years	7%	0%	6%
11-15 years	14%	13%	13%
16-20 years	7%	0%	0%
20+ years	29%	44%	38%

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 WATER CONSERVATION

Runoff volumes, runoff depths, and CN were analyzed and while not significantly different (due to lack of replicates), all three parameters tended to be lowest for compost amended lots compared to tilled and control lots. Tilled lots produced the greatest runoff depths, a 25% increase compared to composted lots, and control lots produced the highest runoff volumes, a 59% increase compared to composted lots, while top-dressing did not affect runoff volumes, depths, or CNs.

It was concluded that during the establishment period, or the first 30 days post sod installation, amendment ratios do not affect leachate volumes. However, the presence of sod and evapotranspiration processes were not present during the column study, and these factors likely would have influenced leachate volumes. In the field study, compost increased leachate by 4.2 in./month compared to the control, due to the increase in macropores, and applying topdressing did not change the volume of leachate produced.

VWC was highest in compost amended lots, an 8% and 36% increase from tilled and control lots. The analyses showed that topdressed lots had a 16% greater VWC compared to lots that were not topdressed, However, upon analyzing the raw data, significant patterns of increase from before top-dressing was applied and after the second topdressing was applied were not observed. Therefore, the significant impact of topdressing was attributed to either long-term cumulative effect or factors such as homeowner landscaping habits and irrigation run times. It was determined that there is potential for decreasing the irrigation run time further than just 25% (45 minutes to 34 minutes), especially in composted lots, since three composted lots that granted viewing access decreased their run time even further from our original reduction (55% reduction; 20 minute run time). The relative field capacity values observed were also highest in the composted lots, a range of 23% to 30% VWC, even with the reduced run time in three of the lots, compared to 12% to 20% VWC in null lots at a reduced irrigation rate.

The existing recommended compost incorporation rate is 1:6, (~1 in of material into 6 in. of soil) which is the rate that was applied at OToW for this study. It was observed that during the 30-day establishment period is when most leachate loading potentially occurs in Candler soils. With the 1:6 amendment incorporation ratio, the amount of irrigation applied during establishment irrigation is recommended to be revisited to better align with the needs of a specific soil type of turfgrass, rather than a general recommendation. This would aid in conserving water but, more importantly, also minimize unnecessary nutrient leachate loadings. After the turfgrass is established, the field study showed that even with a 25% reduction in irrigation run time, the VWC was higher than that of a control lot with 100% run time. With a 1:6 amendment incorporation rate, since there is excess available water in the root zone, reducing the irrigation run time by 50% (from 45 minutes to 23 minutes) could meet the needs of maintaining a healthy landscape while also conserving water.

Results of this study suggests that homeowners with compost amended soils are agreeable to reduced irrigation run times, even reducing run times further than requested, whereas homeowners in the non-amended control group were less agreeable to reduced irrigation run times. These results also may provide a basis for establishing lower IFAS recommended irrigation amounts (or run times) for compost amended lots. Future research should evaluate appropriate reductions that can maintain acceptable turf quality in residential settings. This type of impact to homeowner behavior within the real world is essential to realizing the potential benefits of amending residential soils.

4.2 Water Quality Impacts

Topdressing of lawns with 0.5 yd^3/1,000 ft^2 of compost twice per year did not significantly affect runoff or leached loadings of Nitrogen or Phosphorus. Incorporating 4 yd^3/1,000 ft^2 of compost into the top six inches of soil under sod did not affect Phosphorus loadings to runoff or leachate. Further, compost incorporations less than 1:2 did not have significantly different loadings leached during the simulated establishment irrigation. While Nitrogen loadings in runoff were not significantly affected by compost incorporation, leaching of Nitrogen did significantly increase as a result. Adjusting loadings to developed residential watershed (52% impervious; lawn are = 60% of pervious area), Compost amended lots had an estimated leached loading of 11 lbs. N/ac./yr., which was significantly higher than Control lots that had only 1.7 lbs. N/ac./yr.; Tilled lots were not significantly different from Compost or Control lots with runoff loading of 5.3 lbs. N/ac./yr. This translates to an increased Nitrogen leaching of 9.3 lbs. N/ac./yr. or 2.3 lbs. N/lot/yr., assuming ¼ ac. lot sizes. While the column study also resulted in significantly greater leaching of Nitrogen loadings, the 22 lbs. N/ac. was equal to twice the annual leached rate of 11 lbs. N/ac./yr. By comparison, N leachate loadings over the first few months of monitoring within compost amended lots did not exceed subsequent leaching over the remainder of the study. This further suggests that while the column study may have been a good estimate of relative loading rates, the extreme conditions under which it was conducted resulted in over predicting in-situ N leaching from compost amended lots during establishment irrigation.

Amending soils with compost did not significantly increase TN concentrations or loading nor TP concentrations or loading per month compared to both tilled and control lots. Composted and null lots had the same mean event concentrations, while tilled lots were 40% lower at 0.78 mg/L. There were some fluctuations based on date and this may have been due to the changing environment and activities of residents in the study area since they were told to carry out their lawn maintenance as they would normally. Tilled lots produced the least annual TN loadings, 14% and 32% less than composted and null lots, respectively. Tilled lots also produced the least TP loadings, 28% and 4% less than composted and control lots, respectively. Top-dressing lots would not significantly increase TN or TP loading, as the annual estimate was <15% greater for top-dressed lots compared to lots that were not top-dressed. Amending soils with compost would result in annual TN and TP loadings similar to that of the null. Similarly, top-dressed lots produced similar annual loadings to those that were not top-dressed.

Increasing amendment incorporation rates led to increases in nutrient concentrations during the 30-day establishment period, but in the field, amending a soil with compost did not lead to increased concentrations compared to the tilled lots or the null. Increasing amendment ratios in the column study and amending soils with compost in the field both led to increased nutrient loadings. In the column study, loadings were driven by concentrations, since the leachate volumes were the same across all treatments, whereas in the field, the nutrient loading was driven by leachate volume differences between treatments. Since the annual nutrient loadings are higher in the amended lots and tilled lots than in the control by 15.9 lbs./ac. and 12.8 lbs./ac., respectively, there is the risk of leachate loadings into groundwater, especially within the 30-day establishment period when nutrient losses appear to be greatest based on the 30-day column study. Simulated irrigation rates in the column study were identical across all treatments and resulted in the same volume of leachate, but since the field study involved homeowners, the irrigation rates were left up to them to alter as they saw fit.

Overall, amending or top-dressing newly constructed residential lots with compost would not be expected to significantly affect runoff quality or quantity compared to non-amended lots.

In conclusion, amending newly constructed residential lots or topdressing lawns with compost would not be expected to significantly affect runoff quantity or quality compared to unamended or non topdressed areas based on runoff volumes, depths, CN, and nutrient loadings. Topdressed lots produced more runoff based on CN, a slightly higher runoff depth, but overall less runoff volume. Lots that were topdressed also produced no significant differences in nutrient loading.

4.3 Future Research needs

The limitation for the runoff portion of the study was that due to funding restrictions, runoff was not captured from each lot individually, but rather treatments were grouped into drainage areas. Either being able to capture runoff from individual lots, or a greater number of drainage areas per treatment would aid in better understanding if the results shown are consistent across drainage areas. Additionally with the soil amendment study, examining the composition of amendment in closer detail would aid in determining which type of parent material are better for addressing specific soil issues, whether it be improving soil structure, or restoring the nutrients in the soil via amendment.

A future study could examine a further reduction of irrigation run time on compost amended soils based on the reductions seen from the irrigation scheduling data. The amended soils showed the highest VWC, even with the voluntary extra reduction in run time that some of the homeowners with amended lots chose to do. It is important to determine if this is an anomaly or would be a pattern if all amended lots were to decrease run time.

Adjusting the volume of water applied during the establishment period, as well as the length of the establishment period, could also be another research opportunity to determine if there is not only another chance to conserve water but also decrease the nutrient loadings.

To better understand the nutrient leaching process during the establishment period, it would be useful to collect leachate samples in the field on a daily basis to see what the effects of the presence of turfgrass and thus the evapotranspiration cycle are on leachate volumes and loadings.

Additionally, this study only covered the water conservation and water quality effects based on Candler soils. Broadening the study to look at amendment incorporation in various other soil types would be important since different soils have different characteristics and would react differently to amendments. For example, Candler sands are very coarse and soil amendments help provide smaller pores to aid in water holding. Areas that have finer textured soils need help with infiltration, so an amendment that could provide larger pores would be necessary.

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6 APPENDIX

6.1 A.1 RUNOFF CONCENTRATIONS

6.1.1 A.1.1 Nitrogen Runoff Concentrations

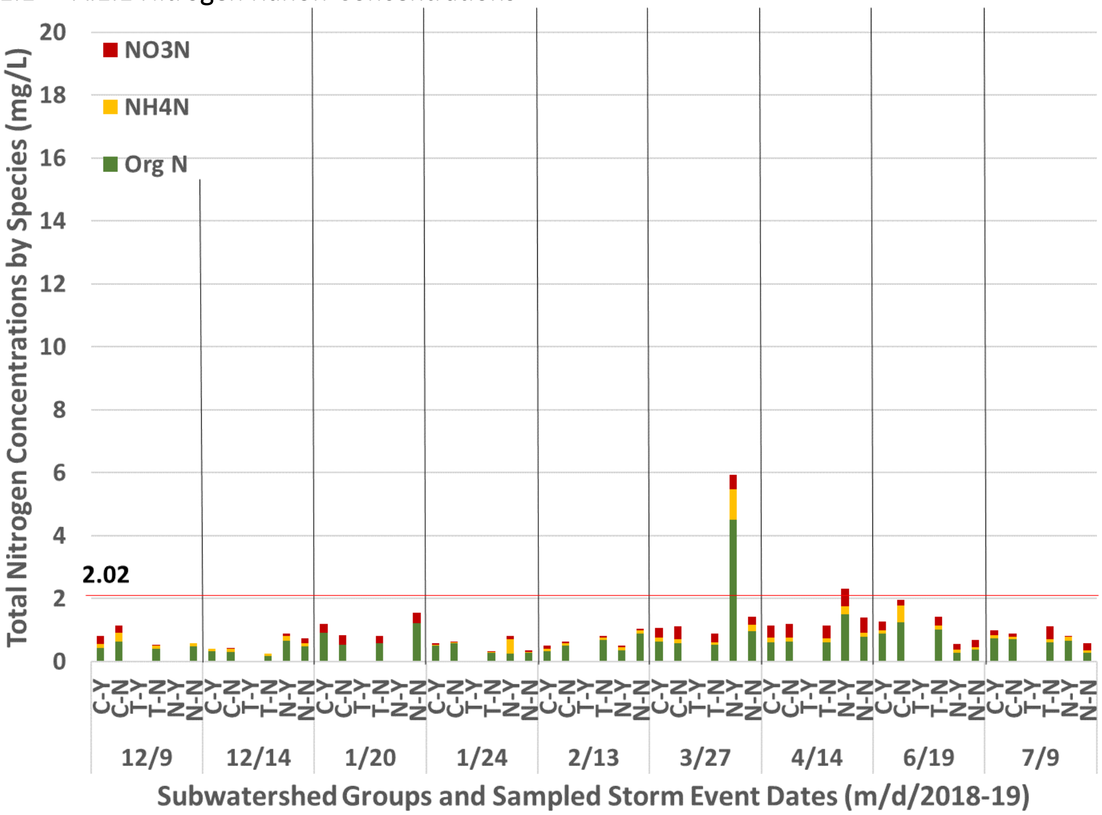

Figure A-1. Total Nitrogen concentrations of stormwater runoff samples collected between 12/9/2018 to 7/9/2019.

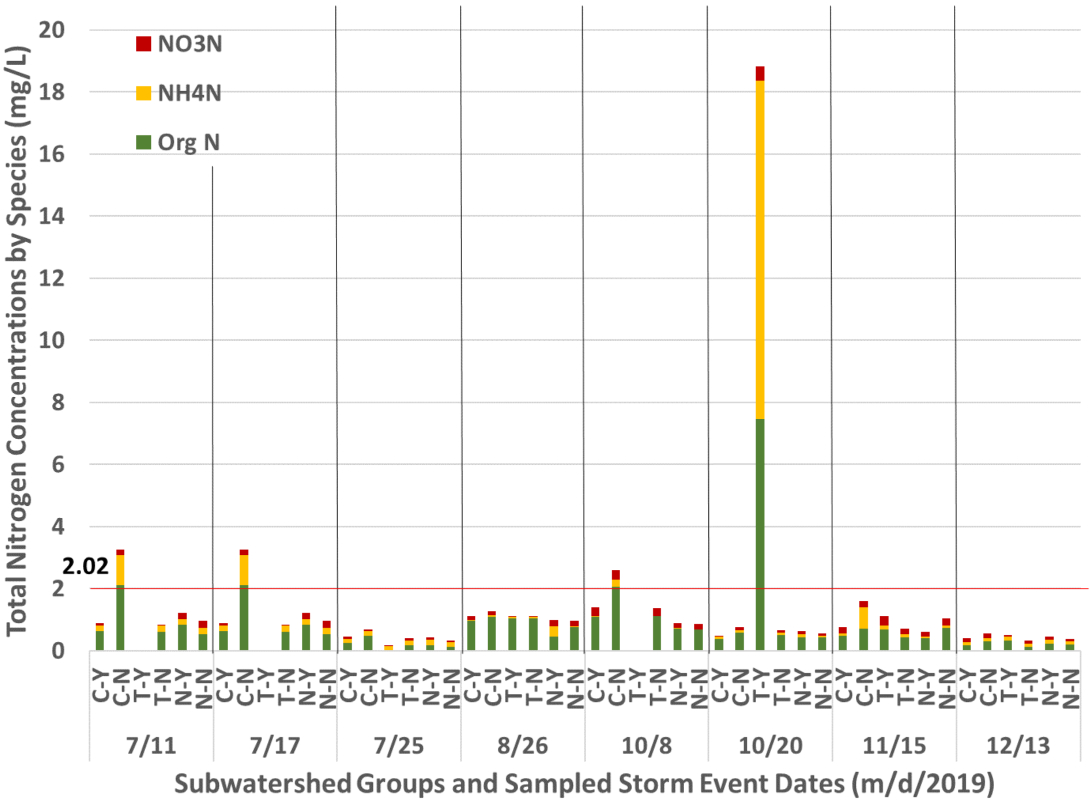

Figure A-2. Total Nitrogen concentrations of stormwater runoff samples collected between 7/11/2019 to 12/13/2019.

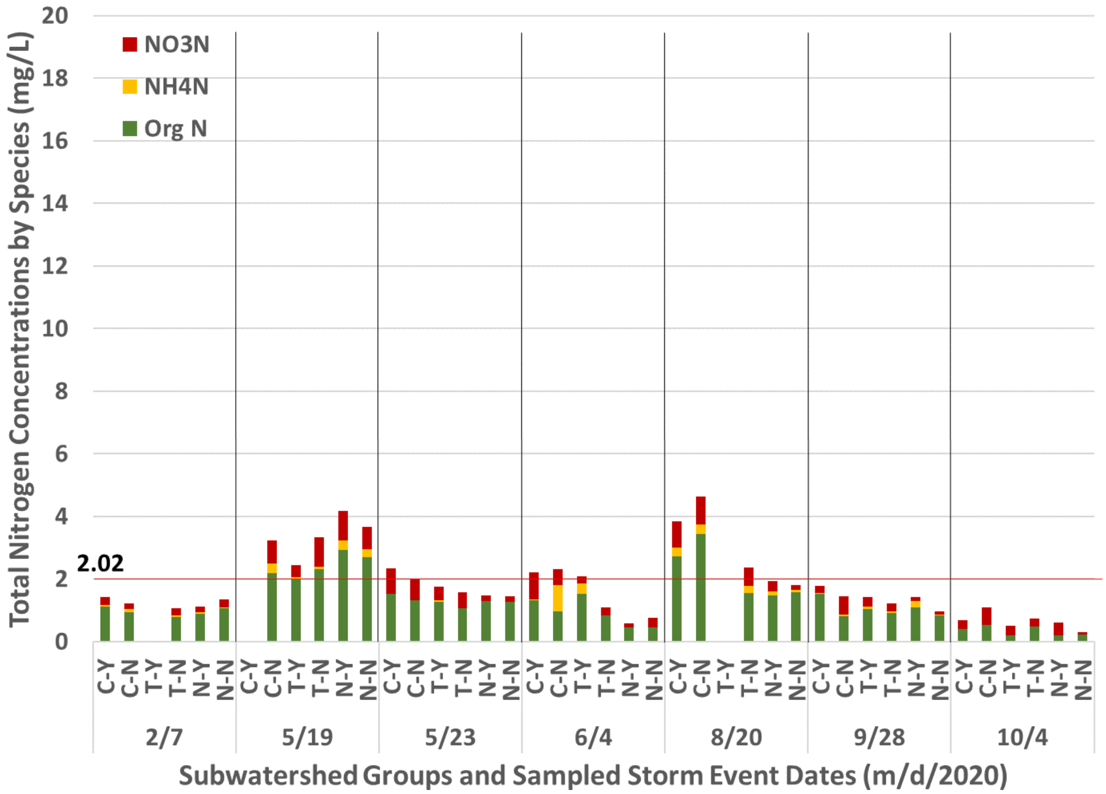

Figure A-3. Total Nitrogen concentrations of stormwater runoff samples collected between 2/7/2020 to 10/4/2020.

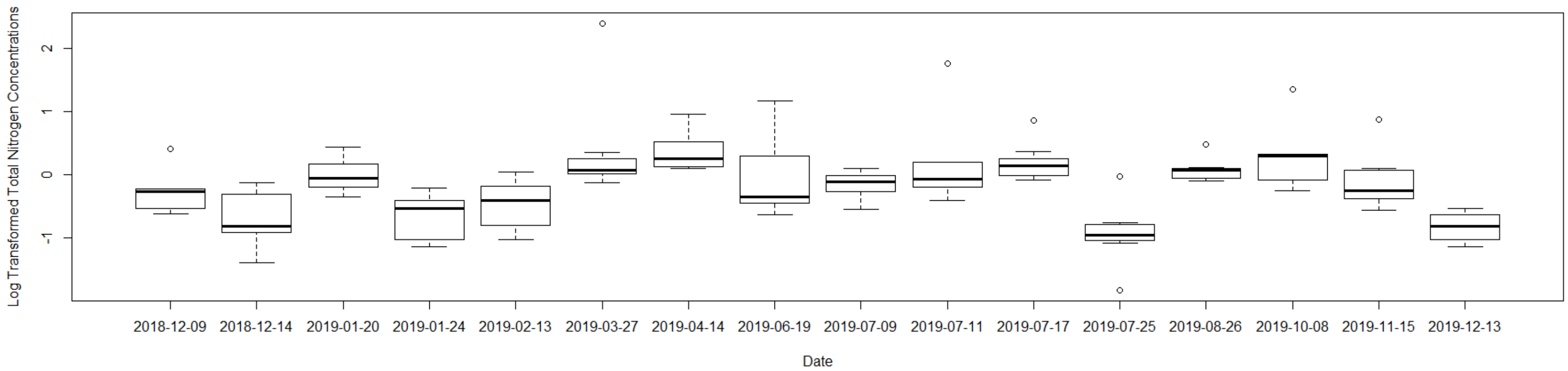

Figure A-4. A boxplot of log-transformed TN concentrations by date from runoff of 16 sampled storm events from 2018-2019.

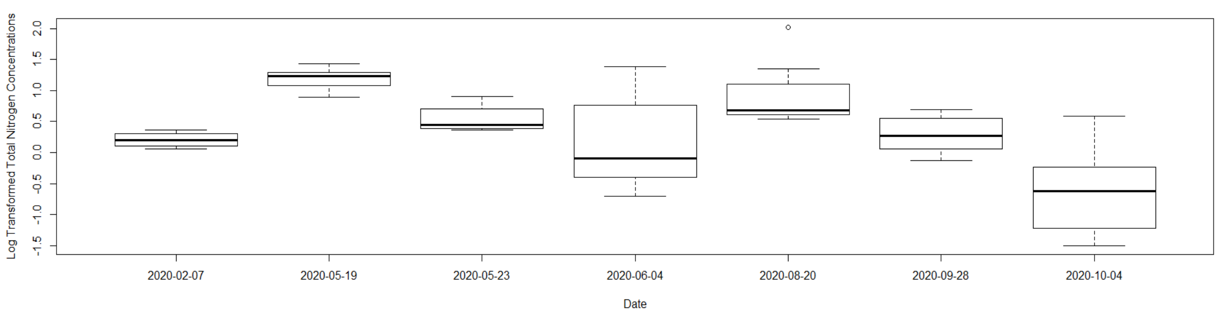

Figure A-5. A boxplot of log-transformed TN concentrations by date from runoff of 7 sampled storm events in 2020.

6.1.2 A.1.2 Phosphorus Runoff Concentrations

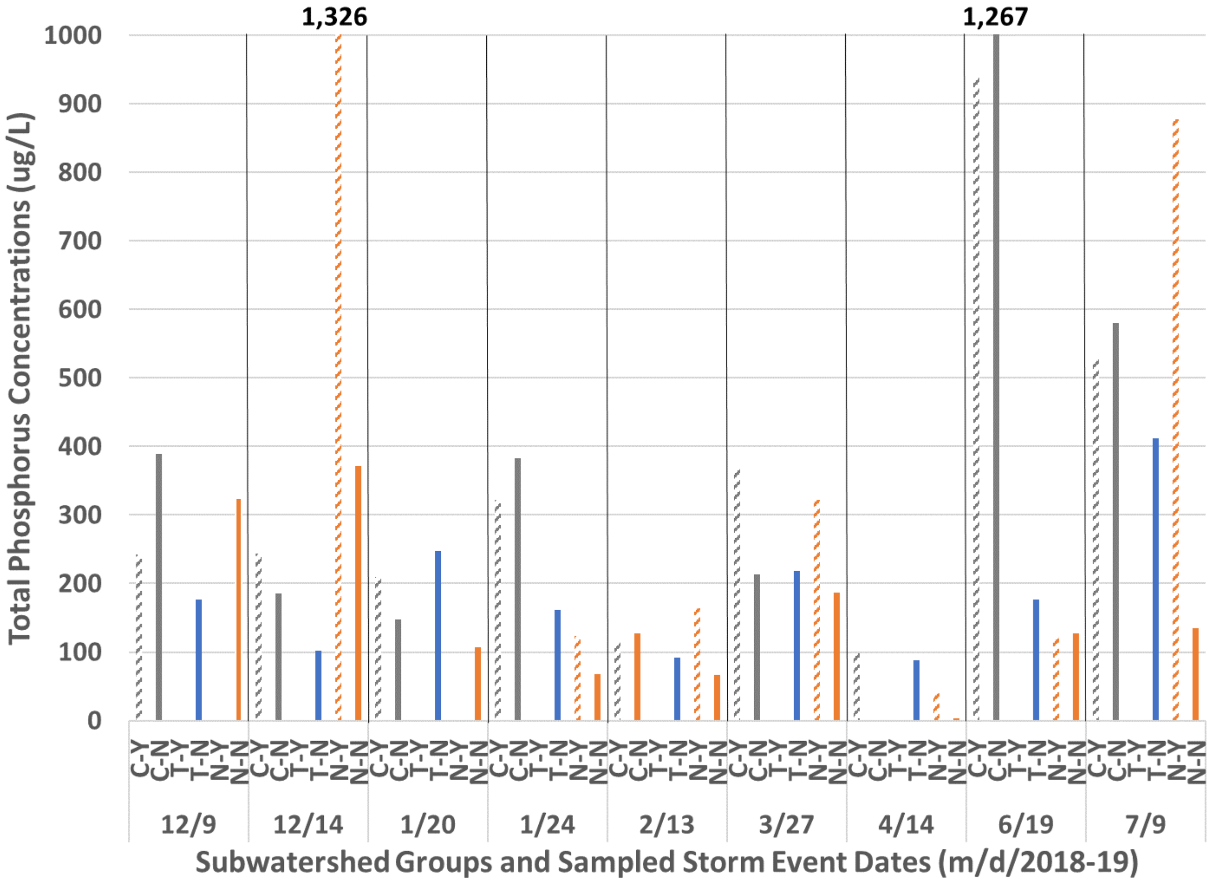

Figure A-6. Average total phosphorus concentrations per treatment from stormwater runoff samples from first 9 of 24 separate storm events sampled from 2018 to 2019. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively). Missing bars indicate that a sample was not taken for that storm event.

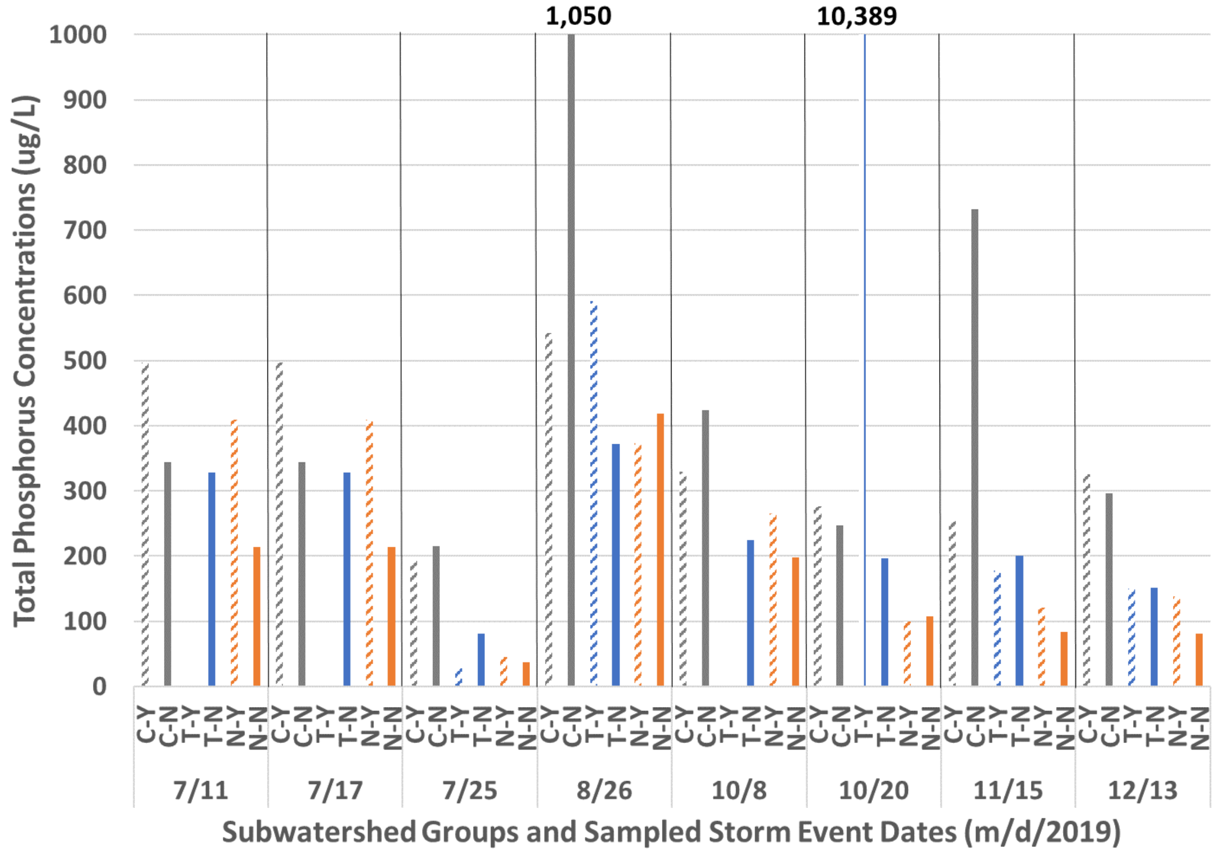

Figure A-7. Average TP concentrations per treatment from stormwater runoff samples of 8 of 24 separate storm events in 2019. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a top-dressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

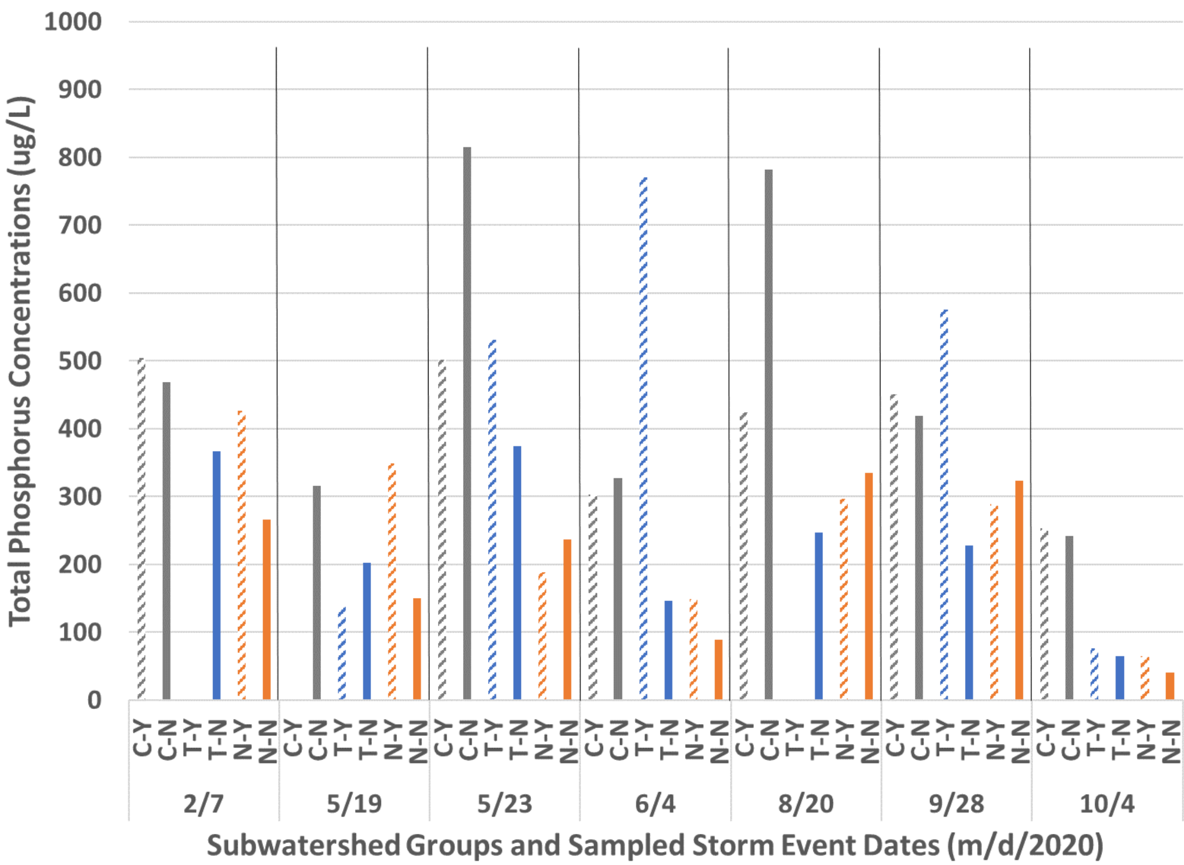

Figure A-8. Average TP concentrations per treatment from stormwater runoff samples of 7 of 24 separate storm events in 2020. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a top-dressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

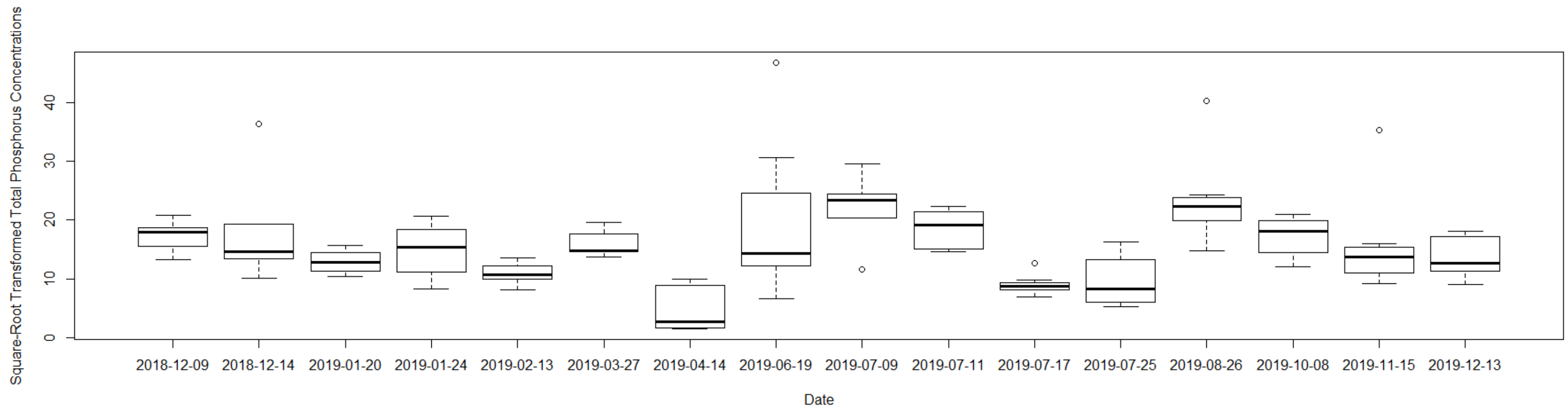

Figure A-9. A boxplot of SR-transformed TP concentrations by date from runoff of 23 sampled storm events from 2018-2020.

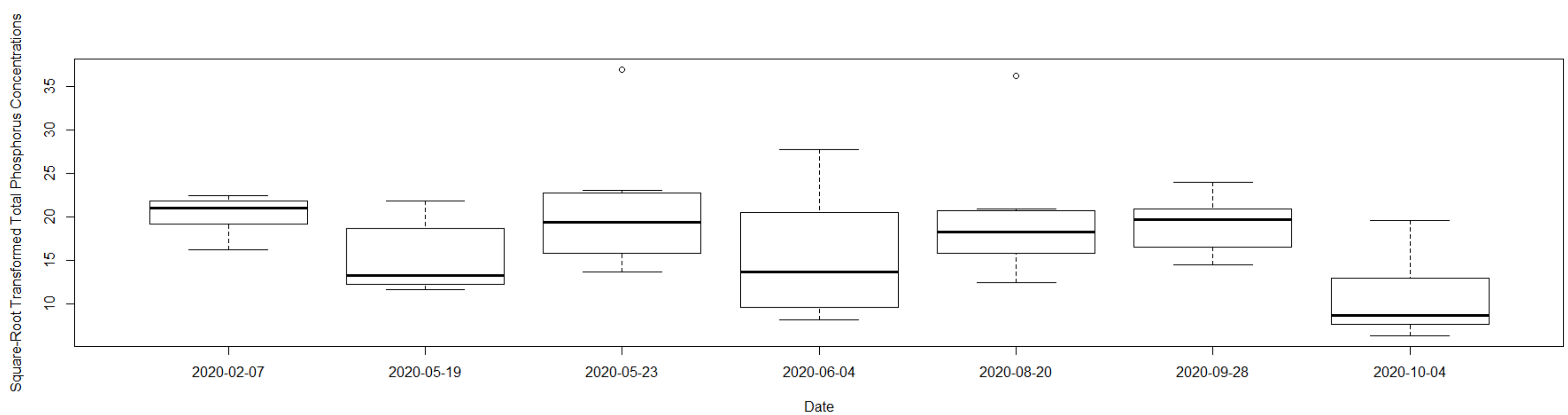

Figure A-10. A boxplot of SR-transformed TP concentrations by date from runoff of 7 sampled storm events in 2020.

6.2 A.2 Runoff Loadings

6.2.1 A.2.1 Nitrogen Runoff Loadings

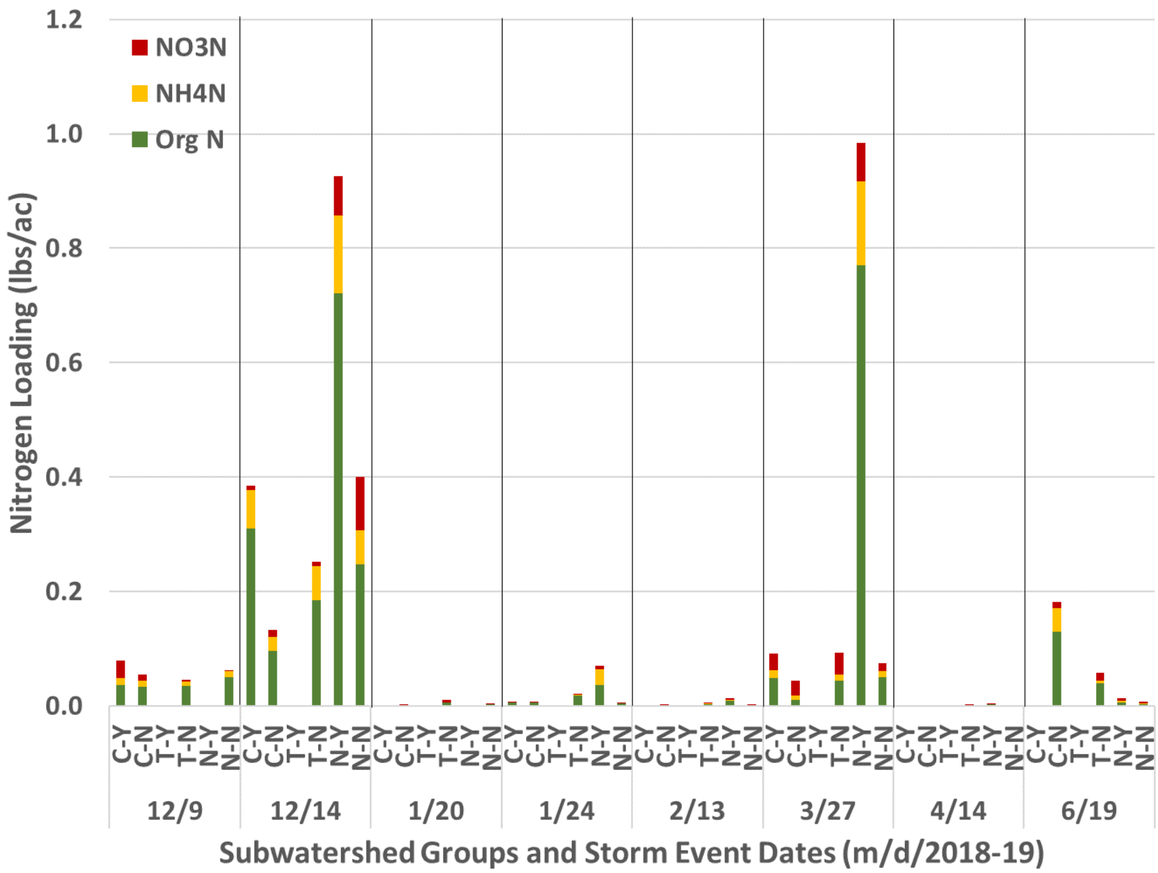

Figure A-11. TN loading (kg/ha) from 8 of 23 sampled storm events from 2018 to 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a topdressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

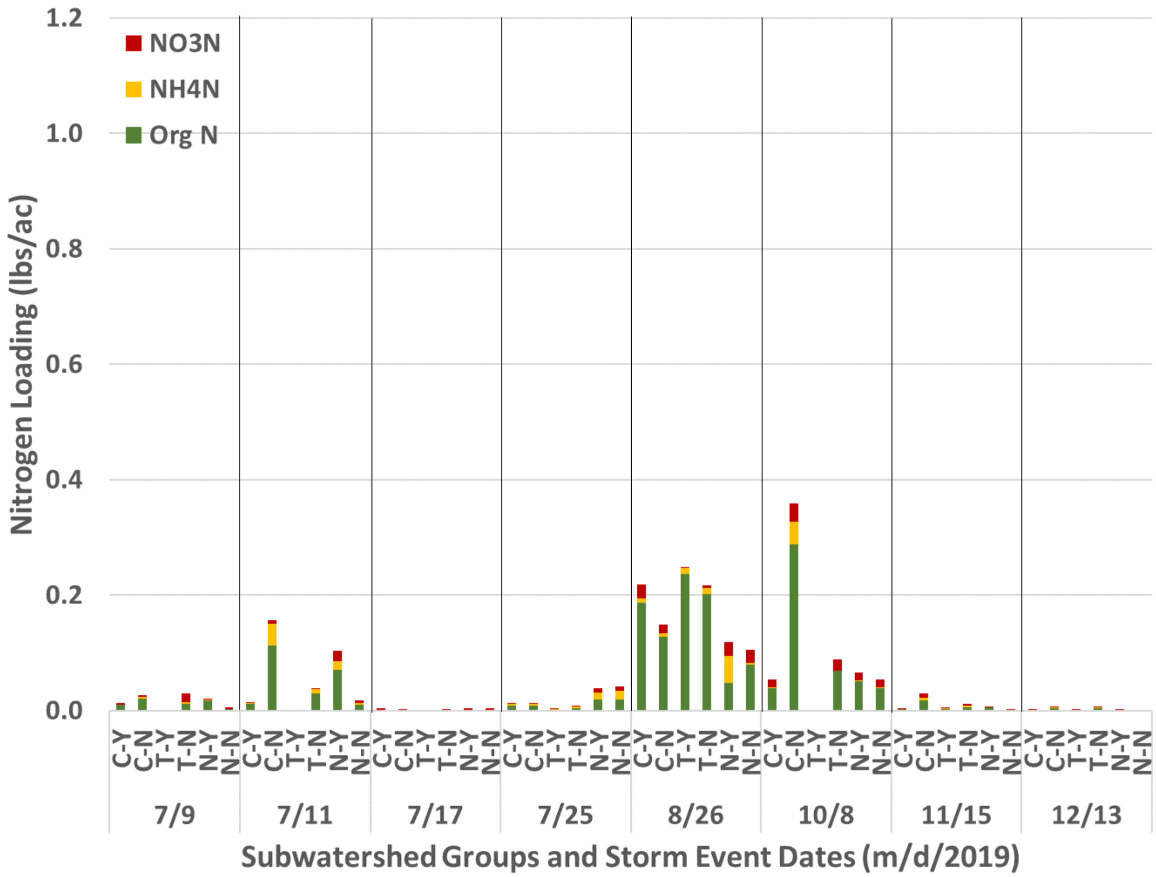

Figure A-12. TN loading (kg/ha) from 8 of 23 sampled storm events in 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a topdressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

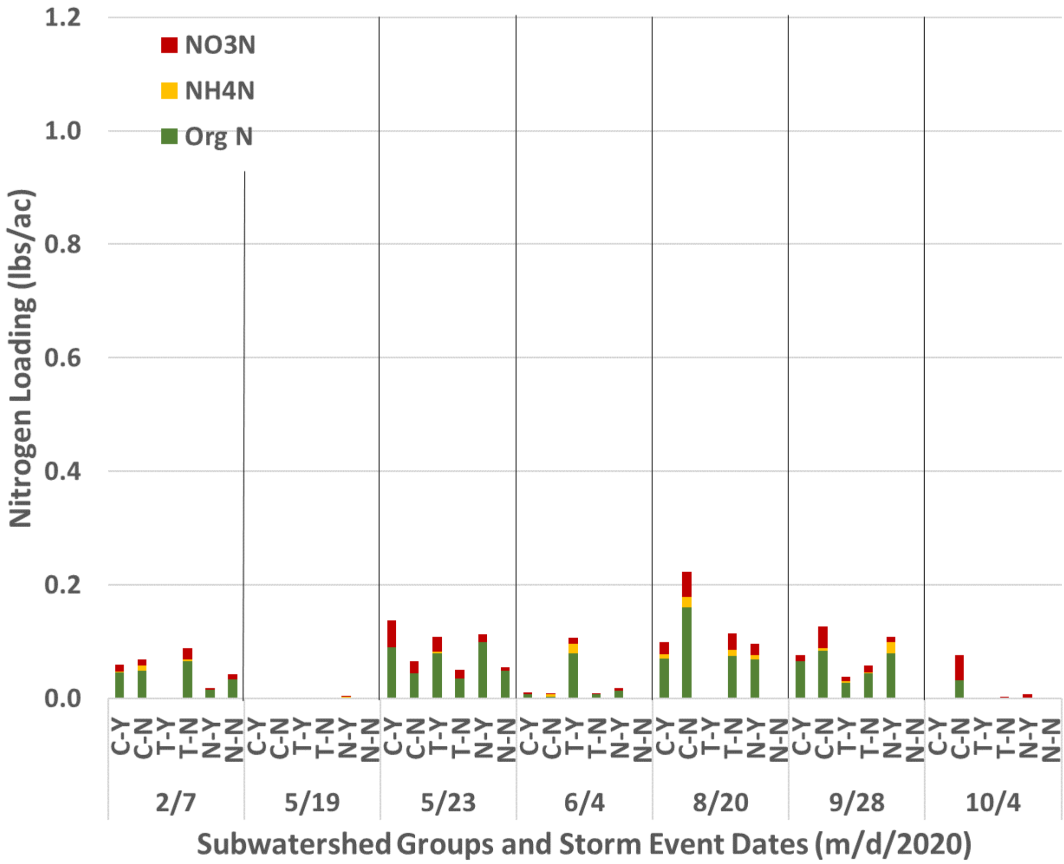

Figure A-13. TN loading (kg/ha) from 7 of 23 sampled storm events from 2018 to 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a topdressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

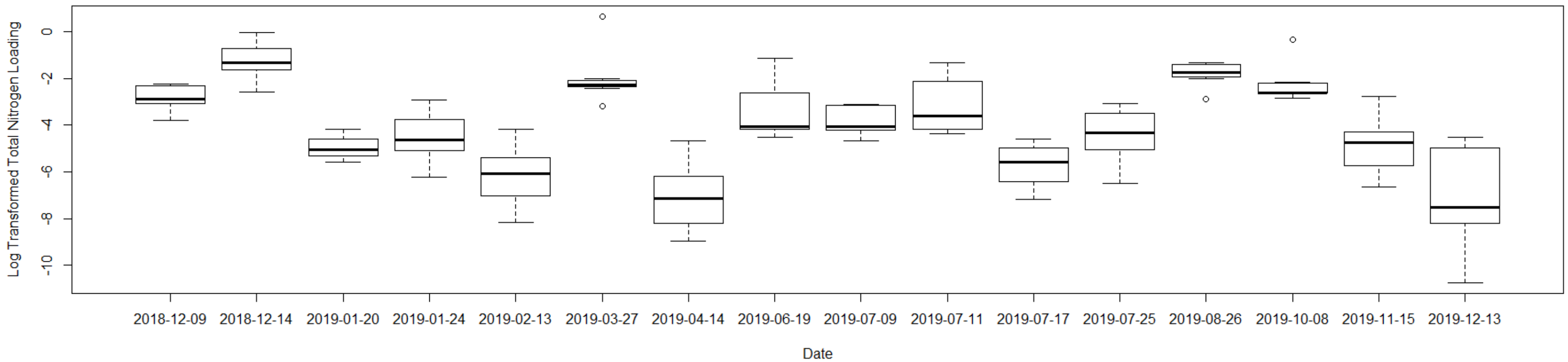

Figure A-14. A boxplot of log-transformed TN loadings by date from runoff of 16 sampled storm events from 2018-2019.

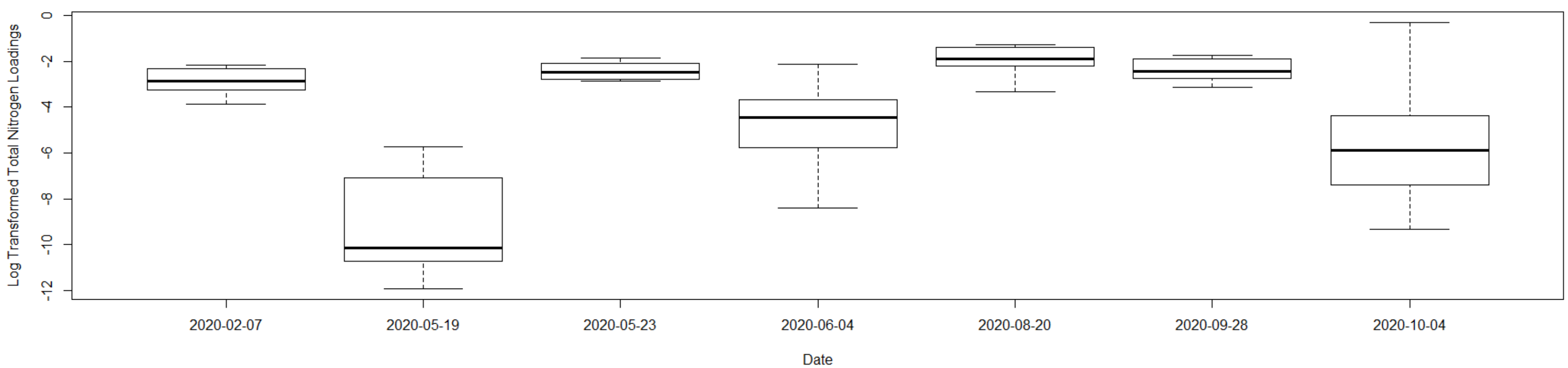

Figure A-15. A boxplot of log-transformed TN loadings by date from runoff of 7 sampled storm events in 2020.

6.2.2 A.2.2 Phosphorus Runoff Loadings

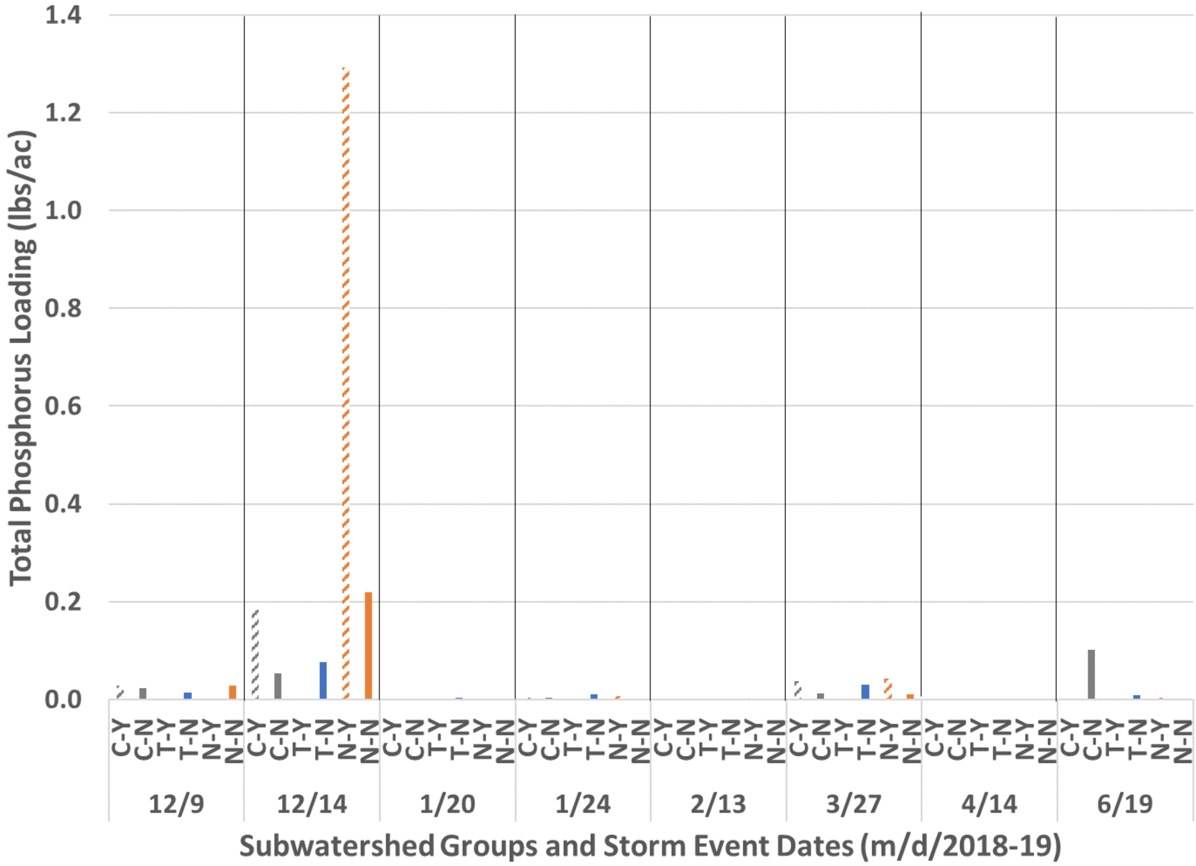

Figure A-16. Raw TP loadings from 8 of 23 sampled storm events from 2018 to 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a top-dressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

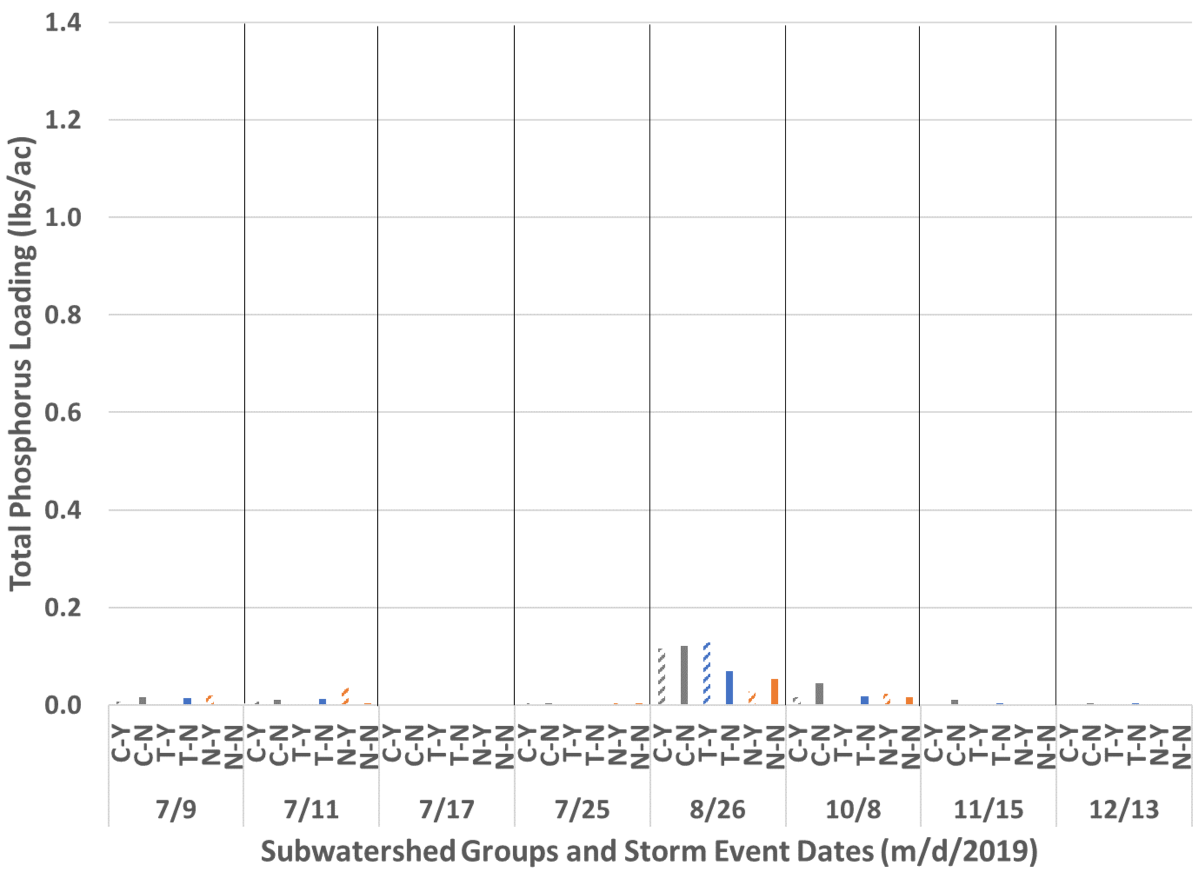

Figure A-17. Raw TP loading from 8 of 23 sampled storm events from 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a topdressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

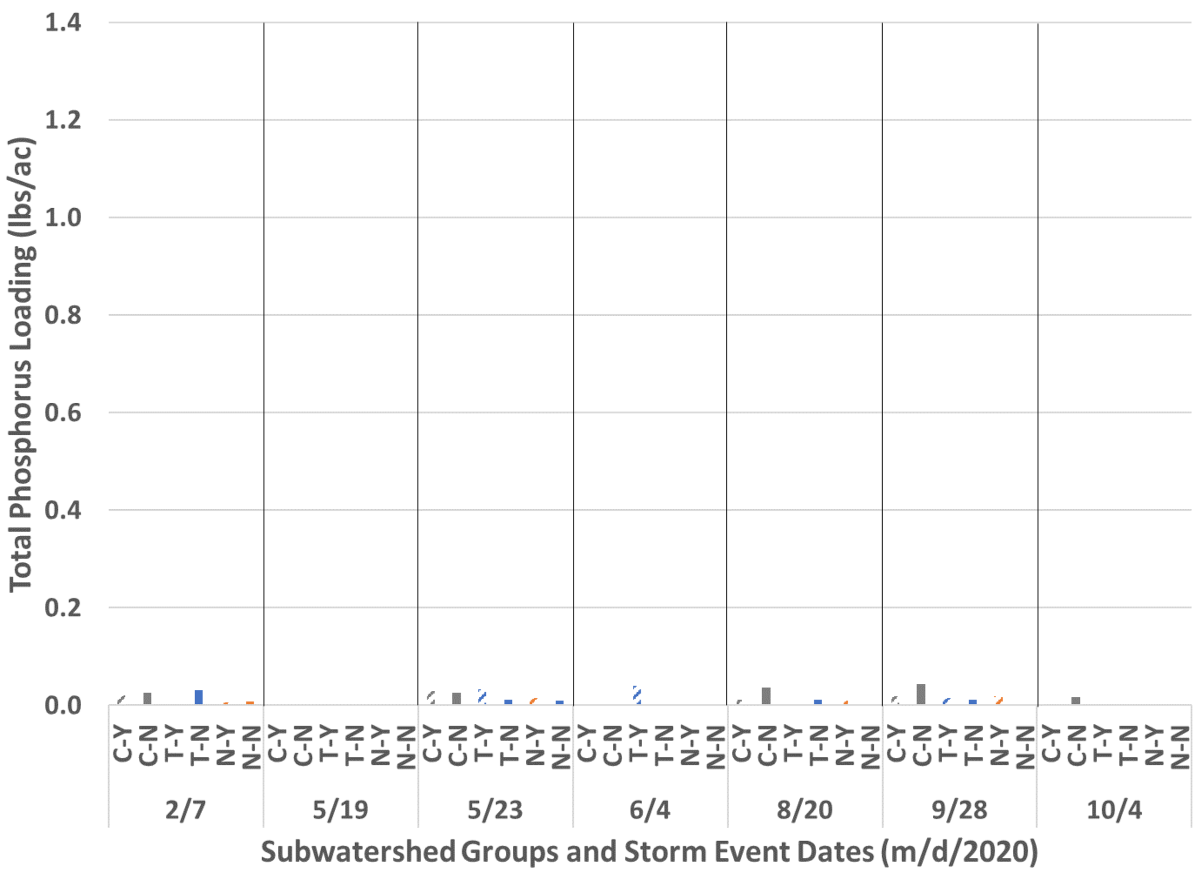

Figure A-18. Raw TP loading from 7 of 23 sampled storm events from 2019 in Ocala, Florida. The first letters in the label (C, T, N) stand for the treatment (compost, tilled, control, respectively), while the second letters (Y, N), indicate whether or not the lot has had a topdressing application (yes, no, respectively). Missing bars indicate that a sample was not taken for that storm event.

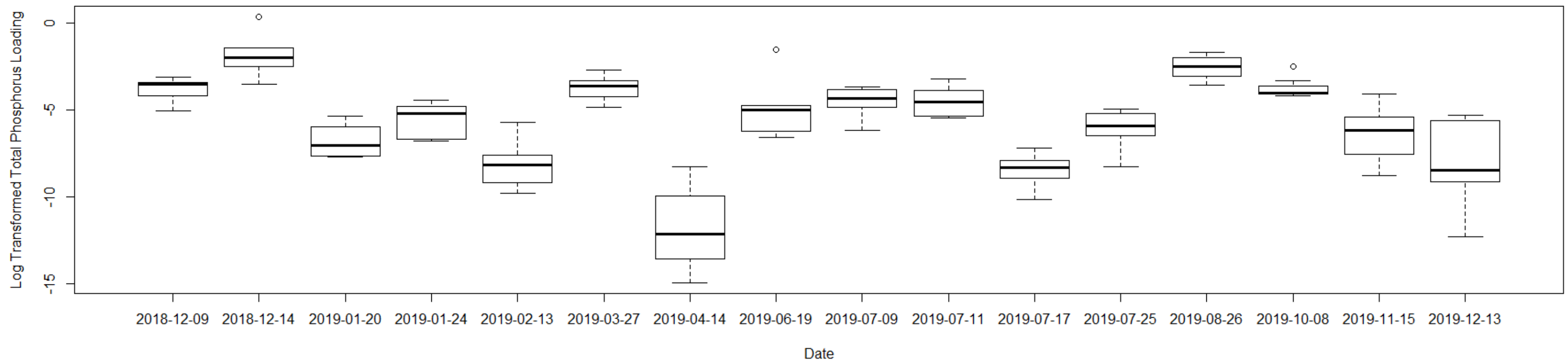

Figure A-19. A boxplot of log-transformed TP loadings by date from runoff of 16 sampled storm events from 2018-2019.

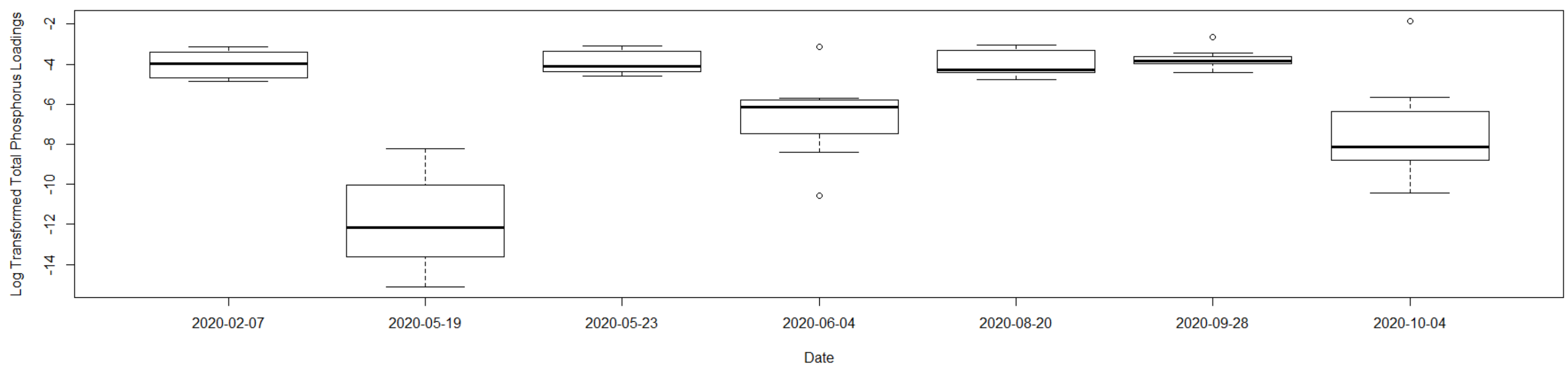

Figure A-20. A boxplot of log-transformed TP loadings by date from runoff of 7 sampled storm events in 2020.

6.3 A.3 Soil Moisture Data Time Series

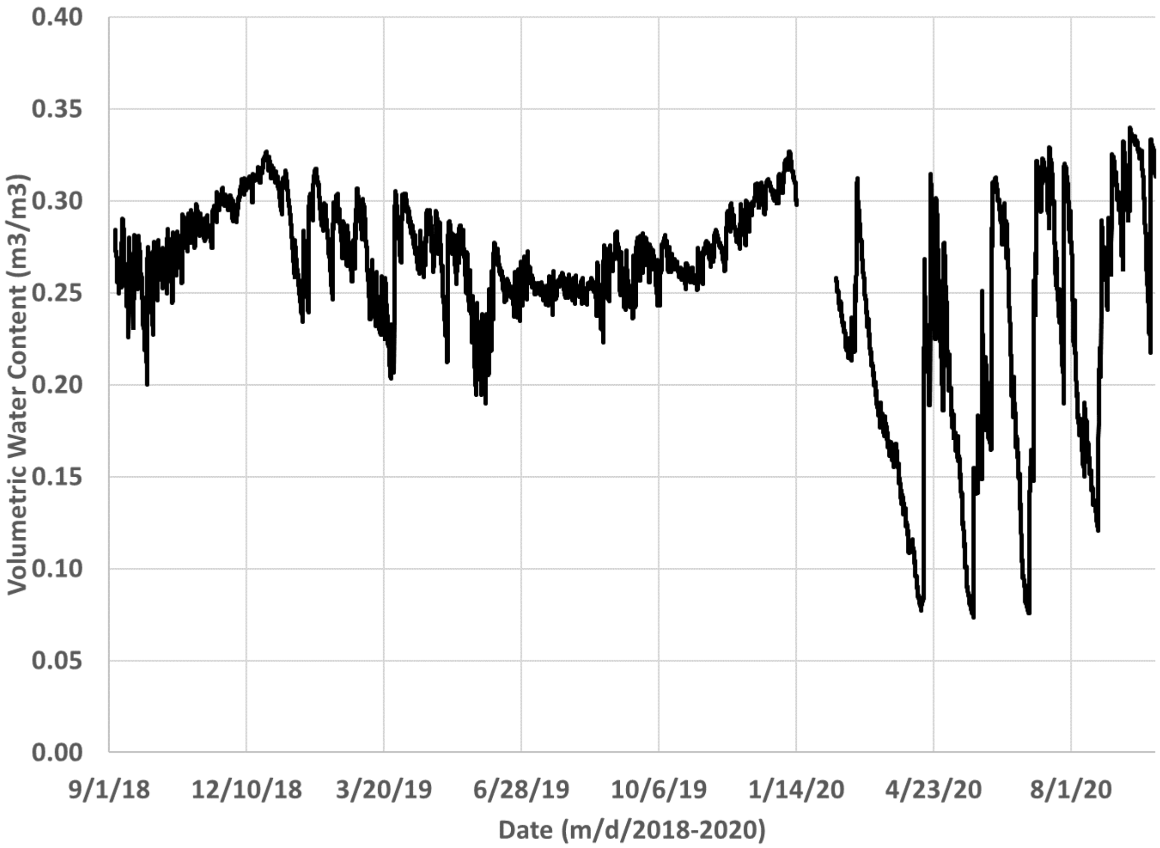

Figure A-21. Lot 26, compost with topdressing

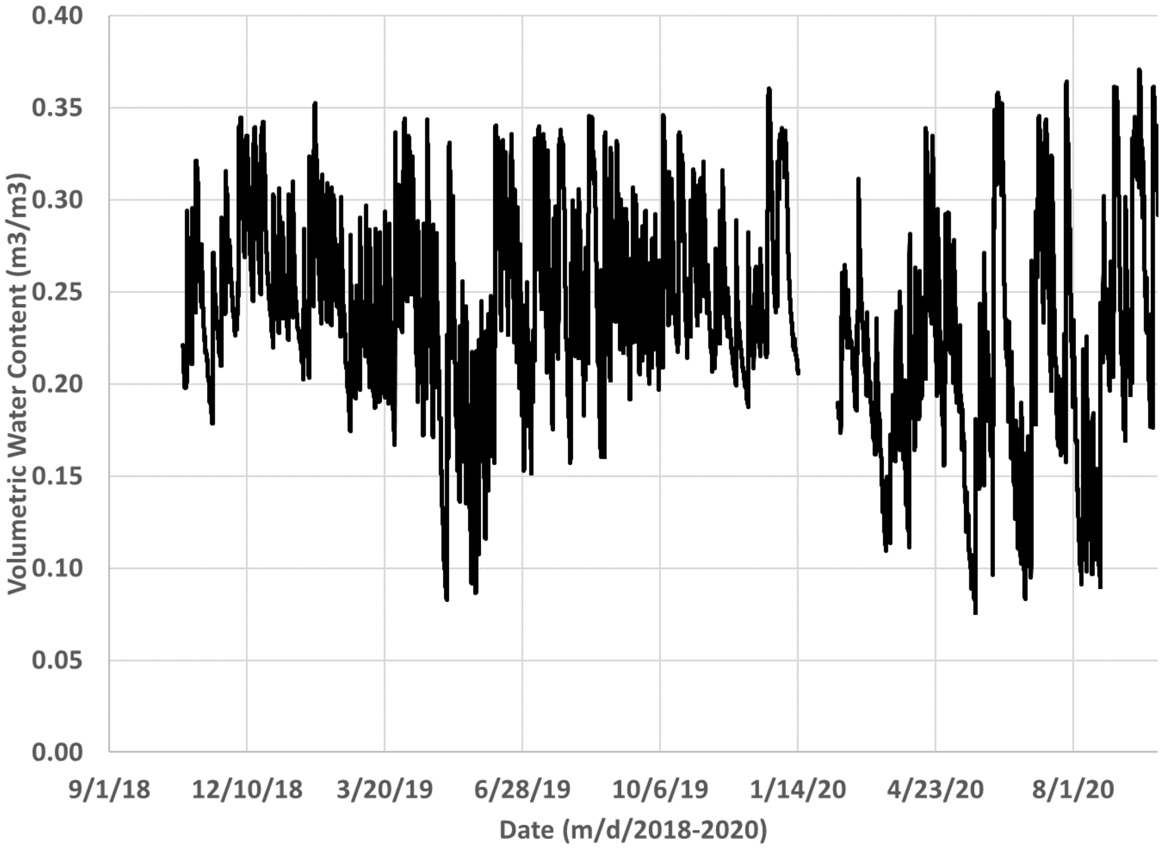

Figure A-22. Lot 27, compost with topdressing

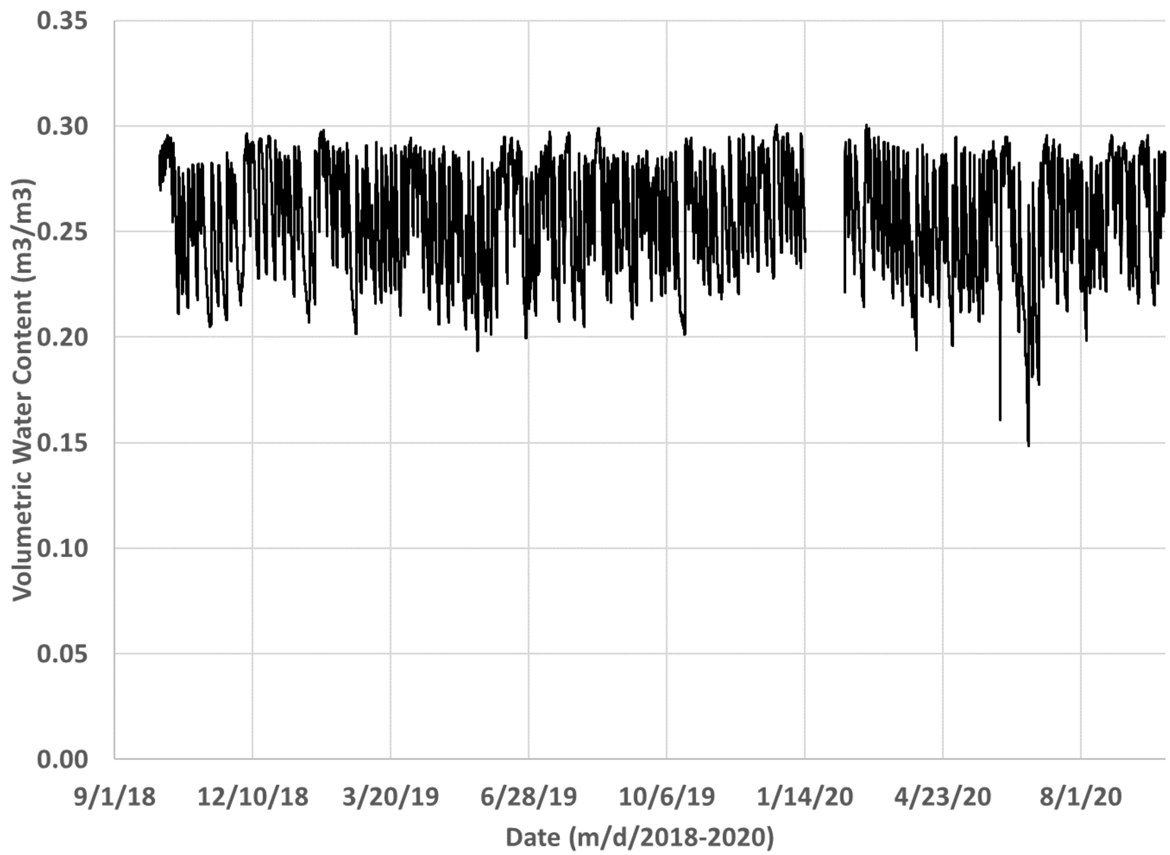

Figure A-23. Lot 35, compost without topdressing

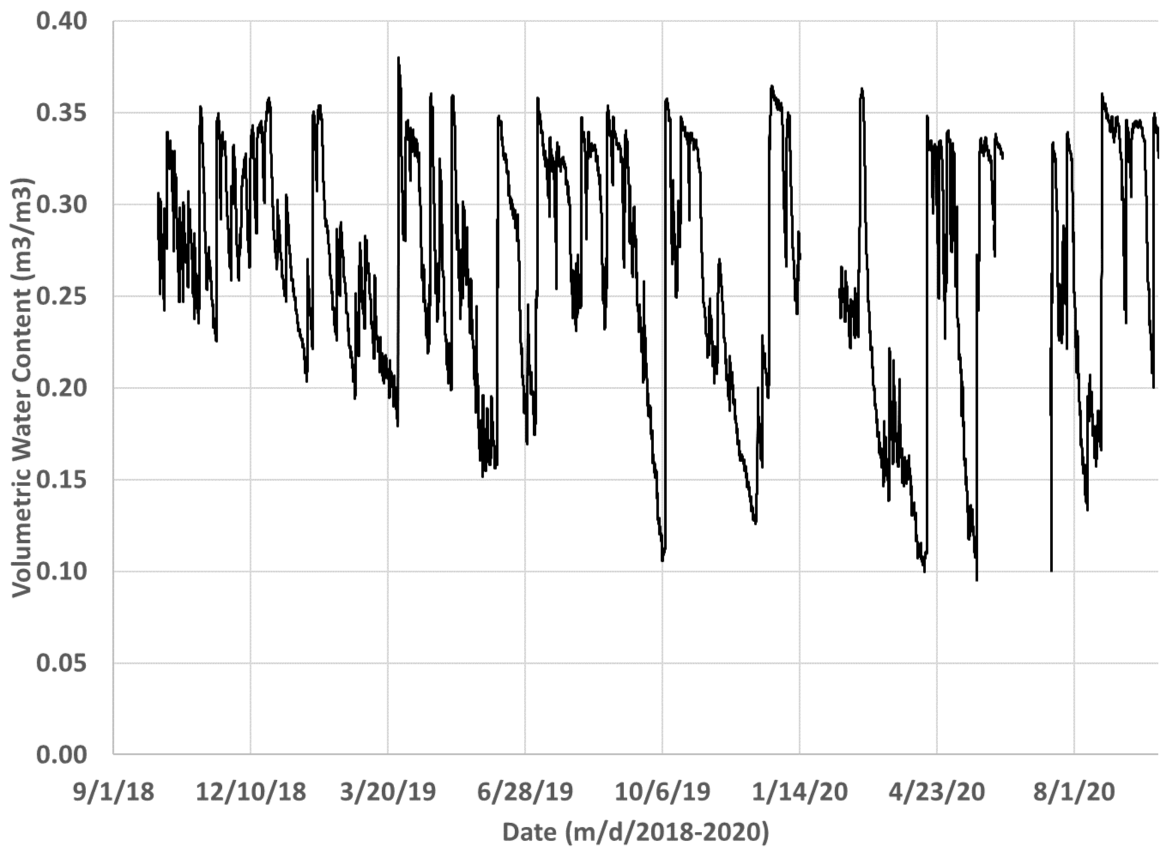

Figure A-24. Lot 36, compost without topdressing.

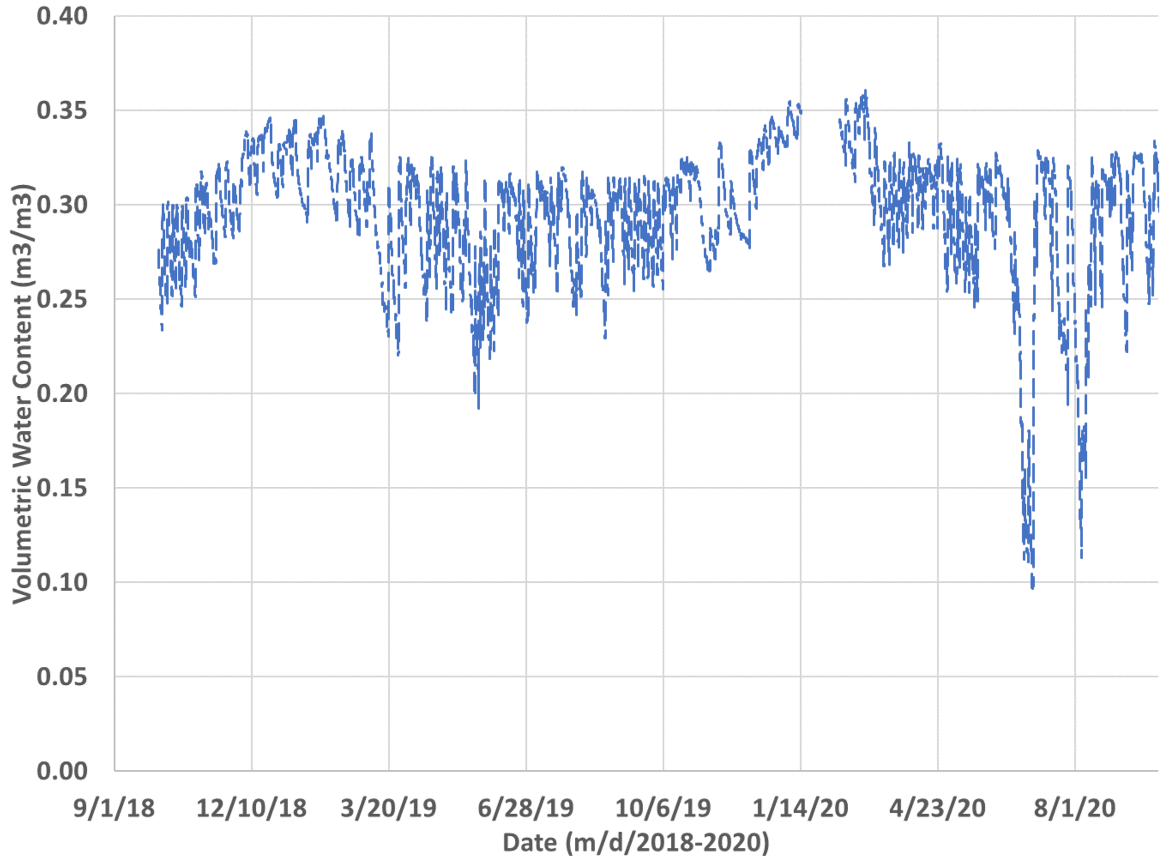

Figure A-25. Lot 20, tilled without topdressing

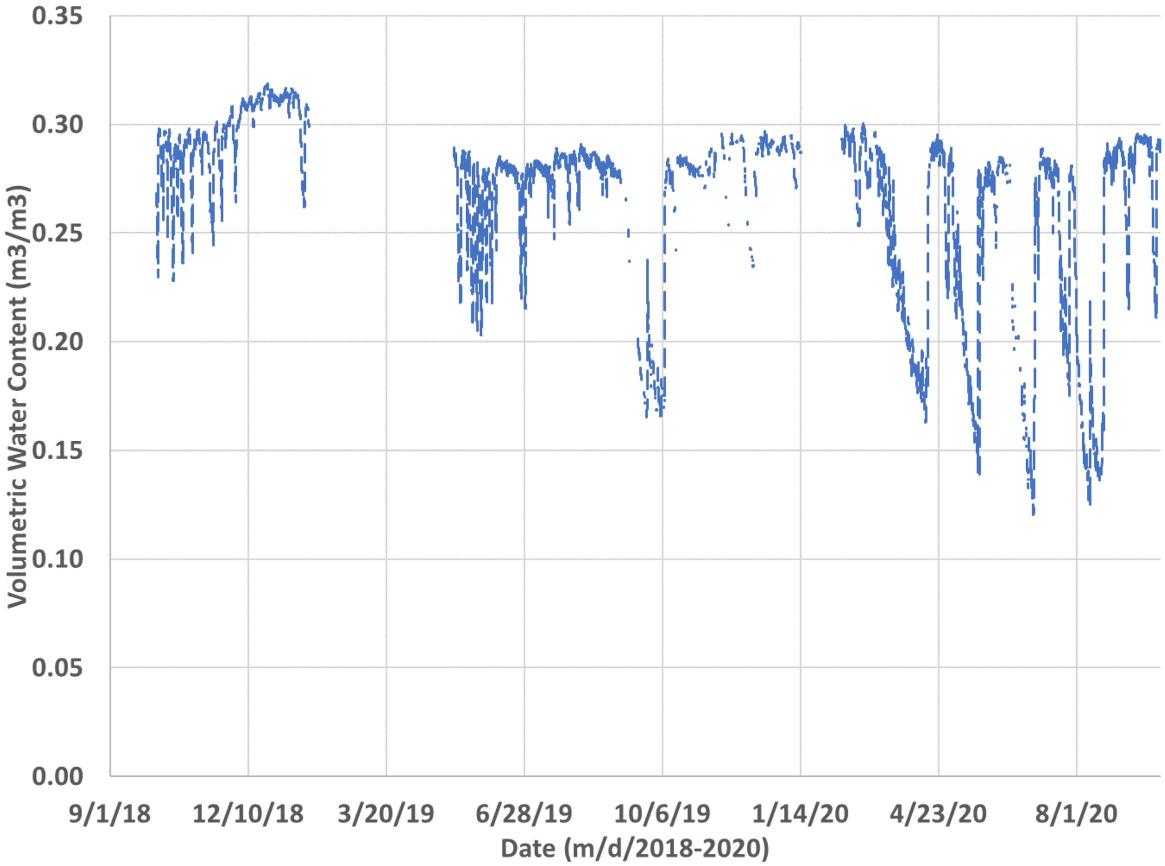

Figure A-26. Lot 21, tilled without topdressing.

Figure A-27. Lot 51, tilled with topdressing

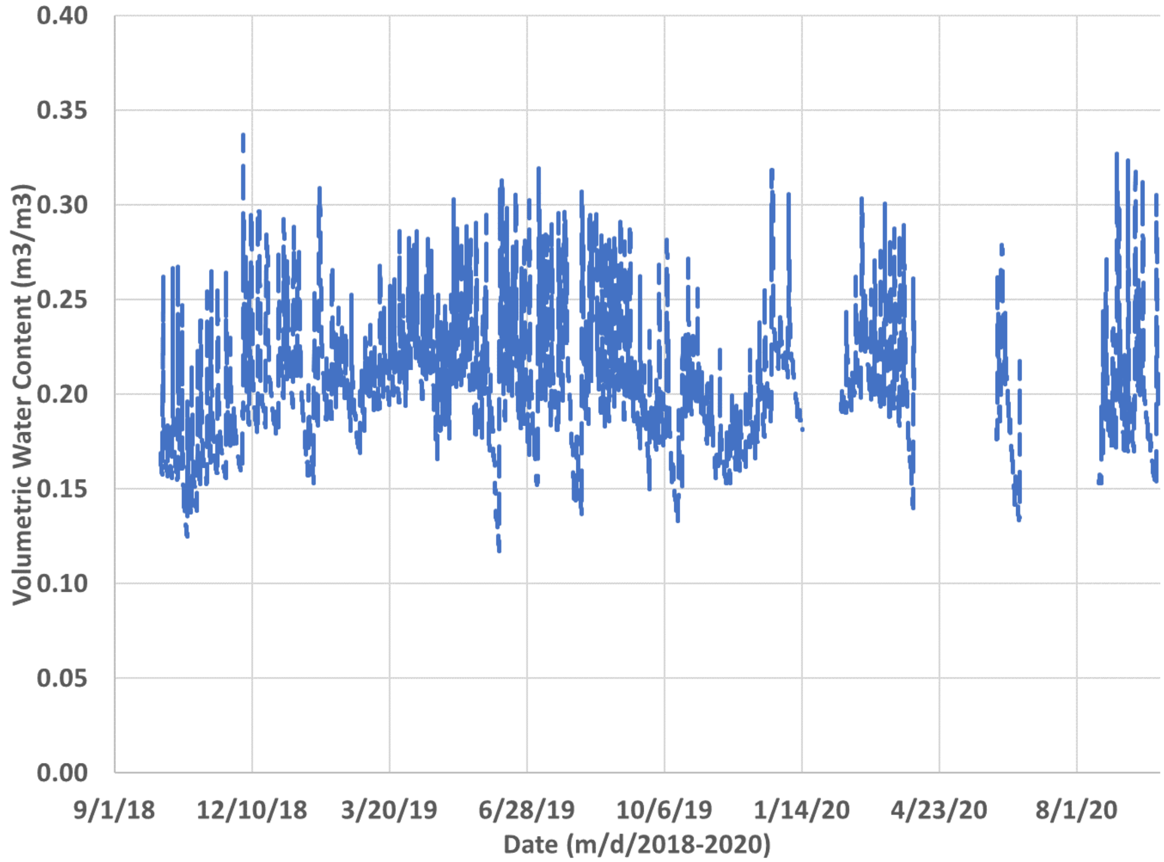

Figure A-28. Lot 53, tilled with topdressing

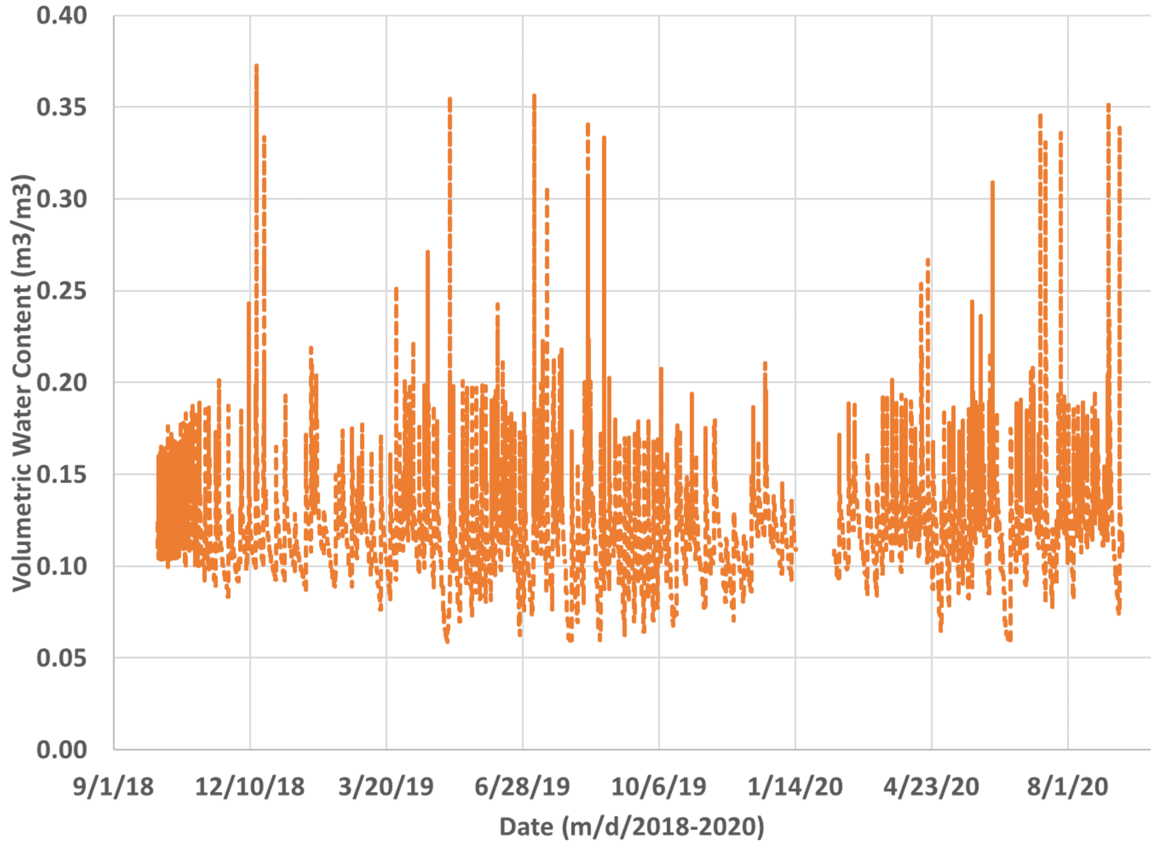

Figure A-29. Lot 63, control without topdressing

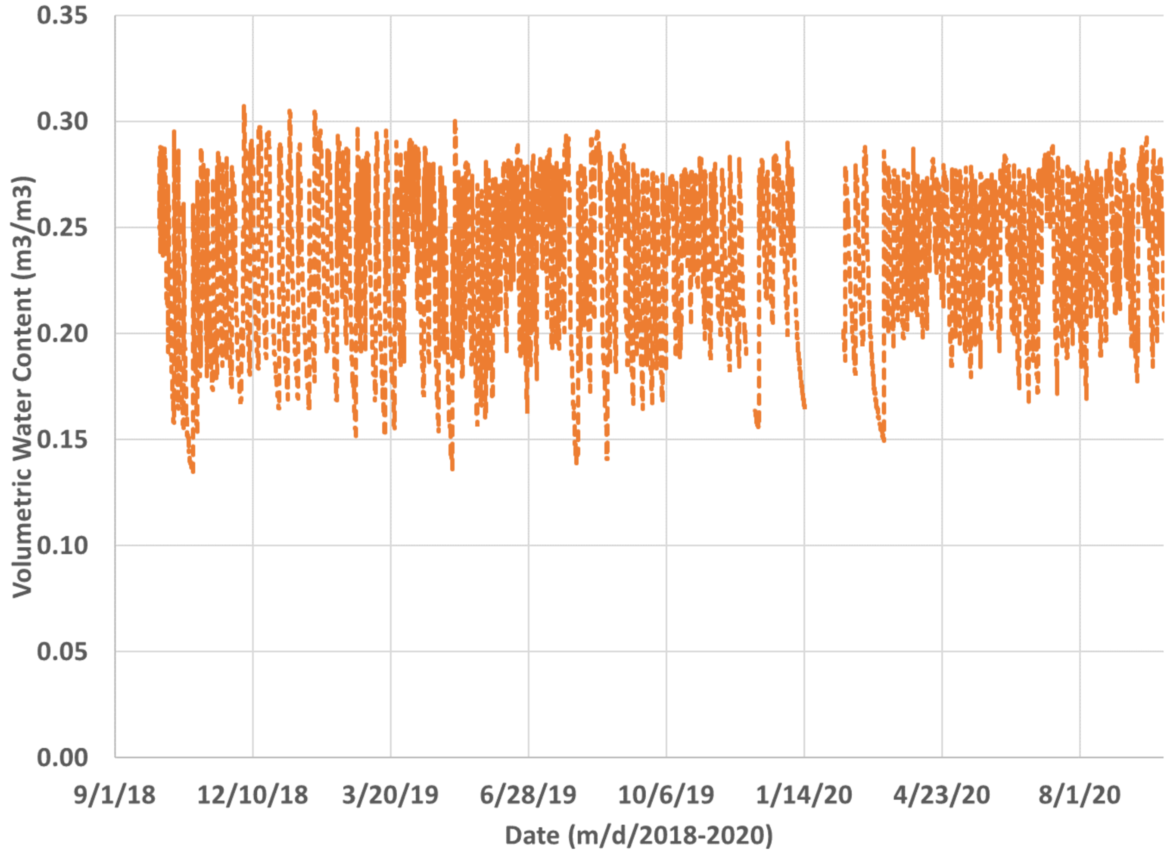

Figure A-30. Lot 65, control without topdressing

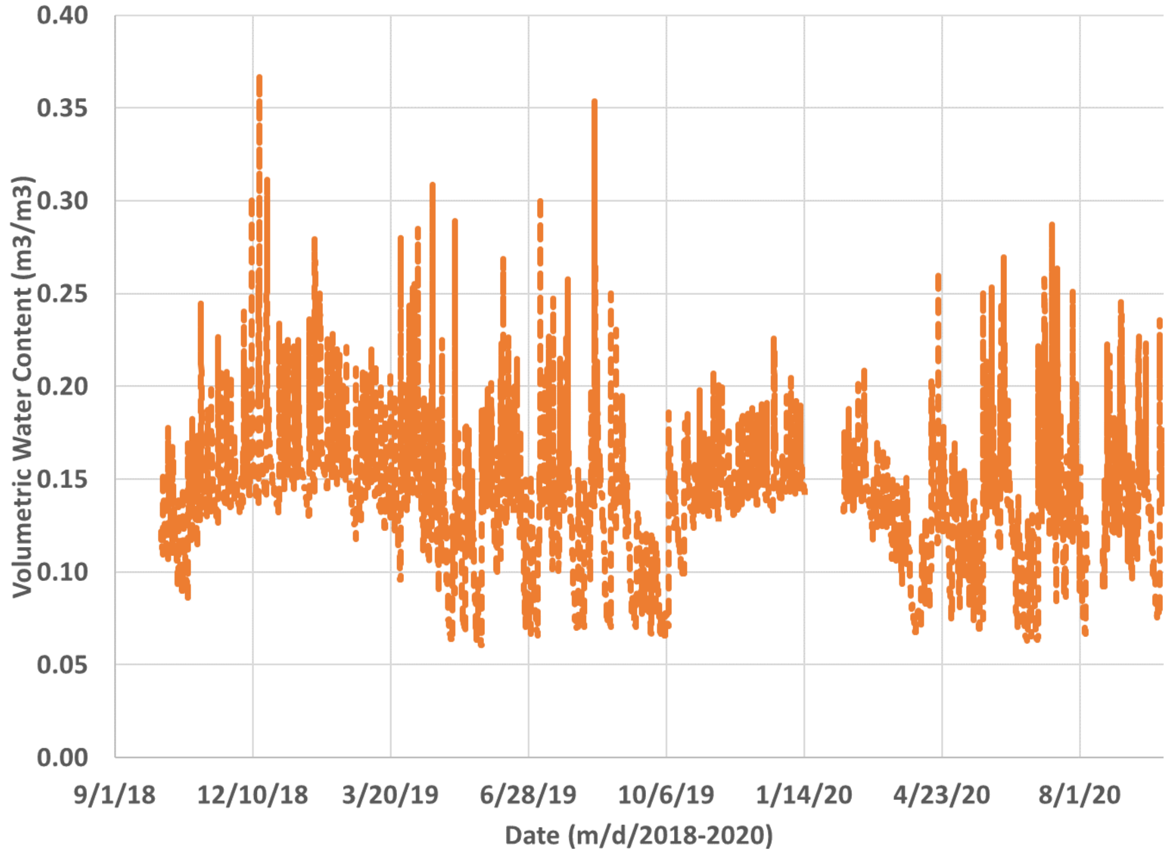

Figure A-31. Lot 67, control with topdressing

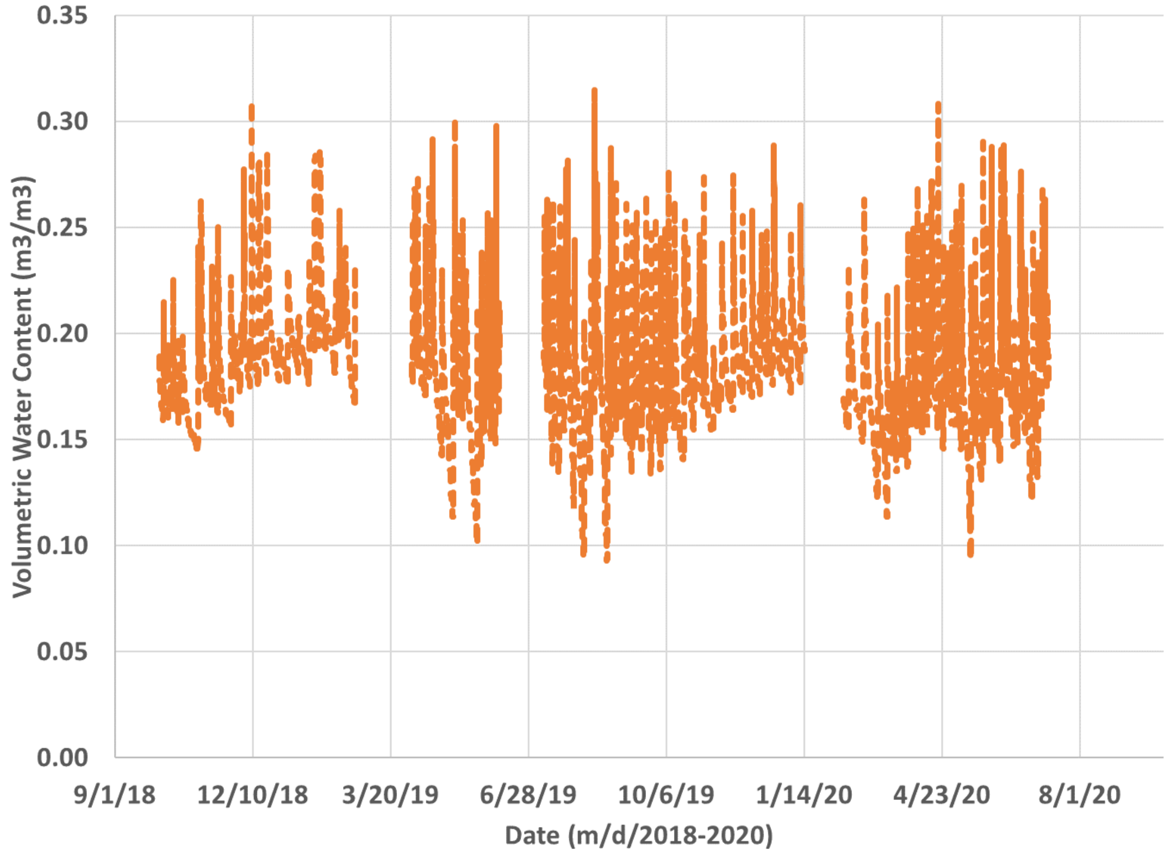

Figure A-32. Lot 69, control with topdressing

6.4 A.4 Column Leaching Results

6.4.1 A.4.1 Column Leaching Concentrations

Concentrations of NO_3-N were inexplicably high (> 15 mg N/l) in the initial leachate collected on Day 4 (Figure A-33). The elevated concentration was not due to the compost though, since the control column (0:1) also had similarly elevated concentrations. This was likely due to a source within the soil or the columns. Day 10 concentrations declined drastically for the control column, while the others increased with amendment rate, with all amendments having significantly higher concentrations than the control (Table A-1). On Day 20, concentrations declined for all amended columns and were no longer significantly higher than the control concentrations. This pattern continued into Day 30 as well.

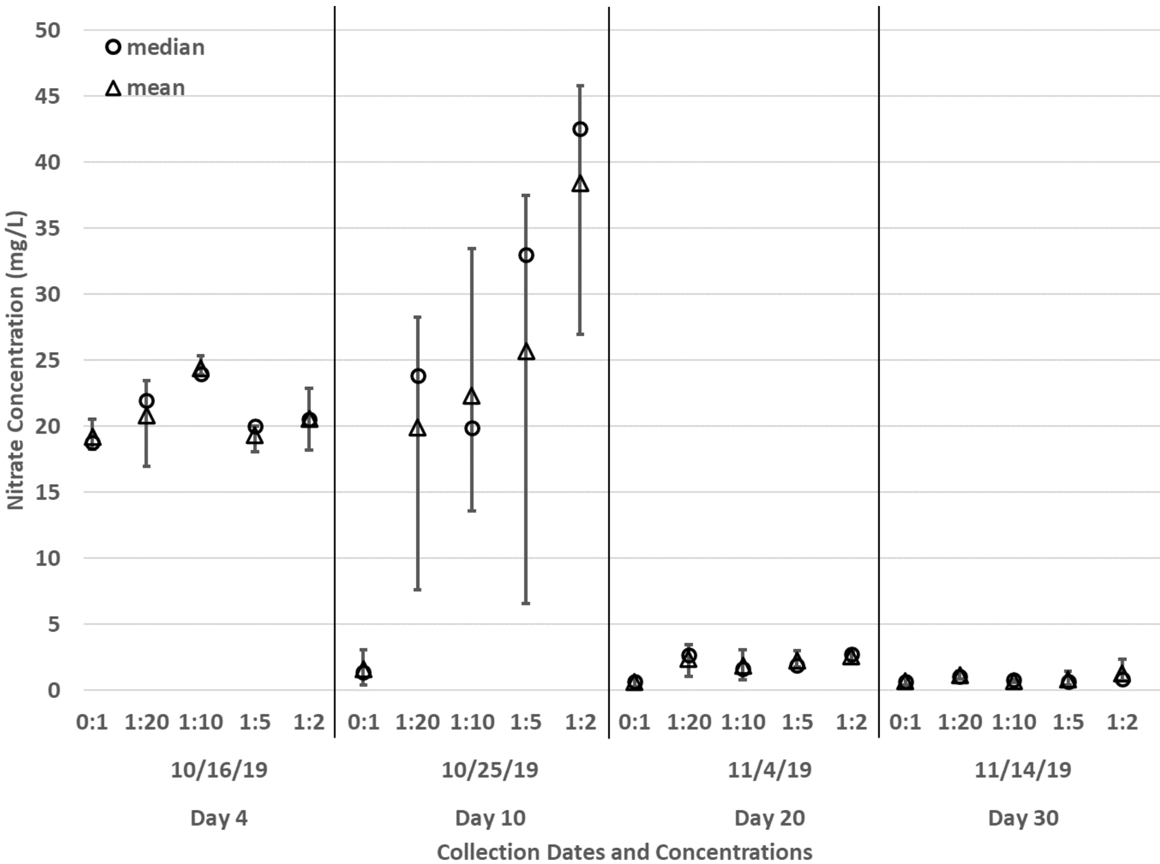

Figure A-33. NO_3-N concentrations for the 30-day column study with error bars representing maximum and minimum values, with circles denoting the median values and triangles denoting means for days four, 10, 20 and 30.

Table A-1. Nitrate concentration (mg N/L) averages from various incorporation ratios on days four, 10, 20, and 30. Significant differences by day, based on Tukey's post hoc analysis, are denoted by different letters as superscripts.

Incorporation Ratio	Days after Irrigation Began			
(Compost:Soil)	4 (first leachate)	10	20	30
1:2	20.5[a]	38.4[a]	2.6[a]	1.3[a]
1:5	19.4[a]	25.7[b]	2.2[a]	0.8[a]
1:10	24.4[a]	22.3[b]	1.8[a]	0.7[a]
1:20	20.8[a]	20.0[b]	2.4[a]	1.1[a]
0:1 (control)	19.2[a]	1.6[c]	0.6[a]	0.7[a]

NH_4-N concentrations (Figure A-34) on day four during the initial flush ranged from 1.16 – 3.06 mg N/L and the differences between treatments were not significantly different. On day 10, the elevated concentrations increased with as incorporation rate increased. The control, 1:20, and 1:10 incorporation rates were not significantly different from each other, but they were significantly less than the 1:5 rate, which was significantly less than the 1:2 incorporation ratio (Table A-2). On day 20, the largest decreases in concentrations were seen in the 1:2 and 1:5 incorporation ratios. The 1:2 incorporation ratio was significantly higher than the control (Table A-2). The ammonium concentrations for the 1:2 incorporation ratio decreased from an average of 43.33 mg N/L to 8.71 mg N/L and from 20.14 mg N/L to 5.62 mg N/L for the 1:5 incorporation ratio. For day 30, the control, 1:20, 1:10, and 1:5 incorporation ratios concentrations were all between 0.16 – 0.60 mg N/L, while the 1:2 incorporation ratio ranged from 0.55 – 3.37 mg N/L. There were no significant differences between incorporation ratios.

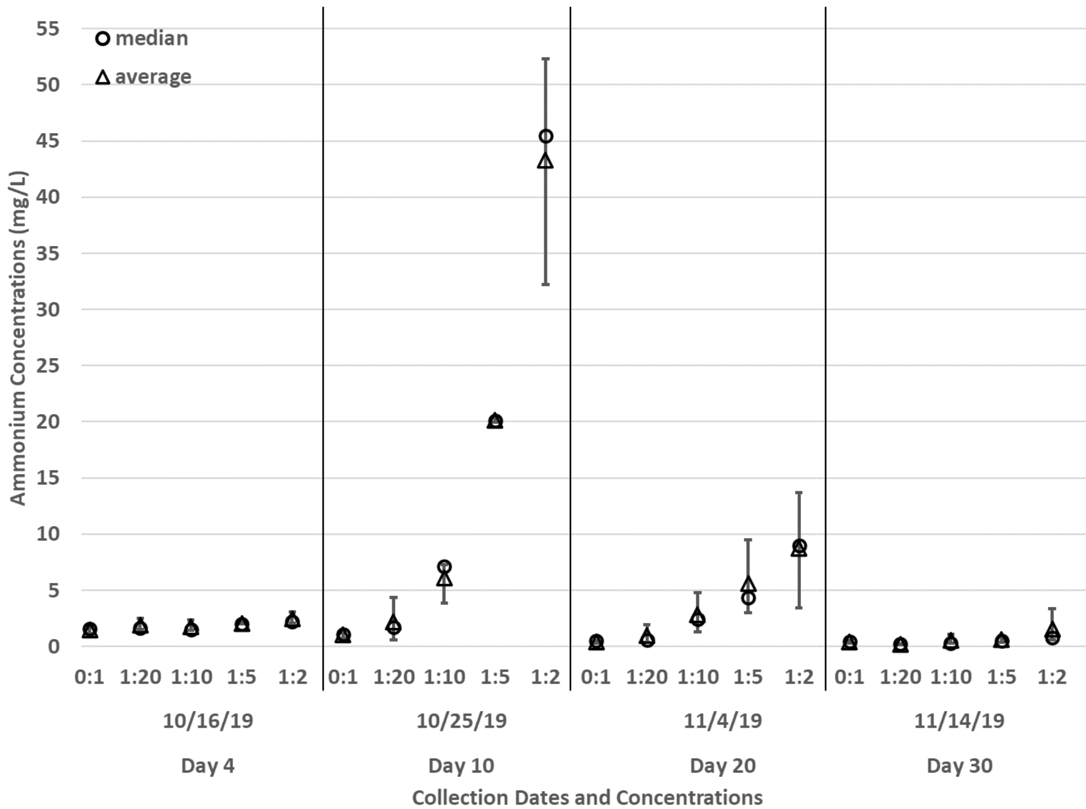

Figure A-34. NH_4-N concentrations for the 30-day column study with error bars representing maximum and minimum values, with circles denoting the median values and triangles denoting means for days four, 10, 20 and 30.

Table A-2. Average NH4-N concentrations (mg N/L) for days four, 10, 20, and 30. Significant differences by day are based on Tukey's post hoc analysis and are denoted by different letters as superscript.

Incorporation Ratio (Compost:Soil)	Days after Irrigation Began 4 (first leachate)	10	20	30
1:2	2.5[a]	43.3[a]	8.7[a]	1.6[a]
1:5	2.1[a]	20.1[b]	5.6[ab]	0.6[a]
1:10	1.8[a]	6.1[c]	2.8[ab]	0.6[a]
1:20	1.9[a]	2.2[c]	1.0[ab]	0.2[a]
0:1 (control)	1.5[a]	1.0[c]	0.4[b]	0.4[a]

Org N concentrations (Figure A-35) were low in the first flush on day 4, ranging from 0.00 mg/L to 1.57 mg/L across all incorporation ratios, resulting in no significant difference (Table A-3). On day 10, as the incorporation ratio increased, so did the concentration of Org N. The 1:2 incorporation ratio was significantly higher than the rest, and the 1:5 incorporation ratio was significantly higher than the 1:20 rate and the control, but not the 1:10 rate (Table A-3). The average concentration for the 1:2 incorporation ratio was 25.86 mg/L, whereas the 1:5 average concentrations was 9.71 mg/L, less than half of the highest incorporation ratio. The 1:10 incorporation ratio was six times less than the 1:2, with an average of 4.14 mg/L, and the averages for the 1:20 incorporation ratio and control were 1.60 mg/L and 1.08 mg/L, respectively. On day 20, the concentrations fell drastically, specifically for the 1:2 incorporation ratio. The 1:2 incorporation ratio had the highest concentration at 6.30 mg/L and the lowest, 0.00 mg/L, with one of the three replicate columns not leaching any Org N. The control columns had the second to lowest Org N concentrations, at 0.61 mg/L. For day 20, there were no significant differences between incorporation rates. On day 30, all columns had concentrations below 6 mg/L, which again resulted in no significant differences in Org N concentrations.

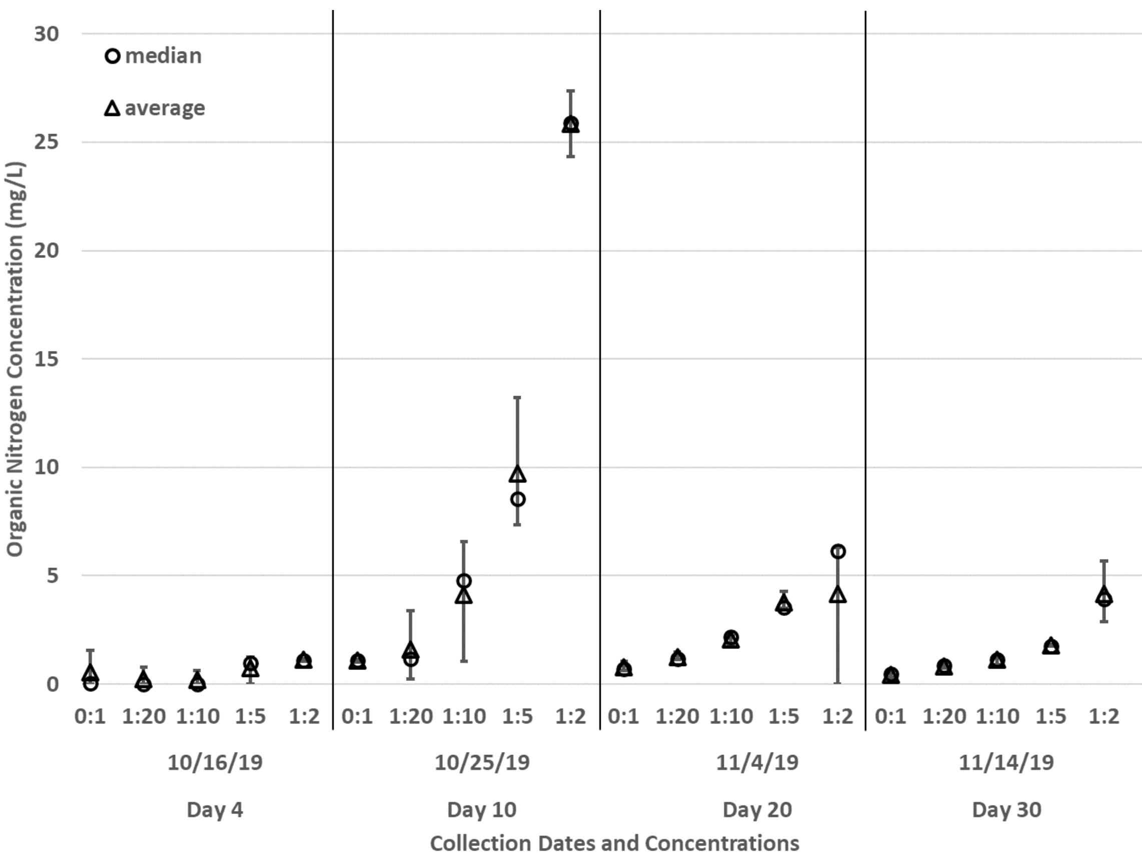

Figure A-35. Org N concentrations for the 30-day column study with error bars representing maximum and minimum values, with circles denoting the median values and triangles denoting means for days four, 10, 20 and 30.

Table A-3. Average Org N concentrations (mg/L) for days four, 10, 20, and 30. Significant differences by day are based on Tukey's post hoc analysis and are denoted by different letters as superscript.

Incorporation Ratio	Days after Irrigation Began			
(Compost:Soil)	4 (first leachate)	10	20	30
1:2	1.1[a]	25.9[a]	2.6[a]	4.2[a]
1:5	0.7[a]	9.7[b]	3.8[a]	1.8[b]

1:10	0.0[a]	4.1[bc]	2.1[a]	1.1[b]
1:20	0.0[a]	1.6[c]	1.3[a]	0.8[b]
0:1 (control)	0.3[a]	1.1[c]	0.8[a]	0.4[b]

For day 4, all of the TKN concentrations (Figure A-36) were below 5 mg/L, ranging from 0.88 mg/L to 4.16 mg/L, and thus were not significantly different (Table A-4). On day 10, the averages for the 1:2, 1:5, 1:10, 1:20, and control were 69.19 mg/L, 29.85 mg/L, 10.23 mg/L, 3.81 mg/L, and 2.09 mg/L, respectively. The 1:2 incorporation ratio was significantly higher than the 1:5 incorporation ratio, which was significantly higher than the 1:10, 1:20, and control rates. On day 20, as incorporation ratio increased, so did the concentration, with the 1:2 incorporation ratio having the highest concentration at 15.31 mg/L. On day 30, the values ranged from 1.36 mg/L in the control to 9.64 mg/L in the 1:2 incorporation ratio. The 1:2 incorporation ratio was significantly higher than the rest of the incorporation ratios (Table A-4).

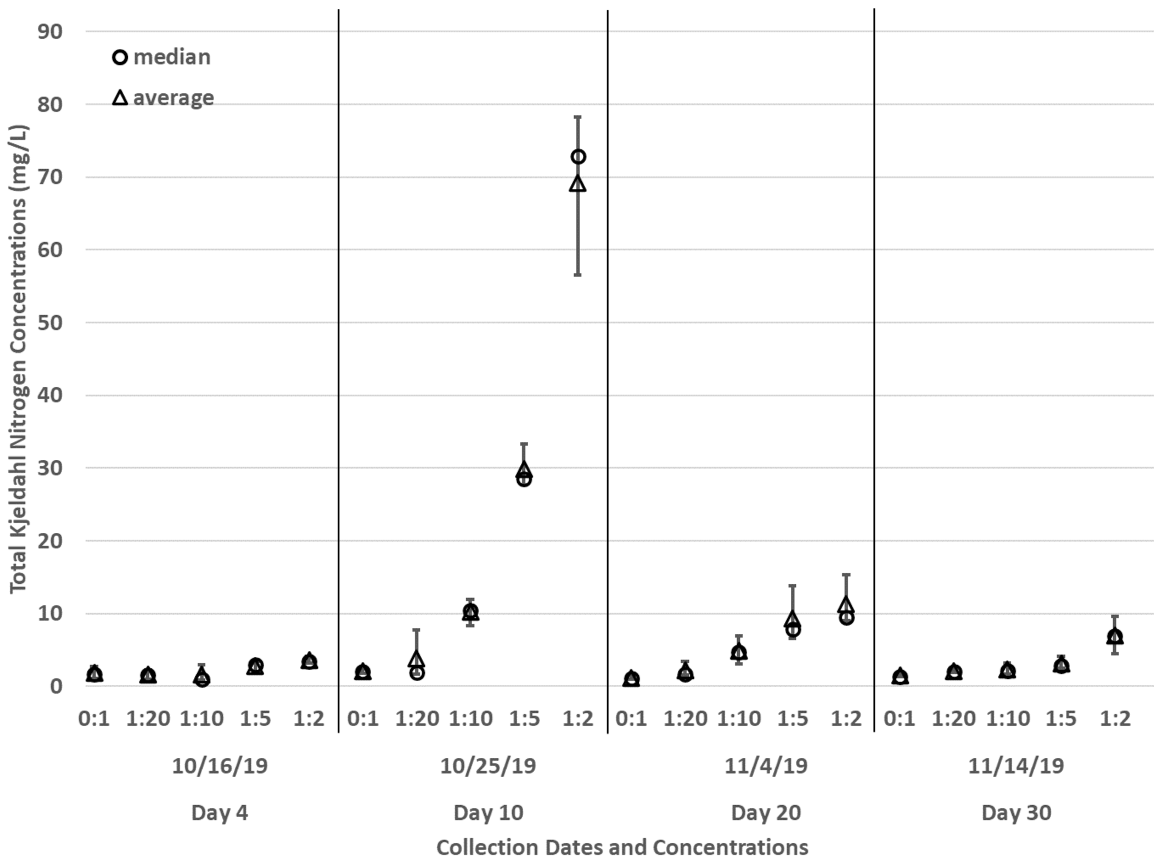

Figure A-36. 30-day column study TKN concentrations with error bars representing maximum and minimum values, with circles denoting the median values and triangles denoting means for days four, 10, 20 and 30.

Table A-4. Average TKN concentrations (mg/L) for days four, 10, 20, and 30 for each incorporation rate. Significant differences by day are based on Tukey's post hoc analysis and are denoted by different letters as superscript.

Incorporation Ratio	Days after Irrigation Began			
(Compost:Soil)	4 (first leachate)	10	20	30
1:2	3.6[a]	69.2[a]	11.3[a]	5.7[a]
1:5	2.8[a]	29.8[b]	9.4[a]	2.4[b]

1:10	1.6[a]	10.2[c]	4.9[ab]	1.7[b]
1:20	1.6[a]	3.8[c]	2.2[b]	1.0[b]
0:1 (control)	1.8[a]	2.1[c]	1.2[b]	0.8[b]

6.4.2 A.4.2 Column Leaching Loadings

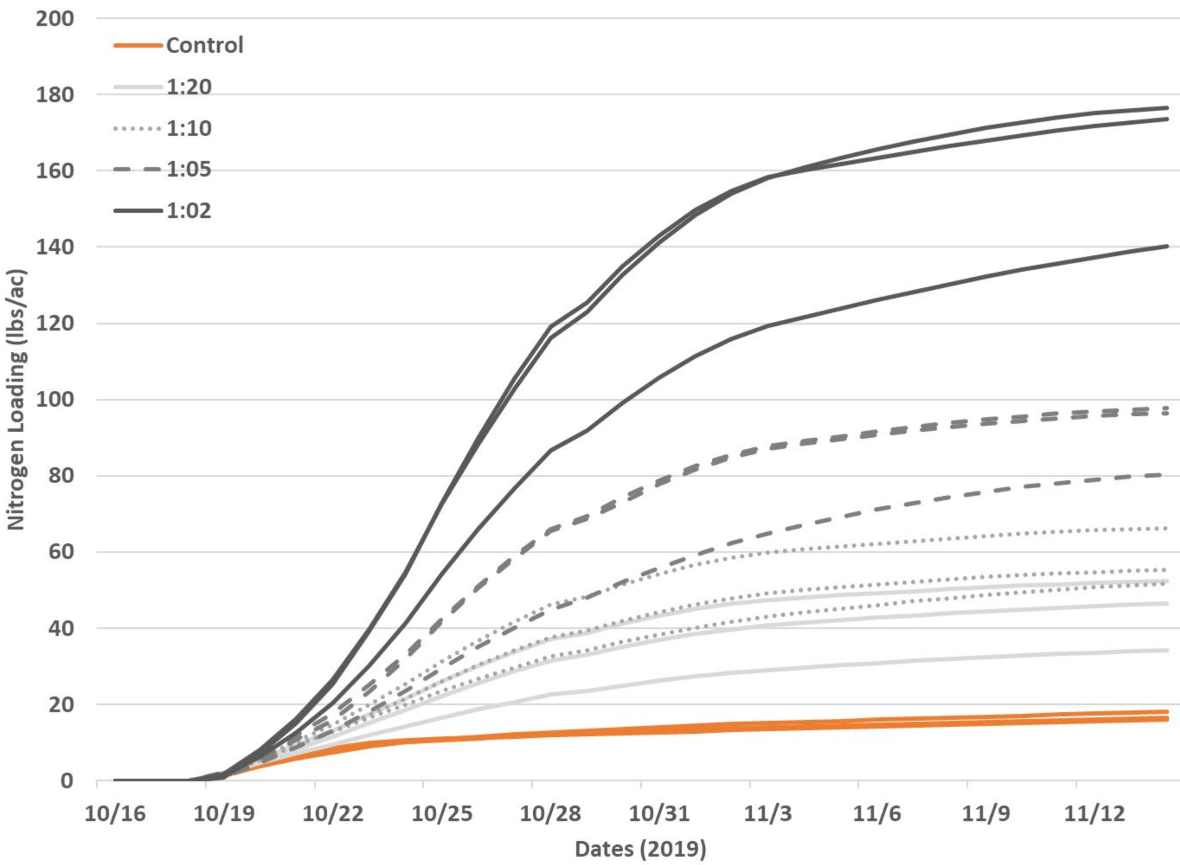

Figure A-37. Interpolated cumulative total nitrogen loading over the course of 30 days for each amendment/soil incorporation ratio.

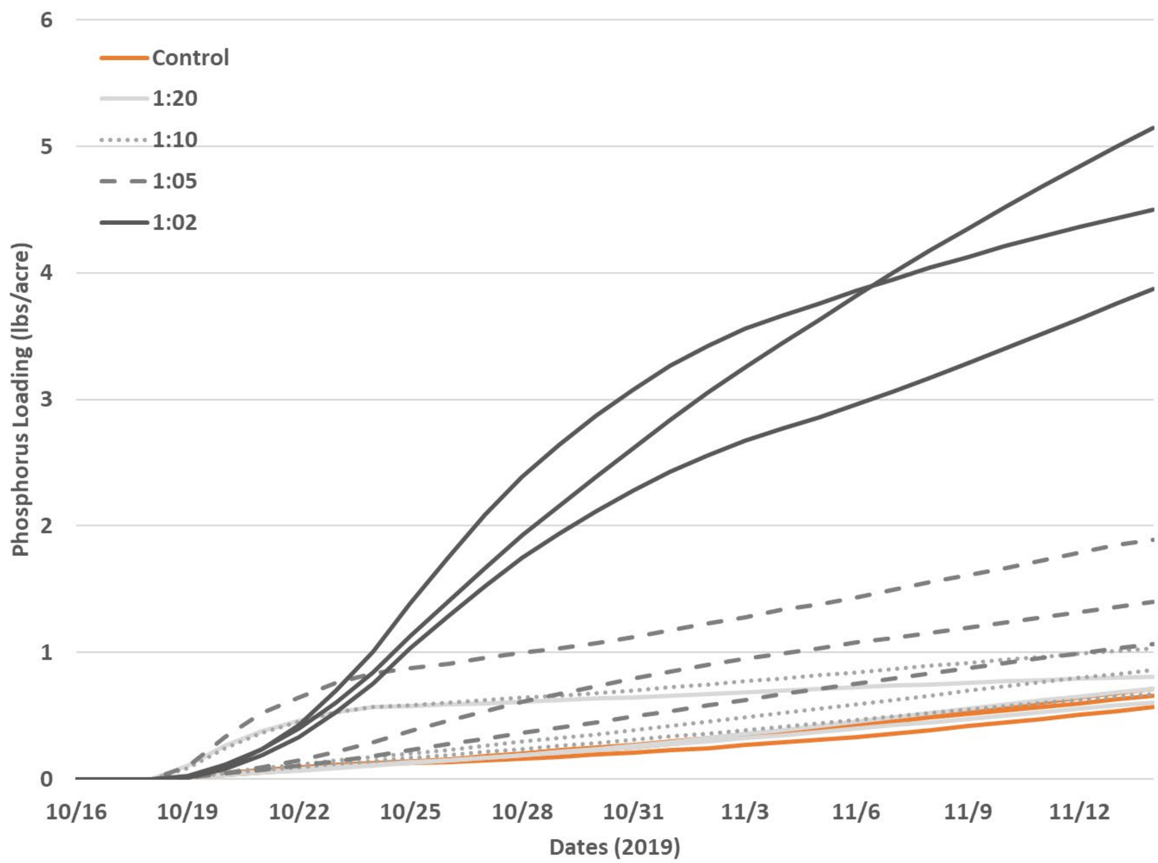

Figure A-38. Interpolated total phosphorus cumulative loading over the course of 30 days for each amendment/soil incorporation ratio.