NUTRIENT AND IRRIGATION MANAGEMENT FOR ENHANCING TURFGRASS ECO-BENEFITS

A Dissertation

by

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ABSTRACT

Turfgrass is a subgroup of grass family, which plays a significant role in modern urban landscapes. While homeowners have traditionally installed and appreciated a landscape of predominantly turfgrass; in recent years many municipalities have begun to offer rebate programs which incentivize removal of turfgrass areas and conversion to alternative 'water-efficient' landscapes, with the goal of reducing outdoor water use. Although scientists have provided evidence that turfgrasses have positive impacts on many environmental concerns, there are still gaps to fill when determining the real role of turfgrasses in future urban societies. To better understand this, a field study was conducted to evaluate the environmental impacts and runoff dynamics after urban landscape conversions. Several environmental impacts were compared among lawns and water-efficient landscapes. Challenges are also being faced by many turfgrass managers; for example, as rapid population growth continues in urban areas, water conservation has become a key priority for many municipalities. Given this problem of water shortage, lower quality water sources are being used for irrigating turfgrasses, particularly on city owned properties and parks. It is important therefore to understand the effects of irrigation chemistry on the efficiency of turfgrass N uptake. Addressing this concern, two greenhouse studies examined interactive effects of several soluble N sources and irrigation water with different salinity levels on turfgrass performance and N uptake efficiency following both foliar and root N fertilization. Wetting agents have been widely used in the turfgrass industry for ameliorating hydrophobic soil conditions and improving water use efficiency. However, limited information is available regarding the potential benefits of

wetting agents on fine textured soil lawns where wettable soils are commonly found. A field study was conducted to evaluate the potential for wetting agents to improve turf quality, as well as to reduce runoff losses of water and nutrients from St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] lawns.

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NOMENCLATURE

N	Nitrogen
P	Phosphorus
C	Carbon
TDN	Total Dissolved Nitrogen
NO_3-N	Nitrate - Nitrogen
NH_4-N	Ammonium - Nitrogen
PO_4-P	Phosphate - Phosphorus
DON	Dissolved Organic Nitrogen
DOC	Dissolved Organic Carbon
ET	Evapotranspiration
ET_o	Reference ET
ANOVA	Analysis of Variance
EC	Electrical Conductivity
SA	Saline
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SP	Sodic Potable
USSL	U.S. Salinity Laboratory
US	United States
KNO_3	Potassium Nitrate
$(NH_4)_2SO_4$	Ammonium Sulfate

NH_2CONH_2	Urea
USGA	United States Golf Association
W	Week
WA	Wetting Agent
FERT	Fertilizer
WK	Week
NS	Not Significant
TSS	Total Suspend Solids
NTEP	National Turfgrass Evaluation Program
EPA	Environmental Protection Agency

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1. INTRODUCTION

1.1. The Role of Turfgrasses in the Urban Ecosystem

According to Oxford Dictionary of English Etymology, the term of turfgrass can be traced back to 16th century, which was first introduced to English from the Sanskrit term *darbha* (means tuft of grasses) (Hoad, 1986). Unlike other grasses species, such as corn (Zea *mays* L.), the major role of turfgrasses are not to support humans and animals as a food resource (Beard and Green, 1994). Instead, they are grown in urban areas mainly for their aesthetical and recreational function, as well as environmental protection (Monteiro, 2017). In modern western countries, such as the United States (U.S.), the trend of having a turfgrass lawn as a component of the urban landscape was adopted from English pre-romantic gardening (Jackson, 1985). Turfgrasses in a traditional European style garden are generally an element of the entire garden, planted along with other ornamental plants, such as flowers and trees (Jenkins, 1994). The use of turfgrass lawns within the American landscape has changed tremendously since the Second World War, primarily through the expansion of the monoculture of lawn (Robbins and Birkenholtz, 2003). While turfgrass lawns are planted privately in a European garden, they have become more common as a focal point of front lawnfor many residential houses in the U.S. (Jenkins, 1994).

In U.S., turfgrass acreage has been estimated to be 163,800 km^2, which is three times larger than any other irrigated crop (Milesi et al., 2005). Although turfgrass has long been an important part of Americans' daily life, it has mainly been appreciated and used for its recreational benefits and aesthetic benefits. Many popular sports including, but not limited to, American football, golf, tennis, and soccer, are dependent on turfgrass, not only as a playing surface, but also as a means of reducing injury due to the cushioning effect provided (Beard and Green, 1994).

A survey revealed that the two largest reasons for homeowners having lawns in U.S are related to aesthetical benefits and the enhancement of property value (Khachatryan et al., 2014). However, given the widespread use of turfgrass in the urban landscape, it's role in urban ecosystem must be more fully understood, which is crucial in order to maintain sustainable development of urban areas. According to data provided by World Health Organization (WHO), by 2014, more than 50% of the world population resided in urban areas, up more than 16% from 1960. This trend is expected to continue at a rate of 1.63% per year between 2020 and 2025, and at 1.44% per year between 2025 and 2030 (WHO, 2020). Given the growing rate of urbanization throughout the world and concomitant increase in turfgrass use, the overall benefits of turfgrass to urban society is receiving increasing scrutiny, due to its perceived high requirements for water, fertilizer and other resources. For reference, it has been estimated that more than 50% of domestic water usage is attributed to residential turfgrass irrigation in many areas of the world, including U.S. (Mayer et al., 1999; Degen 2007; Haley et al., 2007).

Although scientists have demonstrated that turfgrasses offer many positive environmental benefits, there are still questions to consider when determining the overall role of turfgrasses to future urban society. One fundamental review and analyses of turfgrasses in environmental protection was written by Beard and Green (1994). In this review, the benefits of turfgrass were broadly presented. Some of the environmental benefits presented by Beard and Green included soil and dust erosion control, heat dissipation, noise abatement, and air pollution control. As this review was written almost

25 years ago, the environmental challenges we are facing today have grown and become more widespread throughout the world. Therefore, a re-evaluation of the ecosystem services and environmental benefits of turfgrass in the urban landscape is needed at this time, especially as they relate to other commonly used landscape designs. Information of this type will be needed to contribute to efforts towards improving environmental sustainability of urban landscapes for future generations.

1.1.1. Temperature Mitigation

Climate change has been a major focus of the scientific community in recent years, and the increased air temperatures over time is one of the parameters that has being used to demonstrate this phenomenon (Dyurgerov and Meier, 2000). And the temperature increase in urban areas has been even greater than surrounding undeveloped rural area. The higher temperature in urban areas as a result of development is described as the 'heat island effect', and directly affects communities by increasing energy demand for air conditioning as well as contributes to heat-related illness, such as heat stroke, hyperthermia (Stott et al., 2004; Kolokotroni et al., 2006; Tan et al., 2007). Studies conducted to investigate the effect of different land cover types on the urban heat island effect, and most have demonstrated the mitigation of temperature increase by urban greenspace, including turfgrasses. Urban green space reduces air temperature through different processes, and the magnitude of the impact depends on the type of vegetation, which may include a combination of grasses, trees, bushes, shrubs, etc. (Givoni, 1991; Bowler et al., 2010). For example, when solar radiation is captured by plants, only a small fraction of the radiant energy is converted to chemical energy through photosynthesis; however, this conversion rate is very low (approximately 1- 2% of total absorbed solar radiation), and this process is sometimes overlooked (Givoni, 1991). Energy dissipation within the plant can occur through multiple means, including phosphorescence, long wave radiational cooling, and evapotranspiration (Strehler and Arnold, 1951; Jursinic, 1979; McPherson et al., 1988; Akbari et al., 2001; Qiu et al., 2013; Monteiro et al., 2017). The most significant physiological process reducing canopy temperature is evapotranspiration, which releases huge amounts of excess solar energy captured by vegetation back to the atmosphere, and which results in an increase in latent heat rather than sensible heat (Grimmond and Oke, 1991). Within a landscape, the differences in morphology between trees and turfgrasses result in differential effects on air temperatures. As such, trees offer an advantage over grasses in the shading effect they provide due to their large canopies, which attenuate solar radiation prior to reaching understory areas (Upreti et al., 2017). Conversely, the large canopies and trunk regions of trees can restrict airflow and convectional cooling near the ground.to a much greater extent than turfgrasses (Givoni, 1991; Bonan, 1997).

Although numerous studies have characterized the impact of green spaces on urban temperature, few have focused on short vegetation cover, such as grasses (Bowler et al., 2010). Among those, Takebayashi and Moriyama (2012) determined surface heat budgets of various pavements and grasses and found that sensible heat flux was significantly reduced by grass surfaces due to evapotranspiration as compared to other impervious paved surfaces such as asphalt and cement. Surface temperatures measured in the aforementioned study showed that maximum difference in daytime temperature between asphalt and grass, was about 20^{o} C, and differences between these two land covers during nighttime was around 4^{o} C. As municipal water become more and more limited for natural turf, artificial turf has become popular as an alternative surface, as it mimics the look of natural turf and normally does not require irrigation. However, the benefits provided by natural turf in temperature mitigation is not achievable by having artificial turf. Jim (2016) evaluated several components of the radiant-energy environment of natural grass and artificial turf in an urban environment, and found significant surface temperature differences between natural and artificial turf, with differences partially due to the lower net solar radiation received by natural turfgrass as well as its higher albedo (0.23 vs. 0.073 for natural grass and artificial turf, respectively). Trees and grasses both serve as major components of and positively affect urban ecosystem, but the magnitude of shade effect of trees and effect of greater airflow by lawns has not been widely compared. This leaves questions for landscape designers who have to make a decision between trees and grasses when cooling is the major concern. One innovative study conducted by Wang et al. (2016) evaluated the cooling and energy saving potentials of trees and lawns in Phoenix, Arizona (a desert climate). Measuring air temperatures and the conductive heat flux, Wang et al. (2016) concluded that although both trees and lawns are effective in cooling and energy saving, shading by tress exhibited a greater cooling effect than that of an urban lawn. Furthermore, outdoor thermal comfort as affected by shading of trees and cooling of lawns was also evaluated by estimated work suspension rate. Their results showed that the work-suspended time due to thermal discomfort was reduced by increasing trees and lawns, and turfgrass played a more important role in affecting human thermal comfort, because the humidity provided by turfgrass is valuable in desert climate.

1.1.2. Carbon Sequestration

Excessive release of CO_2 by residential and industrial activities has been an issue for many urban cities, as CO_2 is one of the major greenhouse gases that affects climate change by increasing air temperature (Collins et al., 2013). Turfgrasses capture CO_2 for photosynthesis, converting CO_2 to organic carbon stored in biomass shoots and roots, thereby mitigating the greenhouse effect by reducing atmospheric CO_2 concentrations. This is one of the major eco-benefits of turfgrasses compared to non-vegetated urban area.

Other plants such as trees and shrubs are also common components of urban vegetation, so a detailed comparison between plants on their ability to sequester carbon is helpful for future urban landscape design. Unlike woody plants, such as trees and shrubs, relatively greater amounts of C are sequestered in below ground biomass of grasses. Whittinghill et al., (2014) evaluated 9 different ground level landscapes on relative carbon sequestration potential (biomass gain two years after planting), among a variety of plant species including Kentucky bluegrass lawn, broadleaf evergreen shrubs, deciduous shrubs, needle leaf evergreen shrubs, succulent rock garden, vegetable and herb garden, woody ground covers, and native prairie mix. The authors reported that although landscapes containing more woody plants had greater overall carbon content than lawns (approximately 70 kg C m^{-2} vs. 15 kg C m^{-2} for shrubs and lawns, respectively), the below ground biomass (mainly for roots and rhizomes) of lawn was significantly higher than other landscapes, with 3 kg C m^{-2} for Kentucky bluegrass lawn and less than 1 kg C m^{-1} for other landscapes. This high allocation of organic C to belowground biomass of turfgrass suggests it may offer an advantage in drier environments where above ground plant biomass is vulnerable to climate induced fire. In addition, recent modeling work ftom California compared mass of C stored in trees and grassland and showed that grasslands are more reliable carbon sinks than forest in semi-arid regions (Dass et al., 2018). In the Dass et al. (2018) study, under several modeling projection scenarios for future climate, the net C storage of grasslands for the next 20 years was positive, and the net biome productivity (NBP) of forest was lower than grasslands for 3 out of 4 simulations, with a decrease over time. Further, the NBP of forest was estimated to be negative by 2040, indicating that instead of a C sink, forests will be a C source by that time. The reason why grasslands were considered a better C sink than trees was that trees have a lower drought tolerance when monthly precipitation drops below 15 mm per month, and grasslands are more resilient to rising temperatures, drought, and fires likely to be faced in the future.

Researchers have also determined the quantity and rate of soil organic carbon input from grasses. Fisher et al. (1994) found that introduced deep-rooted grasses to South American savannas result in significant soil organic C increases with an estimated rate of sequestration of 100 to 500 Mt carbon per year. In urban areas, Qian et al. (2010) analyzed soil organic C in the top 20 cm soil profile for Kentucky bluegrass, fine fescue, and creeping bentgrass 4-years after establishment in a golf course and found all turfgrasses exhibited significant C sequestration, ranging from 0.32 to 0.78 Mg C ha^{-1} per year. In addition, irrigation was reported to impact the rates of soil organic carbon input from turfgrasses in this study, with both addition and decomposition rates of soil organic C increased under irrigation.

1.1.3. Other Eco-benefits by Turfgrasses

Besides temperature mitigation and carbon sequestration, turfgrasses also provide a wide range of eco-benefits to urban ecosystems, including noise reduction, air pollution control, and glare reduction (Beard and Green, 1994; Bolund and Hunhammar, 1999; Monteiro, 2017). These benefits however have not been as widely studied as temperature mitigation and carbon sequestration. Furthermore, limited information is available comparing effects of turfgrasses and other urban landscape types concerning these parameters.

Urbanization commonly results in greater noise pollution generated from road traffic, new construction, and industrial activities. It was found that more than 44% of people in the European Union in 2000 resided in an environment with road traffic noise levels exceeding 55 dB (Den Boer and Schroten, 2007). Many studies have studied the effects of vegetation on noise reduction. Most of these studies have focused on the noise mitigating effects of trees or shrubs rather than surface covering plants, such as grasses (Cook and Haverbeke, 1971; Kragh, 1981; Watanabe and Yamada, 1996; Fang and Ling, 2003; Lacasta et al., 2016, Baldauf, 2017). Among the limited reports in which grasses were included, one recently published article offered a comprehensive review of the the strategies used for mitigating outdoor noises including vegetation, noise barriers, vegetation belts, building envelope greening, and ground covers (Van Renterghem et al., 2015). Among all the approaches studied, the effectiveness of grasses on reducing noise was highly related to their ground effect, which is due to high porosity of grass system. Basically, a ground surface with high porosity has a low flow resistivity, which means that air can flow through the surface easily, and vice versa. Porosity and flow resistivity of several grass systems were listed in the same review written by Van Renterghem et al. (2015), with flow resistivity almost 10 times lower for lawn as compared to pasture and arable soil. In addition, the study showed that conversion of hard ground to grassreduces road traffic noise. Specifically, through replacing a 50 m strip of hard ground with high flow resistivity grass, the predicted road traffic noise is reduced by 5.3 dBA. Further, the effect of grasses on noise reduction doubled with a value of predicted road traffic noise insertion loss of 10.5 dBA, if using low flow resistivity grass. In a similar study, Ow and Ghosh (2017) investigated the reduction of road traffic noise under varying planting intensities (trees, shrubs, and lawns), confirming the effectiveness of trees in attenuating traffic noise, and highlighting the role of lawns in noise reduction with ground effects attributed to their soft and porous nature.For reference, in the Ow and Ghosh study, soil porosity is 0.75 and 0.5 for grasses and forest floors. In addition, their study highlighted that in order to maximize the effectiveness of vegetation in traffic noise reduction, trees should be paired with soft ground covers such as lawns. Horoshenkov et al. (2013) studied the acoustic properties of 5 low-growing plants, with an average height less than 15 cm, and found that the acoustic absorption coefficient was positively related to leaf area density and dominant angle of leaf orientation of a plant. Here 60% of the incident sound energy in the frequency range of 50-1600 Hz attenuated by *Winter Primula Vulgaris*, the species in the study possessing the highest leaf area density. Although grasses were not included in the study, their findings are still useful for the turf industry, considering that grasses are also low-growing plants. Extending their findings, it would seem reasonable that grass species with wide blades and high leaf area density, such as St. Augustinegrass (*Stenotaphrum secudatum*) should have a greater noise reduction than those with thin blade and low leaf area density, such as buffalograss (*Buchloe dactyloides*).

1.2. Challenges and Concerns Related to Turfgrasses Management

1.2.1. Environmental Impacts of Turfgrass Fertilization

Improving nutrient use efficiency as well as reducing environment contamination is the ultimate goal for the turfgrass manager when using fertilizer. Although around 50% to 70% of homeowners in U.S. regularly apply fertilizer to their lawns, only few of them fertilize their lawns based on a soil testing report and its recommendation (Robbins et al., 2001; Law et al., 2004). Among all fertilizers, N based fertilizers are applied the most as N is the nutrient required in greatest quantity by the plant (Turner and Hummel, 1992). Unfortunately, a survey revealed that only 30% of respondents knew the chemical analysis of their fertilizer, and around 50% did not know their lawn type (Martini and Nelson, 2015). If done improperly, fertilizing turfgrass can contribute to environmental degradation. Given the growing urban population across the United States and globally, understanding all possible ways that an improper fertilization could influence the environment has become of even greater importance.

Once N fertilizers are applied to turfgrass, they have several potential fates. Nitrogen can be absorbed by plants and microorganisms, which is the intended fate of applied N. However, applied N can also leave the soil system through multiple pathways and through various forms. Volatilization of N in ammoniacal form (NH_3) and denitrification of N (N_2O, NO, and N_2) are the major gaseous loss pathways of N (Petrovic, 1990). Nitrogen ions can also be dissolved in water, and leave the soil system with water through surface runoff, throughflow, preferential flow or leaching down the soil column away from the root zone. In order to develop best management practices for industry, it is essential that scientists have a complete understanding how fertilization timing and rate, as well as interactions with other environmental and management practices affects water and air pollution. In this way, it is important to quantify how much fertilizer-derived N leaves the turf system through the various pathways. Scientists have developed many methods to trace fertilizer applications to lawn systems, with mass balance and isotopic labeling being two of the more widely used methods in agricultural research studies (Horgan et al., 2002).

1.2.1.1. Recoveries by Plants and Soil

Amounts of fertilizer-derived N that remain in the soil or are taken up by plants vary among cropping systems (Olson and Kurtz, 1982). In the turfgrass system, the amount of N taken up by turfgrasses varies depending upon the turfgrass species, fertilizer source and rate and grass use patterns. In a review examining the fate of nitrogenous fertilizers applied to turfgrass, Turner and Hummel (1992) compiled fertilizer uptake rates by turfgrass from several different turfgrass systems, presenting the grass species, use, fertilization, soil texture, and uptake components for each study. In their reported findings, the authors showed that fertilizer N recovery in turfgrass ranged from 5 to 74% (Petrovic, 1990). This same paper reported that fertilizer-derived N in the soil and turfgrass thatch was found to represent 15 to 21% and 21 to 26% of applied N, respectively. In comparison, a greenhouse study by Bowman et al. (2002) found that N recovery by turfgrass ranged from 63% of applied N for zoysiagrass to 84% of applied N for hybrid bermudagrass.

For turfgrass systems, application rates highly affect observed recovery rates of applied N by plants and soil, with low recovery rates occurring with high N application rates (Turner and Hummel, 1992). A study evaluating 15-N labeled nitrogen uptake by perennial ryegrass (Barraclough et al, 1985) found that 99% of applied N was taken up by ryegrass when measured a year after fertilization when nitrogen was added at 240 kg N ha^{-1}. However, the annual recovery rate reduced to 76 and 50% of applied N when fertilization rates were higher (500 and 900 kg N ha^{-1}) (Barraclough et al, 1985).

1.2.1.2. Leaching

Several factors can affect leaching, such as soil properties, soil conditions, fertilizer types, turfgrass types, irrigation regime, and fertilizer rate (Barton and Colmer, 2006). In most soils, nitrate has less potential for volatilization than ammonium, but has a higher potential of leaching. Numerous studies have quantified the amount of applied N leaving soil through leaching. Barraclough et al (1983) found that nitrate leaching was positively related to the rate of fertilization, showing that the cumulative nitrate leaching in a grassland over 3 years was equivalent to 1.5%, 5.4%, and 16.7% of the fertilizer applied at 250, 500 and 900 kg N ha^{-1} rate, respectively. Barton and Colmer combined data from other studies that measured N leaching from turfgrass systems and concluded that up to 30% of the fertilizer N was lost through leaching annually, which amounted to total N loss ranged from 0 to 160 kg H ha^{-1} (Barton and Colmer, 2006). A greenhouse study that compared six warm-season turfgrass for leaching and N use efficiency found that 48% to 100% of nitrate and 4 to 16% of ammonium applied were lost after first N application when ammonium nitrate was applied at 50 kg N ha^{-1} (Bowman et al., 2002). In the same study, nitrate leaching loss from subsequent applications was significantly reduced and ammonium leaching loss was essentially eliminated due to a more mature turfgrass with better established root system. In comparison, Zhu et al. (2000) found that 1.8% and 3.4 % of applied N in wheat and rice growth period were lost through leaching. In a wheat/maize rotation system, researchers found that leaching loss was 4 to 19% of the N derived from fertilizer, increasing with an increase in N application rate (Sun et al., 1993).

1.2.1.3. Runoff

Fertilizer N loss through runoff is generally low relative to other pathways for N loss from the turfgrass-soil system. Typically, less than 10% of applied N leaves soil through surface runoff for most cropping systems. A study using simulated rainfall to determine the fate of fertilizer in runoff from a fallow soil showed that losses of nitrate and ammonium with runoff water were 0.8% and 5.3% of the applied N, respectively (Baker and Laflen, 1982). White et al (1967) broadcast granular NH_4NO_3 on fallow and sod plots at a rate of 224 kg N ha^{-1}. After applying 130 mm of simulated rainfall, the authors found that the applied N in surface runoff from those plots ranged from 0.15 to 2.3%. A similar simulated rainfall study conducted on a Tifton loamy sand plots revealed that the amount of NO_3-N in runoff after a simulated irrigation of 250 mm was 1.4% of the applied total N (Gascho et al., 1998).

Another study measured total P and N in runoff following fertilizer application to simulated golf course fairways of 'Tifway' bermudagrass and found total nitrate N lost through runoff after 7 days of fertilization to be 1.5 and 0.9% of that applied for 12 and 24 kg N ha^{-1}application rates, respectively (Shuman, 2002). Ammonium and nitrate in runoff were 1.8 to 4.1% and 2.1 to 5.8% of applied, respectively, from urea or sulfur-coated urea applied at 49 kg N ha^{-1} (Cole et al., 1997).

1.2.1.4. Volatilization and Denitrification

N leaving soil through denitrification is normally less common than through volatilization. However, since N_2O is a major greenhouse gases, even small emissions of N_2O into atmosphere could substantially influence global biogeochemistry. Volatilization and denitrification losses are positively related to soil moisture, and numerous studies has been conducted globally to monitor the amount of fertilizer N leaving soil through both pathways for different cropping systems (Cai et al., 2002; Datta, 1981; Frency et al., 1990).

It has been estimated that numerous factors influence atmospheric loss of fertilizer nitrogen in turfgrass system, and among all of these, nitrogen source is one of the most important. Ammonium volatilization can occur rapidly following an N fertilization. It has been found that when urea and sulfur coated urea (SCU) were applied at the same rate of 293 kg N ha^{-1}, 10% of the applied urea volatilized as NH_3 within 21 days after a fertilization, while only 1 to 2% of SCU was volatilized as NH_3 (Torello et al, 1983). Bowman et al 1987 investigated the effects of irrigation on NH_3 volatilization from Kentucky bluegrass and found that after application of urea at a rate of 49 kg N ha^{-1}, a maximum of 36% of N volatilized as NH_3 when no irrigation was added, while 1 and 4 cm of irrigationwithin 5 min after application reduced NH_3 volatilization losses to 8 and 1%, respectively.

Denitrification has also been shown to be highly correlated with soil moisture content in turfgrass systems. A study measuring denitrification rates following KNO_3 application to Kentucky bluegrass showed that when soil moisture content was at 75% of saturation, less than 1% of the applied N was denitrified, but when soil was fully saturated, denitrification became significant (Mancino et al, 1988). Horgan et al. (2002) directly measured denitrification using ^{15}N-labeled fertilizer for a cool-season turfgrass system, and found that N_2 and N_2O fluxes occurred only after heavy rainfall events, with labeled N losses ranged from 2.1 to 7.3 % for N_2 and from 0.4 to 3.9% for N_2O, relative to that applied. Bremer (2006) reported that 2% of annually applied N was lost to the atmosphere as N_2O when turfgrass fertilized with urea at a rate of 50 kg N ha^{-1}per year.

Based on all available data, it seems that the fate of fertilizer N depends on numerous factors and also varies between cropping systems. Thus, in order to reduce impacts of fertilizer N on global pollution and increase fertilizer use efficiency, specific nutrient management is required for each system, according to the system characteristics such as climate, land use, soil properties, etc.

1.2.2. Water Salinity

High salinity levels of irrigation waters have been an issue for many agricultural systems, including turfgrasses (Arzani,2008; Pitman and Läuchli, 2002; Friell et al., 2013). The major detrimental effects on plants occurring from salinity stress are ionic stress and osmotic stress. In the short-term, plant water availability is reduced through osmotic stress, while plants may experience ion toxicity under -onger term of ionic stress (Acosta-Motos et al., 2017; Munns, 2005). In addition, a high NaCl concentration can contribute to increased formation of reactive oxygen species, and this can disturb redox homeostasis, by enhancing oxidative processes such as membrane lipid peroxidation, protein oxidation, enzyme inhibition, and DNA and RNA damage (Asada, 2000).

Turfgrass managers, especially those who are managing golf course or sports fields in coastal area or in desert climatess must deal with low quality irrigation water such as reclaimed water or recycled water due to unavailability of high-quality water (Huck et al., 2000). One key feature of low-quality water ishigh salinity content. Plants are normally able to tolerate irrigation water salinity up to certain levels, and tolerances vary between plant species (Lee et al., 2004; Arzani, 2008; Uddin et al., 2011; Friell et al., 2012; Friell et al., 2013). For turfgrasses, it has been found that some turfgrass species such as bermudagrass can tolerant salinity up to greater than 10 dS m^{-1}. Salt tolerance of different turfgrass species has been investigated and is often characterized based on the percentage reduction of shoot and root growth, and effects on turf quality at different salinity levels (Marcum; 2006; Marcum and Pessarakli, 2006; Uddin et al., 2012; Chavarria et al., 2019)

Whenever plants face environmental stress including salt stress, there are two primary mechanisms by which plants to respond to stress, adaptation or acclimation or adaptation. Adaptation is characterized by species that have persisted in a saline environment over a long period of time, and have evolved pathways for coping with salinity (i.e. halophytes) (Flowers, 2004; Rozema and Flowers, 2008). Halophytes are able tosurvive under extremely high salt levels without any changes in morphological or physiological traits. In comparison, glycophytes normally prefer a non-saline environment, butare able to acclimate when salinity levels of soil are increase in a short period of time, through adjustments or changes in physiological or morphological traits (Hasegawa, 2013).

Typically, there are several strategies employed by plants for enhancing survival under increased salinity levels, including salt exclusion (preventing salt from entering vascular system), elimination (pumping excessive salt out of plant), succulence (maintaining water potential as needed to increase water uptake as salinity increases), and redistribution (transfer the extra salt throughout the plant) (Acosta-Motos et al., 2017). One advantage of halophytic plants under saline conditions is that they can execute almost all the strategies mentioned above depending on different circumstances. In comparison, salt exclusion has always been believed the primary defensive mechanism for glycophytes (Sykes, 1992; Läuchli et al., 2008; Assaha et al., 2017). However, the differences in response to increasing salinity between halophytic and glycophyte plants are not restricted to these differences. Studies comparing glycophyte and halophyte responses to salt stress showed contrasting responses of photosynthesis to salt stress in Arabidopsis (glycophytes) and Thellungiella (halophyte) (Stepien and Johnson, 2008). During the study period, both species were treated with different levels of NaCl. After 2-weeks of treatment, Arabidopsis was unable to survive exposure to greater than 150mM salt, while Thellugiella could tolerate salt stress as high as 500mM. In addition, there was an inhibition of electron transport through photosystem II, an increased in cyclic electron flow involving only PSI, and increased nonphotochemical quenching of chlorophyll fluorescence for Arabidopsis after treated with NaCl, none of which was found inThellyngiella. This is because that Thellungiella was shown to induce an alternative pathway for electron transport that may protect the leaf under salt stress. For turfgrasses, studies have been conducted to investigate the mechanism of salt tolerance of turfgrass species, and it has been found that the major mechanism involved with salt tolerance for most turfgrass species is related to salt exclusion. Some turfgrass species including eashore paspalum and zoysiagrassare able to tolerate salinity up to 30 dS m^{-1} , which is thought to be related to a combination of salt exclusion, salt secretion, and ability to maintain high K^+ / Na^+ ratio, (Marcum and Murdoch, 1994; Marcum et al., 1998; Huang et al., 2014; Chavarria et al., 2019).

1.3. Urban Runoff to Surface Waters

It has been documented that more than 75% of the population of United States is living in urban areas, including large cities, and more than 60% of the world population is expected to live in urban areas by 2030 (Paul & Meyer, 2001). As the population rapidly urbanizes, urban ecosystems are becoming highly affected by human activities, including alterations on flow routes and the hydrological cycle.

There are three major elements of urban water systems, including water supply, wastewater, and storm water (Walsh et al., 2012). Normally, since imported water supply and exported wastewater management are more directly relevant to water balance of modern urbanized area and people's daily lives, they receive greater attention and regulation. However, water flows through runoff are an important aspect of the hydrological system of urban areas, and to which storm water and redundant irrigation water contribute. Therefore, urban runoff is an important aspect of the hydrological cycle that should receive increasing attention moving forward.

1.3.1. Effect of Land Cover on Runoff Volume

It has been shown that different landscapes have different influences on runoff, which is mainly due toh t eir different soil infiltration coefficients (Holman-Dodds et al., 2003; Olivera & DeFee, 2007; Woltemade, 2010; Sjöman and Gill, 2014). In general, the soil surface of more developed areas such as paved roads and roofs is less permeable than undeveloped areas, , and therefore more water (either from storm water or irrigation water) is transferred as surface runoff, instead of penetrating into the soil, or being taken up by plants (Arnold & Gibbons, 1996).

The effect of landscape conversion on surface runoff has been long documented, with more frequent and greater hydrological issues such as stream channel erosion and flooding occurring in recent years (Holman-Dodds et al., 2003). One study conducted to document the annual runoff depth in Harris County, Texas from late 1950s to 2000s showed that rapid urbanization accompanied by changing of the native landscape to impervious area significantly increased annual runoff depth (Olivera & DeFee, 2007). In this study, the 1970s were considered by the researchers as the beginning of the fastest modern urbanization of this area. They found that before 1973, the annul runoff depth was ranged from 50mm to 600mm with an average of 340mm. However, the annul runoff depth increased to a range of 340mm to 1030 mm between the latter half of the study period (1970's to 2000's). It has also been found that urbanization has increased the annual runoff depth by 77% during the latest 30 years, with extensive landscape conversion responsible for 32% of peak flow increase observed since the 1970's (Olivera & DeFee, 2007).

Researchers have also evaluated the effects of infiltration capacity of soil on runoff rate. From a study conducted with three landscapes including fully pervious (predevelopment), 50% pervious (high impact), and relatively pervious (low impact) soil surface, researchers found that the runoff as a fraction of precipitation was lower on high infiltration capacity soils, and the runoff as a fraction of precipitation was higher on low infiltration capacity soils (Holman-Dodds et al., 2003). In addition, for high infiltration soils, when precipitation was not intense, the runoff fraction did not increase as precipitation increased. However, for low capacity soils, the runoff fraction increased tremendously as precipitation rate was increased. Similar results were also demonstrated by Sjöman and Gill (2014) They found that both population density level and soil type played an important role on surface runoff. As such, more surface runoff was generated in an area where soil was high in clay and silt compared toan area in which soil was specified as sandy loam at the same density level. However, the amount of surface runoff generated from sandy-soil area at high density residential level was close to that generated from a clay-soil area at low density residential level. Soil infiltration could be different under different conditions, even where the landscape is same. Woltemade (2010) determined the impact of residential soil disturbance on soil infiltration rate and storm water runoff and found there is a great difference in soil infiltration rate between residential lawns and agricultural areas. As such, residential lawns had a measured infiltration rate of 2.8 cm/hour, whereas agricultural areas had measured rates of 10.2 cm/hour, which contributed to greater amounts of storm water runoff. Another interesting result of this work was that soil infiltration rate for more recently constructed residential lawns was significantly lower than for older constructed sites, which was attributed to compaction created by heavy construction equipment.

1.3.2. Effect of Landcover on Water Quality of Urban Surface Water

Water losses through surface runoff are often accompanied by nutrient losses, including nitrogen, potassium, and phosphorus losses. Urban storm water runoff has been considered the fourth most extensive factor influencing river quality, and third most extensive factor of influencing lake quality by the U.S. Environmental Protection Agency (EPA) (Novotny and Olem, 1994). Urban activities have been recognized which increase at least one order of magnitude pollutant loads over natural catchment conditions (Tsihrintzis and Hamid, 1998). Numerous studies have been conducted to assess the runoff quality in different watersheds or urban ecosystems across the world. Nitrogen losses through urban runoff has been measured the most, and phosphorus is normally the limiting nutrient in fresh water (Taylor et al., 2005). Typically, nitrogen within urban runoff is divided into dissolved inorganic nitrogen and organic nitrogen. Dissolved inorganic nitrogen includes nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_4^+). Organic nitrogen can be dissolved or particulate, but less data is available for dissolved organic nitrogen because of difficulty in directly measuring of dissolved organic nitrogen. However, dissolved organic N is considered to be a significant component of total dissolved N in urban landscape runoff (Wherley et al. 2015).

Studies have been established to assess the non-point pollution from urban surface runoff for different land uses. Other studies focus primarily on the effect of different management practices on nutrient losses through runoff. Table 1.1 summarizes the major results of those studies, including the runoff concentration of suspended solids (SS), total organic carbon (TOC), total P, total N, nitrate (NO_3), and ammonium (NH_4). As table 1.1 shows, runoff concentrations of different chemicals vary between studies. This variation in water quality is understandable, given the differences in design, climate, soils, and watershed characterizes. However, some useful information can still be derived. For example, some previous studies evaluated the role of land use in urban surface water quality by representing water quality for base flow, storm flow, or both, when available.

Suspended solids (SS) have limited direct influence on drinking water quality, and thus, these were not included on the EPA national drinking water regulations. However, SS can serve as carriers of toxic compounds, such as pesticide, and river, stream, and irrigation systems can be clogged if SS content is too high in the surface runoff water (Bilotta and Brazier, 2008). Several studies havemeasured the total suspended solids (TSS) in stormflow, and investigated the effects of land cover on suspended solids in storm water (Deletic and Maksimovic, 1998; Lee and Bang, 2000; Goonetlleke et al., 2005; Petrovic and Easton, 2005; Mallin et al., 2009). Overall, TSS detected in those studies range from 8 to 673 mg L^{-1}, with higher concentrations associated with more developed areas such as urban residential areas. Goonetilleke et al., (2005) measured the quality of stormwater runoff associated with urbanization through land use modifications in the southeast region of Queensland State, Australia. 6 study sites were included in their study, with variations in size of impervious areas and pervious area. The authors found that forest (98% pervious area) and rural residential area (91% pervious area) had the lowest SS concentration. In comparison, urban area (45% pervious area) and two of three housing areas (30% and 53% pervious area, respectively) had the highest TSS concentration. Similar results were found in another study conducted across several watershed in the cities of Taejon and Chonju, Korea (Lee and Bang, 2000). The results of this study showed that one undeveloped area within those watersheds received the lowest TSS in both stormflow and baseflow, while the highest TSS were measured for areas with high density residence and commercial activity for stormflow and low density residence for baseflow, respectively.

The concept of ‘first flush’ has also believed important for TSS by numerous researchers, in which the initial portion of the runoff always carries more TSS than the remainder due to the washout of deposited pollutants by rainfall (Deletic, 1998; Hathaway et al., 2012). However, some studies have shown that first flush phenomenon is not always present. Deletic and Maksimovic evaluated water quality factors in storm runoff from paved areas and found the first flush effect of TSS only for a limited number of runoff events (Deletic and Maksimovic, 1998). As a result, since variation in this phenomenon still exists, more studies are needed to better understand and validate this concept.

Based on table 1.1, almost all studies measured at least one type of N concentration, and these highlight the importance of N on urban water quality. Like TSS, N concentration is also correlated with landscape cover uses. More specifically, as comparing to TSS, N concentration is highly correlated with size of fertilized area, and turfgrass often appears to plays an important role due to the high requirements for N inputs. For example, for measured total N concentrations in runoff, it has been shown that areas with greater size of turfgrass systems, such as golf courses, often have higher total N concentration in runoff (Petrovic and Easton, 2005; Bachman et al., 2016). In addition, nitrate contributes to a large portion of total N concentration, which is because ammonium is prone to volatilization, and is rapidly converted to nitrate by soil microorganisms following fertilization.

Managed turfgrass- systems receive nitrate or ammonium-based fertilization regularly throughout the growing season. When fertilization is misapplied (i.e., wrong rates or timing), fertilizer N has the potential to be carried by stormwater and eventually accumulated in nearby streams. This was confirmed by Bachman et al. (2016) who separated one urban watershed into 5 treatments, including turf, native meadow, two forests, mixed with parking lot, and mixed with golf course, and found that mixed golf course had the highest Total N (3.16 vs. 2.61 mg $L^{-1}$for baseflow and stormflow, respectively) and nitrate concentration (2.29 vs. 1.98 mg L^{-1} for baseflow and stormflow, respectively). Furthermore, no differences were found for ammonium between treatments, with a range of 0.02-0.06 mg L^{-1} for stormflow and 0.03-0.13 mg L^{-1} for baseflow, respectively. Two studies further investigated the effect of highly managed turfgrass on runoff N, and found that N fertilization increased N losses through runoff of nitrate (King et al., 2001; Easton and Petrovic, 2004). Ammonium concentrations in runoff measured from King et al. (2001) were within the same range as measured by Bachman et al. (2016).

For most turfgrass systems, less P is typically applied through fertilizer compared to N. On the other hand, phosphorus can be tightly fixed by soil particles and lost with sediment. Thus, comparing to N concentration in surface water, less variation is generally found for total phosphorus concentration between measurements within different urban ecosystems, with measured total P concentrations less than 1 mg L^{-1} for most studies (Goonetilleke et al., 2005; King et al., 2001; Mallin et al., 2009; Janke et al., 2014; Petrovic and Easton, 2005). The only outliers were measured by Lee and Bang (Lee and Bang, 2000). In their study, the total P concentration in both stormflow and baseflow were always higher than 3 mg L^{-1}, and it was irrelevant to residential density and urbanization level.

Like SS, dissolved organic carbon (DOC) in urban water does not pose health risk, but organic carbon in water can cause aesthetic problems such as unpleasant taste and color (Van Leeuwen et al., 2003; Dietrich 2006). DOC is normally greater in surface water than in ground waters, because the majority of DOC is derived from soil organic carbon pools that are supplemented by natural organic matter (OM) contents from roots, stems, and leaves of plants that are majorly growing on the top soils (Chang and Carlson, 2005; Chen et al., 2010; Steele et al., 2010). The DOC level in surface water is also highly related to plant diversity and density (Maie et al., 2005; Lamb et al., 2011; Villa et al., 2014). On the basis of this knowledge, an elevated organic C concentration in runoff could be detected for areas with greater amounts of plant cover. For example, most turfgrass-covered areas in urban environments are often intensively managed and clippings are commonly returned to the soil after moving. In this way, organic C stored in the clippings can be dissolved in waterfrom either rainfall or irrigation, and then be flushed out of the soil by any moving surface water. Studies have been conducted to investigate the effect of landscape on DOC in surface water. Goonetilleke et al. (2005) found that TOC concentration level in stromwater were significantly higher for three areas of the study site with highest plant cover (Bonogin Valley (forest catchment), Hardy (rural residential catchment), and Highland Park (urban area catchment)) compared to other subcatchments in which forest and grassland coverage were less than 50%. Similarly, others have found that TOC concentration in rural creeks which have higher percentage of agriculture or forestry coverage were approximately double those of the urban and suburban creeks (Mallin et al., 2009). With regards to effects of turfgrass systems on TOC concentration, Bachman and others found that TOC in stormflow increased the most for turfgrass dominated areas when comparing to forest, mixed-parking lot, and meadow (Bachman et al., 2016). This phenomenon is consistent with another study that measured the dissolved organic carbon and nitrogen in urban and rural watersheds of south-central Texas (Aitkenhead-Peterson et al., 2009). The authors of this study believed that the warm-season C_4 turfgrasses which dominated their urban watersheds played a major role in enhancing DOC concentrations in surface water.

1.4. Use of Wetting Agents to Improve Turfgrass Water Conservation

As greater challenges are being faced in management of turfgrass systems, not only from a functional standpoint, but also considering the potential environmental impacts from cultural management, new technologies have been developed to address future challenges. Of primary importance is maximizing the water use efficiency of turfgrasses. As mentioned previously, excessive water inputs in turfgrass systems contributes to nutrient losses through surface runoff. However, in many cases, water shortages have been a major problem for many regions of the world, because municipal water has become limited due to increased population growth rate in urban areas. Water shortages are especially large concerns for golf course superintendents, as irrigating turfgrass acreage is always not the highest priority for many municipalities compared to sustaining human welfare. In addition, in order to provide high quality turf in terms of aesthetic and playability, sand-based soil systems have been used for many high-end golf courses, which are prone to a greater extent of drought and hydrophobic conditions. A symptom of plant drought due to unevenly distributed irrigation water across the field, Localized dry spot (LDS), has been widely reported for sand-based golf green, fairways and tees (Tucker et al., 1990; Dekker et al., 2003; Baldwin et al., 2006).

One commonly used product by golf course superintendents designed to address LDS is wetting agents, sometimes also referred to surfactants. Before discussing wetting agents, the nature of water molecule needs to be discussed. One water molecule consists of two hydrogen atoms and one oxygen atom. There is an uneven distribution of electron density between hydrogen and oxygen, with oxygen atom having negative charge and hydrogen atoms having positive charge, which determines the polarity of water molecule. Thus, water molecules can form bonds with other polar molecules. Water molecules tend to hold other water molecules together with cohesive force, while adhesive force is involved when water molecules contact with a surface or other substance (Marshall et al., 2010). If cohesive force is stronger than adhesive force, a liquid tends to form droplets on a surface, and on the contrary, liquid tends to spread across a surface. Soil hydrophobicity is the consequence of formation of hydrophobic substances such as organic materials around the soil grains (Karnok et al., 2004). The nonpolar molecules will repel water, which could cause water unevenly distributed which result in localized dry spots. All types of soil can become hydrophobic, but sandy soils tend to be more susceptible to water repellency.

Wetting agents are products making water wetter by reducing the surface tension of water. A typical wetting agent molecule has a water-soluble group (polar/hydrophilic) on one side and an oil-soluble hydrocarbon chain (lipophilic/nonpolar) on another side. When wetting agents are applied to a water-repellent soil, the water soluble or polar end of wetting agents will bind to water molecules and the nonpolar end will bind to water-repellent organic coating, which result in strong linkage between soil particle and water molecule, and thus the soil will become non-water repellent. However, the alleviation of water repellency by wetting agents is not permanent, so repeat applications are required, and how often the application should be made depends on the chemical label recommendation (Zontek and Kostka, 2012).

When classifying the wetting agents, there are two commonly used methods. One is based on the mode of action in terms of how they interact with water and soil, and another is based on the formulation or chemistry of products (Zontek and Kostka, 2012; Hunt, 2015). The first classification method is more common for industrial use and the classification is varied between companies. Basically, the following three categories exist: 1. Penetrant, 2. Curatives, and 3. Residual:

1. Penetrant: this group of wetting agents were mainly used as a preventative strategy. They don’t resolve existing dry patches. To attain the best performance, they must be allowed to build up in the soil profile. Once water is received by soil, they spread water throughout the soil profiles and maintain an even distribution of water across soil surface.

2. Curative: this product is used when localized dry spot is evident. The major mode of action of this product is to remove the water-repellent organic substances coating of soil particle. The curative wetting agent have to be applied over time and believed is not able to

totally alleviate the soil water repellent, especially when topdressing is a routine management, as a new layer of sand was introduced to the soil profile every time.

3. Residual: The information of this group of wetting agents is more obscure than curative and penetrant wetting agent. Based on the limited available information, this product holds water near the surface where dry patch is existed, and it can work over a period of time.

The second method is more scientific. The only scientific work that has been done to categorize the wetting agent so far is done by Zontek and Kostka (2012). Based on their classification, wetting agents can be divided into 4 major groups: 1. Anionic and Anionic Blends, 2. Nonionic, 3. Cationic, 4. Amphoteric:

1. Anionic and Anionic blends: these products are negatively charged. They can provide fast wetting effect, but they can be phytotoxic to turf due to their negative ionic charge. The negative ions can cause soil dispersion which could cause future damage to turfgrass.

2. Nonionic: these products are the mostly used soil wetting agents in turfgrass management, and they can be further divided into different subgroups based on the chemistry. When they are used properly, they have no detrimental effect to plants, however, if applied at too high they can be phytotoxic to turfgrass when used in some situations. A detailed classification of several most commonly used wetting agents can be found in table 1.2.

3. Cationic: although they are surfactants, they are not utilized for soil wetting due to a high toxicity and disinfectant effects, which result in a severe plant damage. No cationic surfactants are sold as soil wetting agents in turf industry.

4. Amphoteric- these products can be cationic or anionic depending on the solution pH. As such, when solution pH is low, they are cationic, whereas they are anionic at high solution pH (Salager, 2002). They are barely used in turfgrass industry due to its relatively high cost and when they are used, they are normally added to pesticides (Salager, 2002; Karnok et al., 2004; Czarnota and Thomas, 2010).

Numerous studies have been quantifying the effect of wetting agents on sand-based turfgrass systems. However, since most available wetting agents in the market claimed an ability to reduce soil hydrophobicity and an ability to enhance water infiltration, and most commonly used wetting agents in turf industry are nonionic products, less has been done to evaluate the effect of wetting agents by formulation groups. Most studies have been focused on evaluating and comparing the efficacy of several most commonly used wetting agents in soil hydrophobic amelioration, regardless of formulation. USGA/GCSAA evaluated top 10 wetting agents that were used by superintendents over 9 study sites across the US (Throssell, 2005). The classification of each water agents used in this study was not indicated. Water droplet penetration test and turf color results of this study showed that Naiad (anionic) has the worst performances for several sites. Similar study has been done in New Mexico to investigate the effects of several wetting agents on sand-based rootzone hydrophobicity and putting green turf appearance (Leinauer et al., 2007). While wetting agents were also not grouped by formulation in this study, the authors found that the efficacy of wetting agents varied over soil depth, and they are more efficient when applied at depths of 2.5 cm or less.

Surfactants have been used for more than 50 years, but researchers have only recently begun to realize the importance of differentiating wetting agents by formulation when evaluate their efficacy. However, the reality is that there is still not enough information available in turf industry. Kostka and Bially (2005) claimed that they are the first to report the synergism between different surfactant chemistries for the enhancement of hydrophilicity in a water-repellent soil (Kostka and Bially, 2005). They found that blends of unrelated nonionic surfactants markedly improved infiltration over other commercial penetrant products. Physical state of wetting agent could also have an impact on efficacy of wetting agent for water-repellent amelioration, while more research is still needed to confirm this concept. Among the limited research that has been done so far, Barton and Colmer (2011) found that both granular and liquid formulations were equally effective on reducing soil water repellency when applied at the same rate of active ingredient. Less has been done to compare wetting agents with different active ingredients for their effects on soil water conservation. Mobbs et al. (2012) tested the effect of four surfactants from four different chemical groups (nonionic, block polymer, reverse block polymer, and anionic) on water properties in sand and silt loam soils, and found that none of these four surfactants improved the movement and conservation of soil water in hydrophilic soils. However, opposite results were found by a study testing the effect of six wetting agents (3 anionic and 3 nonionic) on water infiltration into poorly wettable sand and a layer of dry bermudagrass sod (Miyamoto, 1985). The results of this study showed that application of wetting agents significantly improved the initial water infiltration into both the poorly wettable sand and the dry bermudagrass sod. In addition, polyoxymethylene glycol, polyethylene glycol ether and sulfosuccinate compounds were found more effective than linear sulfonate and ethoxylated alcohol.

Table 1.1 Water quality as affected by management and landscape cover in urban ecosystems measured in different studies.

		Water quality parameters (mg L^{-1}) (means)											
		Stormflow						Base flow					
Study area	Reference	TSS	TOC	TP	TN	NO3	NH4	TSS	TOC	TP	TN	NO3	NH4
Queensland, Australia													
-Forest	Goonetilleke, et al., 2005	80	187	0.1	2								
-Rural residential area		94.4	190	0.1	2								
-Urban area		146.7	134	0.2	3.6								
-Townhouses area		156.4	13.2	0.4	2								
-Duplex housing area		69.5	11	0.7	2.5								
-Detached housing area		356.7	15.2	0.8	1.9								
Brays Bayou Watershed, Houston	Gregory, et al., 1997												
-Far West Houston, rural area		78	8.5					36	6.4				
-Residential area		63	14					56	10				
Golf course in Austin	King et al., 2001												
-Site 1 (inflow)				0.1		0.2	0.1			0.1		0.5	0.16
-Site 2 (outflow)				0.1		0.5	0			0.1		1.4	0.02
Gwynns Fall watershed, Baltimore													
-Surburban/Urban area	Groffman etal., 2004				5.5-11.4	4.8-6.3							
-Forested						0.12-4.8							
-Agriculture						7-30							
Snyder wetland, IA	Woltemade, 2000												
-Site 1 (inflow)						5-13							
-Site 2 (outflow)						2-9							

Table 1.1 Continued

		Water quality parameters (mg L^{-1}) (means)											
		Stormflow						Base flow					
Study area	Reference	TSS	TOC	TP	TN	NO3	NH4	TSS	TOC	TP	TN	NO3	NH4
New Castle County, Delaware													
-Turf			8.11		2.32	0.66	0.1		2.9		1.2	0.7	0.05
-Meadow	Bachman et		5.29		1.67	1.18	0		2.36		1.7	1.3	0.05
-Forest 1	al., 2016		5.12		1.18	0.57	0		2.62		1.1	0.6	0.05
-Forest 2			5.01		1.38	0.74	0.1		4.92		1.3	0.7	0.06
-Mixed-praking lot			5.27		1.41	0.9	0.1		2.88		2.1	1.4	0.13
-Mixed-golf course			5.98		2.61	1.98	0		3.03		3.2	2.3	0.03
Paved area in Yugoslavia and	Deletic and												
-Surbarban area	Maksimovic,	96-673											
-Carpark	1998	5-417											
Watersheds in Taejon and													
-High density residence with		413.5		7.6	12.1	2.28		51		5.3	11	0.1	
-High density residence	Lee and Bang,	72.8		8.9	11.7	0.45		56		5.8	23	0.1	
-Low density residence	2000	346.2		10	11.5	0.47		98		2.7	5.1	0.3	
-High density residence with		552.2		7.2	10.3	0.79		49		7.7	14	0.6	
-Undeveloplent		256		5.1	1.5	0.59		15		4.5	0.4	0.2	
Rain garden and roof, Hadam, CT													
-Roof	Dietz and				1.2	0.5	0						
-Garden 1	Clausen, 2005				0.8	0.3	0						
-Garden 2					1	0.4	0						

Table 1.1 Continued

Study area	Reference	Water quality parameters (mg L^{-1}) (means) Stormflow TSS	TOC	TP	TN	NO3	NH4	Base flow TSS	TOC	TP	TN	NO3	NH4
New Hanover County, NC													
- Urban area (Burnt Mill Creek)	Mallin et al., 2009	8.6	7.1	0.1	0.72	0.14	0.1						
- Suburban area (Smith Creek)		64.4	7.4	0.1	0.67	0.13	0.1						
- Rural area (Prince Georges Creek)		8	14.5	0.1	0.72	0.14	0.1						
Turfgrass systems- cool season	Easton and Petrovic, 2004												
-Plots fertilized by various N fertilizer						2.3-4.8							
-Unfertilized plots						2.9							
Turffrass systemts -cool season,													
-Unfertlized plots	Bierman, et al., 2010			1.1									
-None P applied plots				0.9									
-High P applied plots				2									
Urban watershed, St. Paul, MN													
-East Kittsondale	Janke, et al., 2014			0.3	2.46	0.29	0.2		0.06	3	2.4	0	
-Trout Brook East Branch				0.3	1.82	0.35	0.3		0.12	1.2	0.7	0.1	
-Trout Brook West Branch				0.3	1.93	0.49	0.2		0.09	1.5	0.7	0.1	
-St. Anthony Park				0.2	2.39	0.37	0.2		0.1	1.6	0.9	0.1	
Nationwide Urban Runoff Program													
-Residential	Petrovic and Easton, 2005	101		0.38	1.90	0.74							
-Mixed		67		0.26	1.29	0.56							
-Commercial		69		0.20	1.18	0.57							
-Open/non urban		70		0.12	0.97	0.54							

Table 1.2 Information of some commonly used wetting agents in golf course industry. Data are compiled and updated from paper (Zontek and Kostaka, 2012).

Group	Available product	Mode of action	Other features
Anionic and Anionic blends	AquaAid Naiad Penterra	Allow for water to more easily penetrate the soils. Offering fast wetting	Can cause soil dispersion
Nonionic-Subgroup			
Polyoxyethylene (POE)	APSA-80 E-ZWet Injector	Enhance water movement into the soil.	Can be phytotoxic to fine turf
Block Co-Polymer	Brilliance Primer Select Aqueduct	Alleviate soil water repellency. Enhance the infiltration and overall movement of water in the rootzone	Safer than POEs. Can be tankmixed with other surfactants
Alkyl Polyglucoside	Dispatch Injectable Dispatch Sprayable	Improves the infiltration and penetration of applied irrigation water and rainfall.	More effective when mixed with co-polymer. Naturally derived surfactants
Modified Mehtyl Capped Block Co-Polymer	Revolution	Similar to block co-polymer	Containing a hydrophobic part (methyl groups)
Humic Substance Redistribution Molecules	OARS	Reduce water repellency	Disrupting the hydrophobic supramolecular humic associations
Multibranched Regenerating Wetting Agents	PBS-150	Improve the uniform soil moisture. Reduce hyrophobic conditions	Higher in morecular weight. Longer effect after biodegradation

1.5. References

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2. IRRIGATION SALINITY EFFECTS ON TIFWAY BERMUDAGRASS GROWTH AND NITROGEN UPTAKE [*]

2.1. Overview

Salinity stress is becoming a more prevalent issue for turf managers due to increased use of recycled water for irrigation. While published data are available on EC thresholds for maintaining adequate turf growth and quality, data are lacking on the relationship between increasing irrigation and/or soil EC and turfgrass nutrient uptake efficiency. The objectives of this greenhouse experiment were to evaluate the effects of five irrigation water sources [RO (reverse osmosis), SP (sodic potable), 2.5 dS m^{-1} SA (Saline), 5 dS m^{-1} SA, and 10 dS m^{-1} SA] and two soluble fertilizer N sources (^{15}N-labeled sources of ammonium sulfate and urea) on Tifway bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davy) growth responses and N uptake efficiency. Results demonstrated that Tifway bermudagrass was capable of tolerating irrigation EC levels up to 5 dS m^{-1}, which corresponded to final soil EC levels (at 2.5 cm depth) of ~2 to 2.6 dS m^{-1}. However, with 10 dS m^{-1} irrigation (corresponding to soil EC levels of ~3-5 dS m^{-1}), turf quality declined to unacceptable levels and N uptake noticeably declined. Also, under increasing salinity (2.5, 5, and 10 dS m^{-1} salinity levels), urea produced superior turf quality relative to ammonium sulfate. Collectively, the results indicate that for well-watered, sand-based Tifway bermudagrass, lower N fertilization rates should be considered once irrigation EC levels begin exceed 5 dS m^{-1} or corresponding soil EC levels at the 2.5 cm depth exceed 2 dS m^{-1}. While N uptake efficiency of ammonium sulfate was higher

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than urea across all water sources in year 1, results indicate that urea provided higher turf quality than ammonium sulfate under elevated salinity.

2.2. Introduction

As competition for potable water supplies increases, lower quality water sources are being used for irrigating turfgrass sites including lawns, parks, golf courses, and athletic fields. Currently, more than 1/3 of golf courses in the southern United States use recycled water for turf irrigation (Throssell et al., 2009). While often a less costly source of irrigation relative to potable, recycled or effluent water usually contains elevated levels of salinity arising from a combination of chloride, magnesium, calcium, and/or potassium (Wu et al., 1996). According to Carrow and Duncan (1998), irrigation water poses low salinity hazard at EC < 0.75 dS m^{-1}, medium hazard at EC = 0.75 to 1.5 dS m^{-1}, high hazard at EC= 1.5 to 3 dS m^{-1}, and very high hazard at EC > 3 dS m^{-1}.

Increased root zone salinity lowers the water potential of the soil solution, making it more difficult for plant roots to take up water (Bernstein, 1975; Maas and Grattan, 1999; Koyro, 2006). Previous studies have investigated turf tolerance and/or adaptation to saline conditions within a number of turfgrass species (Alshammary et al., 2004; Chen et al., 2009; Pompeiano et al., 2014). Collectively, these studies demonstrate species-dependent responses to increasing salinity. With regard to warm-season turfgrasses, seashore paspalum (*Paspalum vaginatum*), manilagrass [*Zoysia matrella* (L.) Merr.], and St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) generally exhibit the highest tolerance to salinity, i.e., suffer the least detrimental impacts on shoot growth and/or turf quality due to increasing salinity, bermudagrass (*Cynodon* spp. L. C. Rich) and Japanese lawngrass (*Zoysia japonica*) possess moderate salinity tolerance, and centipedegrass shows little to no salinity tolerance (Marcum and Murdoch, 1994). Carrow and Duncan (1998) summarized an extensive amount of turf salinity literature and reported an overall average ECe (saturated soil paste extract) threshold for hybrid bermudagrass of 3.7 dS m^{-1}, although ECe values ranged between 0 and 10 dS m^{-1}, depending on the study and cultivar used. A study investigating salinity tolerance of 10 bermudagrass cultivars under a range of salinity levels (3.3 to 17.8 dS m^{-1}) found that although shoot and root dry weight of all cultivars decreased with increasing salinity, all cultivars were able to tolerate the salinity levels used in the study, as demonstrated by the minimal amount of leaf firing (Adavi et al., 2006).

According to Feigin et al. (1991), recycled wastewater typically contains between 200 to 3,000 ppm total dissolved salts, corresponding to an EC of 0.3 to 4.7 dS m^{-1}. Although salinity thresholds associated with decreased shoot growth and appearance of warm-season turfgrasses have been published (Carrow and Duncan, 1998), there are limited to no data regarding soil or irrigation EC thresholds at which fertilizer N uptake is impaired in warm-season turfgrasses such as hybrid bermudagrass. Given the growing use of recycled water in turf systems and associated potential for salinity stress, such information would be beneficial to improving current nutrient management practices and ensuring environmental stewardship on sites prone to salinity stress.

While turfgrasses can acquire considerable amounts of N from soil organic matter, fertilizer N often provides the majority of the N used throughout the growing season, especially in sand-based systems. Nitrogen is the fertilizer nutrient used in greatest quantity by the plant, and therefore is the nutrient on which fertility programs are typically based (Xu et al., 2012; Burton and Jackson, 1962). Bermudagrass requires relatively high fertilizer N inputs relative to other species in order to maintain acceptable color, function, and quality. For example, Duble (2004) has recommended bermudagrass N application rates ranging from 2.5 to 9.8 g N m^{-2} per growing month, depending on use and expectation level of the site.

Numerous quick- and slow-release fertilizer N sources are available to the turf manager, and are generally considered in the context of cost, burn potential, salt index, N release mechanism, and N release rate. One consideration that may be overlooked is the potential for irrigation water chemistry to influence the efficiency at which different N sources are taken up by the plant following application. Little previous research has examined the effects of irrigation salinity on N uptake efficiency in warm-season turfgrass, including hybrid bermudagrass. Pessarakli et al. (2005) evaluated ^{15}N-labeled ammonium sulfate uptake by the C_4 halophyte desert saltgrass [*Distichlis spicata* (L.)], and reported increases in both shoot growth and total N uptake with increasing salinity up to ~18 dS m^{-1}. Conversely, Bowman et al. (2006) reported ~60% reductions in plant uptake of NO_3 and NH_4 in cool-season turfgrass tall fescue (*Festuca arundinacea* Shreb. syn. *Schedonorus arundinaceus* Schreb.) with increasing root zone salinity from 0.5 to 11.2 dS m^{-1}, noting that uptake of both NO_3 and NH_4-N sources were affected equally by salinity. Further, although irrigation water pH has been well documented to affect pesticide activity (Brown, 1990; Chapman and Cole, 1982), little research has focused on the effects of irrigation water pH on availability, transformation, or uptake of various N sources by turfgrass. Information on N source and water source interactions are particularly important given the growing use of recycled water on turf facilities around the country, as these water sources are often associated with elevated levels of salts, sodium, and bicarbonates, and increased pH.

The objectives of this experiment were to evaluate the effects of five irrigation water sources [reverse osmosis (RO), sodic potable (SP), and saline (SA) at 2.5, 5, and 10 dS m^{-1}] and two soluble fertilizer N sources (^{15}N-labeled sources of ammonium sulfate and urea) on Tifway bermudagrass growth responses and N uptake efficiency. This information should aid turf managers in selecting the most appropriate N sources and rates for maximizing plant N uptake and minimizing environmental losses following fertilization events.

2.3. Material and Methods

This study was conducted in a greenhouse at Texas A&M University, College Station, Texas from 2 August to 17 October 2016, and repeated from 5 June to 24 August 2017. Greenhouse temperatures were maintained at 30/23 ^{0}C (day/night) for both studies. External mean daily solar radiation levels received during the greenhouse experiment were 17.4 ± 0.5 MJ m^{-2} for 2016 and 20.5 ± 0.5 MJ m^{-2} for the 2017 study period. Multiple measurements obtained both inside and outside the greenhouse at the start of the experiment showed greenhouse reductions of external photosynthetic photon flux to be 22.1 ± 0.7 %.

Washed sod plugs (10.2 cm diameter × 2.5 cm deep) of Tifway bermudagrass were removed from established field plots at the Texas A&M Turfgrass Field Laboratory, and grown into lysimeters constructed from polyvinyl chloride pipe (30.5 cm height × 10.2 cm diameter) in the greenhouse. A 6 mm diameter drainage hole was drilled in the bottom of each lysimeter. Reemay cloth was laid in the base of the lysimeter to prevent sand loss while allowing water drainage. Within lysimeters, grass plugs were established into a USGA (United States Golf Association) spec sand amended with 10% (v:v) sphagnum peat moss. Particle size of the sand on the basis of USGA spec was analyzed with the following distribution: gravel (>2.0 mm) = 0.3%, very coarse (2.0 to 1.0 mm) = 4.7%, coarse (1.0 to 0.5 mm) = 23.1%, medium (0.5 to 0.25 mm) = 55.2%, fine (0.25 to 0.15 mm) = 13.9%, and very fine (0.15 to 0.05 mm) = 1.7%.

Grasses were irrigated with five different irrigation sources including SP, RO, or SA water with EC of 2.5, 5, or 10 dS m^{-1}. Sodic potable water was from a local municipal potable water source and posed a Na, but not salinity hazard based on United States Salinity Laboratory classification (U.S. Salinity Laboratory, 1954). Reverse Osmosis water was produced from an onsite RO unit, and saline water was produced by mixing NaCl with RO water to achieve desired EC levels (Table 2.1).

Table 2.1 Water chemistry for the irrigation treatments used in the study, along with their respective US Salinity Laboratory (USSL) classifications. Water chemistry includes pH, Na hazard, salinity hazard, electrical conductivity (EC), bicarbonate (Bicarb), Na, Cl, and sodium adsorption ratio (SAR). Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA).

	USSL Class.	Na Hazard	Salinity Hazard	pH	EC (dS m^{-1})	Bicarb (mg L^{-1})	Na (mg L^{-1})	Cl (mg L^{-1})	SAR
RO	C1-S1	Low	Low	5.9	0	0	<1	<1	0.1
SP	C1-S4	High	Low	8.4	<1	509	234	81	33.7
2.5 dS m^{-1} SA	C2-S4	High	Medium	6.3	2.5	0	629	971	58.9
5 dS m^{-1} SA	C2-S4	High	Medium	6.3	5	0	1259	1941	117.9
10 dS m^{-1} SA	C3-S4	High	High	6.2	10	0	3147	4853	294.8

At the initiation of the study period, lysimeters were watered to saturation using their respective irrigation source. The saturation weight of each lysimeter was then recorded and subsequently used as a target for irrigating to during each subsequent irrigation event. Twice weekly during the acclimation period, lysimeters were weighed and hand watered back to their respective saturation weights using the respective water sources. Because columns were irrigated back to saturation, drainage was observed from columns for a 4-6 hour period following irrigation. In this way, the salinity of the root zone was less likely to build up beyond the irrigation water EC during the study period.

During the study period, lysimeters irrigated with each irrigation source as described previously were fertilized weekly with N-depleted Hoagland solutions created using either unlabeled ammonium sulfate ($(NH_4)_2SO_4$) or urea (NH_2CONH_2) at a rate of 1 g N m^{-2}. Fertilization events coincided with the first of each week's watering events.

2.3.1. Water Quality and N Fertilizer Effects on Turf and Soil

During the study period, turf quality was evaluated by weekly visual assessments using a 1-9 rating scale, with a rating of 6 or greater denoting acceptable quality (Morris and Shearman, 1998). Percent Green Cover was also determined weekly by analyzing lightbox images via digital image analysis software (Sigma Scan v 5.0, Systat Software Inc, San Jose, CA). Digital images were taken using a Nikon Coolpix camera mounded to a polyvinyl chloride light-box which was placed over a given lysimeter. The light box cancels outside light and creates uniform light within the box (Karcher, 2005).

Shoot growth responses to treatments were evaluated via clipping collection. Turfgrasses were clipped weekly to a height of 1.3 cm, with clippings collected and oven dried at 65^{0}C for dry weight determination. Electrical conductivity (EC) of soil was also measured at the end of the study period using a Fieldscout EC 110 meter (Spectrum Technologies, Aurora, IL.). Measurements were recorded at the 2.5 cm soil depth in order to evaluate salinity stress within the upper root zone.

2.3.2. N Uptake Experiment

At the last week of study period, 10 atom % ^{15}N enriched ammonium sulfate (10 atom % $(^{15}NH_4)_2SO_4$) and urea (10 atom % $H_2{}^{15}NCO^{15}NH_2$) solutions were created with the five respective irrigation water sources used in the acclimation period. ^{15}N labeled fertilizer solutions were applied to each lysimeters at a rate of 5 g N m^{-2} via syringe delivered directly into the upper 5 mm of soil at the surface of each lysimeter in a 30 ml carrier volume. The 30 ml solution was evenly distributed among four quadrants of the 10.2 cm diameter circular grass plug. This approach ensured the solution was evenly distributed across the root zone and that plant uptake occurred through belowground plant roots as oppose to foliage. The ^{15}N fertilizer treatments were applied between 1100 and 1200 hours on 15 October 2016 (Study 1) and 22 August 2017 (Study 2).

A 48-hour uptake period was then provided after which lysimeters were flushed by heavily irrigating with RO water. The 48-hr uptake period was selected based on the findings of Bowman et al. (2006) and Wherley et al. (2009), who reported that complete uptake of this rate of soluble N fertilizer by tall fescue and Tifway bermudagrass during active growth occurred within 24-72 hours.

Above ground tissues were then harvested and analyzed for determination of total N and % ^{15}N. Previous published research has shown shoot ^{15}N recovery to be a reliable indicator of overall plant N uptake, as a major fraction (up to 90%) of assimilated N is fixed and detectable in verdure and shoots within days of fertilization during active growth periods (Bowman et al., 2006; Pessarakli et al., 2005; Wherley et al., 2009). After thorough rinsing with DDI water, above ground tissues were blotted dry with paper towel and immediately harvested by removing all above ground verdure plus shoot tissue using scissors. All harvested above ground tissues were then oven dried at 65°C for 72 hours with tissue dry weights recorded. Dried tissues were ground using a Wiley Mill (Cyclotec 1093 sample mill, Tecator, Hoganas, Sweden) using a 1 mm screen (Tecator, Hoganas, Sweden). Tissues were then frozen before being milled to a fine powder using a geno grinder (SPEX SamplePrep, Geno/Grinder 2010, Metuchen, NJ) operated for 10 minutes at 1600 RPM. Pulverized tissue samples were then encapsulated in tin capsules and analyzed for total N and atom % ^{15}N using a Delta V isotope ratio mass spectrometer (Thermo Scientific, Waltham, MA). The background atom % ^{15}N natural abundance of the field plot from which turf had been removed was also determined, and the value (0.367 atom %) was subtracted from each measured ^{15}N value used to determine total fertilizer N uptake. N uptake efficiency was determined as the ratio of recovered total ^{15}N in plant tissue to the total ^{15}N applied.

The study was arranged as a randomized complete block design with four replicates per treatment. A factorial arrangement accommodated all possible combinations of five irrigation sources (RO, SP, 2.5 dS m^{-1}, 5 dS m^{-1}, and 10 dS m^{-1} SA) and two fertilizer N treatments (^{15}N labeled ammonium sulfate and urea). Data for all parameters were subjected to analysis of variance (ANOVA) using the general linear model, univariate test procedure using SAS ver. 9.4 (SAS Institute Inc., Cary, NC) to determine statistical significance of results. Year × treatments interactions were significant for all parameters, so years were analyzed and presented separately. Mean separation was performed using Tukey's honestly significant difference test at the $P \leq 0.05$.

2.4. Results

2.4.1. Turf Quality and Percent Green Cover

Based on ANOVA, the effect of irrigation source on turf quality was highly significant both years (Table 2.2).

Table 2.2 Analysis of Variance for parameters measured during the bermudagrass nitrogen uptake study. Year × treatment interactions were significant for all parameters, so data are presented separately by year.

Source	Turf Quality		Percent Green Cover		N Uptake		Clipping Dry Weight		Soil EC	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Week (W)	**	**	**	**			**	**		
Irrigation (I)	**	**	**	**	*	**	**	**	**	**
N Source (N)	ns	**	ns	**	**	ns	ns	ns	ns	ns
W × I	**	ns	ns	ns			ns	**		
W × N	ns	*	ns	ns			ns	ns		
I × N	ns	**	ns	*	ns	ns	ns	*	ns	*
W × I × N	ns	ns	ns	ns			ns	ns		

*Significant at $P = 0.05$ probability level
** Significant at $P = 0.01$ probability level
Ns = Not significant at $P = 0.05$ probability level

In 2016, there was a significant irrigation × week interaction. As such, RO irrigation yielded the highest turf quality during weeks 1, 7, and 8, while the 2.5 dS m^{-1} SA treatment resulted in the highest turf quality during weeks 3 to 6 (Figure 2.1).

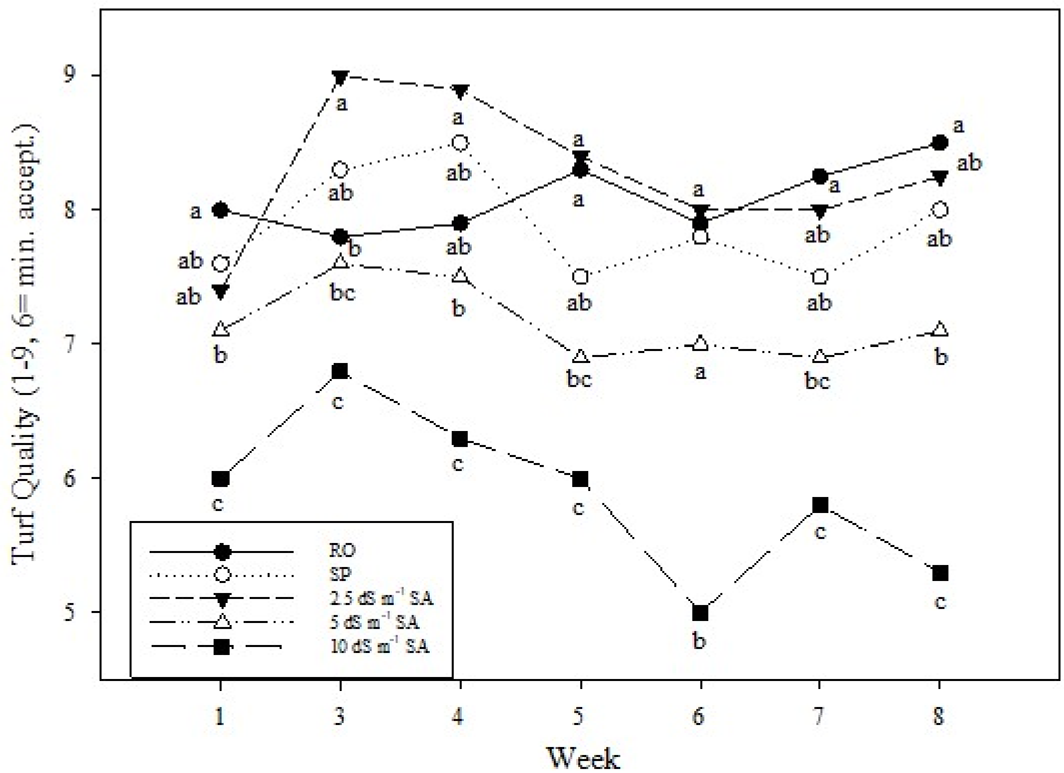

Figure 2.1 Effect of irrigation by week on turf quality during 2016. Data are pooled across N source. Turf quality was evaluated by visual assessments using a rating scale of 1 to 9, with 6 as the minimal acceptable (min. accept.) quality. Irrigation included reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

Although the 10 dS m^{-1} SA irrigation treatment maintained acceptable turf quality through week five, it yielded below acceptable quality (~5.5) through the final 3 weeks of the study. All other treatments maintained acceptable turf quality during the entire 2016 study (Figure 2.1). There was also an irrigation × N source interaction detected for turf quality during 2017 (Table 2.2). When irrigated with low salinity (RO and SP) water, both N sources provided similarly high (~8.3) turf quality (Figure 2.2).

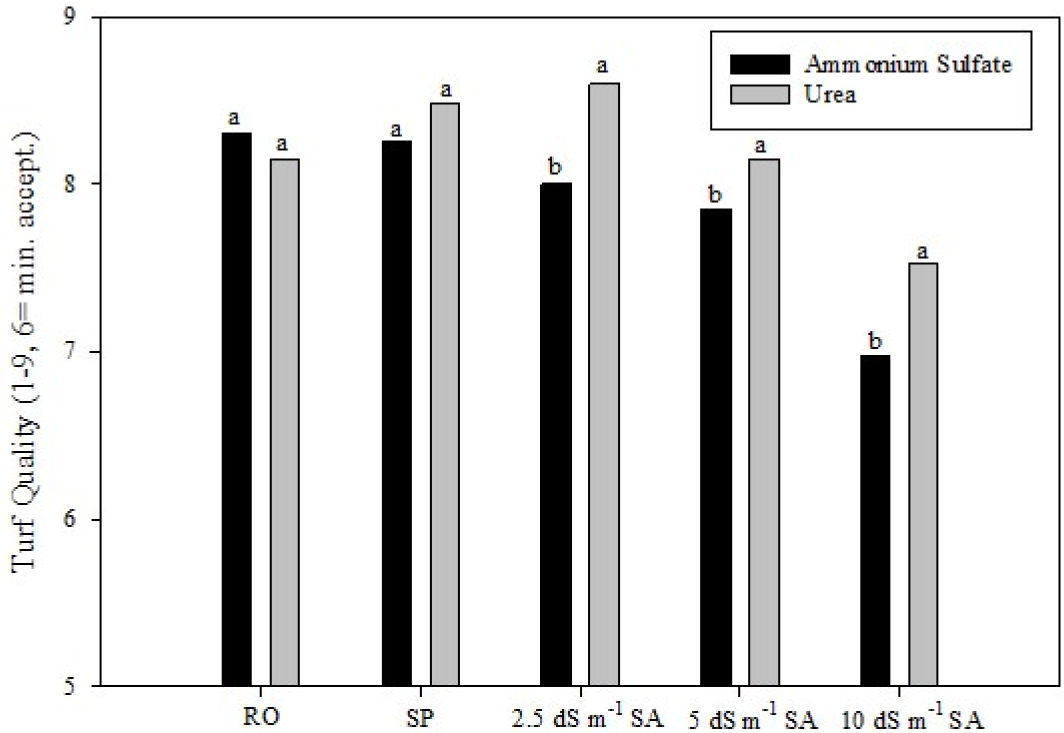

Figure 2.2 Effect of irrigation and N source on turf quality during 2017. Data are pooled across week. Turf quality was evaluated by visual assessments using a 1-9 rating scale, with 6 as the minimal acceptable (min. accept.) quality. Irrigation include reverse osmosis (RO), sodic potable (SP), 2.5, 5, and 10 dS m^{-1} Saline (SA). Means with the same letter in a given irrigation are not statistically different based on Tukey's HSD at P = 0.05.

However, when irrigated using SA water sources, urea N resulted in improved turf quality relative to ammonium sulfate (Figure 2.2). In 2017, there was also a week × N source interaction (Table 2.2). Although no statistically significant turf quality differences occurred due to the N sources during 9 of the 10 weeks, urea led to statistically higher turf quality relative to ammonium sulfate (8 and 7.4 for urea and ammonium sulfate, respectively) during week 8 (Figure 2.3).

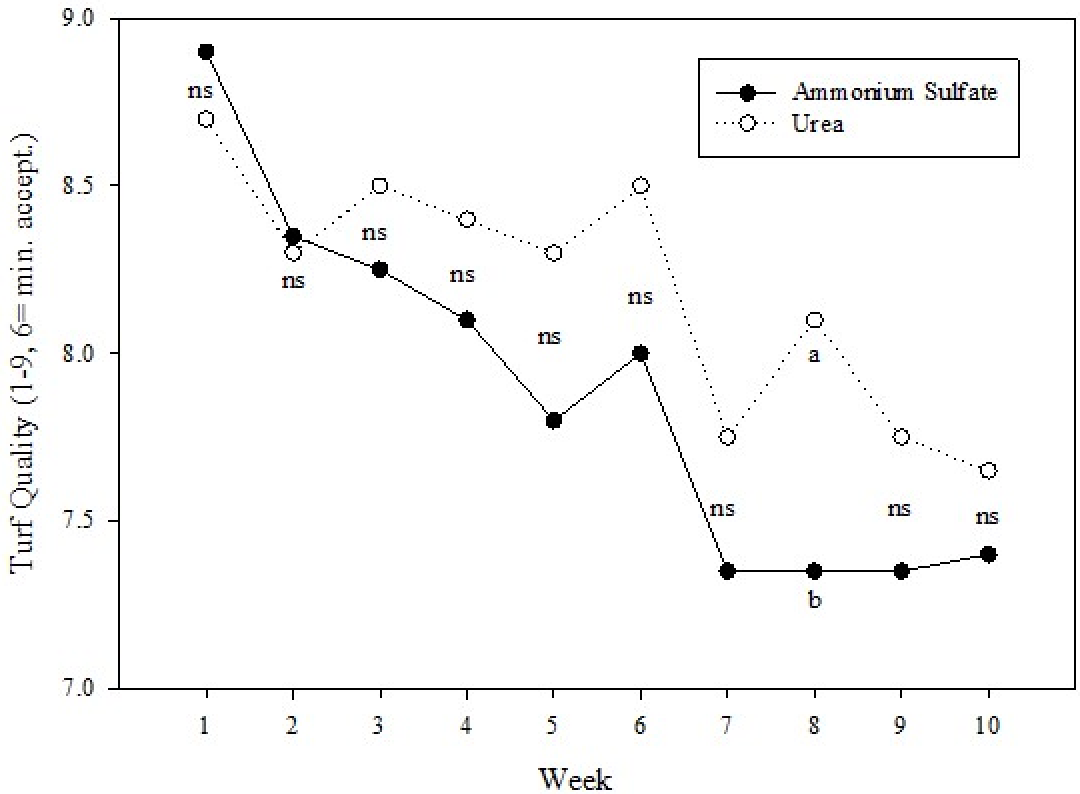

Figure 2.3 Effect of N source by week on turf quality during 2017. Data are pooled across irrigation source. Turf quality was evaluated by visual assessments using a rating scale of 1 to 9, with 6 as the minimal acceptable (min. accept.) quality. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

Percent green cover data followed a similar trend as turf quality, with an irrigation main effect noted both years and N source effect noted during 2017 (Table 2.2). Overall, percent green cover across all treatments were ~20-30% higher during 2017, likely due to the higher levels of solar radiation received compared to 2016. In 2016, the highest percent green cover (~75%) occurred with 2.5 ds/m SA irrigation (Figure 2.4).

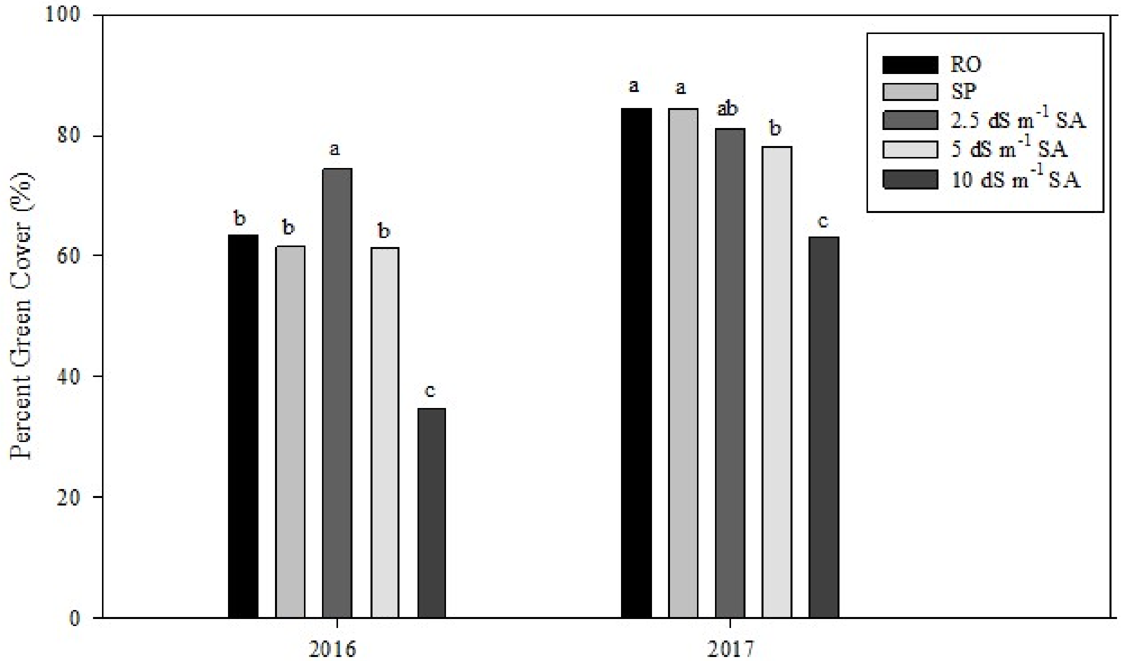

Figure 2.4 Effect of irrigation on percentage green cover during the 2016 and 2017 seasons. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data have been pooled across weeks and N sources. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

Overall percent green cover of RO, sodic potable, and 5 dS m^{-1} SA treatments were nearly identical, at ~60%. However, 10 dS m^{-1} SA irrigation treatment led to ~50% decreased percent green cover relative to RO controls. In 2017, percent green cover was generally higher across all treatments, but steadily decreased from ~80 to 60% with increasing irrigation salinity level (Figure 2.4). In 2017, there was also an irrigation × N source interaction on percent green cover (Table 2.2). As such, turfgrasses irrigated with SP or 2.5 dS m^{-1} SA produced ~10% higher green cover when fertilized with urea as opposed to ammonium sulfate. Among all other irrigation sources, no differences in percent green cover were detected due to N source, with overall percent green cover ranging from 65 to 85%, depending on the water source (Figure 2.5).

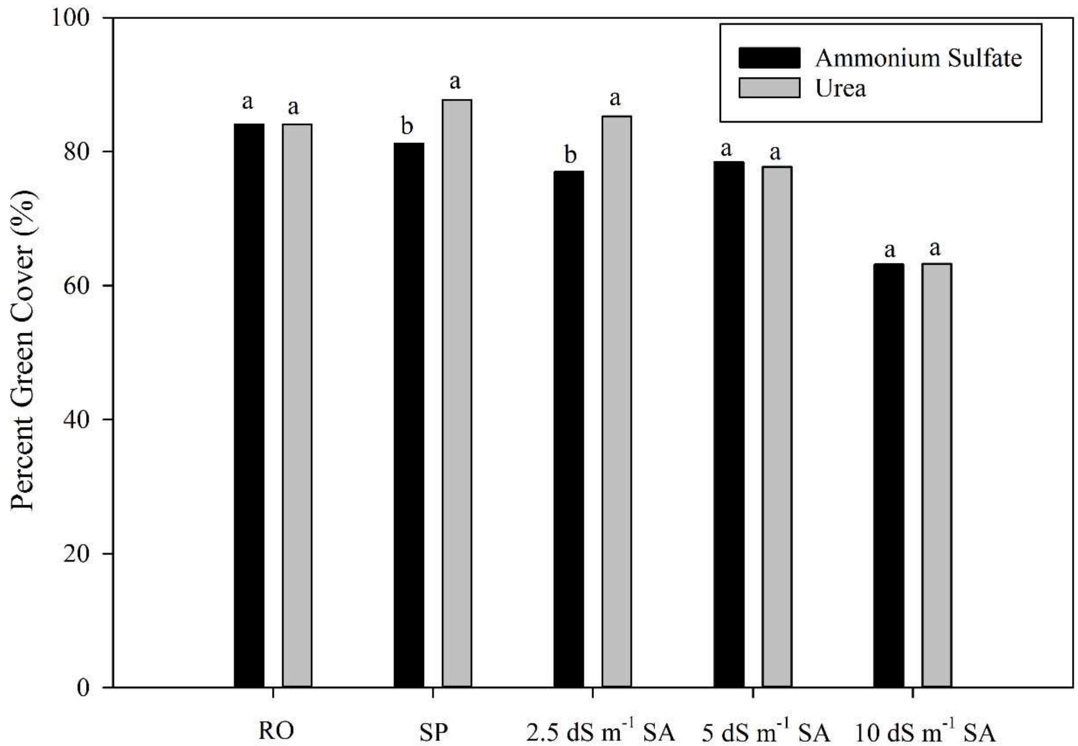

Figure 2.5 Effect of irrigation and N source on percent green cover during 2017. Data are pooled across week. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

2.4.2. Clipping Dry Weights

In both years, irrigation source had a significant effect on clipping dry weights, while N source did not (Table 2.2). Weekly clipping dry weights during the study period ranged from 0.39 g to 0.48 g per pot (Data not shown). Consistent with N uptake trends, the 10 dS m^{-1} SA-irrigated treatments had the lowest clipping production (0.39 g pot^{-1} wk^{-1}) of all treatments. Among the other treatments, the only significant difference was detected between the SP and 10 dS m^{-1} SA, with reduced clipping yields in the 10 dS m^{-1} SA treatment. ANOVA also showed an irrigation × N source interaction on clipping dry weight during 2017 (Table 2.2). With 2.5 dS m^{-1} SA irrigation, clipping dry weights were greater when fertilized with urea as opposed to ammonium sulfate N (0.47 vs. 0.41 g pot^{-1}) (Figure 2.6). Among all other treatments, there were no significant differences in clipping dry weight due to N or irrigation source. There was also a week × irrigation interaction on clipping dry weight during 2017 (Table 2.2; Figure 2.7). As such, differences in clipping dry weights due to irrigation source occurred during weeks 2 and 3, with clipping dry weights of SP exceeding that of 10 dS m^{-1} SA treatment.

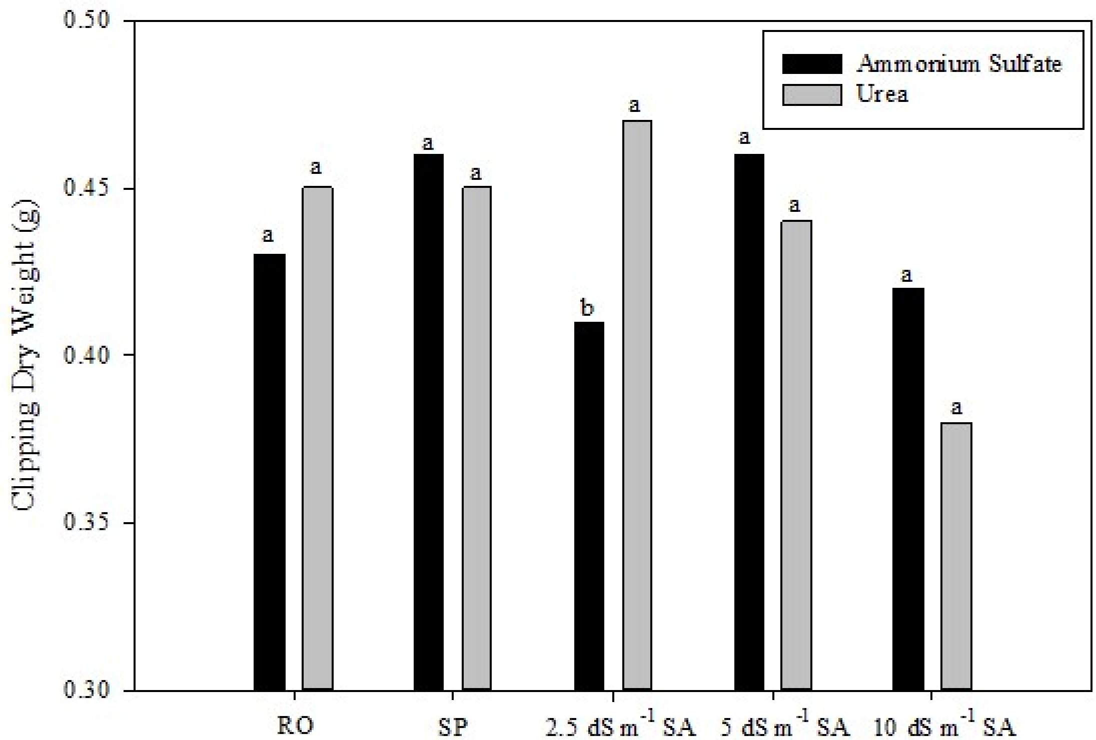

Figure 2.6 Effect of irrigation and N source on clipping dry weight during the 2017 season. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data are pooled across weeks. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

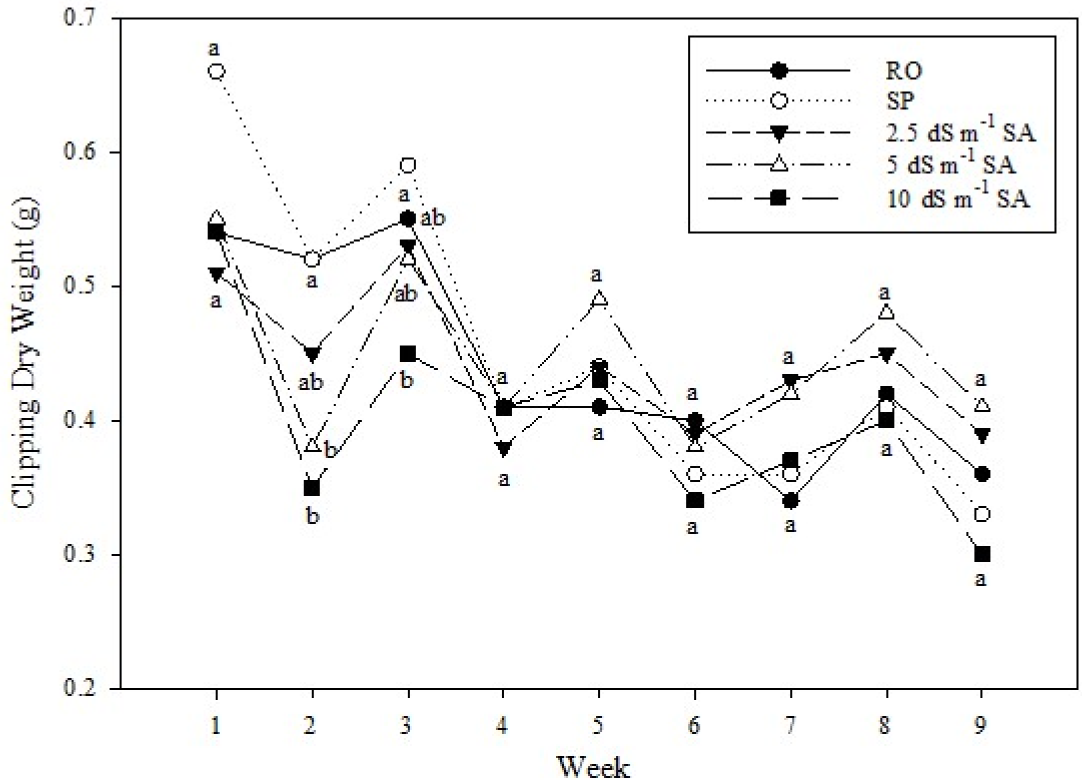

Figure 2.7 Weekly clipping dry weight as affected by irrigation during the 2017 season. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data are pooled across N source. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

2.4.3. Fertilizer Nitrogen Uptake

Analysis of variance detected a main effect of N source on N uptake in 2016 (Table 2.2). Plant N uptake of ammonium sulfate was significantly greater than that of urea following the 48-hr uptake period (53 vs. 33%, respectively) in 2016, and while the same trend occurred in 2017 (35 vs. 31%), the differences were not significant (Figure 2.8).

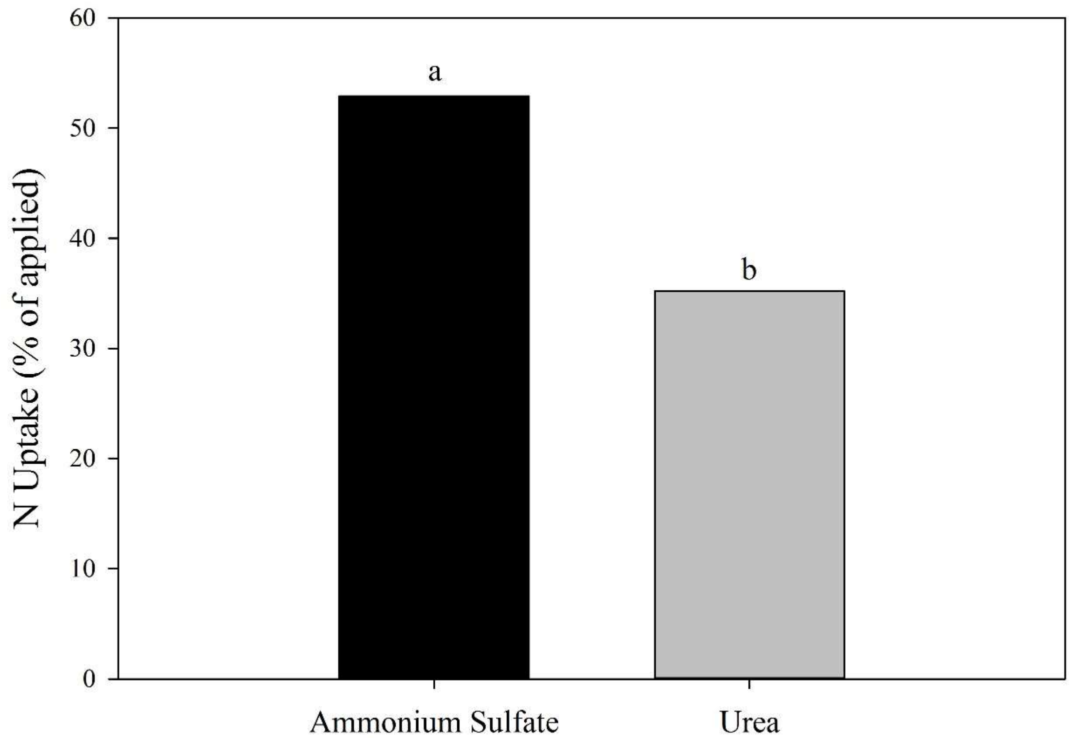

Figure 2.8 Nitrogen uptake as affected by ammonium sulfate or urea fertilization during 2016. Data have been pooled across irrigation source and week. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

ANOVA also showed an irrigation main effect on N uptake in both years (Table 2.2). During 2016, 35% of the applied N was recovered in turfgrasses irrigated using low salinity water (RO and SP). However, N uptake increased with increasing irrigation salinity, approaching 60% recovery of applied N with 5 dS m^{-1} SA. Nitrogen uptake declined to RO and SP levels as irrigation salinity reached 10 dS m^{-1}. When comparing all treatments, the highest N uptake (50-60% of applied) occurred at irrigation salinity treatments of 2.5 and 5 dS m^{-1} during 2016 (Figure 2.9). With the exception of RO, a similar trend occurred during the 2017 season, with N uptake increasing as irrigation salinity increased up to 5 dS m^{-1}, but again declining at 10 ds/m. In 2017, RO, 2.5, and 5 dS m^{-1} SA treatments all had statistically similar N uptake, which ranged from 35-45%. As in 2016, N uptake noticeably declined with 10 dS m^{-1} SA irrigation, but this time to considerably lower levels (20 to 40% of other treatments) (Figure 2.9).

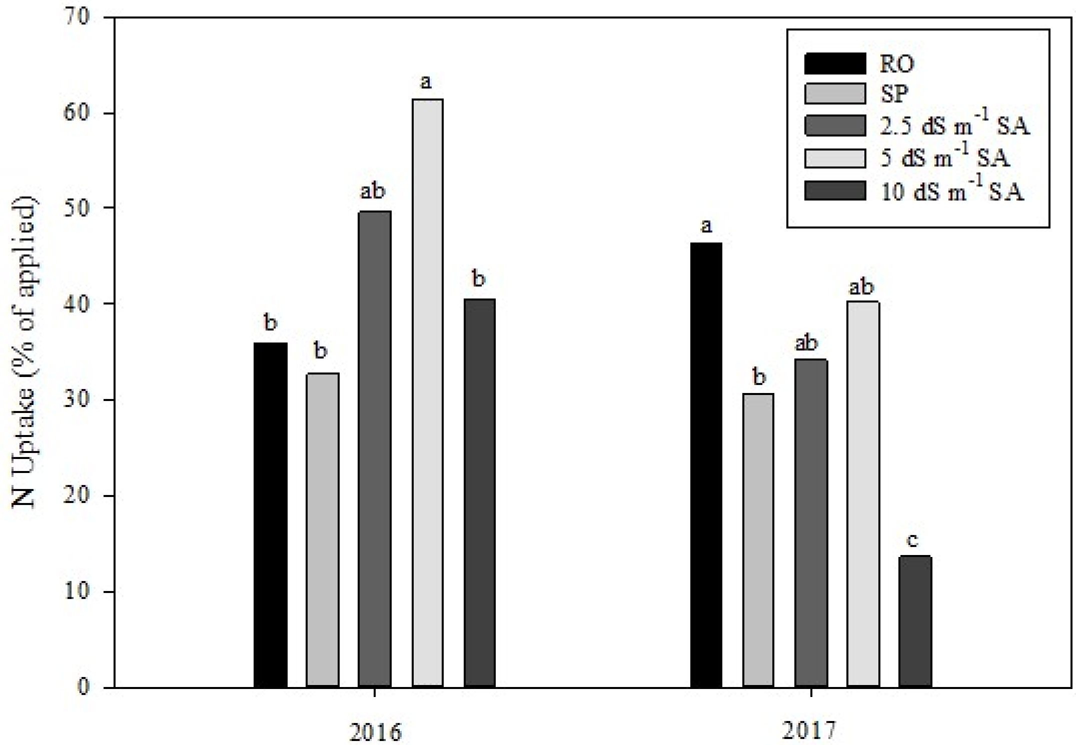

Figure 2.9 Effect of irrigation on N recovery in shoot during the 2016 and 2017 seasons. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data are pooled across N source. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

2.4.4. Soil Electrical Conductivity

Analysis of variance indicated a significant main effect of irrigation source on soil EC for both years, and an irrigation × N source interaction for 2017 (Table 2.2). Soil EC, measured at the 2.5 cm depth at the end of the ^{15}N uptake period just before flushing, showed similar treatment trends in both years, increasing with increasing irrigation salinity. In 2016, Soil EC at the 2.5 cm depth ranged from 0.9 to 2.9 dS m^{-1} (RO and 10 dS m^{-1} SA, respectively) (Figure 2.10).

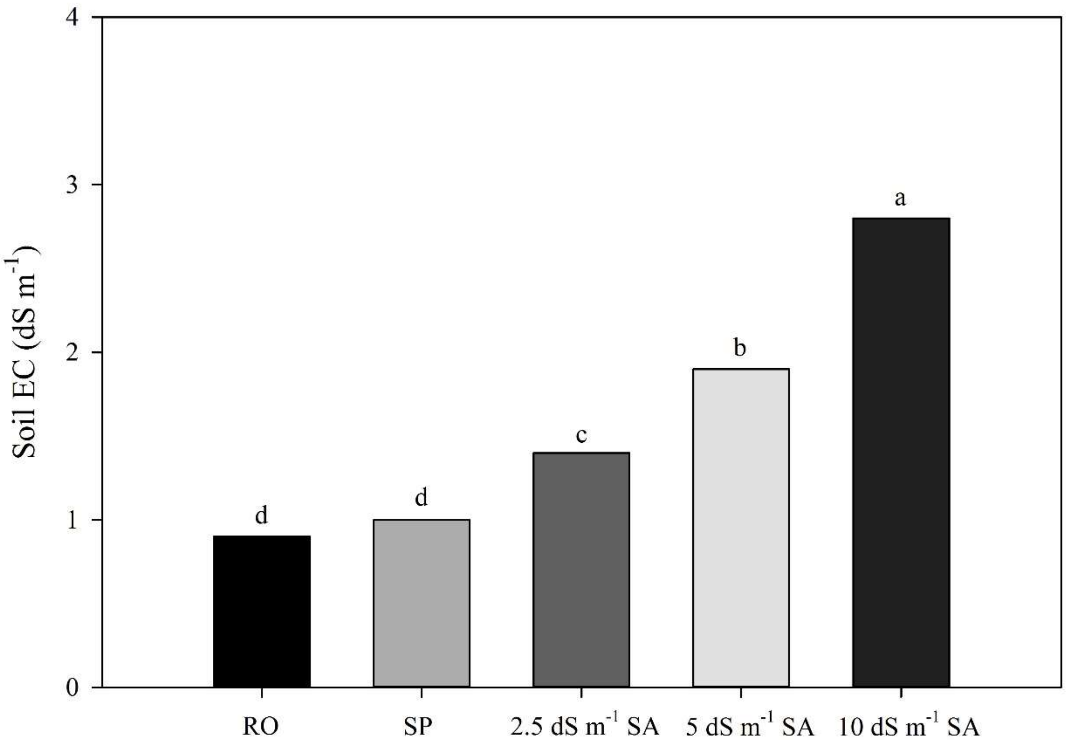

Figure 2.10 Soil electrical conductivity (EC) measured at the 2.5-cm depth as affected by irrigation during 2016. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data are pooled across N source. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

In 2017, soil EC was elevated relative to 2016 in all treatments, and ranged from 1.1 to 5.3 dS m^{-1} (RO and 10 dS m^{-1} SA, respectively) (Data not shown). An interaction between irrigation and N source also occurred for soil EC during 2017 (Table 2.2). As such, ammonium sulfate fertilization resulted in higher soil EC levels compared to urea under RO and 2.5 dS m^{-1} SA, but no statistically significant differences in EC occurred due to N source at 5 or 10 dS m^{-1} SA (Figure 2.11).

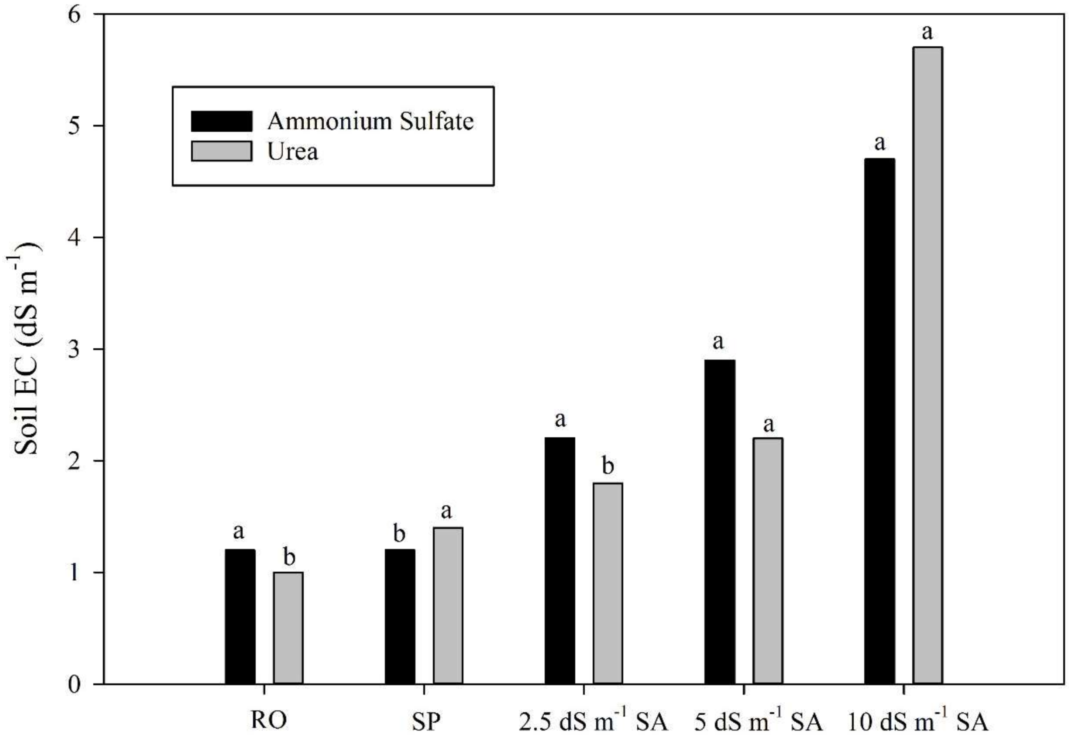

Figure 2.11 Effect of irrigation and N source on soil electrical conductivity (EC) at the 2.5-cm depth during the 2017 season. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5, 5, and 10 dS m^{-1} saline (SA). Data are pooled across weeks. Means followed by a common letter are not significantly different based on Tukey's honestly significant difference test at the 5% level of significance.

2.5. Discussion

To our knowledge, there have been no published reports of irrigation chemistry or salinity effects on fertilizer N uptake capacity in Tifway bermudagrass turf. Our study included five irrigation sources, three of which provided increasing levels of salinity stress (2.5, 5, and 10 dS m^{-1}) to the turf. While irrigation treatment EC levels were consistent between studies, final soil EC was elevated in study 2 relative to study 1. This increase in EC in the second study was presumably due to higher solar radiation levels and longer days occurring during the 2017 study period, which would have increased overall evaporative demand and contributed greater salt deposition within the upper root zone.

This was corroborated by a previous study, which reported elevated EC of leachate from bermudagrass turf occurring during the hottest months of the study period (Schiavon and Baird, 2018). In addition, Soil EC measured at 2.5 cm soil depth at the end of study was somewhat lower than what might have been expected given the irrigation water EC, especially for 5 and 10 dS m^{-1} SA treatments. Although we cannot fully explain this observation, we speculate that salt accumulation near the surface would have been considerably higher. Furthermore, because lysimeters were returned to saturation during each biweekly irrigation event, maintenance leaching of columns presumably resulted in soil EC from accumulating beyond that of the irrigation EC. This, combined with possible plant uptake of salts and clipping removal, may have contributed to the potentially lower than expected salt accumulation at the 2.5 cm depth in the root zone.

Based on the observed turf quality, growth, and percent green cover responses to increasing salinity in this study, Tifway bermudagrass maintained acceptable appearance and growth under prolonged (8-wk) exposure to 5 dS m^{-1} salinity, but fell to below-acceptable quality levels after 5 weeks when irrigated using 10 dS m^{-1} salinity irrigation. The EC levels at which 50% shoot dry weight reductions have been previously reported in Tifway vary from 12 to 33 dS m^{-1} (Smith et al., 1993; Adavi et al., 2006; Marcum and Pessarakli, 2006), however shoot dry weight reductions do not necessarily correspond to turf quality thresholds. Xiang et al. (2017) reported minimally acceptable Tifway bermudagrass turf quality (6.2 out of 9) was maintained following a brief 7-day exposure period at 15 dS m^{-1} salinity, but also reported that Tifway lacked the salinity tolerance of other bermudagrass cultivars including ‘Latitude 36’, ‘Northbridge’, and ‘Celebration’ at this salinity level. Our data also showed that urea provided significantly improved bermudagrass turf quality relative to ammonium sulfate under 2.5, 5, and 10 dS m^{-1} salinity. Although we cannot fully explain this response, it seems somewhat counterintuitive, given the higher salt index of urea (75.4 vs. 69 for urea and ammonium sulfate, respectively) and potential for osmotic stress on plant tissues (Huck et al., 2000).

Our data demonstrate that N assimilation in Tifway remained unaffected or was even enhanced by exposure to irrigation salinity levels up to 5 dS m^{-1} (corresponding to final 2.5 cm depth soil EC levels of ~2 and 2.6 dS m^{-1} for 2016 and 2017, respectively). This is an important observation in light of published recycled irrigation industry water standards, which commonly classify irrigation water as representing a high agronomic concern when exceeding 2 to 3 dS m^{-1} (Westcot and Ayers, 1984; Farnham et al., 1985). It should be noted that ours was a relatively short term (8-wk) study conducted under full irrigation levels and in well-draining, sandy soil. Salt accumulation and associated plant impairment due to EC would presumably increase with longer study periods, heavier soils, and/or under deficit irrigation (Acosta-Motos et al., 2017). The observed increase in N uptake efficiency occurring with moderate increases in salinity has been reported previously in a number of other species, commonly in halophytic plants (Flowers et al., 2008; Munns and Tester, 2008; Acosta-Motos et al., 2017). In studies of grass species, Pessarakli et al. (2005) reported increased N uptake in desert saltgrass with increasing salinity up to ~18 dS m^{-1}, with impaired uptake relative to controls not observed until EC levels approached ~37 dS m^{-1}. Similarly, Langdale and Thomas (1971) reported Coastal bermudagrass [*Cynodon dactylon (*L.) Pers.] N uptake increased with increasing soil EC up to 15 dS m^{-1}, concluding that the saline treatment levels imposed did not limit N uptake in the species. Despite this, the authors noted that dry matter production declined at EC > 9.6

dS m^{-1}. In contrast to these results, Bowman et al. (2006) noted that absorption of NO_3 and NH_4 were both reduced by increasing root zone salinity from 0 to 11 dS m^{-1} in cool-season turfgrass tall fescue. Similarly, many past studies of crop species suggest reduced plant uptake and metabolism of N due to increased root zone salinity (Helal and Mengel, 1979; Aslam et al., 1984; Pessarakli and Tucker, 1988).

Greater apparent uptake of N from ammonium sulfate compared to urea fertilization in 2016 was notable, and occurred regardless of water source. This observation is consistent with the findings of Silveira et al. 2007, who reported significantly greater N recoveries following ammonium sulfate compared to urea (50 and 30% recovery of applied N, respectively) fertilization in coastal bermudagrass. Similarly, greater recovery of applied ^{15}N-labeled ammonium sulfate compared to urea was reported in analysis of 'Tifgreen' bermudagrass [Cynodon dactylon (L.) Pers.× C. transvaalensis Burtt-Davy] clippings (34 and 26% winter recovery and 27 and 18% summer recovery, respectively) (Picchioni and Quiroga-Garza, 1999). The inconsistency in recoveries between winter and summer studies were attributed to differences in photoperiods, which may also help to explain differences in uptake patterns between the two years of our study. While gaseous losses were not measured in this study, lower relative uptake of urea in year 1 could have been associated with higher volatilization potential. However, we expect volatilization losses would have been minimal in this study due to the placement of the fertilizer solutions below the thatch layer where urease has been shown to be most abundant (Nelson et al., 1980). Additionally, there were no irrigation × N source interactions, indicating that neither pH nor salinity differences between irrigation sources affected the relative absorption efficiencies of the N sources.

2.6. Conclusions

Due to increasing use of recycled water for turfgrass, salinity stress is becoming a more prevalent issue for turf managers. While published data are available on EC thresholds for maintaining adequate turf growth and quality, there are a lack of data on the relationship between increasing irrigation and/or soil EC and turfgrass nutrient uptake efficiency. This information is important considering the amounts of N fertilizer used on turf systems, and resulting potential for environmental losses should root function become impaired due to salinity stress. Our results demonstrated that Tifway bermudagrass was capable of maintaining acceptable quality and N uptake efficiency with irrigation EC levels up to 5 dS m^{-1}, which corresponded to final soil EC levels (at 2.5 cm depth) of ~2 to 2.6 dS m^{-1}. However, with 10 dS m^{-1} irrigation (corresponding to soil EC levels of ~3-5 dS m^{-1}), turf quality declined to unacceptable levels and N uptake noticeably declined. Also, with saline irrigation (2.5 to 10 dS m^{-1} salinity levels), urea produced superior turf quality to ammonium sulfate. Collectively, the results indicate that for well-watered, sand-based Tifway bermudagrass, reductions in N fertilization rates should not be necessary until irrigation EC levels begin to exceed 5 dS m^{-1} or corresponding soil EC levels at the 2.5 cm depth exceed 2 dS m^{-1}. While N uptake efficiency of ammonium sulfate was generally higher than urea across all water sources in year 1, the results also suggest that urea may be preferable to ammonium sulfate for providing the highest turf quality under elevated salinity.

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3. WATER CHEMISTRY AND NITROGEN SOURCE AFFECT FOLIAR UPTAKE EFFICIENCY IN 'CHAMPION' BERMUDAGRASS*

3.1. Overview

Given the growing adoption and use of recycled irrigation across the turfgrass industry, there is importance in understanding the effects of irrigation chemistry on N uptake efficiency as it relates to various soluble N sources. The objective of this study was to determine interactive effects of three soluble N sources (ammonium sulfate, potassium nitrate, and urea) and three irrigation water sources (reverse osmosis (R.O.) , sodic potable, and 2.5 dS^{-1} saline) on turfgrass performance and ^{15}N nitrogen uptake efficiency following foliar N fertilization. Results demonstrated that although all water and N source treatments produced above-acceptable levels of quality in Champion bermudagrass, both N and water source significantly impacted nitrogen uptake efficiency. Following an eight-hour uptake period, approximately 40 to 70% of foliar-applied N (from a 0.5 g N m^{-2} application) was recovered across all N sources. The highest uptake efficiency was noted with ammonium sulfate and urea treatments, with noticeably lower recoveries of N detected with potassium nitrate fertilization. Ammonium sulfate produced similar or improved turf quality to other N sources under R.O. and sodic potable irrigation, but reduced turf quality and green cover under saline irrigation. When water sources containing moderately high salinity levels (2.5 dS m^{-1}) are used, KNO_3 may provide the greatest turfgrass quality, however, its uptake efficiency may be lower than other N sources. The results suggest that soluble N source

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and tank mix and/or irrigation water chemistry may be important considerations for maximizing foliar uptake efficiency and minimizing potential for environmental loss.

3.2. Introduction

As availability of potable water for turfgrass irrigation declines, golf course superintendents are increasingly having to manage turfgrass using recycled or reclaimed water sources. It has been estimated that approximately 15% of U.S. golf courses are irrigated with recycled water (Gelernter et al., 2015), and in the southern U.S., it has become the predominant irrigation source, with more than 1/3 of golf courses now using recycled water for turf irrigation (Sevostianova et al., 2011; Golf Course Superintendents Association of America, 2015). Although often less expensive and having greater availability, recycled water is often of lower agronomic quality than potable water due to factors including elevated salinity, pH, sodium, and/or bicarbonates (Harivandi, 2004; Henderson et al., 2009; Throssell et al., 2009).

Irrigation chemistry has been shown to directly impact plant growth, evapotranspiration rates, and soil physical properties (Dudeck et al., 1983; Hayes et al., 1990; Qian and Mecham, 2005; Hejl et al., 2015; Schiavon and Baird, 2018). Of all water quality parameters, salinity has arguably been the most heavily studied and well documented to influence turfgrass growth. Previous research evaluating turfgrass salinity tolerance shows differences exist between species, and this is driven largely by differences in salt-resistance mechanisms (Marcum and Pessarakli, 2006; Chen et al., 2009; Sevostianova et al., 2011; Uddin et al., 2012; Pompeiano et al., 2014; Xiang et al., 2017). Chen et al., 2009 investigated growth responses and ion regulation of four warm-season turfgrasses under long-term salinity stress, found that 'Diamond' zoysiagrass (*Zoysia* *matrella* (L.) Merr.) and 'Adalayd' seashore paspalum (Paspalum vaginatum Sw.) showed improved salinity tolerance compared to 'C291' bermudagrass (*Cynodon dactylon* (L.) Pers), with each species exhibiting a specific ion regulation mechanism that either reduced Na^+ accumulation in the leaves, accumulated K in leaves, or both.

Past research has shown water chemistry, particularly pH and hardness, can affect half-life and performance of pesticides (Fishel and Ferrell, 2007; Whitford et al., 2009; Tharp 2013;). For example, water hardness can negatively impact pesticide performance due to cations such as calcium and magnesium attracting negatively charged pesticide molecules, which result in a low affiliation of pesticide to its target (Whitford et al., 2009). In addition, many pesticides are weak acids (Tharp 2013), which when mixed in an alkaline pH water, break down via hydrolysis into smaller, ineffective molecules. As such, half-life of some pesticides can be reduced from days to hours with a pH increase from 5 to 9 (Whitford et al., 2009). There have been fewer published studies on effects of irrigation/tank-mix water chemistry on soluble N availability and uptake, and these have focused on soil salinity effects on root N uptake efficiency (Bowman et al., 2007; Chang et al., 2019).

Foliar fertilization, which involves frequent, low rate application (0.25 to 0.5 g m^{-2}) of liquid N has become widely practiced by turf managers in recent years for improving fertilizer use efficiency, turf uniformity, and growth consistency (McCarty, 2005; Totten et al., 2008; Guertal 2010). A variety of soluble N sources are available for use by the turf manager in foliar feeding programs, including urea, ammonium sulfate, and potassium nitrate (Fu and Huang, 2003; Guillard and Kopp, 2004; Totten et al., 2008; Pease et al., 2011). As golf course superintendents and sports field managers become more dependent on low-quality water sources, knowledge of water chemistry effects on plant availability and uptake of N are important considerations. This is true both from a tank-mix/ foliar application standpoint, as well as with regard to irrigation effects on root zone/soil chemistry. Improved knowledge of N fertilizer and water chemistry interactions could allow superintendents to make better decisions about appropriate fertilizer N selection as well as consider alternative water sources for use in tank mixing during foliar fertilization.

Ultradwarf bermudagrasses have become the standard for warm-season putting green surfaces around the world, due to desirable attributes including darker green color, smaller leaves, and reduced seed-head production relative to older dwarf-type cultivars (Burton, 1966; Hollingsworth et al., 2005). However, with the rapid adoption of recycled water use, salinity is becoming an increasingly common concern in managing these grasses. Although there are data available for a number of warm-season turfgrasses (Marcum, 2006; Chen et al.,2009; Sevostianova et al., 2011), limited information is available regarding effects of elevated salinity on ultradwarf bermudagrasses. Baldwin et al. (2006) reported that ultradwarf bermudagrass cultivars (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy) 'TifEagle' and 'Champion' could tolerate salinity levels up to 3.2 and 8.7 dS m^{-1}, respectively.

Given the increasing practice of foliar fertilization in golf course and sports turf management, there is growing importance in determining interactive effects of irrigation and/or tank mix water chemistry and nitrogen (N) source on foliar N uptake efficiency of turfgrass. This is especially important in light of the increasing adoption of low-quality water sources for turf irrigation. This information could contribute to improved nutrient use efficiency while minimizing environmental losses of N. Therefore, the objective of this research was to determine the interactive effects of soluble N source urea (NH_2CONH_2), ammonium sulfate ($(NH_4)_2SO_4$), and potassium nitrate (KNO_3) and water source (reverse osmosis (R.O.), saline (2.5 dS m^{-1} SA) made with R.O. water + NaCl), and sodic potable (containing 200 mg L^{-1} Na, elevated bicarbonates ~500 mg L^{-1}, and pH 8.2)) on foliar N uptake efficiency in 'Champion' bermudagrass.

3.3. Material and Methods

This study was conducted in a glasshouse at Texas A&M University, College Station, TX from 5 June to 24 August 2017. The glasshouse was maintained at 30/23 ^{o}C(day/night) temperatures, with the external mean daily solar radiation levels measured at 20.5 ± 0.5 MJ m^{-2} during the study period using an quantum meter (MQ-200, Apogee Instruments, Logan UT). Multiple measurements taken prior to the study both inside and outside the glasshouse showed photosynthetic photon flux reductions of 22.1 ± 0.7%.

To initiate the study, sod plugs (10.2 cm diameter) were removed using a golf cup cutter (PAR1001-1, Par Aide, Lino Lakes, MN) from established 'Champion' bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davy) putting green research plots at the Texas A&M Turfgrass Research Field Laboratory. Sod plugs were washed free of soil and established into medium-coarse USGA spec sand [90:10 (vol:vol) sand:peat moss] in PVC columns (10.2 cm diameter × 30.5 cm deep) inside the glasshouse. A 6 mm hole was drilled at the bottom of PVC columns to allow drainage, and a Reemay cloth (Vigoro, 32128PV, Lake Forest, IL) was laid in the base of the PVC columns to prevent sand loss. All columns were maintained in a well-watered state by irrigating to saturation daily using R.O. water for the initial two weeks to ensure rapid establishment.

Following the two-week establishment, a 10-week irrigation/fertilizer source acclimation period was provided to allow plants to acclimate to the respective irrigation water and N fertilizer sources. During this time, treatments were irrigated two to three times weekly using either R.O., 2.5 dS m^{-1} Saline, or sodic potable water. Reverse osmosis water was obtained from an onsite R.O. unit. Saline water was created by mixing the appropriate amount of NaCl with the previously described R.O. water to produce the desired salinity level (Electrical conductivity (EC) = 2.5 dS m^{-1}). Potable water (tap water) was from a local municipal potable water source, which was classified as having high Na, but not salinity hazard (200 mg L^{-1} Na, elevated bicarbonates ~500 mg L^{-1}, and pH 8.4) based on United States Salinity Laboratory classification (U.S. Salinity Laboratory, 1954). Water quality analysis parameters for the 3 water sources are provided in Table 3.1.

Table 3.1 Water chemistry for the irrigation treatments used in the study, along with their respective United States Laboratory (USSL) classifications. Water chemistry include pH, Na hazard, salinity hazard, electrical conductivity (EC), bicarbonate (Bicarb), Na, Cl and sodium adsorption ratio (SAR). Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5 dS m^{-1} Saline (SA).

	USSL Classification	Na Hazard	Salinity Hazard	pH	EC (dS m^{-1})	Bicarbonate (mg L^{-1})	Na (mg L^{-1})	Cl (mg L^{-1})	SAR
RO	C1-S1	Low	Low	5.9	0	0	<1	<1	0.1
SP	C1-S4	High	Low	8.4	<1	509	234	81	33.7
2.5 dS m^{-1} SA	C2-S4	High	Medium	6.3	2.5	0	629	971	58.9

During acclimation, lysimeters were watered to saturation using their respective water source. The saturation weight of each lysimeter was then recorded and subsequently used as a target for irrigating to during each subsequent irrigation event. Two to three times weekly during the acclimation period, lysimeters were weighed and hand watered back to their respective saturation weights using the respective water sources. Because the sand-based columns were irrigated back to saturation, drainage was observed from columns for a 4-6 hour period following irrigation. In this way, the salinity of the root zone was less likely to accumulate beyond the irrigation water EC during the study period.

During the 10-week acclimation period, plants were trimmed using scissors 2-3 times weekly at 0.5 cm and received fertilization from an N-free Hoagland solution containing one of the following three different unlabeled N fertilizer source treatments: (urea (NH_2CONH_2), ammonium sulfate $(NH_4)_2SO_4$), or potassium nitrate (KNO_3)). All fertilizers were applied at 0.5 g N m^{-2} weekly combined with one of the irrigation events.

During the 10-week acclimation period, light box images were obtained weekly for determination of percent green cover using the method previously described by Chang et al., 2019. Visual turf quality ratings were also determined weekly using a 1-9 scale, with 6 = minimally acceptable quality (Morris and Shearman, 2007). Electrical conductivity (EC) of soil was also measured at the end of the 10-week acclimation period using a Fieldscout EC 110 meter (Spectrum Technologies, Aurora, IL.). Measurements were recorded at the 2.5 and 5 cm soil depths in order to evaluate the degree of salinity stress within the upper root zone.

Following the 10-week irrigation/fertilizer acclimation period, ^{15}N- labeled fertilizer solutions were prepared to include all possible combinations of inorganic N sources (urea, ammonium sulfate, and potassium nitrate) and water sources (R.O., sodic potable, and 2.5 dS m^{-1} saline) used during the ten week acclimation, but now including labeled ^{15}N. Solutions were prepared to a final ^{15}N enrichment of 3.3 atom %. Twenty-four hours following the final irrigation event, bermudagrass columns were moved indoors into a windless lab, with treatments applied using an airbrush (VL-SET, Paasche airbrush company, Chicago, IL) connected to a mini air compressor (AZTEK 50204A, Testor corporation, Rockford, IL) to supply a rate of 0.5 g N m^{-2} in a carrier volume of 511 L ha^{-1}. During fertilization, a metronome was set to a tempo of 20 beats per min, and used to ensure that each column received an identical amount of fertilizer solution. After being treated with ^{15}N-labeled fertilizer, all columns were then transferred back to the glasshouse and an uptake period of 8 hours (0900 to 1700 hrs) was then allotted for uptake of the foliar-applied fertilizer. This timeframe was chosen based on previously published work which had shown maximal foliar N uptake in creeping bentgrass (*Agrostis stolonifera* L.) occurring within 8 hours of application (Steigler, et al., 2013). Immediately after the allotted uptake period was complete, above ground tissues (shoots and verdure) were thoroughly rinsed using distilled water, blotted dry, and trimmed with scissors to the soil surface. Shoot/verdure tissues were again thoroughly rinsed using distilled water to remove any extracellular N. Tissues were then oven dried at 65 °C for 24 hours. All oven-dried tissues were ground using a Wiley Mill (Cyclotec 1093 sample mill, Tecator) with a 1-mm screen (Tecator). Ground tissues were frozen overnight, and then further milled to a fine powder with using a geno grinder (SPEX SamplePrep, Geno/Grinder 2010) operated for 20 min at 1600 rpm for preparation of determination of N uptake. Pulverized tissue samples were encapsulated in tin capsules and analyzed for total N and atom percent ^{15}N

using a Delta V isotope ratio mass spectrometer (Thermo Fisher Scientific, Waltham, MA). The atom percent excess of each sample was determined by subtracting the background atom percent ^{15}N (measured from non-treated turfgrass, with a value of 0.367 atom %) from the measured value of atom percent ^{15}N of each sample. The amount of recovered ^{15}N of each sample was calculated by multiplying dry weight with total N and atom percent excess. The final N uptake efficiency was determined as the ratio of recovered ^{15}N in plant tissue to the total ^{15}N applied.

The study was arranged as a randomized complete block design with four replicates per treatment. A factorial arrangement accommodated all possible combinations of three water sources (R.O., SP, and 2.5 dS m^{-1} SA) and three fertilizer N treatments (ammonium sulfate, urea, and potassium nitrate). Data for turf quality and percent green cover were analyzed using repeated measures analyses of variance (ANOVA). Week was used as the repeated measure, using the 'proc mixed' model in SAS 9.4 (SAS Institute, Cary, North Carolina). Data for N uptake efficiency and soil EC were subjected to two-way ANOVA using the general linear model, univariate test procedure using SAS 9.4 (SAS Institute, Cary, North Carolina) to determine statistical significance of results. Mean separation was performed using Tukey's honestly significant difference test at $P \leq 0.05$.

3.4. Results

3.4.1. Turf Quality

When pooling across all weeks of the study, Champion bermudagrass maintained above-acceptable (>6) levels of turf quality within all water source × N source treatments. The ANOVA showed that turf quality was significantly affected by N and irrigation water source (Table 3.2).

Table 3.2 Analysis of Variance for parameters measured during the study.

	N uptake	Percent Green Cover	Turf Quality	EC (2.5 cm depth)	EC (5 cm depth)
Week (W)		***	***		
Irrigation Water Source (I)	**	***	***	**	**
Nitrogen Source (N)	**	*	*	ns	ns
W × N		*	ns		
W × I		**	ns		
I × N	**	*	***	ns	ns
W × I × N		**	ns		

*Significant at *P* = 0.05 probability level
** Significant at *P* = 0.01 probability level
*** Significant at *P* = 0.001 probability level
ns = Not significant at *P* = 0.05 probability level

Slightly higher turf quality was associated with sodic potable water compared to both reverse osmosis (R.O.) and 2.5 dS m^{-1} saline irrigation, which each showed similar levels of overall turf quality (~7.7 out of 9) during the study period (Figure 3.1). There was also a significant interaction between irrigation and N source on turf quality. As such, N source had no effect on turf quality under R.O. irrigation, whereas under sodic potable irrigation, potassium nitrate and ammonium sulfate (~8.2 out of 9) supported significantly higher turf quality than urea (~7.8 out of 9). Under 2.5 dS m^{-1} saline irrigation, urea and potassium nitrate produced superior quality (~8.1 out of 9) to ammonium sulfate (~7.3 out of 9).

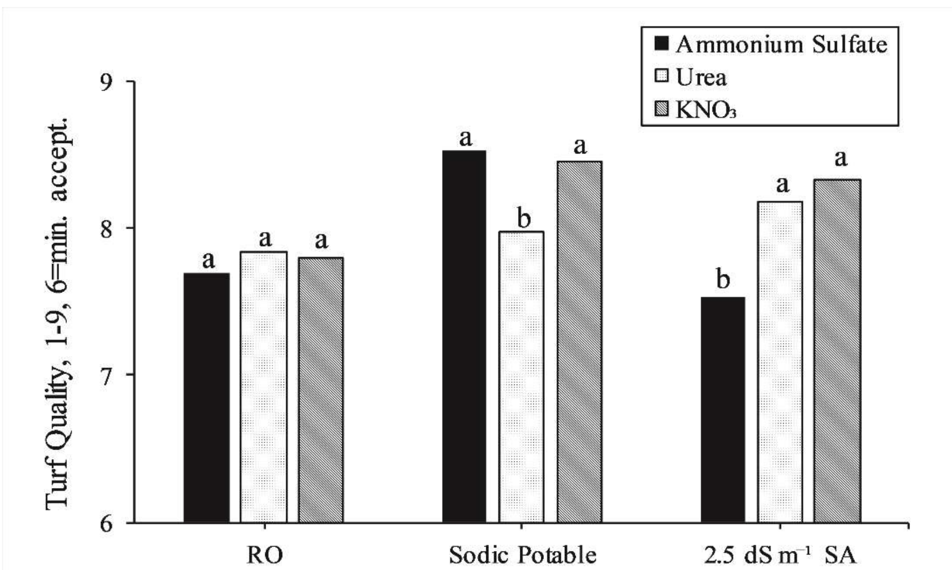

Figure 3.1 Effect of irrigation and N source on turf quality. Irrigation include reverse osmosis (RO), sodic potable, and 2.5 dS m^{-1} Saline (SA). Data are pooled across week. Means with the same letter in a given water source are not statistically different based on Tukey's HSD at P = 0.05.

3.4.2. Percent Green Cover

A week × irrigation water source × nitrogen source interaction was detected for percent green cover in this study (Table 3.2). Under R.O., the effect of N source on percent green cover was not significant (Figure 3.2). Under sodic potable water, ammonium sulfate provided the highest percent green cover, consistent with turf quality results. Under 2.5 dS m^{-1} saline irrigation, the highest percent green cover occurred with KNO_3 for most weeks, followed by urea. In comparison, percent green cover of ammonium sulfate-treated turfgrass was 10 to 20% lower than that of KNO_3 and urea-treated turfgrass during weeks 2, 8, and 9.

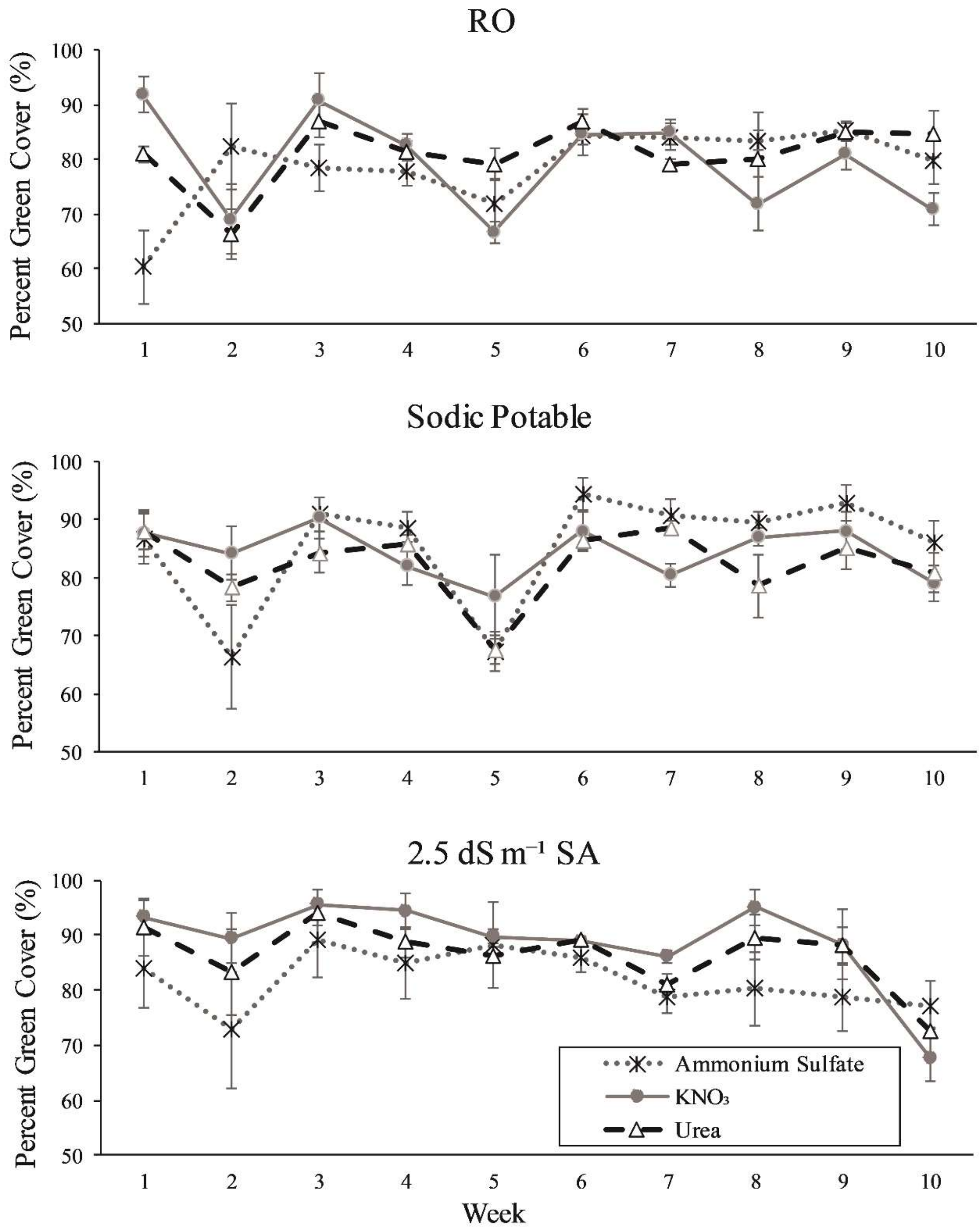

Figure 3.2 Effect of irrigation chemistry and Nitrogen source on percent green cover of pot over the study period. Irrigation include reverse osmosis (RO), sodic potable, and 2.5 dS m^{-1} Saline (SA). Bars indicate standard error.

When data were pooled across weeks, percent green cover followed a similar trend to that of turf quality, with an interaction between irrigation and N source again detected by ANOVA (Table 3.2). Bermudagrass percent green cover was unaffected by N source when irrigated with either R.O. or sodic potable irrigation (Figure 3.3). Ammonium sulfate and potassium nitrate showed slightly greater percent green cover relative to urea N under sodic potable irrigation (86.8, 86.7%, and 84.4 % green cover, respectively). Under 2.5 dS m^{-1} saline irrigation, urea and potassium nitrate led to significantly higher percent green cover than ammonium sulfate.

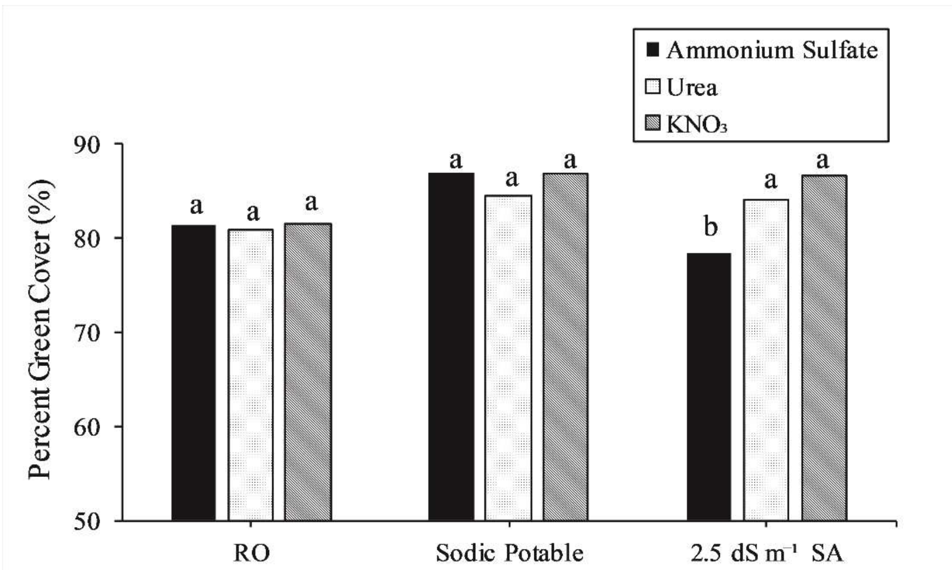

Figure 3.3 Effect of irrigation chemistry and Nitrogen source on percent green cover of pot. Irrigation include reverse osmosis (RO), sodic potable, and 2.5 dS m^{-1} Saline (SA). Data are pooled across weeks. Means with the same letter in a given irrigation are not statistically different based on Tukey's HSD at P = 0.05.

3.4.3. ^{15}N- Nitrogen Uptake Efficiency

Based on ANOVA, both irrigation and N source had significant effects on foliar nitrogen uptake efficiency of Champion bermudagrass, and an interaction between the two factors was also found (Table 3.2). Following the 8-hr uptake period, N uptake efficiency (% of N recovered relative to amount applied) ranged from 40 to 70% of applied N across all treatments (Figure 3.4). When R.O. water was used, no significant differences in N uptake were detected between N sources, with ~50% overall N uptake detected. Although not significant, a trend toward elevated uptake was seen with urea fertilization under R.O. water source. With sodic potable water, elevated N uptake was observed with ammonium sulfate, and the least uptake was noted with potassium nitrate (70 and 45% uptake, respectively). When using 2.5 dS m^{-1} saline irrigation, the highest overall N uptake (~60%) occurred with urea, while potassium nitrate resulted in the lowest uptake (~43%).

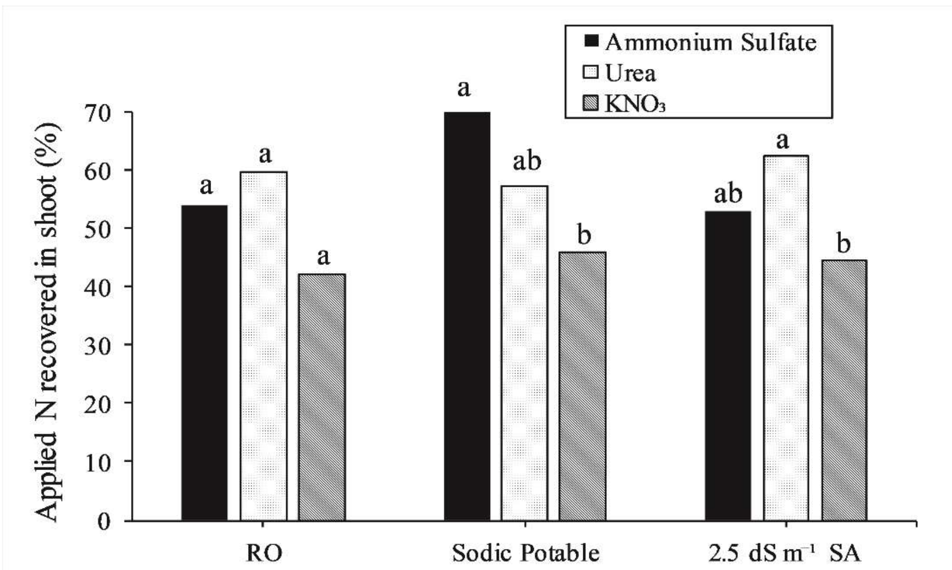

Figure 3.4 Effect of irrigation chemistry and Nitrogen source on N recovery in shoot. Irrigation include reverse osmosis (RO), sodic potable, and 2.5 dS m^{-1} Saline (SA). Data are pooled across weeks. Means with the same letter in a given irrigation are not statistically different based on Tukey's HSD at P = 0.05.

3.4.4. Soil Electrical Conductivity Levels

Irrigation water source was the only factor influencing soil salinity at both the 2.5 and 5 cm depths, with no significant differences in soil EC occurring due to the three fertilizer N sources (Table 3.2). Soil EC at both the 2.5 and 5 cm depths increased with increasing irrigation water source EC (Figure 3.5). As such, R.O.-irrigated turf showed the lowest soil EC (0.9 and 0.8 dS m^{-1} for the 2.5 and 5 cm depths, respectively), while 2.5 dS

m^{-1} saline irrigation resulted in the highest soil EC (1.5 and 1.3 dS m^{-1}, respectively, for the 2.5 and 5 cm depth).

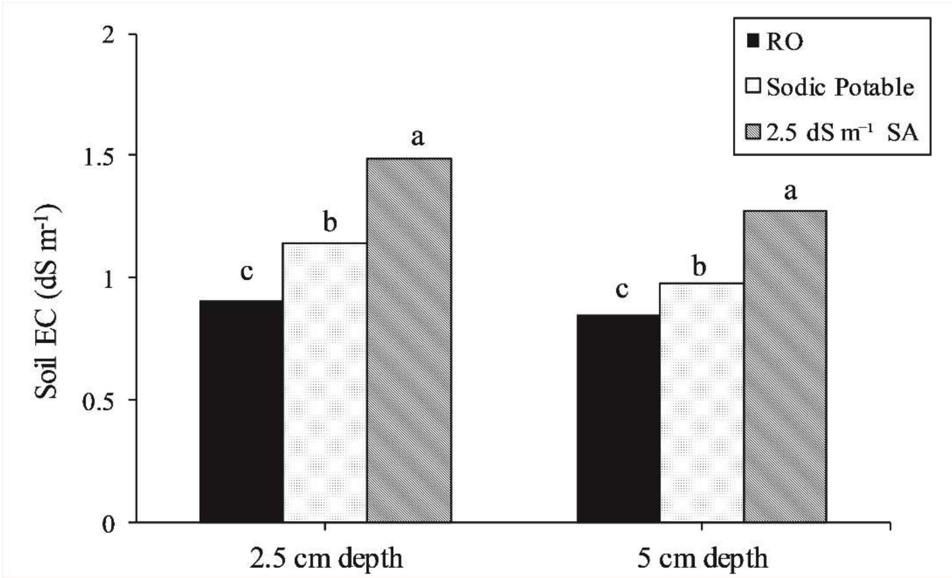

Figure 3.5 Soil electrical conductivity (EC) measured at the 2.5 cm and 5 cm depth as affected by irrigation. Irrigation include reverse osmosis (RO), sodic potable (SP), and 2.5 dS m^{-1} Saline (SA). Data are pooled across N source. Means with the same letter for each depth are not statistically different based on Tukey's HSD at P = 0.05.

3.5. Discussion

Use of recycled water for golf course irrigation is rapidly increasing in many regions of the world (Bahri and Brissaud, 1996; Candela et al., 2007; Throssell et al., 2009), and these water sources can present agronomic concerns related but not limited to elevated salinity, as well as sodium, bicarbonates, and pH. Stowell et al. (1999) showed that the EC level for recycled waters emanating from six water treatments plants in California averaged 1.1 dS m^{-1}. Asano et al., 2007 reported typical EC for recycled water was 2 dS m^{-1}. However, when precipitation is low and evaporation is high, recycled water EC may even approach levels as high as 5 dS m^{-1} (Rahman et al., 2015). Thus, the 2.5 dS m^{-1} salinity level chosen for this study was intended to present a moderate to high irrigation EC level, not atypical for many situations where recycled water is used.

Published guidelines for irrigation water quality indicate that irrigation with EC of 2.5 dS m^{-1} represents a moderate (Huck et al., 2000) to high agronomic risk (Carrow and Duncan, 1998). While data for ultradwarf bermudagrasses are limited, Baldwin et al. (2006) suggested Champion bermudagrass could tolerate EC up to 8.7 dS m^{-1} before growth reductions occurred. Our results are in agreement with these findings, as Champion bermudagrass quality appeared to be unaffected by the 2.5 dS m^{-1} EC levels used. Other common and hybrid bermudagrass cultivars have shown tolerance of EC levels of up to 5 dS m^{-1} or higher (Huck et al., 2000; Uddin et al., 2009) Chang et al. (2019) reported that Tifway bermudagrass (*Cynodon dactylon* × *C. traansvalensis* Burt Davy) root N uptake increased with increasing EC up to 5 dS m^{-1}, but decreased at 10 dS m^{-1} levels.

Our results showed that irrigation chemistry can interact with N source to affect ultradwarf bermudagrass performance as well as foliar nitrogen uptake efficiency. Thus, turfgrass managers should consider the influence of water chemistry from the standpoint of both tank-mixing fertilizer solutions as well as that of subsequent irrigation following fertilizer application. Under R.O., indicative of a high-quality water source, no differences were seen with regard to fertilizer N source for bermudagrass quality, green cover, or foliar nitrogen uptake efficiency, which suggests that N source may not be as critical where higher water quality sources are used. While R.O. is occasionally used on golf facilities, it has a very high cost (Miller, 1998), and is generally used for blending with poor quality water or solely for use on higher priority areas (Aylward 2005; Hartwiger, 2013). Under sodic potable irrigation, which was characterized by elevated pH, Na, and bicarbonates, ammonium sulfate was assimilated at similar or slightly greater efficiency, and also led to the highest quality and green cover compared to other N sources tested.

The elevated turf quality produced by ammonium sulfate under sodic potable water, which has a pH of 8.2, is indicative of the slight acidifying effect of this N source and associated benefits under high pH conditions. Ammonium sulfate has been suggested to have a stronger acidifying effect on soil pH compared to urea (Hafez and Kobata, 2012). Under 2.5 dS m^{-1} saline irrigation, ammonium sulfate led to somewhat reduced turf quality, which could be related to its higher salt index relative to the other two N sources (325.5, 161.8 and 121.8 per unit (9 kg) of nutrient for ammonium sulfate, urea, and potassium nitrate, respectively) (Kamburova and Kirilov, 2008).

Under sodic potable irrigation, nitrogen uptake efficiency of urea was comparable to ammonium sulfate, however, urea-treated turfgrasses showed lower turf quality and green cover compared to ammonium sulfate. This response may be partially related to urea metabolism in turfgrasses. Urea is only involved in plant biochemical reaction after hydrolysis to ammonia and carbon dioxide, and this conversion as well as synthesis of N reduction enzymes such as nitrate reductase and nitrite reductase has been shown to be delayed by elevated levels of sodium and/or chloride (Ashraf et al., 2018). Although not considered an essential plant nutrient, sodium has at times, been shown to be beneficial in C4 plants, able to substitute for potassium in some plant functions, and with chlorosis and necrosis observed in some plant species in its absence (Subbarao, et al., 2003). Hejl et al. (2015) reported increased evapotranspiration as well as shoot growth rates occurring with sodic potable irrigation, as compared to R.O. or 7.5 dS m^{-1} saline irrigation in Tifway bermudagrass, and although the basis for responses could not be determined, suggested that differences may have be related to elevated Na and/or bicarbonates. This agrees with the trend toward elevated quality, green cover, and N uptake observed with sodic potable water source during this study.

Under 2.5 dS m^{-1} saline irrigation, urea and potassium nitrate led to improved turf quality, percent green cover, and N uptake compared to ammonium sulfate in this study. The relatively higher salt index of ammonium sulfate compared to urea and potassium nitrate may partially explain this response, with the elevated salt index somewhat exacerbating the detrimental effects of the already saline irrigation water. While low N rates were applied during the foliar N application, ammonium sulfate was regularly applied previously during the ten-week acclimation phase. Although unlikely, it is possible that excessive ammonium could also have contributed to reduced turf quality (Britto et al., 2001; Bittsanszky et al., 2015). When turf is under salinity stress, not only is synthesis of nitrate/nitrite reductase reduced, but also glutamine synthetase/synthase production, each of which are major enzymes in the detoxification of ammonium of plants (Hossain et al., 2012; Bittsanszky et al., 2015).

A primary pathway for nutrient absorption into the leaf following foliar fertilization is through the cuticular membrane, and rates of penetration of various ions differ (Mcfarlane and Berry, 1974; Kannan, 1986). In general, cations have been shown to be more easily absorbed by foliage than anions, largely due to the presence of negatively charged carboxylic groups, especially when the concentration of solution is low (Schönherr and Huber, 1977; Scherbatskoy and Tyree, 1990; Fernandez and Eichert, 2009). While there may be some disagreement in the literature as to whether the primary means of foliar absorption occurs through transcuticular pores or stomatal openings, there appears to be general consistency with regard to higher uptake rates of positively (NH_4^+)

versus negatively (NO_3^-) charged anions (Peuke et al., 1998; Bondada et al., 2006; Schönherr, 2006). Lea-Cox and Syvertsen (1995) studied foliar uptake of ^{15}N-labeled urea and potassium nitrate by citrus leaves, and found that overall uptake of N from urea was greater than that from potassium nitrate. In the current foliar feeding study, both ammonium sulfate and urea led to greater uptake efficiency compared to potassium nitrate, highlighting the greater efficiency at which ammonium and urea N sources may pass through the cuticle during foliar N absorption.

The lower N uptake efficiency of potassium nitrate under sodic potable and 2.5 dS m^{-1} saline water could be related to the competition between Cl^- and NO_3^- during uptake and translocation in plants, which has been reported in several previous studies (Wang et al., 2012; Yu et al., 2015; Hasana and Miyake, 2017). However, the presence of K from potassium nitrate may have helped to offset this competition.

3.6. Conclusions

Given the growing adoption and use of recycled irrigation across the turfgrass industry, there is importance in understanding effects of irrigation chemistry on N uptake efficiency as it relates to various soluble N sources. This study evaluated interactive effects of three soluble N sources (ammonium nitrate, potassium nitrate, and urea) and three irrigation water sources (R.O, sodic potable, and 2.5 dS m^{-1} saline) on turfgrass performance and nitrogen uptake efficiency following foliar N fertilization. Our findings showed that although all water and N source treatments produced above-acceptable levels of quality in Champion bermudagrass, both factors significantly impacted nitrogen uptake efficiency. Following an eight-hour uptake period, approximately 40 to 70% of applied N (from a 0.5 g N m^{-2} application) was recovered across all N sources. The highest foliar uptake efficiency was noted with ammonium sulfate and urea treatments, with noticeably lower recoveries of N detected with potassium nitrate fertilization. Ammonium sulfate produced similar or improved turf quality to other N sources under R.O. and sodic potable irrigation, but reduced turf quality and green cover under saline irrigation, possibly due to its higher salt index and/or NH_4^+ accumulation. Our results suggest that when water sources containing moderately high salinity levels (2.5 dS m^{-1}) are used, KNO_3 may provide the greatest turfgrass quality, however, its uptake efficiency may be lower than other N sources, which could result in potential for greater environmental losses. While additional work should be conducted under field conditions to validate these findings, the results suggest that soluble N source and tank mix and/or irrigation water chemistry may be important considerations for maximizing foliar uptake efficiency and minimizing potential for environmental loss.

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4. EFFECT OF WETTING AGENT ON NUTRIENT AND WATER RETENTION AND RUNOFF FROM SIMULATED URBAN LAWNS*

4.1. Overview

Wetting agents have been widely used in the turf industry for ameliorating hydrophobic soil conditions and improving water use efficiency. However, limited information is available regarding potential benefits of wetting agents on fine textured soil lawns where wettable soils are commonly found, because most prior studies have been conducted in sand-based turf systems. This two-year field study evaluated the potential for wetting agents to improve turf quality, as well as to reduce runoff losses of water and nutrients from St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] lawns. Over two seasons, turfgrass quality, percent green cover, and soil moisture in plots were evaluated in response to wetting agent and fertilizer treatments. During precipitation events, total runoff volumes were measured, as well as total export of nutrients including NO_3-N, NH_4-N, total dissolved N, dissolved organic N, dissolved organic C, and PO_4-P. No runoff was detected from any treatments when precipitation was less than 13 mm. St. Augustinegrass turfgrass quality and soil moisture were slightly improved by wetting agent and fertilizer treatments during the study, but no significant effects of either of the treatments were found on runoff volumes or nutrient exports. Although turf was managed under deficit irrigation levels of 0.3 × reference evapotranspiration, irrigation events were

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not withheld due to rainfall, and thus, little to no drought stress was observed during the study.

4.2. Introduction

How to properly manage nutrients and irrigation have been major concerns for the turfgrass and ornamental industry in recent decades, especially within densely populated urban areas (Beard and Green, 1994; Carey et al., 2012; Hochmuth et al., 2012). It is estimated that 40% to 60% of residential water-use in the US is applied for irrigating landscapes, which are typically composed primarily of turfgrass (White et al., 2004). In Texas, lawn and landscape use of municipal water is significant (Cabrera et al. 2013). Due to the magnitude of use, water conservation and mitigation strategies have been used in the US to reduce domestic water usage (Ozan and Alsharif, 2013). The environmental fate of nutrients has also become the focus of government policies restricting fertilizer use (Hochmuth et al., 2012). Several potential environmental concerns have also been attributed to turfgrass management, including offsite movement of water, nutrients, and pesticides in surface and ground water and excessive use of potable water (Carey et al., 2012; King et al., 2001; King and Balogh, 2001; Racke, 2000). Management practices and/or application of products which enhance water and nutrient use efficiency could therefore aid in producing a more sustainable turfgrass system while reducing environmental impacts (Carrow et al., 2001).

Soil water repellency, or hydrophobicity, is a widespread problem for turfgrass managers, and is usually associated with sand-based turfgrass systems (Zontek and Kostka, 2012). Hydrophobicity develops due to formation of hydrophobic organic substances around soil particles associated with living or decomposing plants or microorganisms

(Doerr et al., 2000; Zisman, 1964). Although all types of soil can become hydrophobic, sandy soils tend to be more susceptible to water repellency due to their lower surface area per unit volume than finer textured soils (DeBano et al., 1970; Karnok et al., 2004).

Soil water repellency not only reduces water use efficiency but may also increase runoff volumes during rainfall or irrigation events (Doerr et al., 2003; Mitra et al., 2006). Water lost as surface runoff has the potential to transport nutrients including nitrogen, potassium, and phosphorus (Burwell et al., 1975; Göbel et al., 2007; McDowell and Sharpley, 2001). Urban storm water runoff has been considered by the US Environmental Protection Agency (EPA) to be a major factor influencing surface water (rivers, streams and lakes) quality (Hoss et al., 2016; Novotny and Olem, 1994). Nitrogen and phosphorus losses in urban runoff have received considerable attention due to their impacts on surface water quality, including contributions to eutrophication (Taylor et al., 2005; Wherley et al., 2017).

Wetting agents reduce thesurface tension of water, and thus have been widely used to reduce soil water repellency (Laha et al., 2009). Wetting agent molecules commonly consist of a lipophilic/nonpolar head and polar/hydrophilic tail, which when applied to water-repellent soil, the polar side of wetting agent molecules was bonded to water molecules and and nonpolar side was bonded to water-repellent soil, respectively, wetting soil particles (Karnok et al., 2004). Repeated applications of wetting agents are often necessary to alleviate soil water repellency. A number of wetting agents are available on the market, and Zontek and Kostka (2012) have proposed a classification system for these products based on mode of action and/or interaction with water and soil, which include anionic & anionic blends, nonionic, cationic, or amphoteric wetting agent groups.

Most commercially available wetting agents claim an ability to reduce soil hydrophobicity and/or enhance water infiltration (Karnok et al., 2004; Pelishek et al., 1962). An evaluation of ten wetting agents was conducted over nine predominantly sand-based study sites across the US, with the authors reporting efficacy for several of the selected wetting agents at reducing water drop penetration time (WDPT) across multiple study sites (Throssell, 2005). Kostka and Bially (2005) tested the synergetic effects of different wetting agent chemistries for the enhancement of hydrophilicity columns filled with water-repellent sand and reported that blends of unrelated nonionic wetting agents markedly improved infiltration over other commercial penetrant products. Most of these prior wetting agent studies have been conducted on sand-based systems, as putting greens are prone to local dry spot resulting from poor moisture retention, and limited studies have conducted on loam or clay soils typical of many lawns (Aamlid et al., 2009; Cisar et al., 2000; Leinauer et al., 2001; Soldat et al., 2010).

Given the benefits of wetting agents at improving water infiltration and consequent nutrient availability in the root zone of plants growing in coarse textured soils, there is growing commercial interest in evaluating wetting agents for use in home lawns. Application of these products may also be beneficial for lawns established on non-hydrophobic but poorly drained native soils given their reported potential to improve water infiltration and water content uniformity at greater soil depths (Lehrsch et al., 2011; Lowery et al., 2002; National Cooperative Soil Survey).

With a hypothesis that applying wetting agent can improve turf quality and allocate more water and nutrient in the soil, the objectives of this research were to 1) evaluate the potential of wetting agents to improve turf performance and 2) test the effect of wetting agents on water and nutrient conservation, in terms of soil moisture content and the losses of water and nutrients in runoff from St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] lawns.

4.3. Material and Methods

This study was conducted at the Urban Landscape Runoff Facility located at the Texas A&M University Soil and Crop Sciences Field Research Laboratory, College Station, TX. The first study period was from 15 June 2015 to 26 Oct. 2015, and the second study period was from 21 July, 2016 to 6 Dec. 2016 (each year comprised 21 weeks). The facility consisted of 24 individually irrigated plots (each 4.1 m x 8.2 m) with 3-4 year old 'Raleigh' St. Augustinegrass established on a 3.7 +/- 0.5% slope atop a relatively undisturbed Boonville fine sandy loam soil (fine, smectitic, thermic, Chromic Vertic Albaqualf). Four soil samples were randomly taken at the depth of 10 cm on each plot using a 2 cm wide soil sampler probe (TSS2-S, Turf-Tec International) prior to the initiation of the study, and samples were sent to Texas A&M University soil testing lab for nutrient analyses. All soil samples were oven dried at 65 ^{o}C for at least 16 hours. Following oven drying, samples were pulverized using a soil grinder (Agvise Laboratories, Benson MN), and all particles that cannot pass a 2 mm soil sieve were removed. An extracted soil solution with a ratio of 1:2 (soil: deionized water) was used to determine soil pH using a pH meter (Model 215, Denver Instrument, Bohemia Ny). P, K, Ca, Mg, Na and S were extracted using the Mehlich III extractant (a dilute acid-fluoride-EDTA solution of pH 2.5 that consists of 0.2 N CH_3-COOH, 0.25 N NH_4NO_3, 0.015 N NH_4F, 0.013 N HNO_3, and 0.001 M EDTA) and were determined by Inductively coupled plasma spectroscopy. Organic C were determined by a combustion procedure. Soil testing report showed average of 1.95 g kg^{-1} organic C, pH 6.9, and adequate levels of soil P (190 g kg^{-1}), K (217 g kg^{-1}), Ca (1243 g kg^{-1}), Mg (117 g kg^{-1}) (for reference, the critical levels provided by the soil testing report are P (50 g kg^{-1}), K (175 g kg^{-1}), Ca (180 g kg^{-1}), Mg (50 g kg^{-1})) , which likely resulted from prior use of the area as a dairy research farm.

Prior to the initiation of the study, water droplet penetration time (WDPT) testing was conducted at the 2.5 and 5 cm soil depths for plots that were assigned for all treatments, according to the method of Bisdom et al. (1993). Four 15 cm soil cores were randomly collected from each plot using a soil sampler probe (TSS2-S, Turf-Tec International). In the field, one water drop was placed on the exposed soil core at 2.5 and 5 cm soil depths. The time that the water drop fully penetrated the soil core was recorded and averaged for each plot.

Each plot was equipped with a flow meter (ISCO 4210, Teledyne Isco, Lincoln NE) and auto-sampler (ISCO 6712, Teledyne Isco, Lincoln NE), installed at the end of a flume that was attached to a runoff collection trough at the base of each plot. This setup allowed for measurement of runoff flow rate as well as the collection of runoff samples during runoff events, whether occurring due to precipitation or irrigation. A detailed description of the facility was published (Wherley et al. 2014).

Temperature data (average ºC) were obtained from Weather Underground archives for station KCLL in 2015 and an on-site weather station in 2016. Rainfall volumes (mm) were measured on site using a tipping rain gauge (Isco 647, Teledyne Isco, Lincoln, NE) at a two minute temporal resolution.

In an effort to produce moderate soil moisture stress in plots, turfgrasses were irrigated once weekly at a rate of 30% of historical (30-year) reference evapotranspiration

($30\% \times ET_o$) for the City of College Station, based on data from the Texas ET network (Texaset.tamu.edu). For reference, the consumptive water requirement for most warm-season turfgrasses including St. Augustinegrass is ~$0.6 \times ET_o$ (Wherley et al., 2015). Analysis of applied irrigation water was as follow: pH (8.4), Bicarbonate (509 mg L^{-1}), Na (234 mg L^{-1}), Cl (81 mg L^{-1}), sodium adsorption ratio (33.7). The irrigation volumes alone were not sufficient to induce runoff from plots and so data presented are the result of runoff derived from precipitation. Rainfall was not accounted for during irrigation application; thus the experiment mimicked a 'set-it and-forget-it' practice common among urban lawn landscapes in the region. Plots were mowed up to 2 times weekly at 7.6 cm height of cut during the study period, with clippings returned to their respective plots. Oxadiazon (Ronstar G, Bayer, Research Triangle Park, NC) was applied to all plots at 4 kg a.i. ha^{-1} in Mar. of each season to prevent annual weed encroachment. For fall disease prevention, pyraclostrobin + triticonazole (Pillar G Intrinsic Brand Fungicide, BASF, Research Triangle Park, NC) was applied to all plots during Oct. and Nov. at a rate of 14.7 g m^{-2}.

The study was arranged as a randomized complete block design with 4 replicate plots per treatment. Treatments were arragned as a 2×2 factorial design with wetting agent (WA) and fertilizer (Fert) as the main factors. Wetting agent (WA) (Everydrop, Scotts Miracle-Gro, Marysville, OH) were applied 4 times annually at either 0 or 0.9 g a.i. m^{-2} per application, and urea and ammoniacal based fertilizer (Fert) (32N–0P–8.3K) applied twice annually at 0 or 4.5 g N m^{-2} per application (Table 4.1).

Table 4.1 Application date of fertilizer and wetting agent for 2015 and 2016. wk = week.

Product	Application Time					
	2015					
Fertilizer	5 June (wk 1)		14 July (wk 6)			
Wetting agent	5 June (wk1)	2 July (wk 5)	28 July (wk 9)	27 Aug. (wk 13)	22 Sept. (wk 17)	21 Oct. (wk 20)
	2016					
Fertilizer	21 July (wk 1)		22 Sept. (wk 9)			
Wetting agent	21 July (wk 1)	18 Aug. (wk 5)	15 Sept. (wk 9)	13 Oct. (wk 13)	10 Nov. (wk 17)	

Thus, four treatments were included in this study (1. Both Fert and WA applied, 2. Only Fert applied, 3. Only WA applied, and 4. Control). Fertilizer and wetting agent treatments were applied using a drop spreader (Turf Builder 76565, Scotts Miracle-Gro, Marysville, OH) and incorporated with 0.3 cm irrigation.

Measurements for turfgrass quality, turfgrass coverage, and soil volumetric water content were recorded on the day prior to irrigation and again 2 days post irrigation. Turfgrass quality was visually evaluated using a 1-9 scale, with 1 representing poorest or completely dead grass, 9 representing outstanding turf with perfect green color and density, and 6 being minimally acceptable quality (Morris and Shearman, 2007). In addition, light box images were taken twice weekly on Tuesdays and Fridays for evaluation of percent green cover in a randomly-selected location within each plot using a Nikon Coolpix 7100 digital camera (Nikon Co. Minato, Tokyo, Japan) mounted on a 0.6 x 0.6 m square light-box equipped with four compact fluorescent bulbs. Images were analyzed for percentage green cover using SigmaScan version 5.0 (Systat Software Inc., San Jose, California) and a batch analysis macro with hue and saturation settings of 45 to 120 and 0 to 100, respectively. (Karcher and Richardson, 2003; Karcher and Richardson, 2005; Richardson et al., 2001). Percentage green cover data were normalized by dividing all values by the maximum coverage value with a given date. On Tuesdays and Thursdays, 0-5 cm soil volumetric water content was measured at four random locations in each plot (two located within upper half and two in lower half of each plot using a hand-held soil moisture meter with a 5 cm probe (Fieldscout TDR 300, Spectrum Technologies Inc., Aurora IL), and the plot soil volumetric water content was the average of four measurements.

Flow meter triggered collection of a runoff sample after every 0.13 cm (37.8 L) of runoff. Total runoff volume (L) of each event was determined. Aliquots of the runoff samples from each plot were vacuum filtered through 0.7 µm nominal pore size glass microfiber filters (Ahlstrom, Munksjo Filtration LLC, Madisonville, KY) to provide sediment removal and rapid flow rate. Electrical conductivity (EC) of unfiltered runoff samples were measured for each runoff event with a portable EC meter (C65, Milwaukee Instruments Inc, Rocky Mount, NC). Filtered runoff samples were used to measure concentrations of NO_3-N, NH_4-N, and PO_4-P by using a discrete wet chemistry analyzer (SMARTCHEM 200, Unity Scientific, Brookfield, CT). Colorimetric with automated Cd-Cu reduction (Method: EPA 353.2), colorimetric automated phenate (Method: EPA 350.1), and colorimetric automated ascorbic (Method: EPA 365.1) were used to measure NO_3-N, NH_4-N, and PO_4-P, respectively. Concentrations of total dissolved nitrogen (TDN) and non-purgeable dissolved organic carbon (DOC) were measured using high temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX). Because a direct measurement of dissolved organic nitrogen (DON) was not achievable, DON was derived by subtracting NO_3-N and NH_4-N (inorganic form) from TDN. Nutrient exports were calculated by multiplying average nutrient concentrations for each plot and runoff event by the total runoff volume and then dividing by the plot area.

Data for all parameters were analyzed using repeated measures analyses of variance (ANOVA). Sample date was used as the repeated measures, using the ‘proc mixed’ model in SAS 9.4 (SAS Institute, Cary, North Carolina) to determine statistical significance of results. Data were analyzed and presented by years. Means were separated following Tukey's HSD test at $P \leq 0.05$.

4.4. Results

4.4.1. Water Droplet Penetration Time

At the initiation of the study, water droplet penetration time was less than 1 s for all treatments at the 2.5 cm depth, and ranged from 4.9 to 6.5 s at the 5 cm depth. Based on the classification of water repellency developed by Bisdom et al. (1993), soils at the 2.5 cm depth would be considered wettable while the 5 cm depth would be considered slightly water repellent.

4.4.2. Environmental Conditions

Weekly average air temperature ranged from 20 to 30^{o} C in 2015. For 2016, air temperatures averaged between 20 to 30° C for the initial 12 weeks, but reduced after week 13 through the remainder of the study (Figure 4.1). Weekly average ET_o were greater for 2015 study period than 2016 study period for most weeks, with a range of 2.0 to 7.5 mm and 1.3 to 6.6 mm for 2015 and 2016, respectively (Figure 4.1).

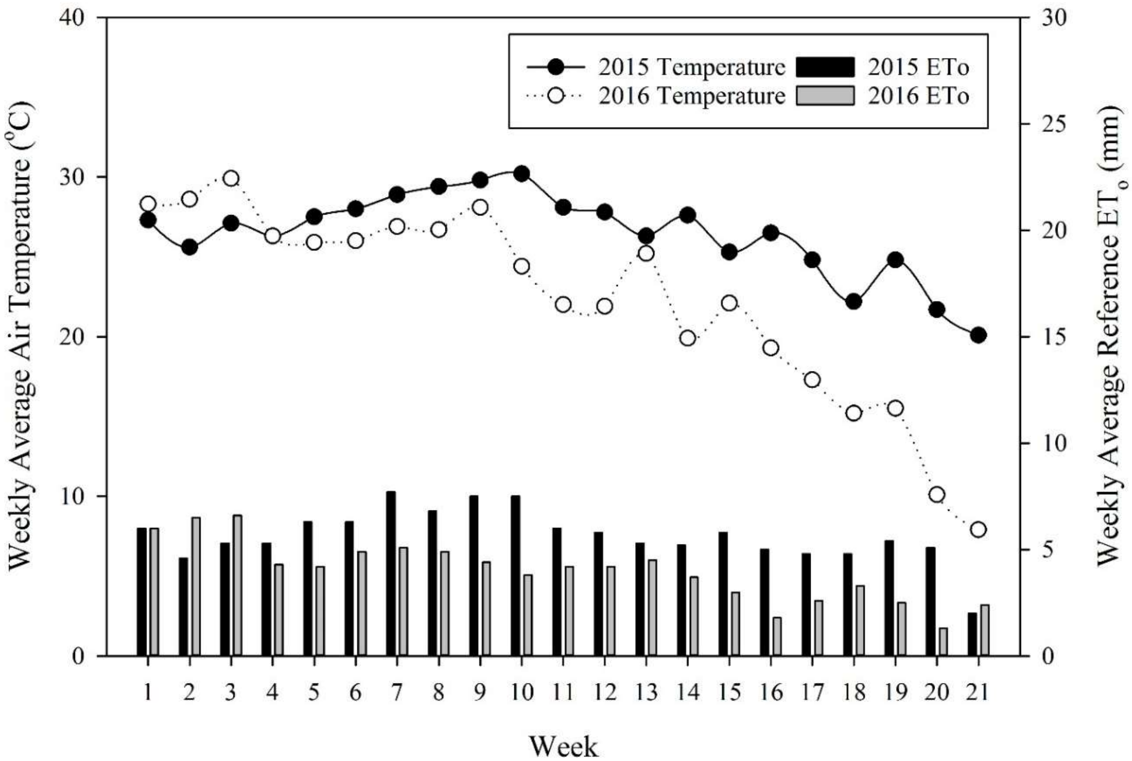

Figure 4.1 Weekly average air temperatures (°C) and reference evapotranspiration (ET_o, mm) during the study periods for two years. The 2015 study was conducted from 5 June to 26 Oct., while the 2016 study was conducted from 21 July to 6 Dec. Data were obtained from an onsite weather station.

Precipitation is presented as weekly cumulative precipitation rather than daily precipitation during the study period for both years, because several rainfall events lasted for several days and runoff was only measured after rainfall had completely stopped. Precipitation patterns varied each year (Figure 4.2). Total precipitation for the 2015 study period was 379 mm, which was less than the 35-year historical average (417 mm) for the time period at the location. Precipitation events were erratic in 2015, with relatively little rainfall between weeks 5 and 20 before a rain event resulting in 190 mm of water during week 21 (Figure 4.2). For 2016, rainfall was 7% greater than normal for the 21-week study period (452 vs. 421 mm). Several heavy rain events leading to weekly cumulative precipitation greater than 50 mm occurred during 2016 (Figure 4.2). Reduced ET_o resulted from lower temperatures and greater precipitation in 2016 creating an overall wetter season compared to 2015.

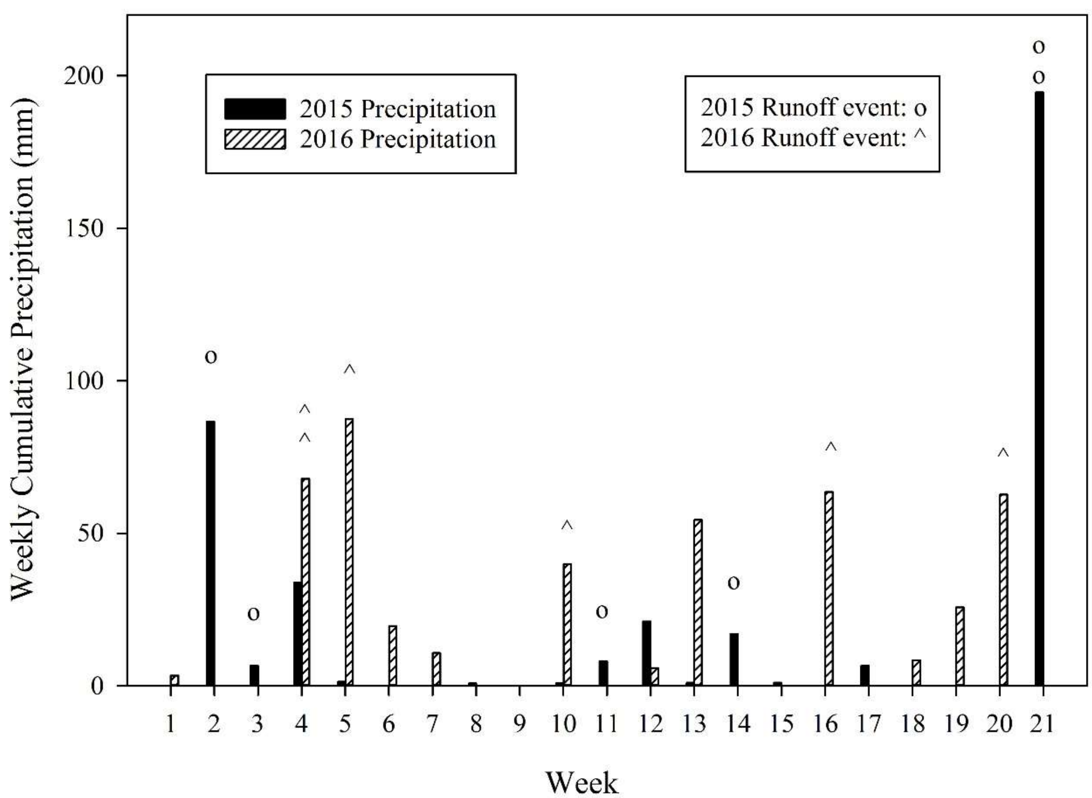

Figure 4.2. Weekly cumulative precipitation (mm) and all runoff events detected in 2015 and 2016. The 2015 study was conducted from 5 June 2015 to 26 Oct. 2015, while the 2016 study was conducted from 21 July 2016 to 6 Dec. 2016. For 2015: O = 1 runoff event and 2 x O = 2 runoff events for that week. For 2016: ^ = 1 runoff event and 2 x ^ = 2 runoff events for that week.

4.4.3. Treatment Effects on Soil Moisture

Effect of wetting agent and fertilizer on soil moisture, turfgrass quality, percent green cover, and runoff volumes for both years are presented in Table 4.2.

Table 4.2 Repeated measurement analysis of variance (ANOVA) for turf canopy and soil moisture parameters measured during the study for both years. Vol = Volume; D= measuring date; WA= Wetting Agent; F= Fertilizer.

	ANOVA							
	Soil Moisture		Runoff Vol		%Green Cover		Turfgrass Quality	
Source	2015	2016	2015	2016	2015	2016	2015	2016
Date (D)	***	***	***	***	***	***	***	***
Wetting Agent (WA)	NS	*	NS	NS	NS	***	**	***
Fertilizer (F)	NS	*	NS	NS	***	**	*	***
D ×WA	NS	NS	NS	NS	NS	NS	NS	NS
D × F	NS	NS	NS	NS	NS	NS	NS	NS
WA × F	***	*	NS	NS	NS	NS	NS	NS
D × WA × F	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at $P = 0.05$ probability level
** Significant at $P = 0.01$ probability level
*** Significant at $P = 0.001$ probability level
NS = not significant at $P = 0.05$ probability level

Analysis of variation indicated an interaction between wetting agent and fertilizer on soil moisture for both years. As such, wetting agents influenced volumetric water content differently within each fertilizer level, but under each fertilizer level, wetting agents result in similar volumetric water content as untreated plots during both years (Figure 4.3). Overall soil volumetric water content for all treatments was also noticeably lower in 2015 than 2016 (30 vs. 40% mean volumetric water content for 2015 and 2016 rating dates, respectively (Figure 4.3).

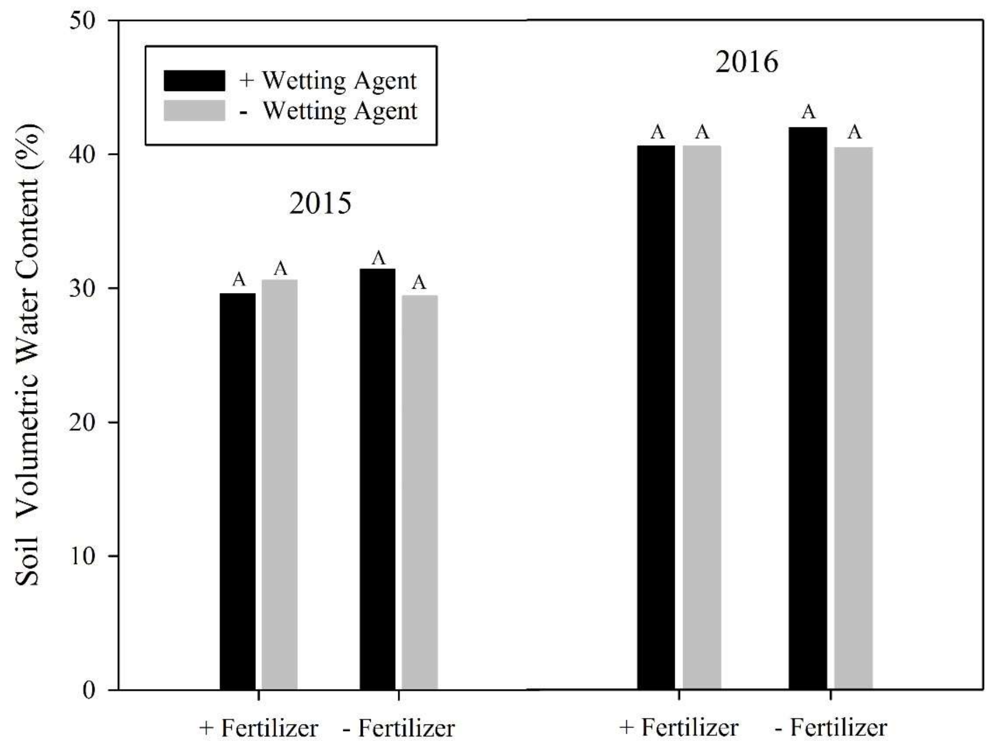

Figure 4.3 Effect of wetting agent and fertilizer on soil volumetric content (%) during the study period in 2015 and 2016. Means were compared at each fertilizer level in each year with Tukey's HSD at P= 0.05. Same letter means no significant difference.

Soil water content differences between years likely resulted from greater precipitation amounts and low ET_o during the 2016 study period (Figures 4.1 and 4.2).

4.4.4. Treatment Effects on Runoff Volumes

No significant differences in runoff volumes were detected during the study due to wetting agent or fertilizer treatments (Table 4.2). Rather, runoff differences occurring from the St. Augustinegrass plots were only affected by date, primarily due to differences in rainfall intensity and soil moisture content between runoff dates (Figure 4.2 and Table 4.2). Although 14 total precipitation events occurred during 2015 and 12 during 2016, only six of the precipitation events each year generated runoff (Figures 4.2 and 4.4).

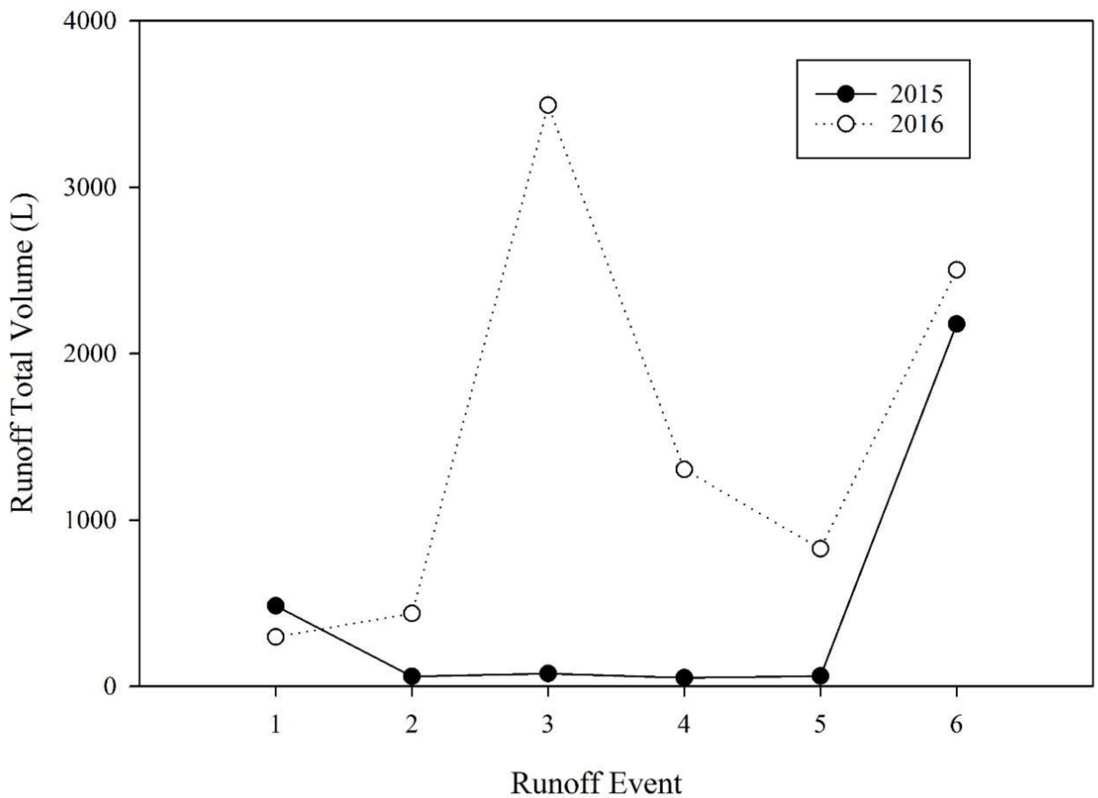

Figure 4.4 Total runoff volumes occurring with measured rain events during both years. For reference, total precipitation occurring with each event is noted in the figure. Dates for each event are as follows: (2015) 1= 17 June (week 2), 2= 19 June (week 3), 3= 12 Aug. (week 11), 4= 23 Sept (week 14), 5= 20 (week 21), 6= 26 Oct. (week 21); (2016) 1= 16 Aug. (week 4), 2= 19 Aug. (week 4), 3= 23 Aug. (week 5), 4= 24 Sept. (week 10), 5= 7 Nov. (week 16), 6= 6 Dec. (week 20).

In general, precipitation events greater than 13 mm were required to generate measurable runoff. The greater rainfall which occurred in 2016 compared to 2015 resulted in greater runoff volumes in 2016 than in 2015 (Figures 4.2 and 4.4). The greatest runoff volume of 2016 (~3500 L), was associated with runoff event 3 that was measured on week 5, following two weeks of intensive rainfall (weeks 4 and 5), whereas the greatest runoff volume of 2015 (~2200 L) was associated with runoff event 6 when a 190 mm rain event occurred, detected on week 21 (Figures 4.2 and 4.4).

4.4.5. Treatment Effects on Turfgrass quality and Percent Green Cover

St. Augustinegrass turfgrass quality was affected by wetting agent and fertilizer treatments during the study (Table 4.2). For turfgrass quality and percent green cover, no interaction of main effects was measured. Therefore, the influence of wetting agent and fertilizer levels are presented by main effects. However, although an effect of fertilizer was detected on turfgrass quality (Table 4.2), no differences were observed between fertilized and unfertilized plots in 2015. Fertilized plots resulted in greater turfgrass quality than unfertilized plots in 2016, with values of 8 and 7.5 for fertilized and unfertilized plots, respectively (Figure 4.5). In comparison, wetting agent application as a main effect led to increased turfgrass quality for both years (Figure 4.6).

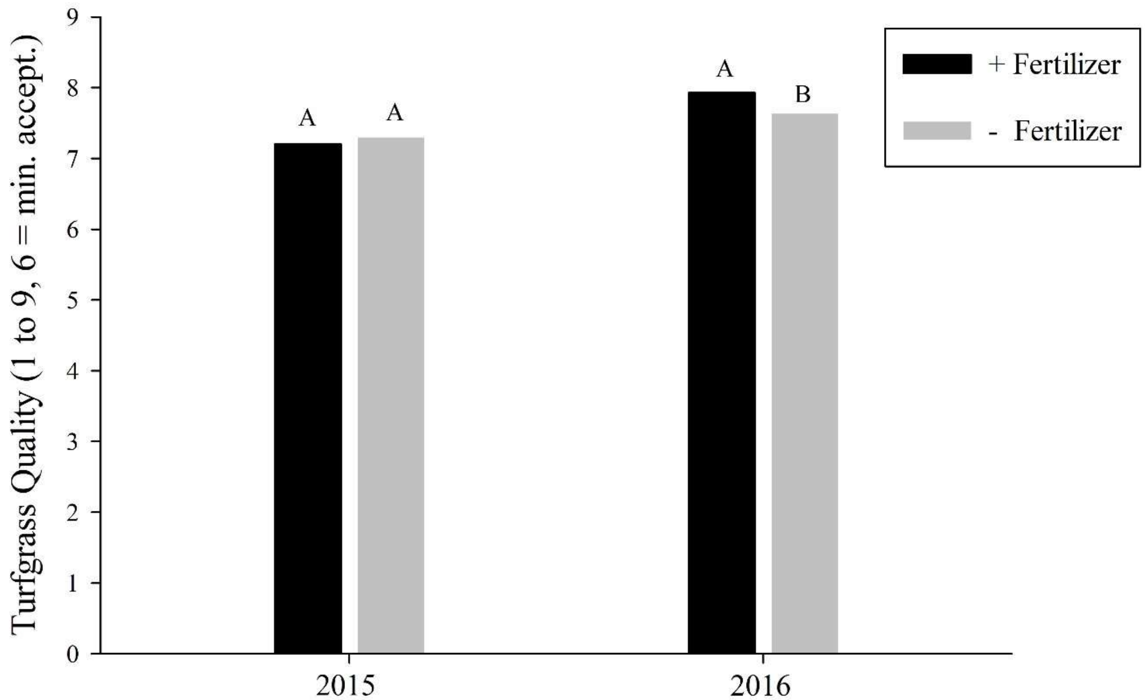

Figure 4.5 Turf quality as affected by fertilizer during the study period in 2015 and 2016. Data are pooled across weeks. Means with the same letter in a given year are not statistically different based on Tukey's HSD at P = 0.05.

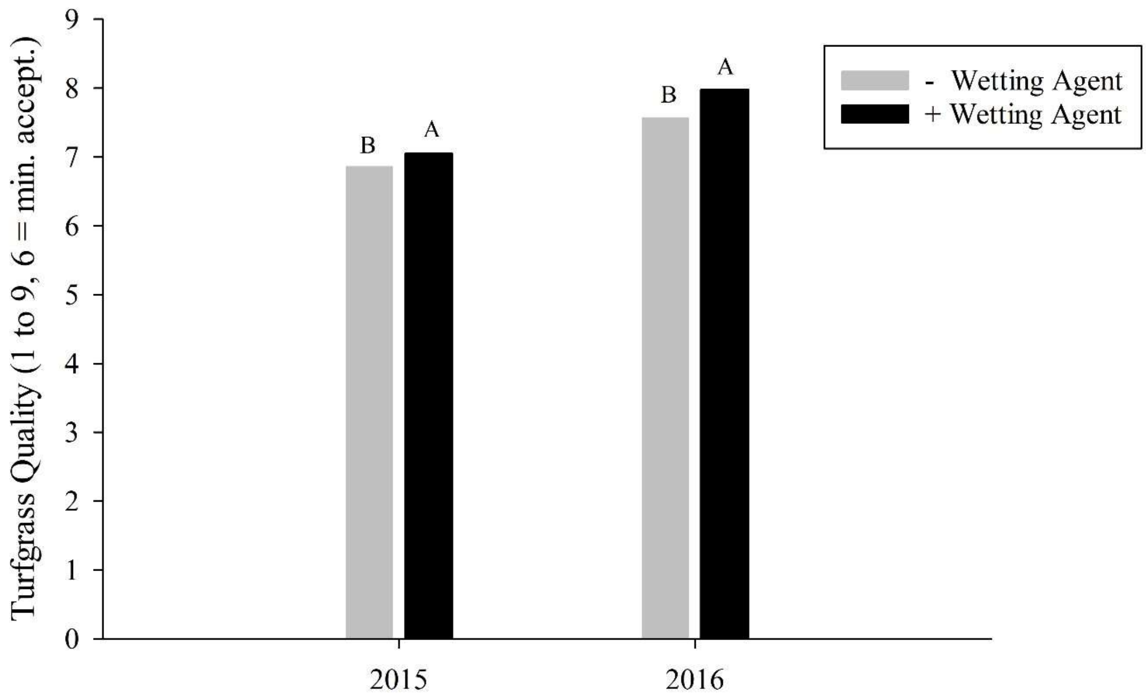

Figure 4.6 Effect of wetting agent on turf quality in 2015 and 2016. Data are pooled across weeks. Means with the same letter in a given year are not statistically different based on Tukey's HSD at P = 0.05.

In 2015, wetting agents resulted in a turfgrass quality of 7.1, compared to non-treated plots, which averaged 6.8 in value. In 2016, the turfgrass quality rating value was 8 and 7.6 for wetting agent-treated and non-treated plots, respectively. Despite the deficit levels of supplemental irrigation (0.3 × ET_o), turfgrass quality for all treatments remained above the minimally acceptable level both years due to periodic rainfall events occurring during the study period.

Percent green cover was affected by fertilizer both years, and by wetting agent in 2016. Despite a statistical difference, fertilizer treatments had only minimal effect on percent green cover, with 87 and 89% for unfertilized and fertilized plots, respectively (data is not shown in figure). Percent green cover was increased by the application of wetting agent, especially in the absence of fertilizer (Figure 4.7). Wetting agent application resulted in greater percent green cover, with 91 and 85% green cover for wetting agent treated and non-treated plots, respectively (Figure 4.7).

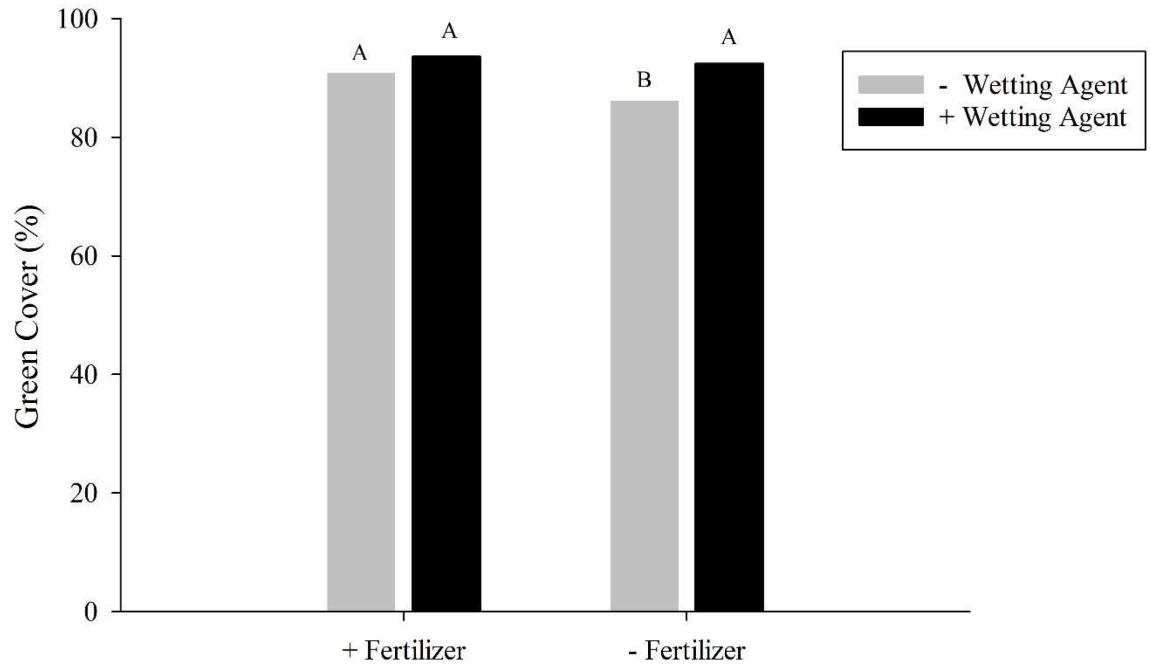

Figure 4.7 Effect of wetting agent and fertilizer on plot percent green cover during 2016. Means with the same letter are not statistically different based on Tukey's HSD at P = 0.05.

4.4.6. Runoff Nutrient Exports

The main effects of wetting agent, fertilizer, and their interaction on nutrient exports in runoff are shown in Table 4.3.

Table 4.3 Repeated measurement analysis of variance (ANOVA) for chemical exports measured during runoff events in 2015 and 2016.

	ANOVA (export)											
	NO_3-N		NH_4-N		TDN		DON		DOC		PO_4-P	
Source	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Date (D)	***	**	***	***	***	***	***	***	***	***	**	***
Wetting Agent (WS)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer (F)	NS	NS	*	NS	*	NS	*	NS	*	NS	NS	NS
D × WA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D × F	NS	NS	NS	NS	**	NS	**	NS	**	NS	*	NS
WA × F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D × WA × F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at $P = 0.05$ probability level
** Significant at $P = 0.01$ probability level
*** Significant at $P = 0.001$ probability level
NS = not significant at $P = 0.05$ probability level

Results showed that NO_3-N exports in runoff were not affected by wetting agent or fertilizer treatments. However, there was a main effect of fertilizer on NH_4-N export in runoff detected in 2015. As such, fertilization increased NH_4-N export in runoff to 16 mg m^{-2}, and in comparison, that of unfertilized plots was 5 mg m^{-2} (Figure 4.8).

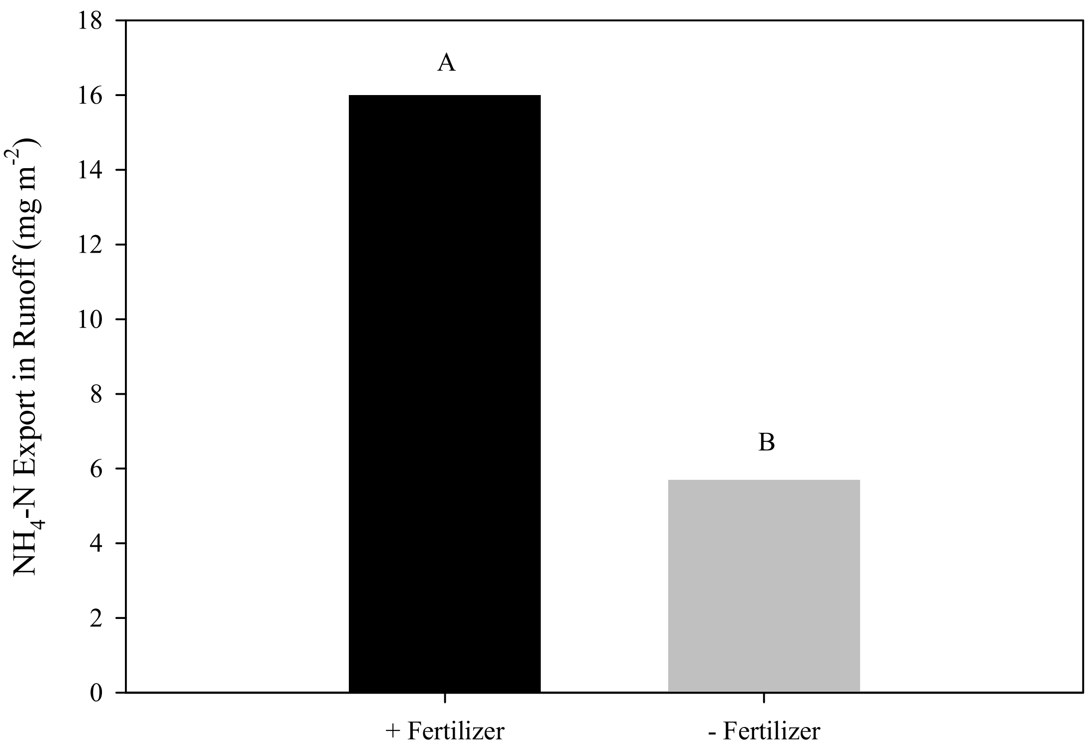

Figure 4.8 Effect of fertilizer on NH4-N export in runoff during 2015. Data were pooled across all runoff events. Means with the same letter are not statistically different based on Tukey's HSD at P = 0.05.

For TDN and DON, an interaction between date and fertilizer was observed in 2015. In 2015, TDN exports in runoff differed due to fertilizer treatment on two of six runoff dates when fertilizer was applied before the runoff event, or runoff intensity was significantly high (Figure 4.9a). Specifically, fertilized plots had greater TDN exports on both the initial (80 vs. 40 mg m^{-2} for fertilized and unfertilized, respectively) and final (700 vs. 200 mg m^{-2} for fertilized and unfertilized, respectively) runoff dates in 2015. No main effect of wetting agent or fertilizer were found on TDN in 2016. The interaction between date and fertilizer on TDN and DON found in 2015 was also not found in 2016.

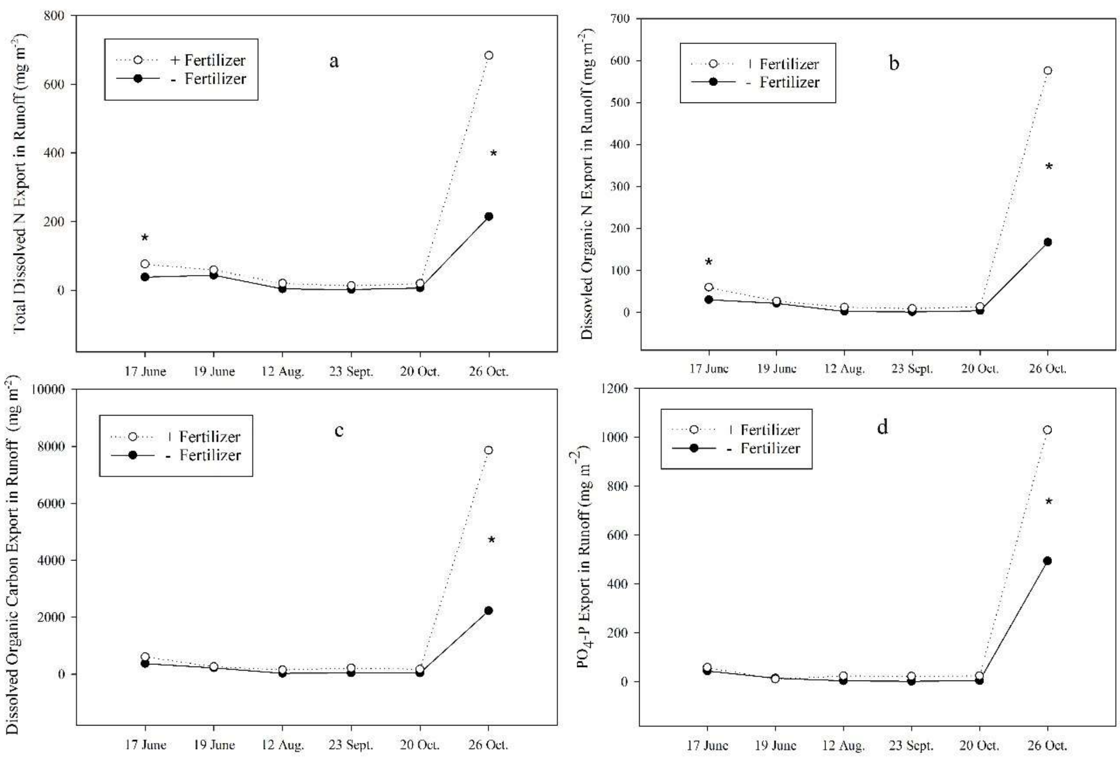

Figure 4.9 Effect of Fertilizer on total dissolved N, dissolved organic N, C, and PO_4-P export in runoff during each runoff event in 2015 season. Data are pooled across surfactant treatment. * indicate a significant mean difference between fertilizer treatment based on Tukey's HSD at P =0.05.

Effects of wetting agent and fertilizer on DON and DOC were similar to that of TDN exports during both years of the study (Table 4.3), which is not surprising given that organic nitrogen was the largest fraction of TDN and it was also related to DOC. Dissolved organic nitrogen represented 70-90% of all N exports during runoff events in 2015, and greater DON export was associated with fertilized rather than unfertilized plots on two of six dates (Figure 4.9b). A similar pattern was found for DOC in 2015, but a significant difference between fertilized and unfertilized plots was only found on 26 Oct. 2015 (Figure 4.9c).

Total PO_4-P exports were not influenced by wetting agent or fertilizer treatments (Table 4.3). In 2015, PO_4-P exports for all plots averaged less than 60 mg P m^{-2} per event for the first five runoff events, and PO_4-P export from fertilized plots were greater than from unfertilized plots on the final (26 Oct. 2015) event (1029 vs. 494 mg P m^{-2} for fertilized and unfertilized plots, respectively) (Figure 4.9d).

4.5. Discussion

Wetting agents have been widely used in the turf industry for ameliorating hydrophobic soil conditions and improving water use efficiency. This study evaluated runoff, soil moisture, and turf canopy responses to wetting agent applications on a fine sandy loam soil with little to no detectable hydrophobicity at the onset of the study. No benefits from wetting agent were observed in terms of reduction in runoff. Previous studies have also shown limited effects of wetting agents on improving water retention and reducing runoff from non-hydrophobic soils (Lehrsch et al. 2011; Miller et al. 1975; Mitra et al. 2006; Miyamoto, 1985). For example, a controlled laboratory experiment found wetting agents did not affect runoff from three wettable soils for which water droplet penetration times were less than 5 s (Lehrsch et al., 2011). Another study evaluating the effect of wetting agent on runoff of irrigation water found that application of a widely used wetting agent (Dispatch, Aquatrols, Paulsboro, NJ) reduced total irrigation runoff relative to controls, however, subsurface seepage was identified as contributing to these differences (Mitra et al., 2006). It has been suggested that wetting agents may influence soil moisture through affecting dynamics of water movement in the soil. Miller et al. (1975) evaluated wetting agent effects on water infiltration through wettable and water-repellent soils and noted that while infiltration rate was constant for wettable soils treated with wetting agent, an initial decrease and subsequent sharp increase in infiltration rate was observed for wetting agent-treated water-repellent soils, reflecting the benefits of wetting agent. Similarly, it has been reported that application of several selected wetting agents actually reduced infiltration time by 10 to 15% in the initial irrigation event following application to wettable soils (Miyamoto, 1985). Based on our results and those of other researchers', we postulate that although soil volumetric content and surface runoff volumes may not be affected by wetting agents, wetting agents may improve water holding capacity of soil by reducing leaching or deep percolation of water below the root zone, thus increased turfgrass quality as a result of greater water use efficiency by plants.

Several studies have confirmed the positive benefits of wetting agents on turfgrass quality; however, the majority of these studies have been on sand-based systems (Barton and Colmer, 2011; Kostka, 2000; Leinauer et al., 2007; Miyamoto, 1985; Soldat et al., 2010). Schiavon et al. (2014) reported turfgrass quality of *Cynodon dactylon* L. 'Princess 77' and *Paspalum vaginatum* Swartz 'Sea Spray' was not improved by wetting agent application and hypothesized that the negative effects of the saline irrigation water used may have offset beneficial effects of wetting agents. Although the irrigation water used in our study was sodic (SAR > 15), application of wetting agent provides turfgrasses a greater opportunity to maintain a high quality over a longer period of time.

The observed increase in turf quality due to wetting agent, even though practically speaking the difference is of little value, could also be related to effects on plant nutrient uptake. Chaichi et al. (2017) evaluated the effects of wetting agents on nutrient uptake efficiency of 'Bush Beefsteak' tomato plants, and reported that wetting agents aided uptake of N and K in saline soils. Similarly, a study testing growth of *Argyranthemum coronopifolium* (daisy) on wetting agent treated peat found that plant Ca uptake was increased by the wetting agent (Cid-Ballarin et al., 1998). However, since effects of wetting agents on either turfgrass foliar or root uptake of nutrients were not directly measured in this study, these need to be confirmed through future studies.

In established turf, runoff losses of N can be relatively low compared to other pathways (Sebilo et al., 2013), which may explain why differences due to wetting agent were difficult to detect. Shuman (2002) measured N and P runoff losses following fertilizer applications to simulated 'Tifway' bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy) golf course fairways and found that total nitrate-N loss via runoff 7 days after fertilization was 1.5 and 0.9% of applied for both 12 and 24 kg N ha^{-1} application rates, respectively. Similar results were reported by Cole et al. (1997), who applied N as either urea or sulfur-coated urea to bermudagrass at 49 kg N ha^{-1} and reported runoff N losses of only1.8% of NO_3-N and 2.1% of NH_4-N from sulfur-coated urea and 2.4% of NO_3-N and 6.4% of NH_4-N from urea. In addition, a study conducted at the same study site as ours examined the effects of fertilizer and irrigation regimes on NO_3-N export and reported that NO_3-N exports in runoff from the system were predominantly driven by water inputs, especially during winter and early spring when soil moisture was high and turf growth was minimal (Fontanier et al., 2017).

In this study, the effect of wetting agent on reducing nutrient and water losses through runoff was not significant, and fertilizer was a greater contributor to nutrient exports in runoff. In addition, the interaction between date and fertilizer on TDN and DON found in 2015 but not in 2016 is likely due to fertilizer being assimilated by turfgrass or moved into soil before the following runoff event (approximately two weeks after fertilization in 2016), and as a reference, several studies have shown thatmost uptake of N fertilizer by turfgrasses could be within days of fertilization during active growth periods (Bowman et al., 2006; Chang et al., 2019; Wherley et al., 2009). Although wetting agent treatment did not affect DOC exports as runoff, return of clippings to plots during mowing events and effects of high Na concentrations in irrigation likely contributed to the relatively high DOC exports observed (Steele and Aitkenhead-Peterson, 2013). Accordingly, we recommended that wetting agents should not be used as a common practice by turfgrass managers for the purpose of minimizing nutrient losses through runoff, especially for N. Timing of fertilization, however, should be given greater attention, as the potential for nutrient losses in runoff could be enhanced if fertilizer application is made just prior to heavy rainfall.

Although wetting agent was found ineffective at ameliorating water and nutrient losses through runoff, we found increased turfgrass quality resulting from application of wetting agent. One possible assumption is that wetting agent aids retention of water and nutrients in the soil for a longer period of time, resulting in fewer losses. While nutrient leaching in our study was not measured, previous studies have shown that wetting agents offer potential to reduce NO_3-N leaching (Arriaga et al., 2009; Cooley et al., 2009), making this a meaningful topic for turfgrass scientists for their future studies.

4.6. Conclusions

This two-year field study evaluated potential for wetting agents to improve turf performance as well as to reduce runoff losses of water and nutrients from St. Augustinegrass lawns. Based on the results of this two-year field study, wetting agents provided mild improvements in turfgrass quality and percent green cover in plots and no negative effects on runoff and nutrient movement. However, their benefits did not extend to significant reductions in runoff water volumes or nutrient exports during precipitation events. Fertilizer application resulted in improved turfgrass quality only in the second season, likely due to nutrient losses in runoff in first year. Despite irrigating plots to 0.3 × ET_o, all plots maintained acceptable quality throughout the study, regardless of wetting agent treatment. This was likely due to the occurrence of timely rainfall events, which may have limited the potential benefits of wetting agent treatments. Therefore, wetting agent application regardless of year is more an insurance application due to unknown drought. Future research should examine these treatments under greater levels of water stress to fully understand the extent of benefits they may offer for lawn situations. If limited benefits would still be observed at greater levels of water stress, additional research could address wetting agent effects on nutrient leaching and/or soil water dynamics.

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5. ENVIRONMENTAL IMPACTS AND RUNOFF DYNAMICS ASSOCIATED WITH URBAN LANDSCAPE CONVERSIONS

5.1. Introduction

As rapid population growth continues in urban areas, water conservation has become a key priority for many municipalities. According to the data provided by World Health Organization (WHO), by 2014, more than 50% of the world population is living in urban towns and cities. This is up from 34% in 1960, and the trend is expected continue for next the couple of decades, with 1.63% per year between 2020 and 2025, and 1.44% per year between 2025 and 2030 (WHO, 2020).

Outdoor landscape irrigation takes large portion of total municipal water usage. More than 50% of domestic water usage is attributed to residential landscape irrigation in many areas of the world, including the U.S. (Mayer et al., 1999; Degen 2007; Haley et al., 2007). While homeowners have traditionally installed and appreciated landscapes comprised predominantly of turfgrass; in recent years many municipalities have begun to offer rebate programs which incentivize removal of turfgrass areas and conversion to alternative 'water-efficient' landscapes, with the goal of reducing outdoor water use (Addink, 2005; Zhang and Khachatryan, 2018; Chesnutt, 2019; Pincetl et al., 2019). For example, one of the famous rebate programs called "cash for grass" developed by North Martin Water District, CA offered a per-square-foot cash incentive for landscape transformation (Chesnutt, 2019). As such, residential customers get a monetary compensation up to $50 per 100 square feet of lawn area (9.3 m^2) by removing automatically irrigated lawn and replacing with approved, low water use planted landscapes. As a component of these programs, homeowners are often encouraged or required to adopt specific landscape designs and planting materials, presumably with good adaptation to the region. The typical restrictions of these rebate programs include, no turf to turf conversion, use of smart irrigation installation, and less than 50% of turf area for final landscape (Wilkinson et al., 2013; Zhang and Khachatryan, 2018). One of the most popular water-efficient landscapes is xeriscaping, which is a native plant landscape that requires little to no water and chemical input. Studies to estimate the overall water savings from landscape transformation have been conducted. For example, Chesnutt (2019) evaluated changes in water consumption of landscape owners who participated in landscape transformation programs. They reported that water savings for every 0.1 m^2 turf replaced, ranged from 42 to 288 L per year, with the savings increasing over time, with 2897 L m^{-2} and 3317 L m^{-2} for the first year following conversion and 10 years after conversion, respectively. Similarly, another study estimated the annual water use and annual cost of water before and after landscape renovation showed that at least $60 per year can be saved on water and sewage costs from a conversion of 93 m^2 irrigated landscape to a non-irrigated area (Wade et al., 2010).

While water efficient landscape conversions are shown to reduce outdoor water use, the long-term environmental impacts and consequences for ecosystem services resulting from these landscape changes following lawn removal are rarely considered. Turfgrass lawns have been shown to provide an array of benefits both to the environment and to humans (Bread and Green, 1994; Bolund and Hunhammar, 1999; Monteiro, 2017). A fundamental review and analyses of turfgrasses in environmental protection listed the benefits provided by turfgrasses, which include soil erosion control, heat dissipation, noise abatement, and air pollution control (Bread and Green,1994). However, the benefits were broadly described, with little evidence of controlled research studies conducted. Thus, studies are still needed to reveal the overall influence of turfgrass in urban ecosystems when comparing to other alternative landscapes.

The objectives of this research were to 1. Examine runoff dynamics including flow rates, volumes, and chemistries associated with urban landscape conversions, 2. Monitor the surface temperature of several residential landscapes types, and 3. Document the maintenance requirement of each landscape, in terms of weed pressure.

Our Hypotheses were 1. Less surface runoff will be generated from lawns than alternative landscapes, 2. Different landscapes will influence runoff chemistries differently, 3. Lawns will maintain a lower surface temperature during growing season, while the surface temperature of artificial turf should be significantly higher, and 4. Weed pressure will be minimal for lawns, especially during growing season.

5.2. Material and Methods

This on-going study is being conducted at the Urban Landscape Runoff Facility located at the Texas A&M University Soil and Crop Sciences Field Research Laboratory, College Station, TX. The facility previously comprised 24 individually irrigated 4.1 m × 8.2m plots established with 6-yr old 'Raleigh' St. Augustinegrass established on an average 3.7 % slope atop of a fine sandy loam soil (Aitkenhead-Peterson et al. 2018; Wherley et al., 2014). Each plot has its own irrigation control and runoff collection system composed of an ISCO flow meter ((ISCO 4210, Teledyne Isco, Lincoln NE)) and auto-sampler (ISCO 6712, Teledyne Isco, Lincoln NE). This provides full documentation of the runoff dynamics including flow patterns and runoff water volumes from irrigation and rainfall events, and also collects 1 L samples (maximum of 24) from these events for subsequent chemical analysis.

Landscape conversions were initiated during August 2018, with five treatments (Figure 5.1.) comprising:

1. St. Augustinegrass Lawn: A 6-year-old St. Augustinegrass (*Stenotaphrum secundatum*) established atop of native fine sandy-loam soil in 2012 and irrigated 2x weekly at 60% reference evapotranspiration levels (60% ETo).
2. Xeriscaping: Native, water conserving drip-irrigated plants (50% of total plot area) including Red Yucca (*Hesperaloe parviflora*), Texas sage (*Leucophyllum frutescens*), Muhly grass (*Muhlenbergia capillaris*), and Dwarf yaupon holly (*Ilex vomitoria*) established in 7.6 cm of compacted decomposed granite. Plants were irrigated twice a week at a rate of 0.8 L, according to a recommended rate of 0.23 L per day.
3. Water Efficient Landscape- Mulch: Native, water conserving drip-irrigated plants (50% of total plot area) including Red Yucca (*Hesperaloe parviflora*), Texas sage (*Leucophyllum frutescens*), Muhly grass (*Muhlenbergia capillaris*), and Dwarf yaupon holly (*Ilex vomitoria*) grown in native fine sandy-loam soil and mulched with 5 cm of dark hardwood mulch (New Earth Compost, San Antonio, TX). Plants were irrigated twice a week at a rate of 0.8 L, according to a recommended rate of 0.23 L per day.
4. Artificial Turf: Premium II (EPS Turf, (Ewing irrigation and landscape supply, Phoenix, AZ) un-irrigated synthetic turf was installed atop of 5 cm of compacted

decomposed granite. Grit silica sand infill (Ewing irrigation and landscape supply, Phoenix, AZ) was incorporated into the base of the turf at a rate of 9.76 kg m^{-2}.

5. Sand-Capped Lawn: Washed St. Augustinegrass sod laid atop of 10 cm of sand (medium-coarse concrete sand (Knife River Corp. Bryan, TX) plated over native fine-sandy loam soil. Irrigated 2 times weekly at 60% × reference evapotranspiration levels (60% ETo).

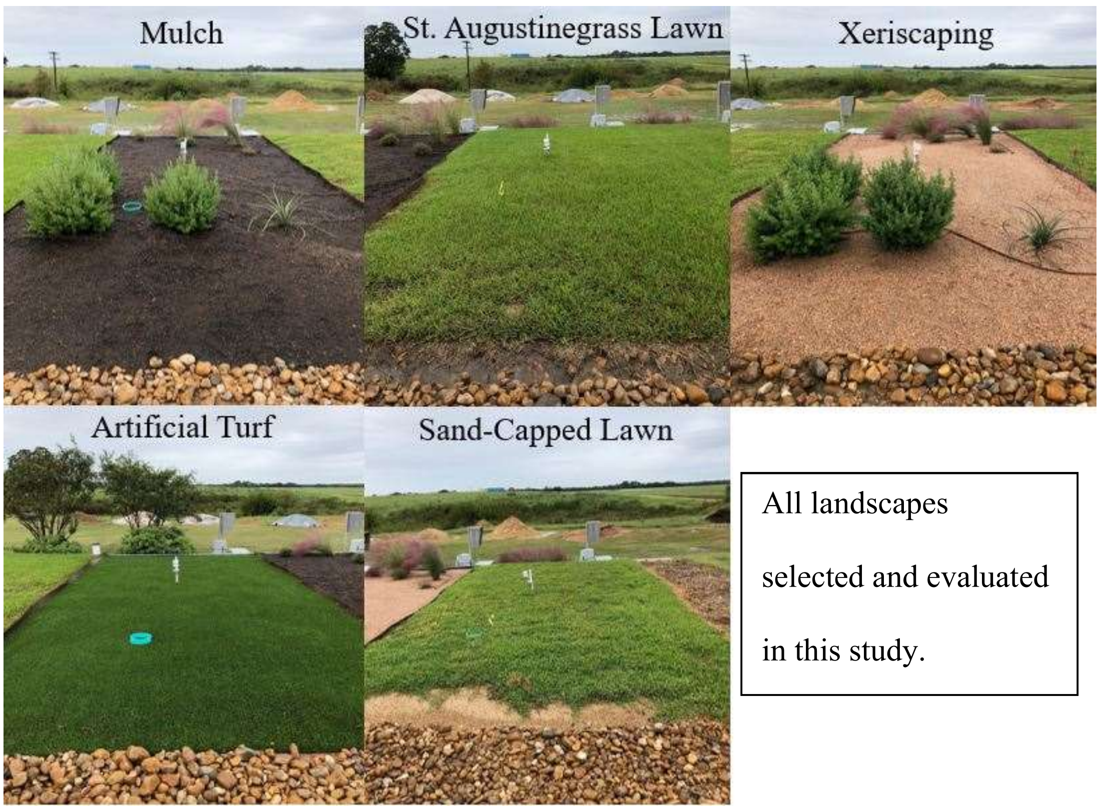

Figure 5.1. Turfgrass Lawn and alternative 'Water-Efficient' Landscape Treatments being tested at the Urban Landscape Runoff Facility at Texas A&M University.

Table 5.1. All fertilizers applied during the study period.

Treatment	Fertilizer analysis	Date applied	Rate
St.Augustinegrass Lawn	Bonus S (29-0-10)	5/27/2018	4.88 g N per m^2
	Sulfur Coated Urea (21-7-14)	8/27/2018	4.88 g N per m^2
	Turfbuilder (32-0-10)	4/23/2019	4.88 g N per m^2
	Turfbuilder (32-0-10)	7/10/2019	4.88 g N per m^2
	Turfbuilder (32-0-10)	8/27/2019	4.88 g N per m^2
Sand-capped Lawn	Bumper Crop (13-13-13)	8/15/2018	6.34 g N per m^2
	Sulfur Coated Urea (21-7-14)	8/27/2018	4.88 g N per m^2
	Turfbuilder (32-0-10)	4/23/2019	4.88 g N per m^2
	Turfbuilder (32-0-10)	7/10/2019	4.88 g N per m^2
	Turfbuilder (32-0-10)	8/27/2019	4.88 g N per m^2
Xeriscaping	Miracle-Gro All Purpose Plant Food (24-8-16)	10/29/2018	16 g N per plot
Mulch	Miracle-Gro All Purpose Plant Food (24-8-16)	10/29/2018	16 g N per plot
Artificial Turf	-	-	-

The two water-efficient landscapes were drip-irrigated, while the St. Augustinegrass plots were overhead irrigated to meet plant demand, and synthetic turf received no irrigation. Fertilizer was applied by drop spreader for turfgrass plots, while fertilizer was mixed in a watering can and applied to Texas sedge and dwarf yaupon holly only for xeriscaping and mulch. A fertilization plan for all treatments was documented (Table 5.1).

Rainfall volumes (mm) were either obtained from an onsite tipping rain gauge (Isco 647, Teledyne Isco, Lincoln, NE) at a two-minute temporal resolution, or from an on-site weather station that was registered in Texas ET Network, with a station name of TAMU Turf Lab.

5.2.1. Soil Moisture Content

Soil volumetric moisture content (Volume%) was measured once weekly for all landscapes commencing10/11/2018. Moisture meter (HH2, Delta-T Devices Ltd., Cambridge, UK) was used for St. Augustinegrass lawn, sand-capped lawn, and mulch, and a different soil moisture meter with 7.6 cm probes (FieldScout TDR 350, Spectrum Technologies, Aurora, IL) was used for measuring artificial turf and xeriscaping.. For each measurement, a final reading was an average of 4 random readings taken at four locations within each plot. For evenly distributed plots: St. Augustinegrass lawn, sand-capped lawn, artificial turf, and sand-capped lawn readings were taken in one of each of the four quarters of the plot. For planted treatments, mulch and xeriscaping, all 4 readings were done at four random spots in the center potion of plots, in order to avoid any damage of the plants.

5.2.2. Runoff Dynamics

Peak Flow and Volumes: Runoff characteristics were evaluated for all naturally occurring rainfall event from throughout the study. Peak flow rates (L s^{-1}) as well as total runoff volumes from each landscape type were compared to determine influence of landscapes on runoff characteristics. Flow rates were downloaded from ISCO 4210 flow meter (Teledyne Isco, Lincoln, NE), and total runoff volume was determined by multiply the 2-minute recorded runoff flow rates for the duration of the event. Total runoff volume data was analyzed for all rain events. Hydrographs were created by plotting flow rate of runoff along with precipitation with a rate of L s^{-1} for one typical runoff event to understand the response of each landscape to precipitation.

Runoff samples were collected by an ISCO 6712 autosampler (Teledyne Isco, Lincoln, NE) with the sampling interval set at every 150 L of runoff water. This gave a greater opportunity to capture the entire runoff spectrum as only 24 of 1 L bottles were installed in each sampler. Samples were collected the next day after a rainfall event. If intermittent rainfall lasting several days occurred, then sample collection occurred after the event was completed. When samples collected by the autosampler were greater than 4, only 4 samples were kept. For example, when all 24 bottles are full, bottle numbers 1, 8, 16, and 24 were kept. Otherwise, all samples were kept for future analysis. This procedure was based on early analyses which showed that concentrations of nutrients did not differ significantly for samples during runoff events but that the first and last sample tended to have higher concentrations (Aitkenhead-Peterson et al. 2018). pH, electrical conductivity, and total suspend solids (TSS) were measured for raw runoff samples on the same day of sample collection.

All samples were tested for pH and EC, and pH meter (Sension+ PH3, HACH, Loveland, CO) and EC meter (C65, Milwaukee Instruments Inc, Rocky Mount, NC) were always calibrated prior to testing. Only the first sample and the last sample of each plot were analyzed for TSS (labeled as TSS (First) and TSS (Last), respectively). This was meant to test the first-flush phenomenon of runoff. An oven-dried and pre-weighed 0.7µm nominal pore size glass microfiber filter paper (Ahlstrom, Munksjo Filtration LLC, Madisonville, KY) along with a 80mm aluminum smooth weighing dish (UX-01018-28, Cole-Parmer, Vernon Hills, IL) that held the filter paper were oven dried for at least 24 hours at 65^{o} C before filtering. The used filter paper and the same weighing dish were oven dried again after aliquots of runoff samples were vacuum filtered. Weighing was done 30 mins after aluminum weighing dishes were taken out of oven for both before and after filtering. The final TSS was then calculated using following equation:

$$TSS\ (mg\ L^{-1}) = (Weight\ of\ (dish + used\ filter\ paper) - Weight\ of\ (dish + new\ filter\ paper)) / (Volume\ of\ sample\ (L))$$

After TSS determination, all runoff samples were filtered through the same type of filter paper used for TSS determination, placed on the bottom of a magnetic filter funnel (4247, PALL Corp., New York, NY). The magnetic filter was installed on top of a 500mL vacuum filter flask that was powered by an oil free laboratory vaccum pump (Rocker 300, Rocker Scientific Co., Ltd. Taipei, Taiwan). During each filtering, roughly 100 mL filtered sample was produced, and 60 mL was transferred into an acid washed high density polyethelene (HDPE) sample bottle and then refrigerated until analysed.

Nutrients for filtered samples included: Total dissolved N (TDN), nitrate-N (NO_3-N), ammonium-N (NH_4-N), orthophosphate-P (PO_4-P) and dissolved organic Carbon (DOC). Dissolved organic nitrogen (DON) was estimated by deducting NO_3-N and NH_4-N from TDN.

Because there is a hold time for the analyses for NO_3-N of 18 h, analyses of runoff was conducted within 18 h of collection for NO_3-N and the next day for other nutrients. Colorimetric analyses was used for NO_3-N, NH_4-N, and PO_4-Pwhich were measured using a discrete wet chemistry analyzer (SMARTCHEM 200, Unity Scientific, Brookfield, CT). Ammonium-N was analyzed using the phenate hypochlorite method with sodium nitroprusside enhancement (EPA 350.1; MDL: 0.005 mg L^{-1}) and nitrate-N was analyzed using Cd–Cu reduction (EPA 353.2; MDL: 0.005 mg L^{-1}). Orthophosphate-P was quantified using the ascorbic acid, molybdate blue method (EPA #365; MDL: 0.005 mg L^{-1}). TDN and DOC were measured using high temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX) (EPA 415.1 and Merriam et al. 1996; MDL: 0.1 mg L^{-1}).

Total nutrient losses from each landscape for each runoff event were measured as export calculated as following equation:

$$\textit{Export (mg m}^{-2}\textit{) = average concentration for rain event (mg L}^{-1}\textit{)} \times \textit{total runoff volume (L)} \div \textit{plot size (m}^{2}\textit{)}$$

5.2.3. Surface Temperature

Reflective surface temperature was measured once a week for each landscape on a clear day with an infrared thermometer (E6-XT, FLIR, Wilsonville, OR). Measurements were taken during the window of 12:00 pm to 2:00 pm on each measuring day in order to minimize the influence of the diurnal change of solar radiation. The thermometer was aimed perpendicularly to the center of the plot at a height of 1 m, and the median number of a temperature range that was measured for a detectable area by the thermometer was recorded as the surface temperature for the plot. If there was no clear day for weeks during the study period, measurements were not taken.

5.2.4. Weed Pressure and Weed Control

Weed pressure was used as an indicator of maintenance requirement of each landscape, with total amount of weeds, no matter what species, counted on a weekly basis. Once the number of weeds was recorded, all weeds were removed from each plot to avoid repetitive counting over time. Large weeds were hand-pulled and small weeds were controlled by point spraying post-emergent herbicide (Roundup, Bayer, Leverkusen, Germany) for xeriscaping, mulch, and artificial turf, while weeds were only removed by hand pulling for two the two lawns. Sometimes, mushrooms thrived, especially for mulch during the rainy season of late fall and winter. However, since they normally die off relatively quickly, they were not considered a weed.

5.2.5. Landscape Aesthetics

Since there is no existing evaluation mechanism for comparing the quality of water efficient landscapes and home lawns, a scoring system commonly used for the turfgrass industry developed by the National Turfgrass Evaluation Program (NTEP) was revised and used for this study (Morris and Shearman, 2007). The NTEP system evaluates turfgrass based on visual rating on density, color, and vigor of turfgrass, with a scale of 1 (totally died) to 9 (perfect), and a rating of 6 or greater denoting acceptable quality. This system has considered the complexity and difficulty of quality evaluation for different turfgrasses, given the diversity of morphology of different species or cultivars, and thus was used for this study, as all plants selected in this study were mainly for aesthetics. One score was given to Sand-capped lawn, St. Augustinegrass lawn, and artificial turf, while all four plants grown in xeriscaping and mulch received a score and the average of those four scores were used as the final score to qualify the overall landscape quality of xeriscaping and mulch.

5.2.6. Statistical Analyses

Data of this study meet the assumption of normal distribution and thus a parametric test were used. All data including Runoff (volume, pH, EC, nutrient concentration, and nutrient export), surface temperature, weed density, and aesthetics were analyzed as a single continuous experiment over one year (Sept. 2018 to Sept. 2019) using two factor ANOVA repeated measures (SAS 9.4, SAS Institute, Cary, North Carolina), with date as the repeated measures. Date is runoff event for all runoff data, and is the day when measurement was conducted for other parameters. Date and landscapes are two major factors. Both main factor date, landscapes and their interactions were considered fixed effects. Where significant main effects or interactions were detected, treatments means were compared by using Tukey's HSD at $P = 0.05$. If the date by landscape interaction was significant, mean separations were analyzed under each date, and data were not averaged across dates even main effects were also significant. Correlation was also conducted with SAS for most of the runoff parameters, with Pearson correlation analyses.

5.3 Results and Discussion

5.3.1. Runoff Events

During the one-year study period (September 2018 – September 2019), 24 runoff events from naturally occurring rainfall were observed. (Figure 5.2). The magnitude of runoff volume closely related to the intensity of rainfall, and runoff was only detected when rainfall was greater than 12mm. Most runoff events occurred during fall and winter (late September 2018 to March 2019) when turfgrasses were dormant and native plants had stopped growing. Significant differences in runoff volume among treatments only started to occur 4 months after installation of alternative landscapes (Figure 5.2).

No significant differences in runoff volumes were found among landscape treatments during the first half period of the study (September 2018 – January 2019) (Figure 5.2). The lack of effect of landscape treatment observed for this earlier period is easily explained: newly constructed landscapes take time to settle and their water holding capacity may be higher after construction compared to after settling and compaction. For example, the newly applied mulch was able to hold more water after it was laid compared to later during the study when it had settled and compacted somewhat. This likely resulted in a larger soil water pool that released more water over a longer period time, as the results demonstrated for first two dates 9/13/2018 and 9/24/2018 where the abnormally highest total volume of runoff was found for mulch (Figure 5.2)

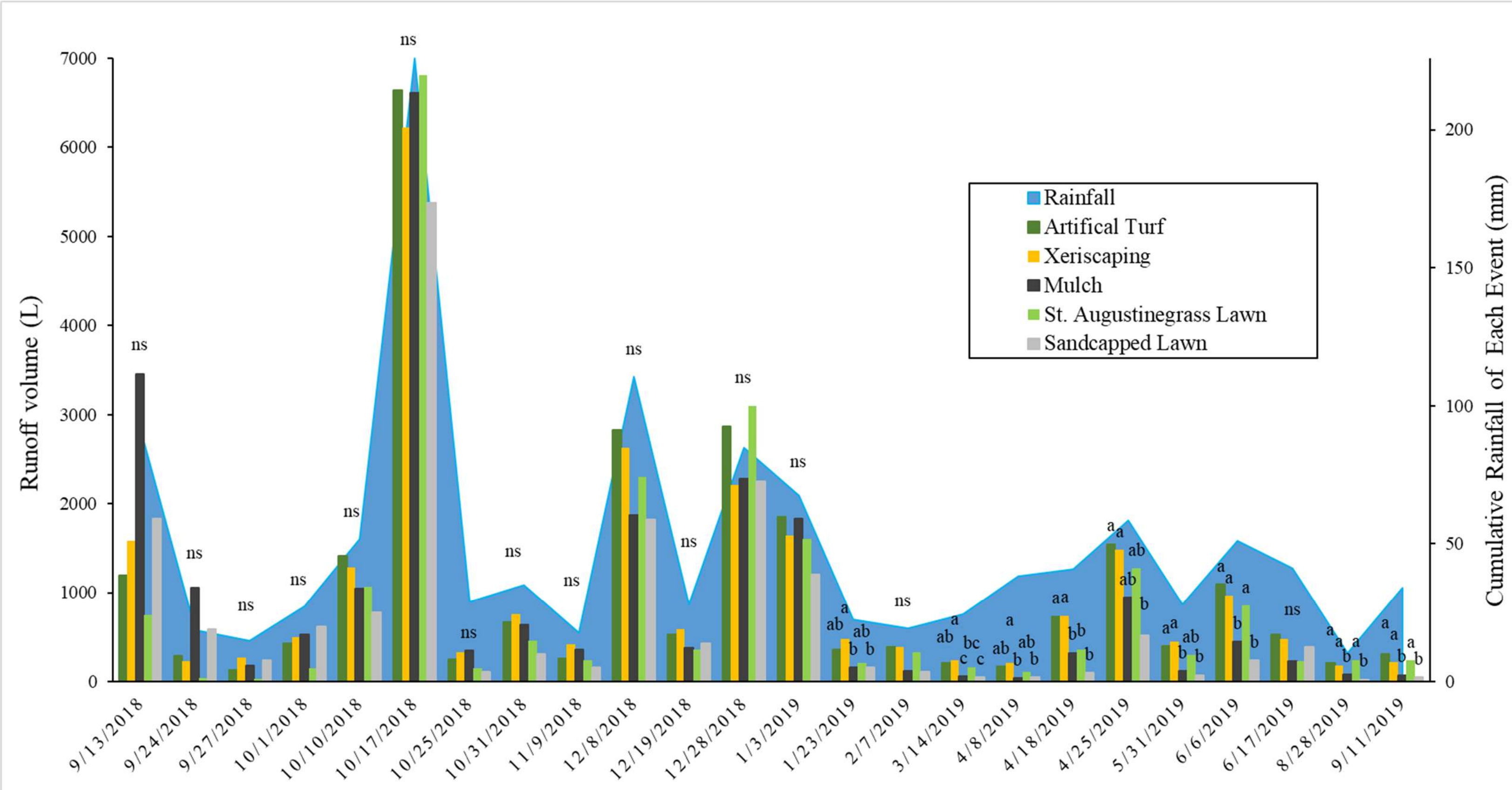

Figure 5.2. Cumulative rainfall of each runoff event and total runoff volume of all landscapes for each runoff event during the study period. Different lower case letters signify a significant difference within each runoff event, while ns indicates no significant difference.

This same phenomenon is applicable to sand-capped lawns since 10 cm coarse sand was placed on top of the native soil on August 2018 and likely took time to settle and compact. The second reason is that the effect of landscape is diluted when rainfall received is higher than 60 mm, as the results demonstrated for date 10/17/2018, 12/8/2018, 12/28/2018, and 1/3/2019 (Figure 5.2). Thirdly, turfgrass was either newly established (sand-capped lawn), or under dormancy (6-year-old St. Augustinegrass), so the overall water requirement for the turfgrass treatments was low, which weakened the advantage of turfgrasses in reducing runoff volumes through uptake and evapotranspiration. While these explanations can describe the lack of significant differences in runoff volume early in the study it should be noted that St. Augustingrass lawn generated the lowest runoff volumes for most events during this period (Figure 5.2).

During the growing season (March 2019 – September 2019), a significant effect of landscape on runoff volumes was observed for most runoff events (Figure 5.2). During this period, the cumulative rainfall of each event was lower than 60 mm and turfgrasses took up more water to fulfill growth. Overall, sand-capped lawn had significantly lower runoff volume than other landscapes (Figure 5.2). Mulch and St. Augustinegrass lawn maintained a medium runoff volume, while xeriscaping and artificial turf showed the highest runoff volume which was significantly higher than the other landscapes, especially for sand-capped lawn for most events (Figure 5.2).

5.3.2. Landscape Effect on Runoff Volumes, pH and EC and suspended solids

Over the 1 year study period, significantly different runoff volumes were observed among landscape treatments (Table 5.2) and by date of rain event (Table 5.2). There was also a significant interaction effect on runoff volume of date of rain event × landscape treatment (Table 5.2). All variables measured (pH, EC and TSS) showed a significant effect of rain event date, landscape treatment and an interaction between rain date and landscape treatment (Table 5.2; Sections 5.3.5).

Table 5.2. ANOVA for effect of landscape treatment and date of rain event on runoff volume and quality during the study period. TSS (first) is the total suspended solids of first runoff sample. TSS (last) is the total suspended solids of last runoff sample.

	Runoff Volume and Quality				
Source	Volume	pH	EC	TSS (First)	TSS (Last)
Replication	NS	*	NS	NS	NS
Date (D)	***	***	***	***	***
Landscape (L)	***	***	***	***	***
D x L	***	**	***	***	*

ns, ***, **, *; Not significant, significant at *P*=0.001, 0.01, and 0.05, respectively

5.3.3. Runoff Flow Rates

In order to fully understand the runoff dynamics of all landscapes, hydrographs were created for all landscapes for two representative runoff events (10/10/2018 and 6/6/2019) (Figure 5.3 and 5.4).

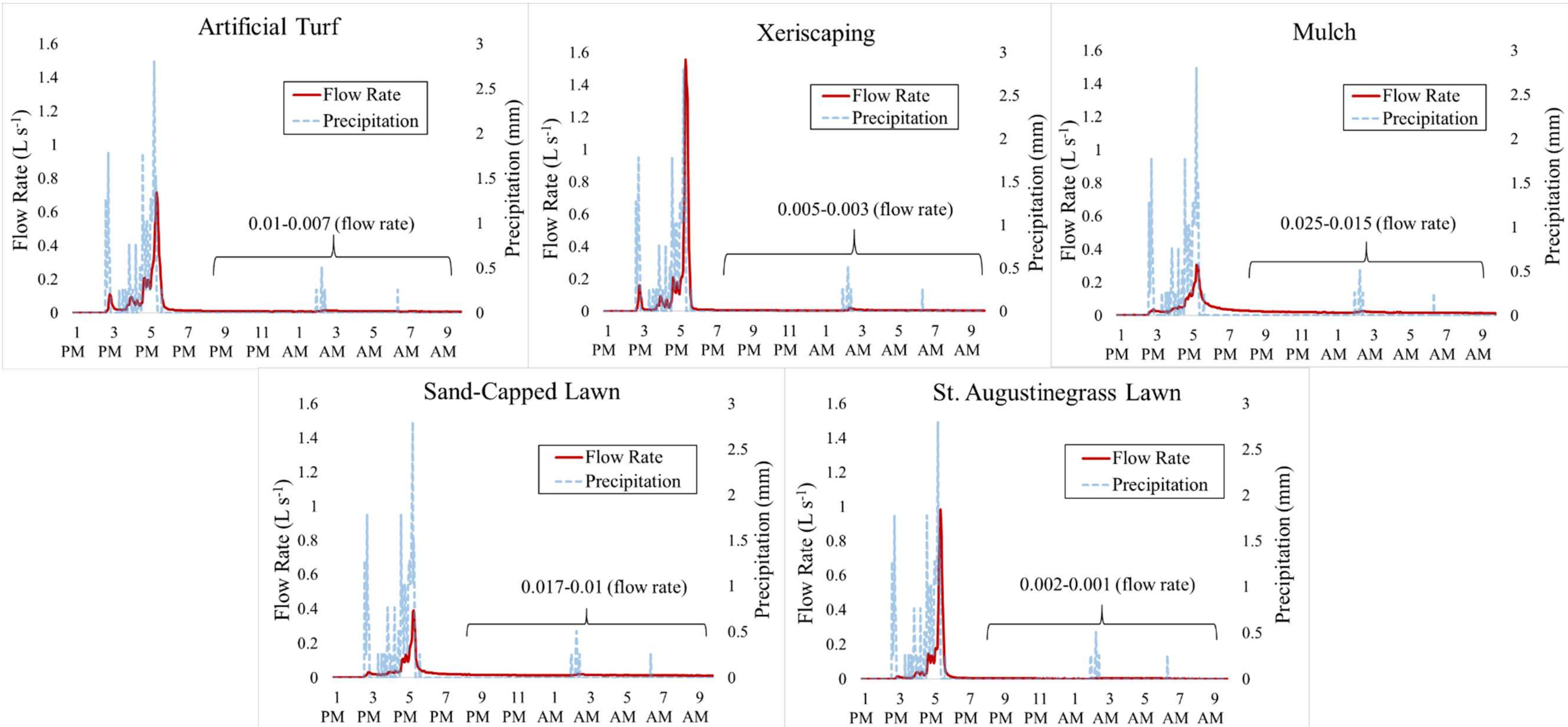

Figure 5.3. Runoff flow rates occurring from each landscape during 10/10/2018 rain event. Flow rate and precipitation were measured on 2-minute intervals.

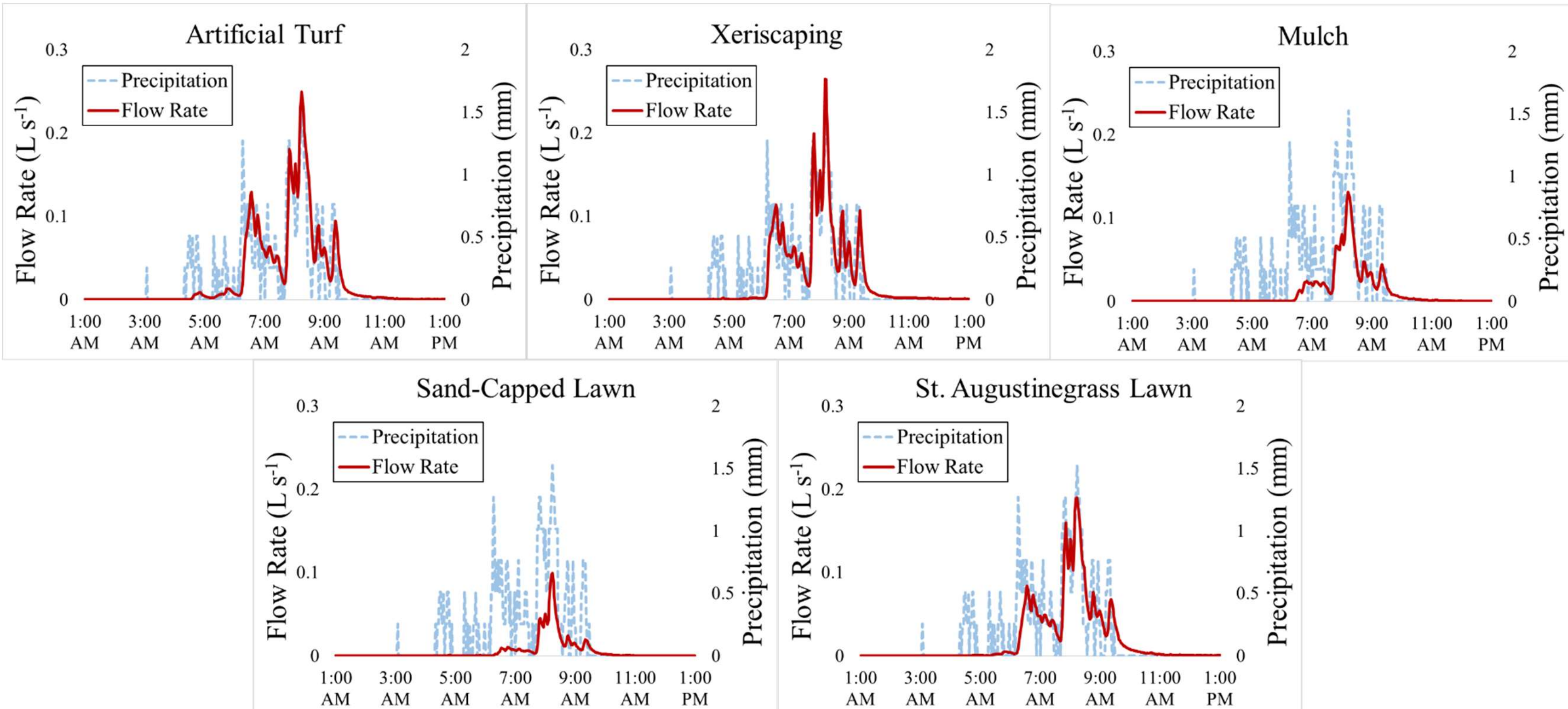

Figure 5.4. Runoff flow rates occurring from each landscape during 6/6/2019 rain event. Flow rate and precipitation were measured on 2-minute intervals.

For 10/10/2018 event (Figure 5.3), on each graph, flow rate (y-axis) was plotted along with precipitation (z-axis), and the runoff event timing (x-axis) can be divided into two phases, during rainfall and after rainfall. The flow rate of runoff mirrored the pattern of precipitation during rainfall, and the peak of flow rate and peak of precipitation coincided. Among all landscapes, xeriscaping, artificial turf and St. Augustinegrass lawn had a relatively larger peaks compared to sand-capped lawn and mulch. In addition, there was another small peak found for artificial turf and xeriscaping, following the first peak of precipitation, which was not observed for other three landscapes. Thus, it can be concluded that water infiltration rate was relatively low for impervious landscapes, artificial turf and xeriscaping, which both display an early peak in runoff after rainfall initially commences, and this contributes to the overall high runoff volume. This result is in agreement with previous studies which reported that decreased runoff by turfgrass is a result of high infiltration given by high shoot density of turfgrasses (Beard and Green, 1994; Easton and Petrovic, 2004). Another notable result was within the after-rainfall period, that the flow rate of artificial turf, mulch, xeriscaping, and sand-capped lawn were around 5 to 10 times higher than St. Augstingegrass, which suggests that the native soil had a better water holding capacity than mulch, coarse sand, and decomposed granite at the early stage of landscape conversion. As such, the flow rate of after rainfall period ranged between 0.001 to 0.002, 0.003 to 0.005, 0.07 to 0.01, 0.01 to 0.017, and 0.015 to 0.025 L s^{-1} for St. Augustinegrass lawn, xeriscaping, artificial turf, sand capped lawn, and mulch, respectively. Thus, it can be seen that after rainfall, runoff was detected from all newly constructed landscapes, which attributed at least partially to their total runoff volume. Similar results were found by Liang et al. (2017) who tested surface runoff for turfgrass and bare soil, and suggested that reduced surface runoff by turfgrass was due to the presence of thatch, which holds more water during rainfall period, allowing a longer period of time for soil infiltration.

Runoff dymanics of all landscapes during growing season were determined on 6/6/2019 (Figure 5.4). During this event, all runoff was occurred during the precipitation, and the highest flow rates were still found for artificial turf and xeriscaping. For St. Augustinegrass lawn, the actively growing grasses pulled more water out of soil through evapotranspiration resulting in a lower soil moisture content that allowed more rainfall to be infiltrated in the soil, which resulted in the lower flow rate when comparing to artificial turf and xeriscaping. The lowest peak of flow rate was detected from sand-capped lawn and mulch, and no peak was detected at 7:00 AM for those two landscapes, which confirmed the high soil infiltration rate of sand-capped lawn and mulch. In addition, water was hold more tightly by sand-capped lawn and mulch when comparing to 10/10/2018 event, as coarse sand and hard wood mulch should have already settled in by 6/6/2019. The overall greater infiltration rate and water holding capacity of sand-capped lawn and mulch giving them the best runoff control.

5.3.4. Soil Moisture Content

A significant interaction between rain date and landscape treatment was observed for soil moisture content (Table 5.3).

Table 5.3 ANOVA table of plot quality, weed pressure, surface temperature, and soil moisture content of landscapes on different measuring dates.

Source	Plot Quality	Weed Pressure	Surface Temperature	Soil Moisture Content
Replication	NS	***	NS	NS
Date (D)	***	***	***	***
Landscape (L)	***	***	***	***
D x L	***	***	***	***

ns, ***, **, *; not significant, significant at P=0.001, 0.01, and 0.05, respectively

During the winter or dormant season, when irrigation was turned off, the effect of landscape on soil moisture content was highly significant (Figure 5.5). More specifically, St. Augustinegrass lawn had the highest soil moisture content, followed by mulch. Sand-capped lawn and xeriscaping were at the third tier where soil moisture content ranged between 15 to 20 %. The lowest soil moisture content was found for artificial turf (below 10%), and it was consistent during the entire year. During the growing season, soil moisture content of turfgrass dropped, except for several peaks that were measured after a rainfall event, such as 4/26/2019, 6/4/2019, 6/25/2019, and 9/13/2019 (Figure 5.5). Mulch surpassed St. Augustinegrass lawn in soil moisture content during 4/26/2019 to 7/9/2019 when several rainfalls were experienced during that period. During 7/17/2019 to the end of the study, soil moisture content was highest for St. Augustinegrass, followed by sand-capped lawn, which was likely due to irrigation operated twice a week. Although slight amount of water was received by mulch from drip irrigation, its captured rainwater kept its soil moisture content always higher than 20%. The same drip irrigation and irrigation plan was used for xeriscaping as the mulch, but the soil moisture content of xeriscaping was significantly lower than mulch. No irrigation was provided to artificial turf, which resulted in the lowest soil moisture content (less than 10%), and it was significantly lower than that of other landscapes. To conclude, the soil moisture content reflected the nature of different landscapes in response to water input. In brief, mulch and lawns had the best ability to holding water within the system for an extended time period, however, the soil moisture content of artificial turf and xeriscaping was not sensitive to water input, thus a higher chance of water losses through runoff can be expected for those two landscapes.

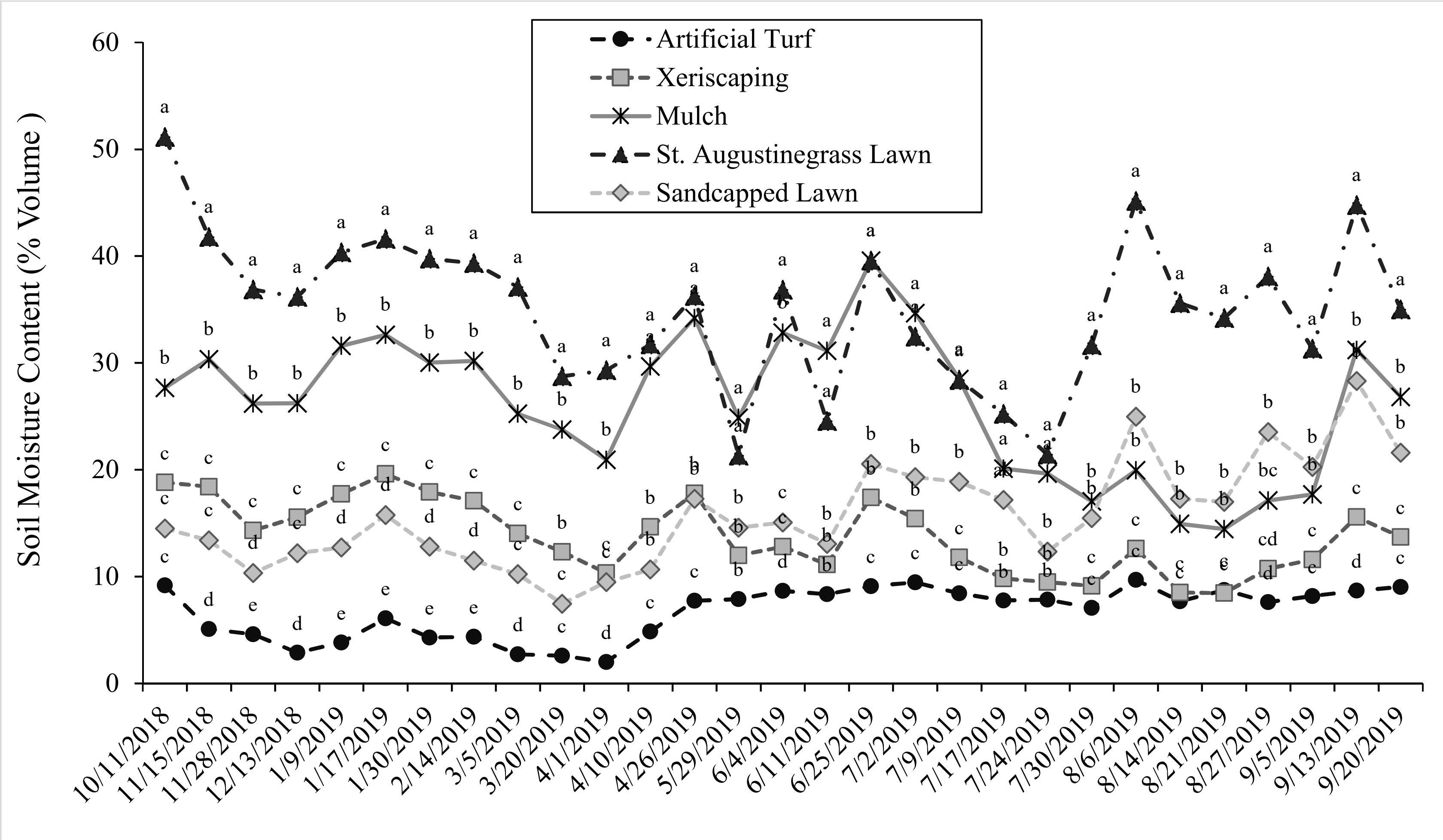

Figure 5.5 Soil moisture content of all landscapes. Means with the same letter in a given date are not significantly different based on Tukey's HSD at P = 0.05

5.3.5. Runoff Quality

For each runoff event detected during the study period, runoff water quality was analyzed for several parameters, including pH, EC, TSS, and concentration of NO_3-N, NH_4-N, PO_4-P, TDN, DON, and DOC. There was a significant interaction between landscape and date on all parameters measured (Tables 5.2 and 5.4).

Table 5.4 ANOVA for effect of landscape and date on nutrient concentration.

	Nutrient Concentration (mg L^{-1})					
Source	NO_3-N	NH_4-N	PO_4-P	TDN	DON	DOC
Replication	**	NS	NS	NS	NS	NS
Date (D)	***	***	***	***	***	***
Landscape (L)	***	***	***	***	***	***
D x L	***	***	***	***	***	***

ns, ***, **, *; not significant, significant at *P*=0.001, 0.01, and 0.05, respectively

5.3.5.1. pH

Runoff pH for all landscapes over the study period, dropped slightly; the range of runoff pH dropped from 7.5 - 8.5 in fall and winter months to a pH range of 7 - 8 (except for a couple outliers) during early spring and summer (Figure 5.6). Effect of landscape was not significant for most runoff events (Figure 5.6). Mulch always had the lowest pH, especially for those dates that a significant effect of landscape was found, such as 10/10/2018, 10/31/2018, 12/19/2018, 3/14/2019, 6/6/2019, 8/28/2019, and 9/11/2019 (Figure 5.6). The effect of organic mulch on reducing soil pH has been documented by previous studies, where it was reported that the decrease in pH is proportional to the depth of mulch (Billeaud and Zajicek, 1989; Duryea et al., 1999; Alharbi, 2017).

Fertilization sometimes also has an influence on runoff pH. Fertilizer influence on runoff pH likely explains the pH outliers occurring on 8/28/2019 and 9/11/2019 a couple days after fertilization applied on 8/27/2019. This suggests that avoiding fertilization before rainfall can reduce potential environment impact resulting from turfgrass management.

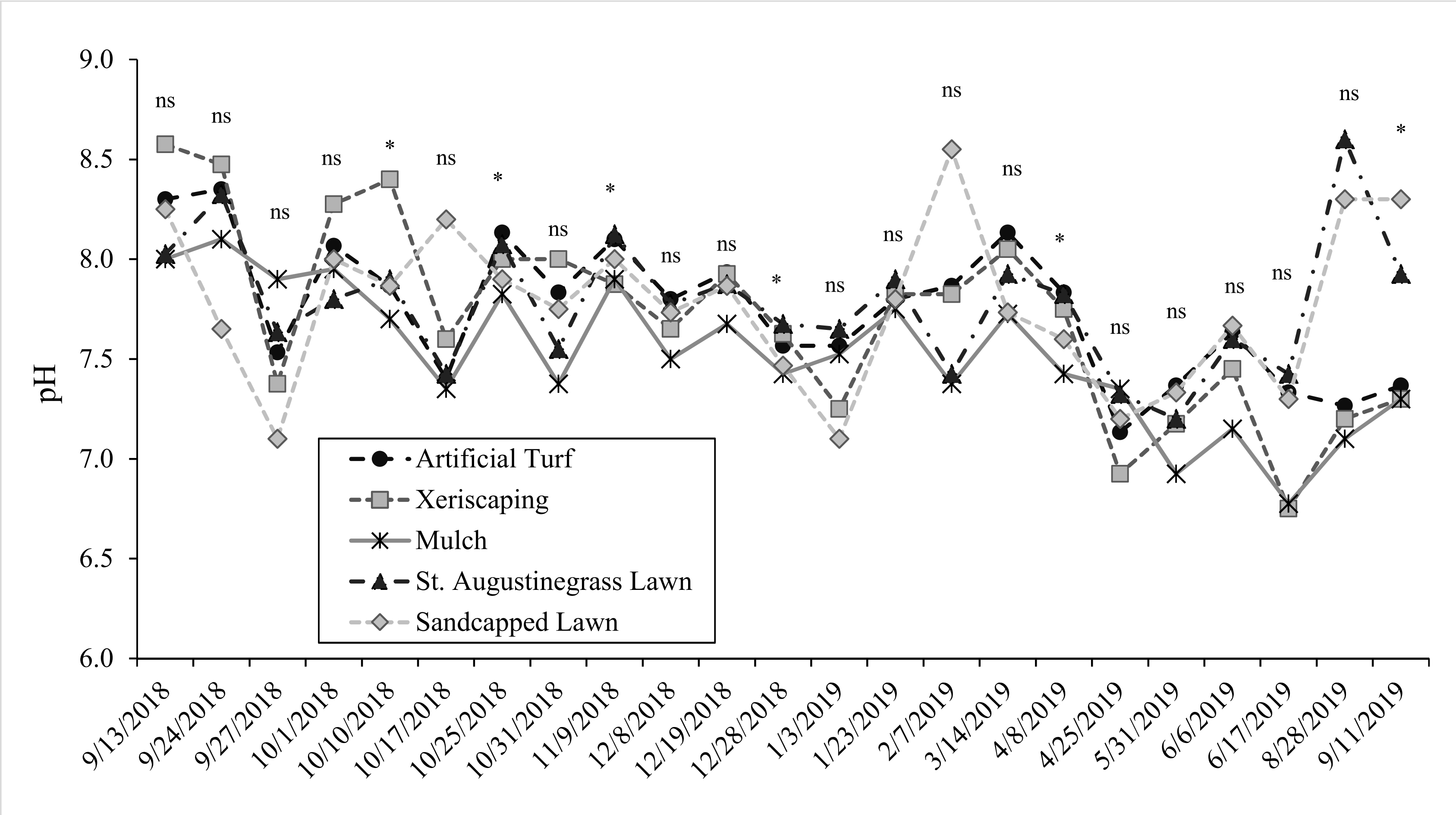

Figure 5.6 Effect of landscape and date on runoff pH. ns indicates no significant difference and * indicates significant differences on each date, based on Tukey's HSD at P = 0.05.

5.3.5.2. Electrical conductivity (EC)

Electrical conductivity (EC) has been used as an indicator of water quality, as it is affected by the presence of organic and inorganic dissolved solids (Thompson et al., 2012; De Sousa et al., 2014). Thus, water with high EC contain high concentrations of cations, anions and other solutes. Effect of landscapes on runoff EC was significant during the study period (Table 5.2), and a seasonal pattern was also observed (Figure 5.7). The highest runoff EC was observed on 9/24/2018. Runoff EC values then dropped to below 400 $\mu S\ cm^{-1}$) until a second peak was observed on 8/28/2019. During the entire study period, xeriscaping and artificial turf displayed a significantly lower EC than other three landscape treatments, and the largest difference among treatments was observed on 9/24/2018 (500 $\mu S\ cm^{-1}$ for xeriscaping and artificial turf vs.1000+ $\mu S\ cm^{-1}$ for the other three landscapes). The low EC value of xeriscaping and artificial turf is related to low nutrients in the runoff, which will be discussed later. In addition, a significant negative correlation was observed between EC and runoff volume, (Table 5.5, Figure 5.7). For example, several EC peaks occurred on 9/24/2018, 9/27/2018, 10/25/2018, 11/9/2018, 4/8/2019, and 8/28/2019, and comparing to Figure 5.2, on these dates, landscapes also had the lowest runoff volume that derived from a low rainfall event. The negative correlation illustrates that "dilution is the solution" in terms of runoff. These results also suggest that most nutrients stored in the soil could be moving out of systems with a small fraction of runoff, which is sometimes referred to as the first flush. A significantly elevated EC can be tested in runoff when soils have not been flushed by water for an extended period of time, as the peak shown on 8/28/2019 when the last runoff was 2 months earlier.

Table 5.5 Correlation of parameters measured for runoff samples. All nutrient parameters presented here are concentrations (mg L^{-1}).

Parameter	pH		EC		NO_3-N		NH_4-N		PO_4-P		TDN		DON		DOC		TSS (First)		TSS (Last)	
Volume	-0.10	*	-0.17	**	-0.02	ns	-0.01	ns	-0.07	ns	-0.07	ns	-0.03	ns	-0.05	ns				
pH			0.31	***	0.12	*	0.10	ns	0.10	*	0.12	*	0.10	*	-0.02	ns				
EC					0.23	***	0.30	***	**0.70**	***	0.60	***	0.37	***	0.54	***				
NO_3-N							0.15	**	0.06	ns	0.32	***	0.18	***	-0.12	*	-0.05	ns	0.09	ns
NH_4-N									0.27	***	**0.78**	***	0.31	***	0.18	***	-0.02	ns	-0.02	ns
PO_4-P											0.59	***	0.32	***	**0.72**	***	-0.06	ns	-0.05	ns
TDN													0.46	***	0.54	***	-0.09	ns	-0.05	ns
DON															0.31	***	-0.09	ns	-0.08	ns
DOC																	-0.05	ns	-0.09	ns

ns, ***, **, *; not significant, significant at P=0.001, 0.01, and 0.05, respectively

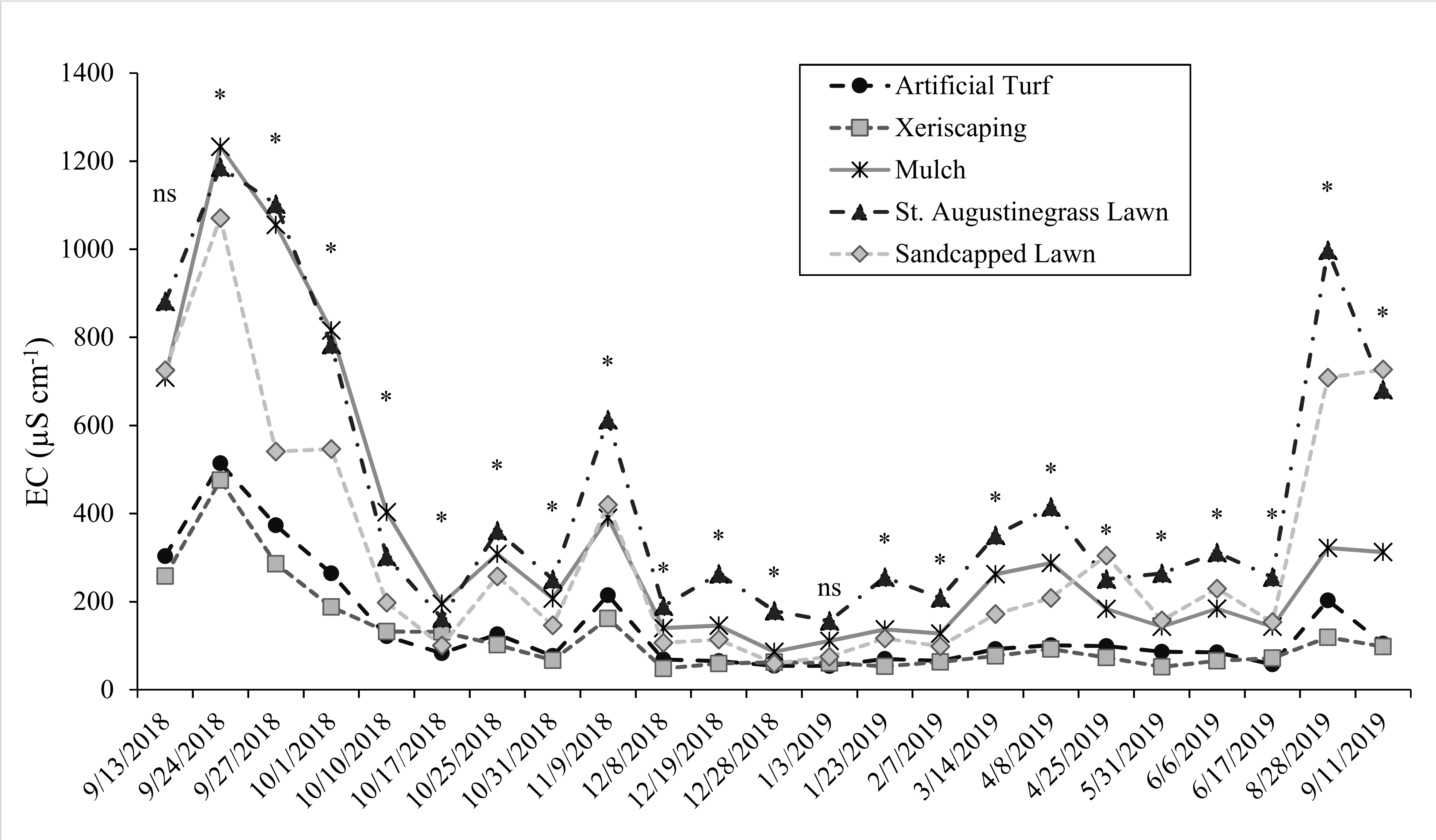

Figure 5.7 Effect of landscape and date on runoff electrical conductivity (EC). ns and *, respectively, indicate that no significant difference and significant difference were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

5.3.5.3. TSS

Total suspend solids were analyzed by separating the first runoff samples and last runoff samples for each landscape treatment. A significant interaction between date × landscape was found for both the first and last runoff samples (Table 5.2). Higher concentrations of TSS were always carried by the first sample of runoff than the last sample of runoff (Figure 5.8) TSS was first measured on 10/10/2018, almost two months after the landscape conversion was initiated. However, the TSS losses for newly constructed landscapes, especially for xeriscaping were still extremely high, even though all decomposed granite used for this landscape was compacted using a plat compacter. This suggests that TSS loses must be considered in a higher priority for new construction where surface was covered by decomposed granite. TSS losses from xeriscaping were significantly higher for both the first sample and last sample when compared to other landscape treatment. The magnitude of TSS (first) of xeriscaping was 5 to 10 times higher than other landscapes for several runoff events, such 10/10/2018, 10/17/2018, 11/9/2018, and 4/8/2019 (Figure 5.8). Although decomposed granite was also used for beneath artificial turf, the synthetic turf mat that was installed appears to have secured and protected against TSS loss resulting in the lowest TSS concentration (Figure 5.8). Moreover, the raw runoff samples received from artificial turf were clear whereas samples from xeriscaping were always turbid (picture not shown). High TSS concentrations in runoff water, specifically of decomposed granite high in iron and aluminum can serve as carriers of negatively charged potentially toxic elements (PTE's) and other negatively charged compounds of herbicides and pesticides. Furthermore, irrigation systems or surface waters can be clogged by these solids (Bilotta and Brazier, 2008).

Several studies have measured the total suspended solids (TSS) in stormflow and investigated the effect of land covers on suspended solids in storm water. (Deletic and Maksimovic, 1998; Lee and Bang, 2000; Goonetlleke et al., 2005; Petrovic and Easton, 2005; Mallin et al., 2009). Overall, the range of SS detected from those studies are from 8 to 673 mg L^{-1}, with a higher rate found at more developed areas than vegetated areas. Similarly, an review study by Steele et al. (2010) summarized sediment loss in urban ecosystems and claimed that urbanization has a significant impact on erosion, and high peak flows and decreases in vegetation result in increased stream channel erosion. Maniquiz et al. (2009) investigated soil loss from several major urban construction sites, such as road construction, urban development, athletic facility construction, industrial complex construction, etc. They found that most soil loss occurred during active construction and 20 to 40% of the soil loss is contributed to pre and post-construction, which is in agreement with the trend of a decreased TSS over time found in this study. In addition, their study demonstrated that post-construction soil losses were even lower for recreational area development and athletic facility construction as comparing to pre-construction soil losses (Maniquiz et al., 2009). As turfgrass and artificial grass are major surface covers for athletic and recreational sites, the low TSS losses from lawns and artificial grass observed in this study reconfirmed the advantage of grasses in sediment control.

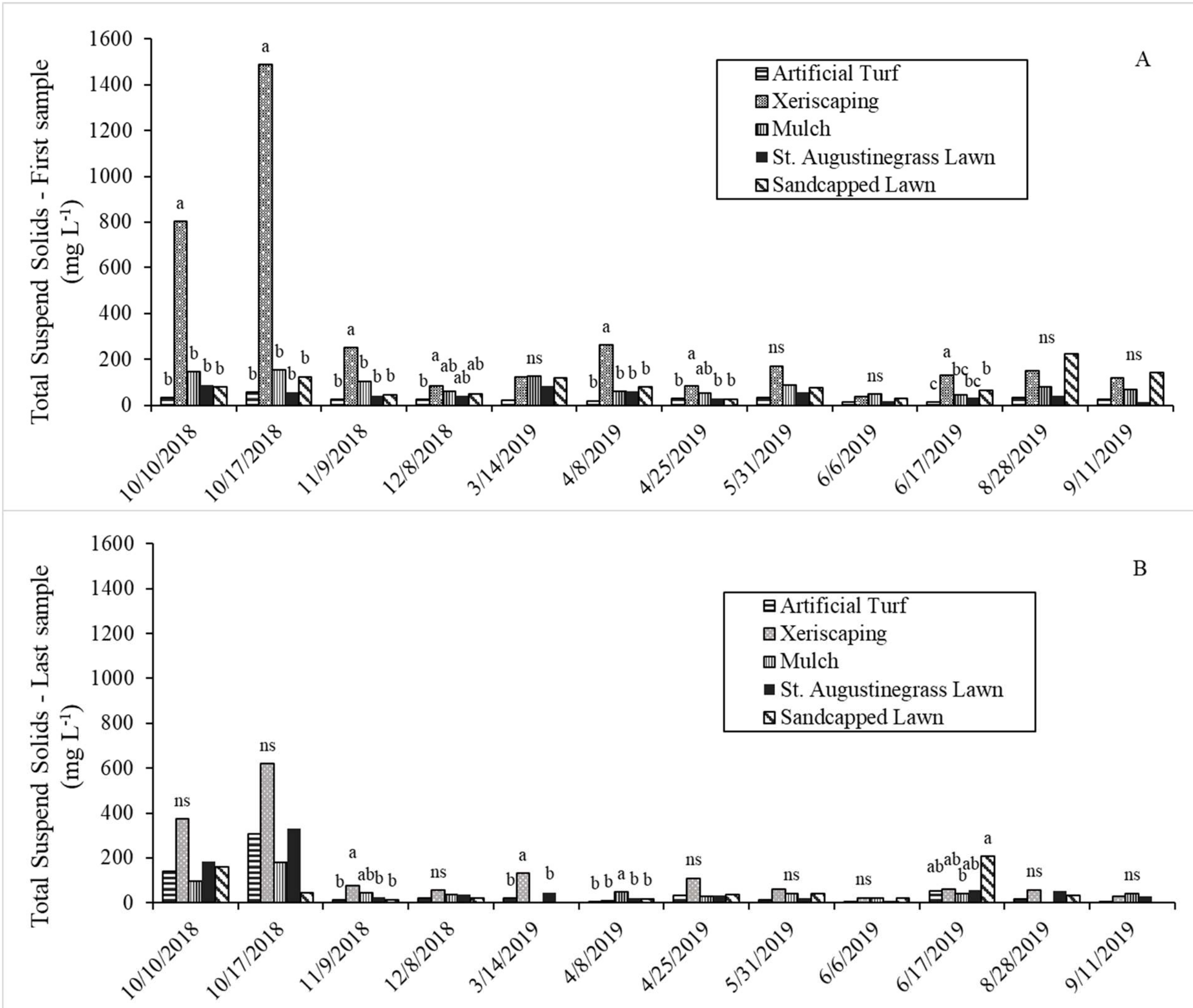

Figure 5.8 Total suspend solids of the first runoff sample (A) and the last runoff sample (B) for all landscapes. Means with the same letter in the same date are not significantly different based on Tukey's HSD at P = 0.05.

"First flush" of TSS is believed important by researchers, which is that the initial portion of the runoff always carries more TSS than the reminder portion due to the washout of deposited pollutants by rainfall (Deletic, 1998; Hathaway et al., 2012). Although some studies showed that first flush phenomenon is not always present. For example, Deletic and Maksimovic (1998) evaluated the water quality factors in storm runoff from paved areas found that the first flush effect of TSS only in a limited number of runoff events, our result confirmed the importance of this concept on surface water quality evaluation.

5.3.5.4. NO_3-N

Runoff NO_3-N concentrations ranged from 0.1 to 2.6 mg L^{-1} for all landscapes during the study periods, which are lower than the standard of maximum contaminant level (10 mg L^{-1}) for drinking water developed by EPA (Figure 5.9).

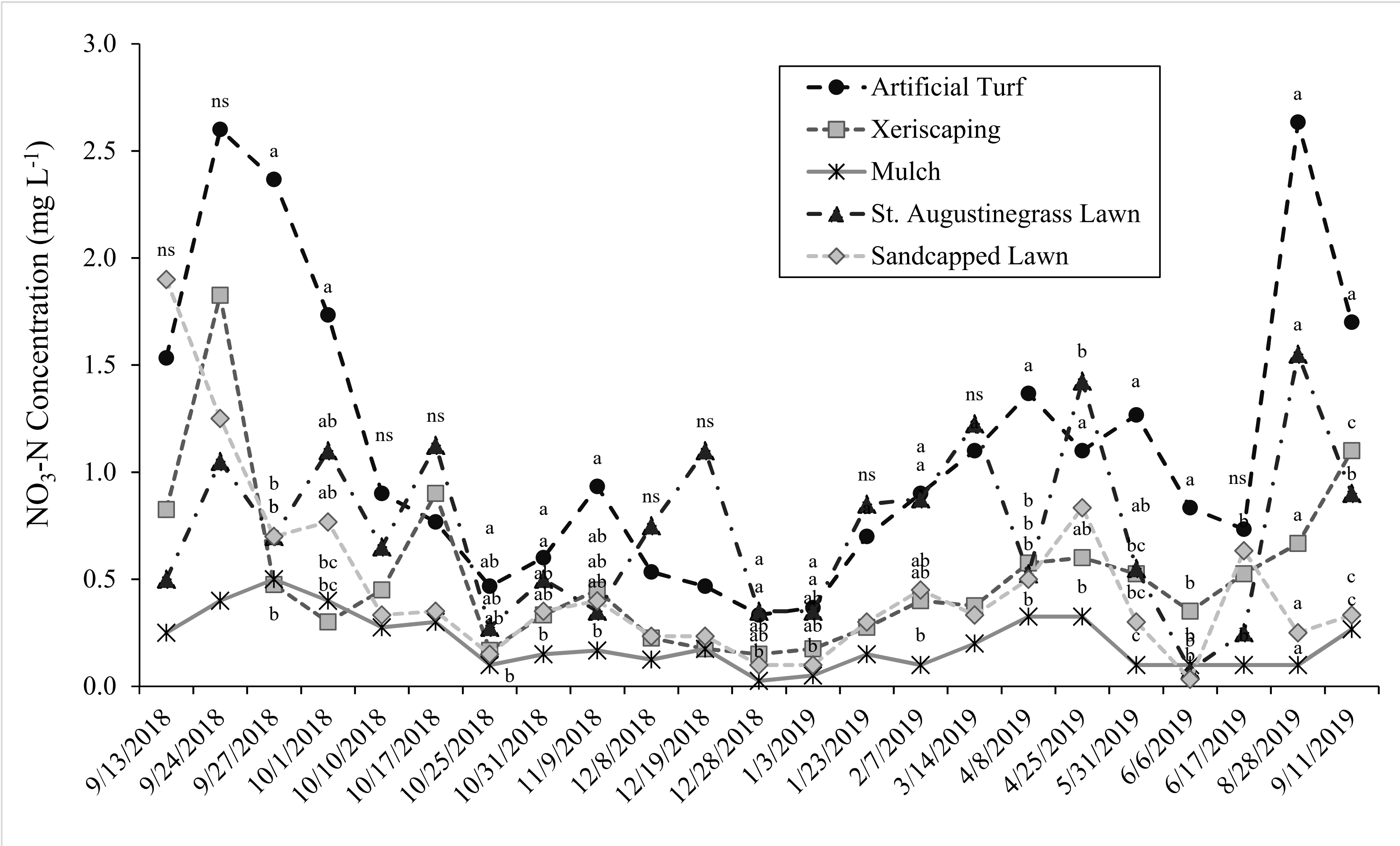

Figure 5.9 NO_3-N concentration as affected by landscapes and date. Means with the same letter on the same date are not significantly different based on Tukey's HSD at P = 0.05.

The highest NO_3-N concentration was observed for artificial turf and St. Augustinegrass lawn for most events (Figure 5.9). A significant difference was observed between mulch and artificial plots for several runoff events, with a range of 0.03 to 0.5 mg L^{-1} and 0.5 to 2.6 mg L^{-1} for mulch and artificial turf, respectively (Figure 5.9). The unexpected high NO_3-N runoff concentrations of artificial turf could be related to animal activities, as it has been found that several wild animals have shown up on those plots at night, leaving feces or urines in the plot while they were there. However, even though animal urine can increase N between 20 to 80 g N m^{-2}, over 70% of the N is present as urea (Haynes and Williams, 1993). Thus, the high NO_3-N runoff may be due to soil aeration from ground disturbance from wildlife. Concentrations NO_3-N in runoff from artificial turf is likely due to lack of plant uptake of NO_3-N. The concentration of NO_3-N of St. Augustinegrass was correlated with fertilization. As such, a significant difference between St. Augustinegrass lawn and xeriscaping, mulch, and sand-capped lawn was observed on 4/25/2019 and 8/28/2019 when fertilizers were applied two days earlier (Table 5.1; Figure 5.9).

5.3.5.5. NH_4-N

Runoff NH_4-N concentration was relatively stable for all landscape treatments and stayed at a lower concentration for xeriscaping and artificial turf over the entire study period, with a range from 0.1 to 0.6 mg L^{-1} (Figure 5.10). There was an exception of 3 peaks of NH_4-N during the study period (Figure 5.10) when runoff concentrations exceeded 2 mg L^{-1}.

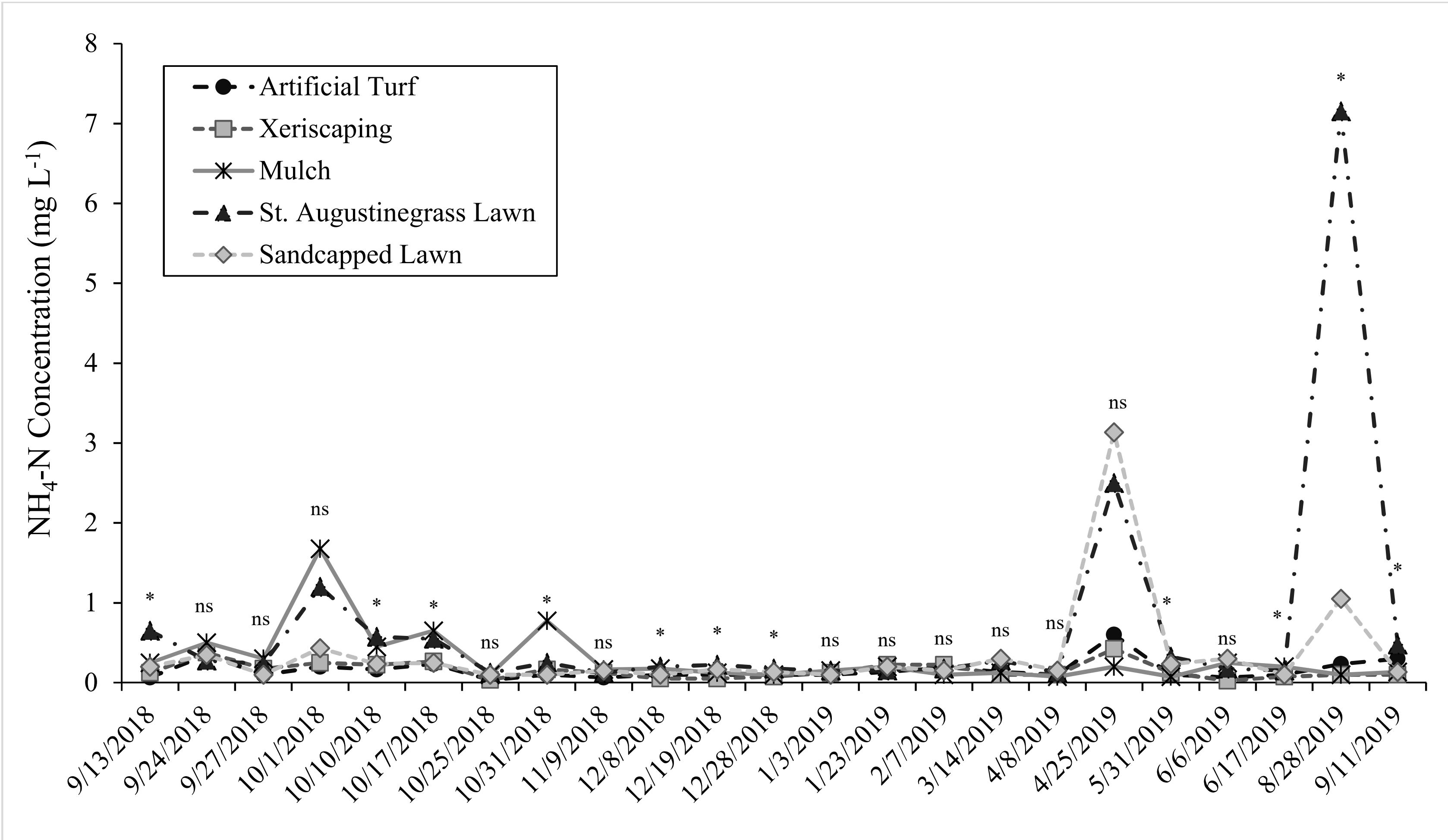

Figure 5.10 NH4-N concentration of runoff water for all landscapes. ns indicates no statistically significant difference and *statistically significant difference were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

All three peaks for NH_4-N had observed significant differences (10/31/2018, 4/25/2019, and 8/28/2019) were likely due to fertilization. As such, on 10/31/18, two days after mulch were fertilized, NH_4-N concentration was significantly higher for mulch when comparing to unfertilized artificial turf. Similarly, significantly higher concentration was found for sand-capped lawn and St. Augustinegrass lawn on 4/25/2019, and 8/28/2019 were due to fertilization that was applied 2 days before a rainfall (Table 5.1 and Figure 5.10), which means that checking the weather forecast and avoiding fertilization before a rain event can minimize the NH_4-N losses through runoff. Similarly, Erickson et al. (2001) found a slight increase in N loss in the percolate following fertilization on St. Augustinegrass, and all inorganic N loss was in NH_4-N. According to EPA's aquatic life ambient water quality criteria for ammonium, there will be no concern if ammonium concentration was lower than 24 mg L^{-1} for acute criterion (1-hour average), and 4.5 mg L^{-1} for chronic criterion (30-day rolling average).

In this study, fertilization received by landscape treatments were different, with turfgrass plots receivong the highest fertilization rate, while alternative landscapes received little to no fertilization, and thus, the efficiency of using applied N by lawns and alternative landscapes is not able to be compared in this study. Erickson et al. (2001) compared nitrogen runoff and leaching between newly established St. Augustinegrass turf and a mixed-species alternative landscape found that N leaching losses from low maintenance alternative landscape were 10 times higher than that from St. Augustinegrass, due to the lower density of planting, which supplemented the potential benefit of turfgrass on reducing nutrient losses.

5.3.5.6. TDN, DON, and DOC

According to ANOVA table (Table 5.4), significant interactions between landscapes and runoff events were found for TDN (total dissolved nitrogen), DON (dissolved organic nitrogen), and DOC (dissolved organic carbon). Most N in runoff was derived from organic N, around 70 to 90% for mulch and St. Augustinegrass lawn, and thus the total dissolved N (TDN) concentration followed a similar pattern to dissolved organic N (DON) concentration (Figures 5.11 and 5.12).

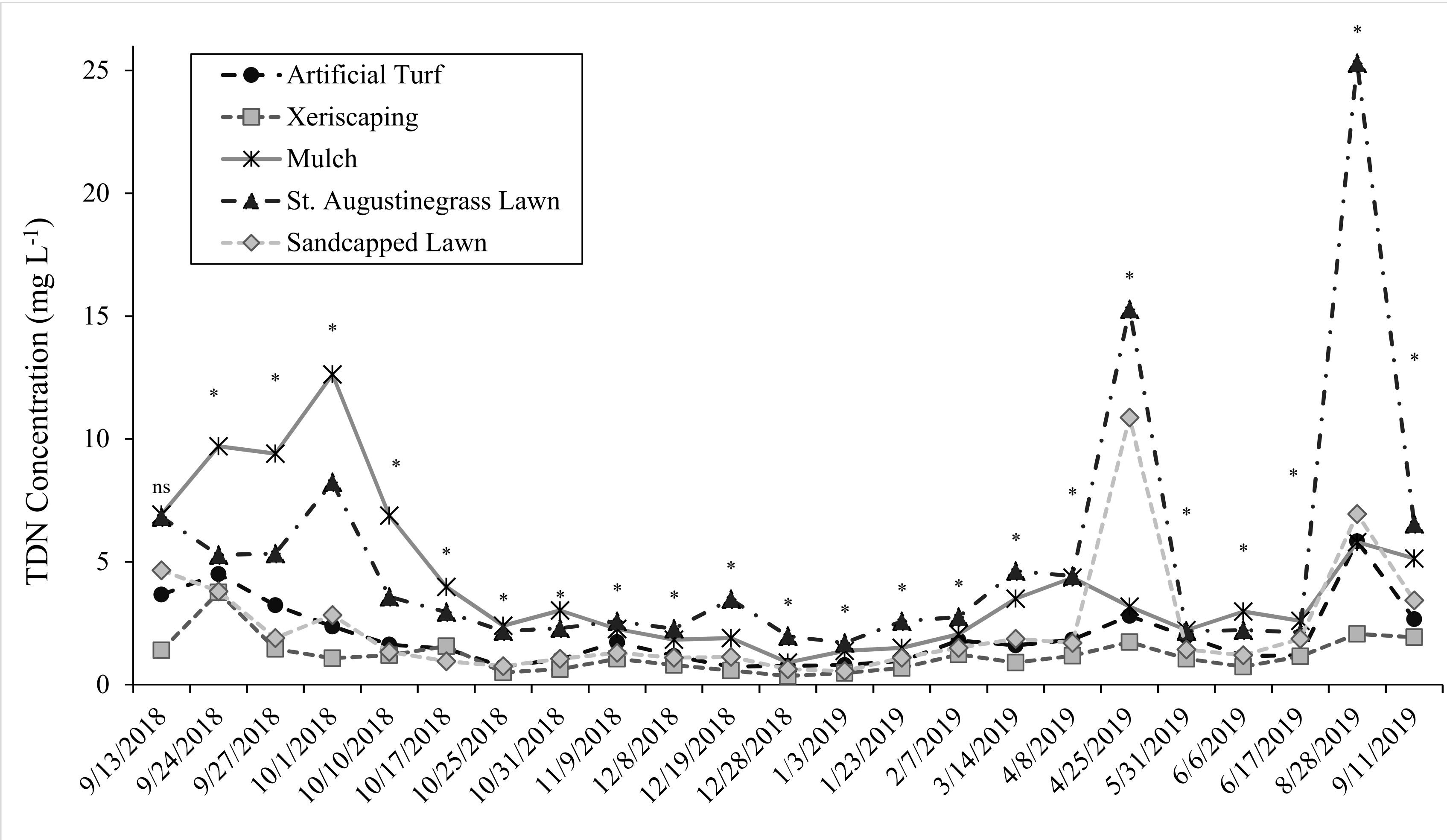

Figure 5.11 Total dissolved nitrogen (TDN) concentration of runoff water for all landscapes. ns and *, respectively, indicate no statistical difference and statistical difference between treatments on each date, based on Tukey's HSD at P = 0.05

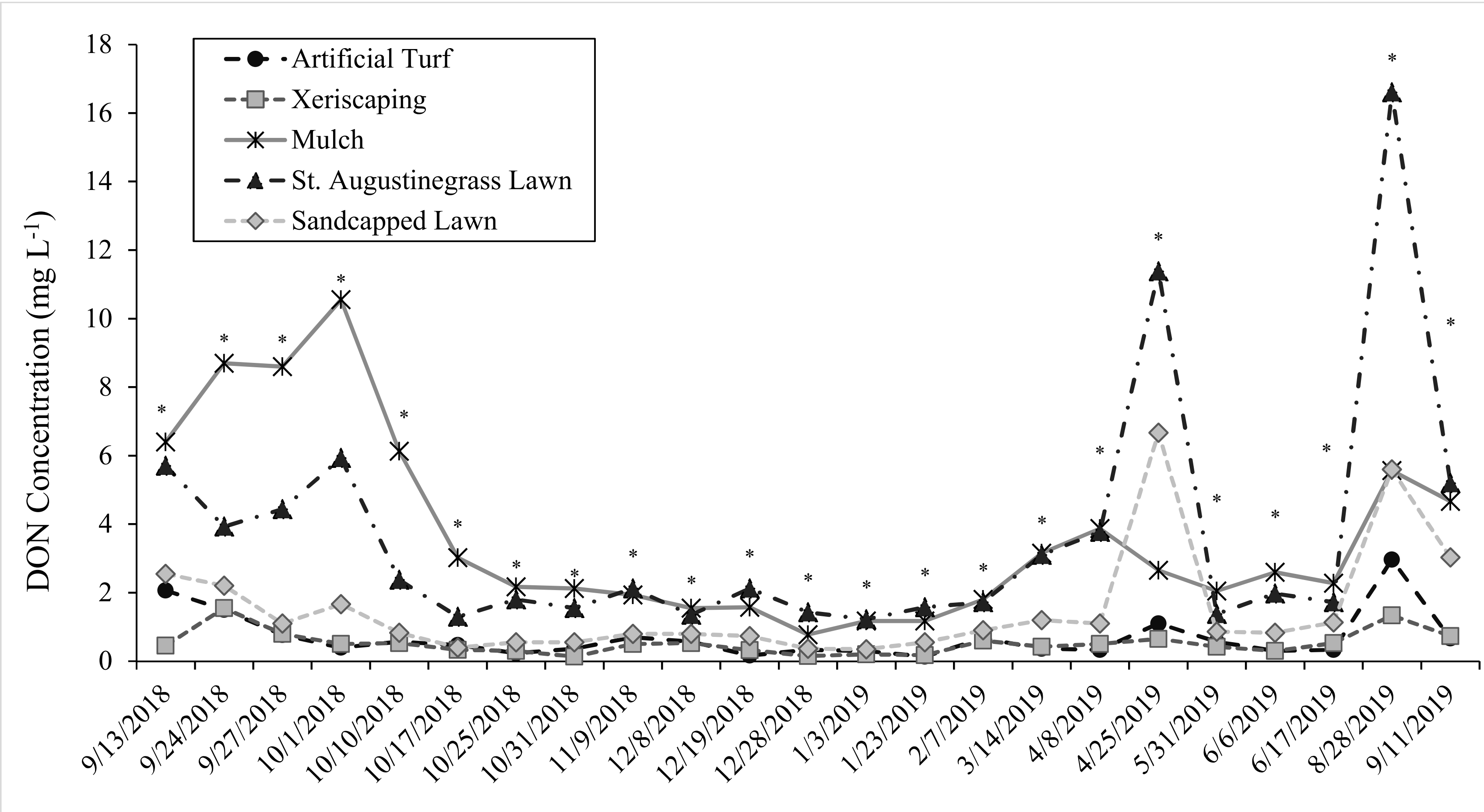

Figure 5.12 Dissolved organic nitrogen (DON) concentration of runoff water for all landscapes. ns and *, respectively, indicate no statistical difference and statistical difference between treatments on each date, based on Tukey's HSD at P = 0.05

For TDN and DON, the highest concentrations were found for mulch plots, which were followed by St. Augustinegrass lawns during the growing season (9/13/2018 – 10/31/2018) after landscape installation. During this period, DON concentration of mulch and St. Augustinegrass lawns were always significantly higher than other three landscapes, and the runoff DON concentration of mulch was significantly higher than all other landscapes, with a range of 4 to 11 mg L^{-1}. Starting from 11/9/2018, the difference of TDN and DON among landscapes were reduced, and St. Augustinegrass started showing the highest concentration for most of the dates (Figures 5.11 and 5.12). In comparison, DON concentration was relatively stable and almost negligible for xeriscaping, artificial turf and sand-capped lawn (less than 2 mg L^{-1} for most cases), except for two peaks found for sand-capped lawn, which were due to fertilization (Figure 5.12). TDN of xeriscaping and artificial turf was dominated by inorganic N (more than 50%), and their trend was discussed in previous sections on NO_3-N and NH_4-N.

Many studies have evaluated the impact of land use on DON losses to aquatic ecosystems. Unlike my study where treatments were specific to urban residential landscapes, otherstudies compared undeveloped areas, such as agricultural areas and forested watersheds with developed areas (Neff and Hooper, 2002; Pellerin et al., 2004; Mattsson et al., 2008; Aitkenhead-Peterson et al., 2009; Pannkuk et al., 2011). Thus, direct comparison between my study with other studies are limited. That being said, most of those other studies highlighted a positive correlation between soil disturbance and DON losses. For example, areas with more development or with with finer scale disturbances exhibited relatively greater DON losses, which is more or less in agreement with the result found in this study. As such, St. Augustinegrass lawn and sand-capped lawn were more finely managed when compared to other the other landscapes in my study, and thus highest DON concentration was observed for turfgrasses lawn for several events.

Means separation were clear among landscapes for DOC concentration during the study period, with a seasonal pattern presented. This is not unusual, as many researchers have reported seasonality of DOC (Mulholland and Hill, 1997; Ågren et al., 2007; Wilson et al., 2013). Basically, DOC in runoff water was dependent upon the organic carbon pool of each landscape (Aitkenhead et al. 1999). For example, mulch, 5 cm of shredded dark wood was used as infill material and contributed a large amount of organic carbon to the landscape. This organic carbon was leached into the plot water after rain and left plot with runoff water when during high rainfall events which resulted in the highest DOC concentration in runoff during the entire study period. An analogy here would be a coniferous or boreal forest with a deep forest floor which also results in higher exports of DOC compared to grassland cover (Aitkenhead and McDowell 2000). A warmer environment seems facilitated the wood breakdown, releasing organic C, as peaks found on dates within April to October 2019 (Figure 5.13). This breakdown is likely linked to the fungal growth reported earlier (referring to section 5.2.4).

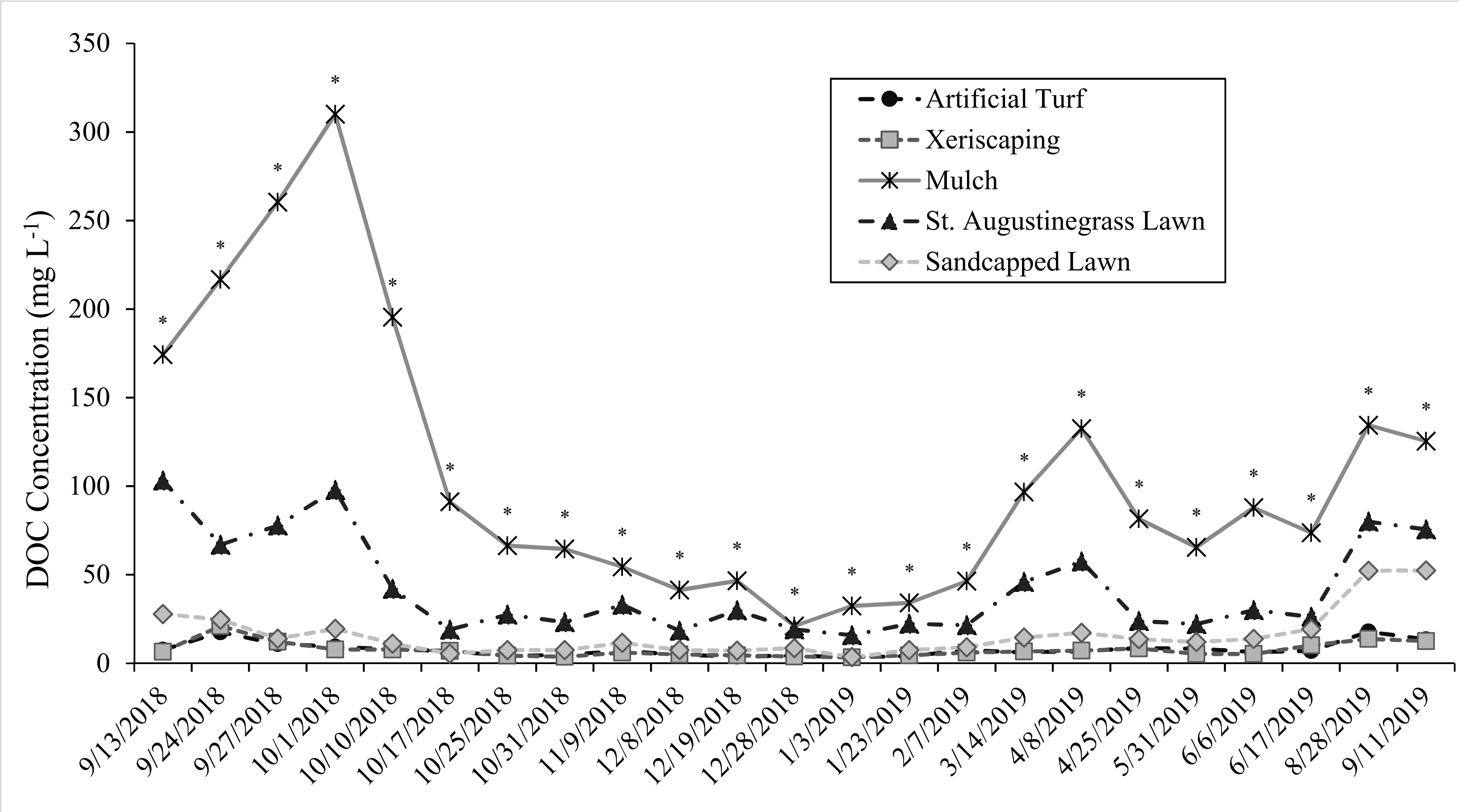

Figure 5.13 DOC (dissolved organic carbon) concentration of runoff water for all landscapes. ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

Turfgrass biomass was the major organic C source for St. Augustinegrass lawn and sand-capped lawn, and the organic carbon pool was large when more biomass was produced during growing season, which directly impacted the DOC concentration in runoff. Two big DOC curves were found for St. Augustinegrass lawn for both years, while there was only one curve found in 2019 for sand-capped lawn, because not much biomass was produced by newly sodded sand-capped lawn in 2018. This is also the reason why St. Augustinegrass had higher DOC concentration than sand-capped lawn, as 6-years-old turfgrasses should have produced more biomass and hence thatch than less than 1-year old turfgrasses. Aitkenhead-Peterson et al. (2018) reported runoff DOC concentrations of between 80 and 100 mg L^{-1} for St. Augustine turfgrass lawns after installation. However, most of the runoff in this study was induced by excess irrigation and not rain events that may have been a function of irrigation water sodicity. New sod can produce 50 mg L^{-1} in runoff DOC during a rain event however (Aitkenhead-Peterson et al. 2018), higher than observed for the sand-capped newly laid sod which may be an indication that iron and aluminum oxides contained in the sand cap adsorbed DOC preventing its runoff.

DOC concentration of xeriscaping and artificial turf was less than 20 mg L^{-1} for most runoff events, likely because there was little to no above-ground organic input for these two landscapes. Alternatively, iron and aluminum oxides contained in the decomposing granite may have adsorbed DOC emanating from the native soil beneath (Aitkenhead-Peterson et al. 2003).

5.3.5.7. PO_4-P

Significant differences in runoff PO_4-P concentration was observed among landscape treatments. The location of the runoff facility was previously used for dairy animals. Therefore, the soil at the study site has a high PO_4-P content (legacy PO_4-P) (Wherley et al., 2014). High PO_4-P concentrations in runoff samples have been detected before starting this project when all plots were still covered by St. Augustinegrass. The high concentrations of PO_4-P in the native soil still existed in this study, as evidenced by significantly higher PO4-P in St. Augustinegrass lawn when compared to the three newly constructed landscapes, xeriscaping, artificial turf and sand-capped lawn. (Figure 5.14).

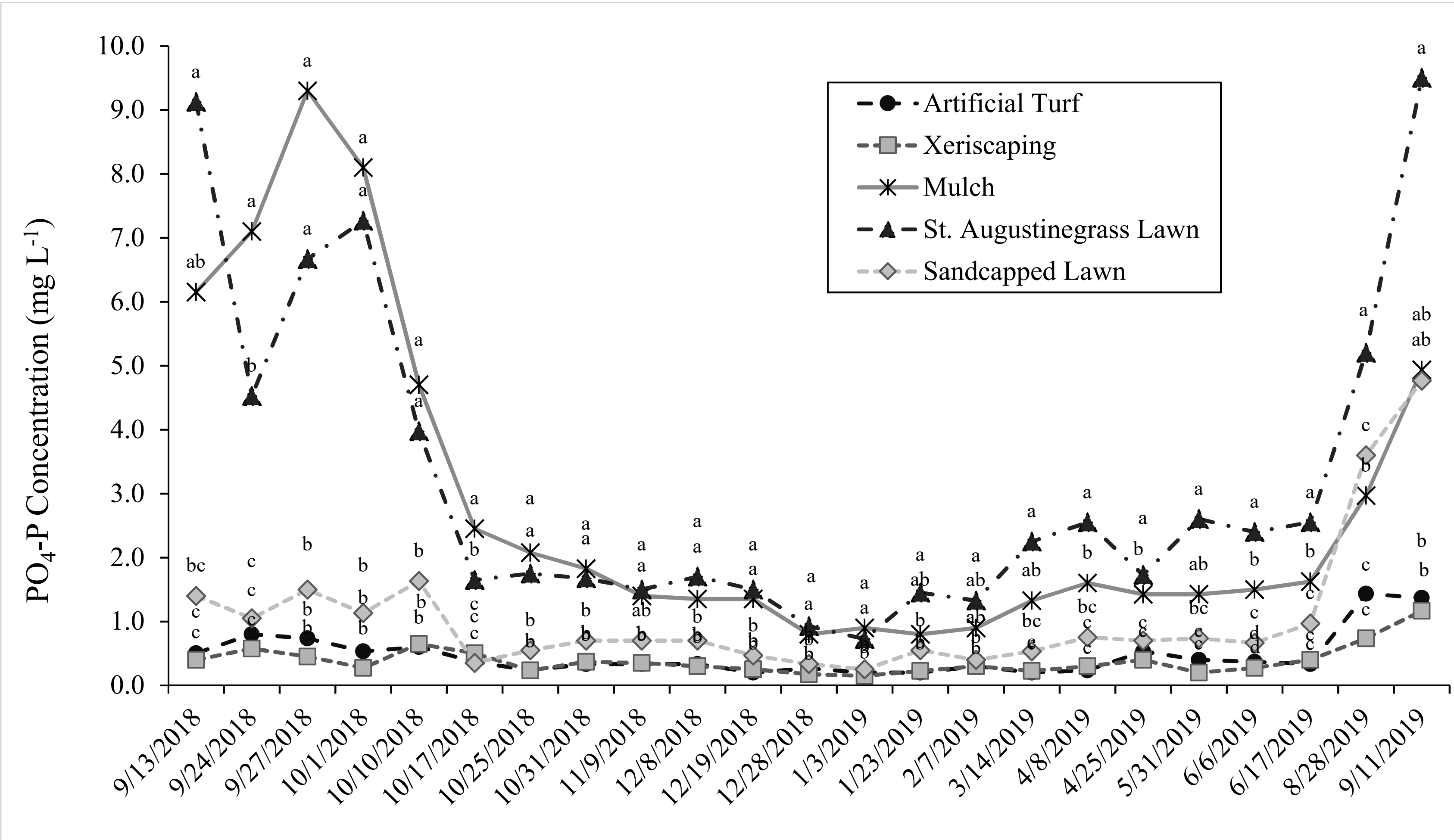

Figure 5.14 PO_4-P concentration of runoff water for all landscapes. Means with the same letter at the same date are not statistically different based on Tukey's HSD at P = 0.05.

Mulch showed the same concentration of PO_4-P concentration as St. Augustinegrass between 9/14/2018 to 10/10/2018 with a range of 4 to 10 mg L^{-1}, then dropped to a stable range of 1.3 to 2.3 mg L^{-1} that was not significantly higher than other three newly established landscape anymore. However, PO_4-P concentration was relatively stable for sand-capped lawn, xeriscaping, and artificial turf over the entire study period, with a range of 0.2 to 1.5 mg L^{-1} (Figure 5.14). These results suggest that putting an additional layer on top of native soil could help reduce PO_4-P losses through runoff. One possible reason of the function of PO_4-P control provided by newly established plots is that PO_4-P is adsorbed with the infill materials, such as coarse sand, decomposed granite than native soils due to the presence of iron and aluminum oxides, thus, less PO_4-P would be leaving the system. However, according to a Pearson correlation test, a relationship with TSS and PO_4-P was only observed for mulch (Table 5.6).

Table 5.6 Correlation of TSS with parameters of runoff quality measured for runoff samples. All nutrient parameters presented here are concentrations (mg L^{-1}).

	St.Augstinegrass Lawn				Sand-capped Lawn				Xeriscaping				Mulch				Artificial Turf			
	TSS (First)		TSS (Last)		TSS (First)		TSS (Last)		TSS (First)		TSS (Last)		TSS (First)		TSS (Last)		TSS (First)		TSS (Last)	
NO_3-N	0.08	ns	0.23	ns	0.00	ns	0.35	ns	0.12	ns	0.24	ns	0.30	*	0.40	*	0.15	ns	-0.12	ns
NH_4-N	-0.09	ns	-0.04	ns	-0.12	ns	-0.14	ns	0.56	***	0.37	*	0.54	***	0.51	**	0.26	ns	0.15	ns
PO_4-P	0.13	ns	-0.12	ns	0.33	ns	0.19	ns	0.23	ns	0.18	ns	0.36	*	0.64	***	0.16	ns	0.10	ns
TDN	-0.01	ns	-0.09	ns	-0.03	ns	-0.03	ns	0.23	ns	0.16	ns	0.48	***	0.69	***	0.22	ns	-0.02	ns
DON	-0.01	ns	-0.12	ns	0.00	ns	-0.03	ns	0.10	ns	-0.03	ns	0.44	**	0.64	***	0.19	ns	0.05	ns
DOC	0.39	**	-0.22	ns	0.42	*	0.25	ns	0.24	ns	0.03	ns	0.46	**	0.65	***	0.11	ns	0.04	ns

ns, ***, **, *; not significant, significant at P=0.001, 0.01, and 0.05, respectively

The second theory is that an additional layer on top of native soil protected the PO_4-P from leaving the system in runoff. If the second theory is correct, it helps to explain the unique performance of mulch that large amount of PO_4-P was lost only in the beginning of the study similar to St. Augustinegrass and then it was reduced significantly due perhaps to compaction and hydrophobicity. In the beginning of the study, native soil was not covered very well by the new shredded dark wood mulch, and PO_4-P was still leaving the soil easily when native soils along with mulch materials were flushed by runoff, however, once mulch materials have become compacted over time, a better protection was given and less native soil can be flushed by runoff, which resulted in a lower PO_4-P loss.

5.3.6. Nutrient Export

Nutrient export was calculated by multiplying nutrient concentration by runoff volumes and divided by the size of plot. As shown in table 5.7, there was a significant landscape main effect on all nutrient export measured in this study. In addition, there were significant interactions between landscape and date on all nutrient export as well.

Table 5.7 ANOVA for effect of landscape and date on nutrient export.

	Total Nutrient Export (mg m^{-2})					
Source	NO_3-N	NH_4-N	PO_4-P	TDN	DON	DOC
Replication	NS	NS	NS	NS	NS	NS
Date (D)	***	***	***	***	***	***
Landscape (L)	***	***	***	***	***	***
D x L	*	***	***	***	***	***

ns, ***, **, *; not significant, significant at *P*=0.001, 0.01, and 0.05, respectively

5.3.6.1. NO_3-N Export

While the graphs were similar between runoff volume and NO_3-N export as nutrient export were highly affected by runoff volume, landscape treatment affected NO_3-

N export differently when comparing to their effect on runoff volume. As such, during the study period, no significant differences were observed for landscape treatment for almost half of the rain events, no matter if the rain event was high or low (Figure 5.15). However, when a significant difference was detected, it tended to be observed when export was less than 50 mg m^{-2}. Artificial turf always had the highest NO_3-N export, and it was significantly greater than all other landscape treatments (Figure 5.15). The high NO_3-N exports observed in the turfgrass treatment may be related to the potential disturbance of the plot by wildlife.

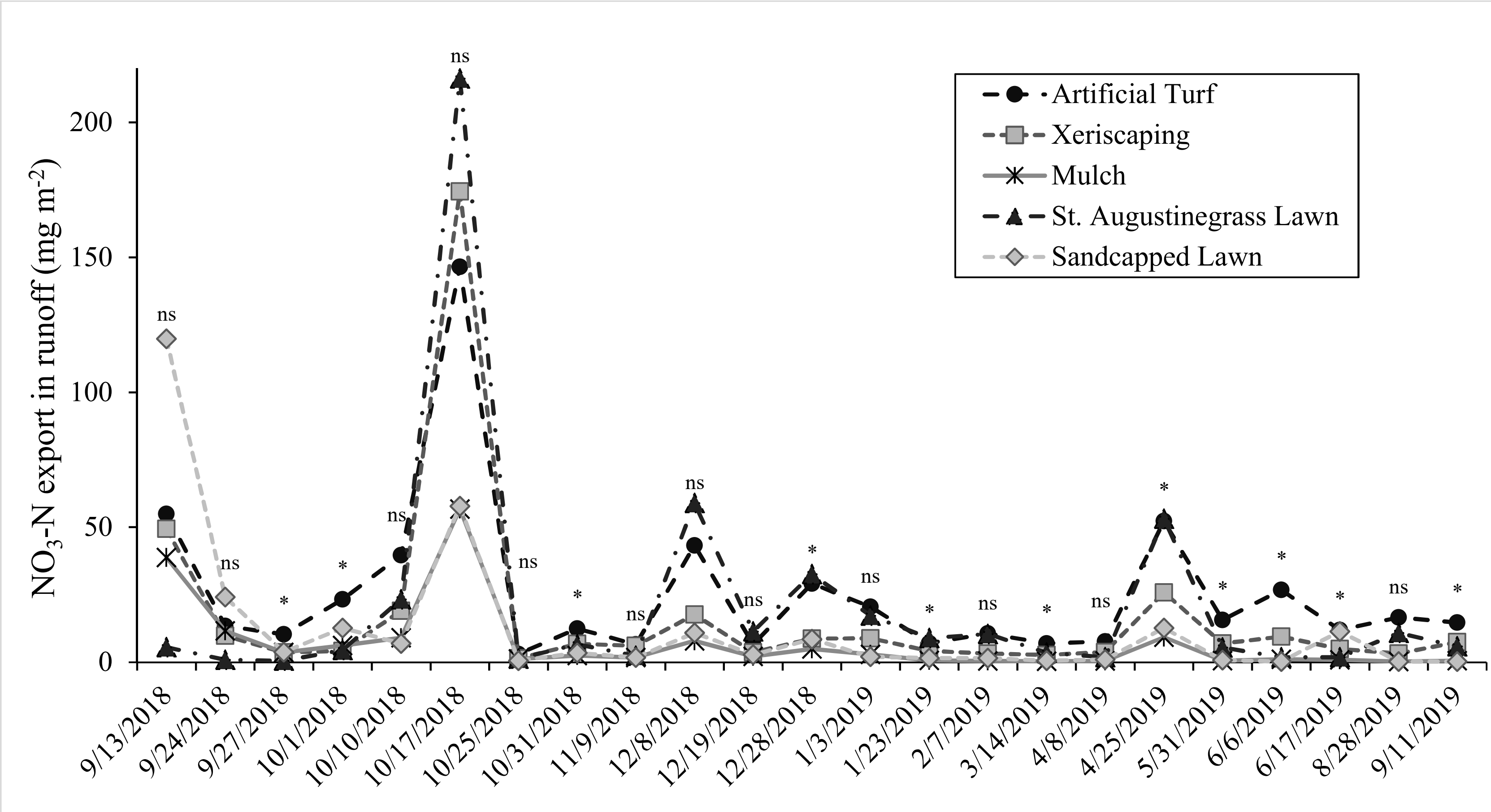

Figure 5.15 Effect of landscape and date on runoff NO_3-N export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

5.3.6.2. NH_4-N Export

NH_4-N export was significantly higher for mulch for the first few events such as 9/13/2018, 9/24/2018, 9/27/2018, and 10/17/2018 (Figure 5.16). Export ofNH_4-N then declined to a stable level (below 20 mg m^{-2}) and no effect of landscape was observed. The landscape treatments with decomposed granite and sandcap tended to hold steady over the study period. One large peak was observed on 8/28/2019 when NH_4-N export was extremely high for St. Augustinegrass lawn compared to other landscapes; this was likely due to the high NH_4-N concentration in runoff that was derived from previous fertilization. It is interesting to note that the NH_4-N export on the same date for sand-capped lawn was low, although the same fertilization was applied. This should give the credit to the great runoff volume control of the sand-capped lawn treatment. Similarly, another peak was also found on 4/25/2019, but the overall NH_4-N export was not significantly higher for St. Augustinegrass lawn and sand-capped lawn. Likely because more of the applied fertilizer was taken up by the turfgrasses two days after fertilization. In contrast, runoff occurred 1 day after fertilization (8/27/2019) on 8/28/2019. These results suggested that NH_4-N losses through runoff from lawns can be avoided if a better nutrient management is adhered to and a rule of thumb is that never spray fertilizers ahead of a rain event.

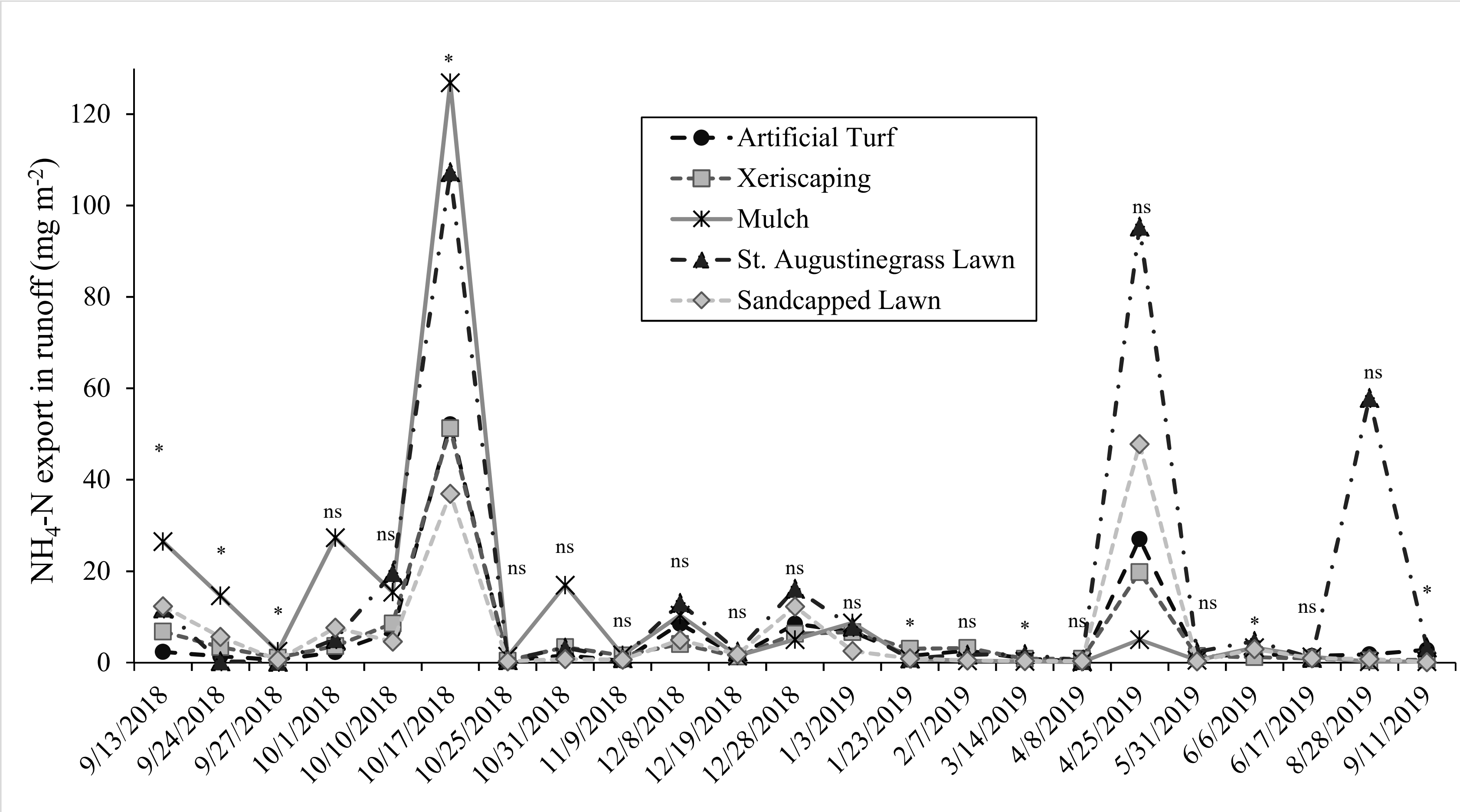

Figure 5.16 Effect of landscape and date on runoff NH_4-N export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

5.3.6.3. TDN, DON, and DOC Export

DON is the largest portion of TDN export (around 60 to 80%, depending on the runoff event). A significant effect of landscape and date, and their interaction were also found for TDN and DON export (Table 5.7). On the early stage of the study, mulch showed a significantly higher TDN and DON export, followed by either sand-capped lawn, or St. Augustinegrass lawn. However, as mulch was rinsed by rainfall over time, TDN and DON export dropped significantly (less than 100 mg m^{-2}). Starting from winter until the second summer, whenever there was a heavy rain (greater than 50 mm), such as 12/8/2018, 12/28/2018, and 4/25/2019, or a runoff event occurred after fertilization, such as 8/2/2019, the greatest peak for TDN and DON was found for St. Augustinegrass lawn (Figures 5.17 and 5.18). Studies have confirmed that vegetation type plays a dominant role in regulating the decomposability of soil organic matter, and several have in agreement with our results that grass have a high potential of DON losses. Neff and Hooper (2002) investigated vegetation on potential DOC and DON production in northern latitude soils with conducting a 1-year incubation study, found that tussock vegetation exhibited the highest DON flux at one study site, followed by spruce and wet sedge vegetation. DON losses were also measured by the study of Steele and Aitkenhead-Peterson (2013), and the impact of vegetation on DON were similar to DOC losses, with the highest DON from turfgrass systems and the lowest from live oak, riparian litter, and mulch.

Because DON is a subset of DOC (a DOC molecule with an amino group), the effect of landscape on DOC export over time was expected. Surprisingly, their patterns were only comparable for the early stage of the study. As such, the DOC export was significantly greater for mulch plots during the first growing period (9/14/2018-

10/31/2018) when comparing to other landscapes (Figure 5.19). However, not like TDN and DON, St. Augustinegrass lawn dominated for several runoff events during winter to the second growing season. Few to no significant differences among landscapes were observed during spring, and when there was a significant difference among landscape treatments, the highest export was still found for mulch plots (Figure 5.19). St. Augustinegrass only showed significantly higher DOC export on 8/28/2019 and 9/11/2019, when turfgrass were actively growing, returning decent amount of Carbon to the plots through clippings.

DOC losses through aquatic ecosystems is correlated to soil disturbance and land use (Neff and Hooper, 2002; Atkenhead-Peterson and Cioce, 2013). DOC in undisturbed soils is either mineralized by soil microbes or absorbed to soil minerals and therefore result in less losses through surface runoff (McDowell et al., 2006; Kaiser and Kalbitz, 2012). However, for highly managed soils, greater DOC losses have been found as a result of various land management practices, such as irrigation and fertilization (Aitkenhead-Peterson and Cioce, 2013). Aitkenhead-Peterson and Cioce (2013) measured the DOC and DON leaching from several locations with variation in land use, found that commercial parking lots and city parks where grass were grown released significantly higher DOC than remnant native soils. They concluded that high salt, especially for sodium, in the irrigation water has played an important role on DOC losses. Excessive sodium in soil exchanges with H^{+} at cation exchange sites, which decrease soil solution pH and thus solubilize humic acids (Stevenson, 1994). Furthermore, another mechanism of DOC retention in soil is due to polyvalent cation bridging (Tipping and Woof, 1991). Polyvalent cations such as, Ca^{2+}, Al^{3+} binding negatively charged organic molecules to soil particles, reduce the potential of DOC losses; however, DOC becomes more soluble when those cations are replaced by Na^+. Steele and Aitkenhead-Peterson (2012, 2013) found that DOC losses from urban turfgrass were much higher than that from live oak, riparian leaf litter, and mulch. However, even though turfgrass lawns were irrigated twice a week in this study with similar sodic municipal potable water used by Aitkenhead-Peterson and Cioce (2013), the highest DOC losses were from mulch (Figure 5.19), which probably because that all runoff captured were from rainfall, and thus reduced the impact of sodic water on DOC losses.

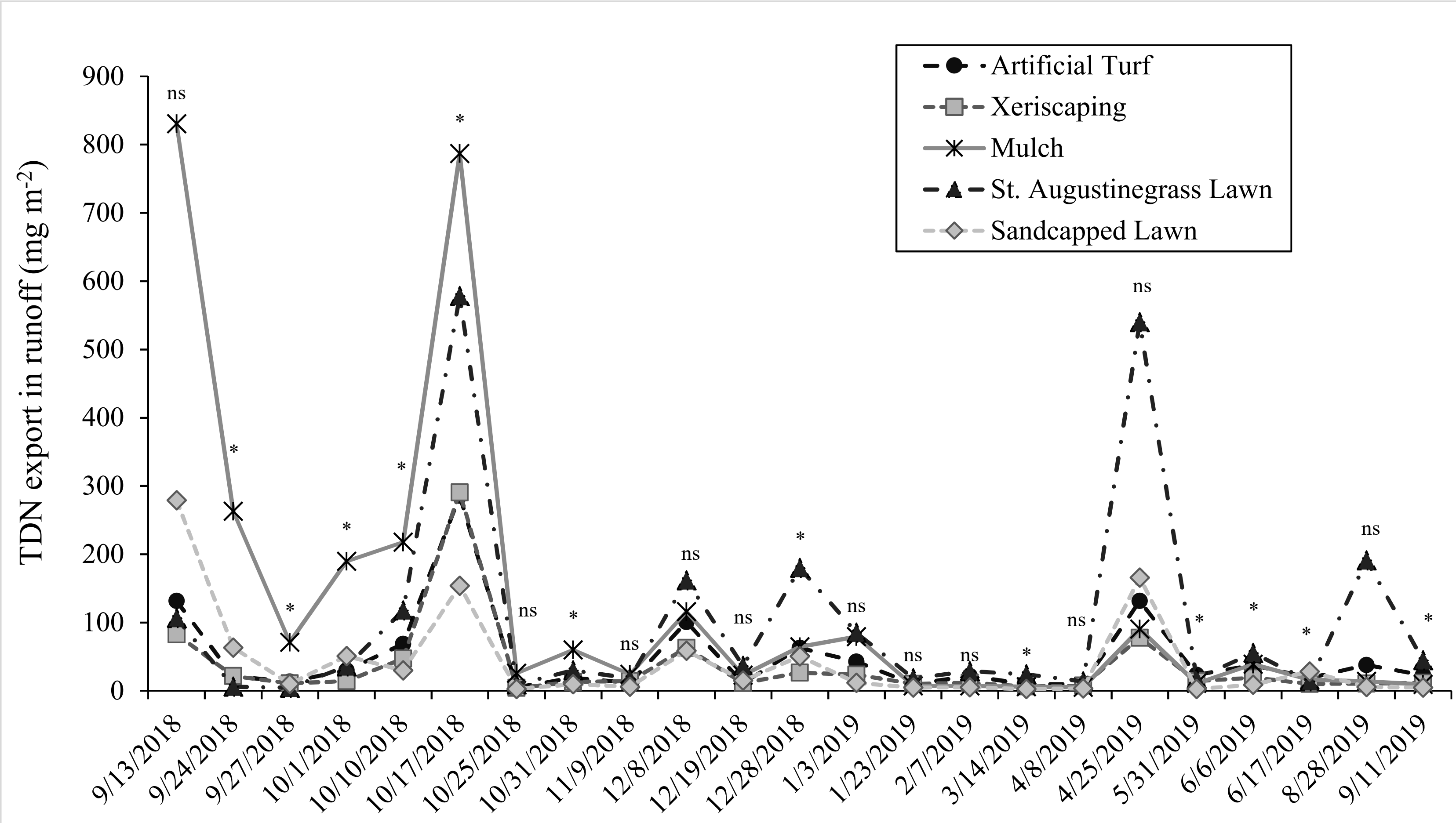

Figure 5.17 Effect of landscape and date on runoff TDN (total dissolved nitrogen) export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

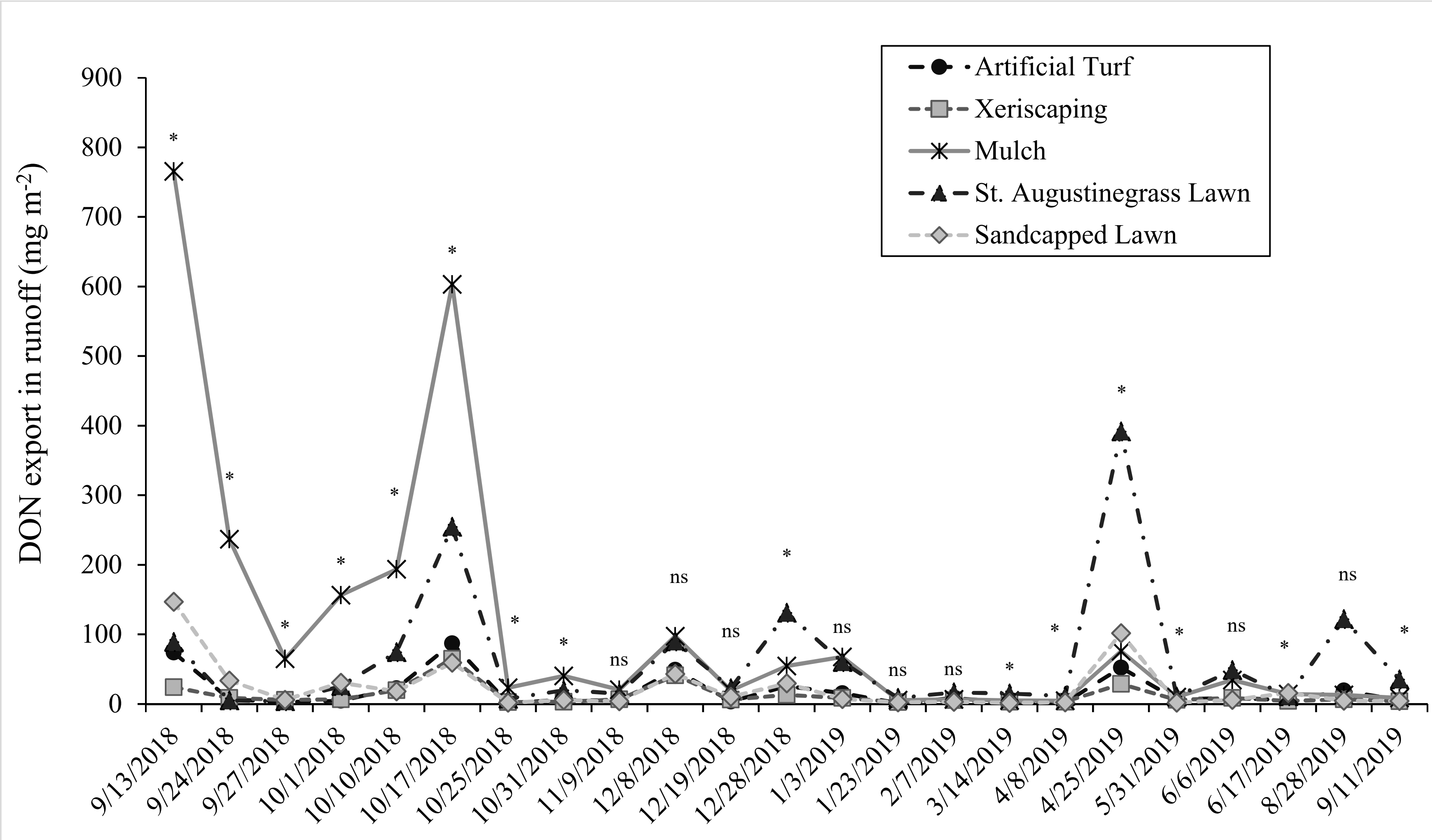

Figure 5.18 Effect of landscape and date on runoff DON (dissolved organic nitrogen) export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

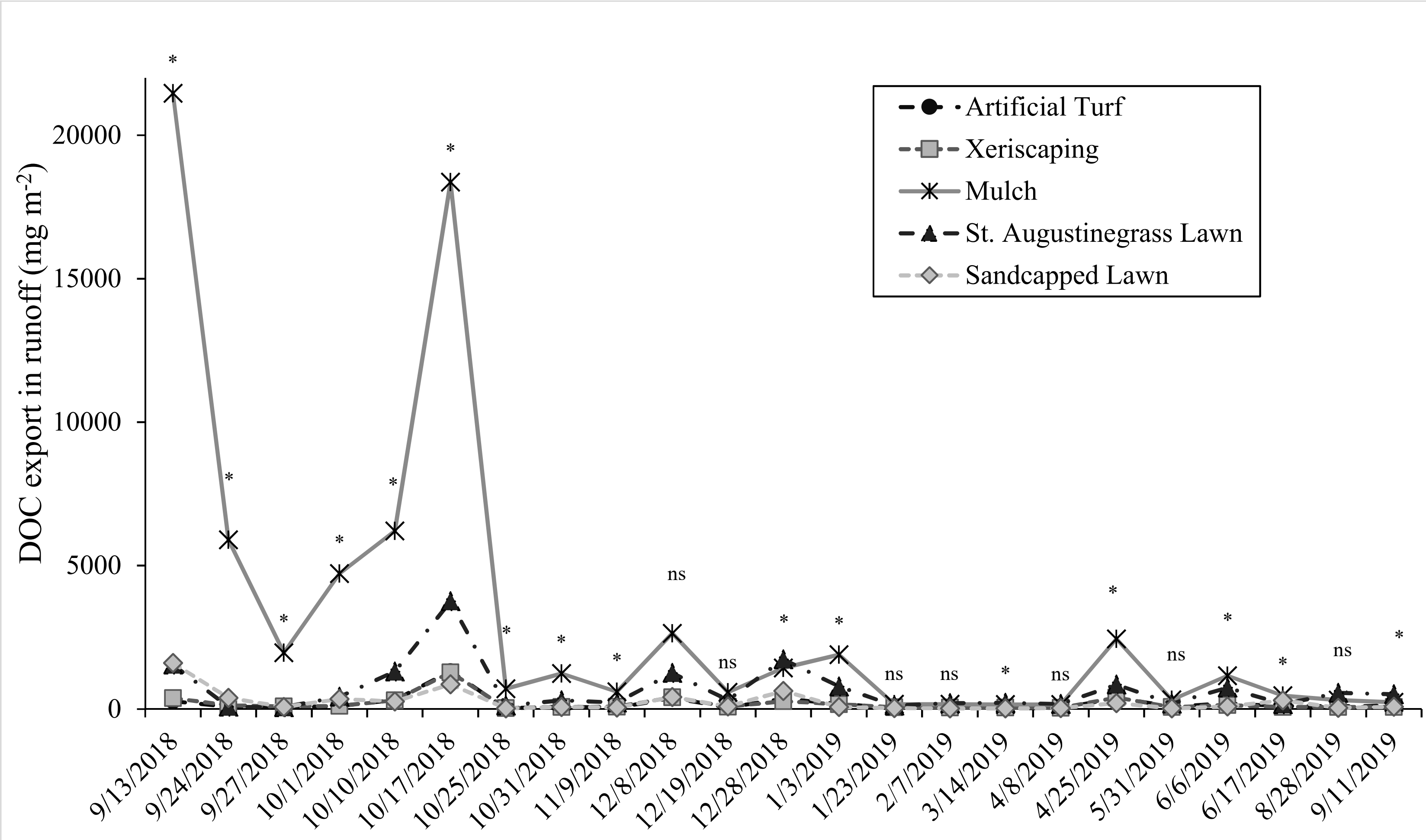

Figure 5.19 Effect of landscape and date on runoff DOC (dissolved organic carbon) export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

5.3.6.4. PO_4-P Export

Unlike PO_4-P concentration, which was relatively stable effect from landscape treatments over the study period, the effect of landscapes on PO_4-P export was varied (Table 5.7; Figure 5.20). The highest export was detected for mulch during September 2018 to November 2018, as both its concentration and runoff volume were high. Although concentration was also high for St. Augustinegrass lawn during this period as shown in Figure 5.14, export of St. Augustinegrass lawn was not significantly higher than that of xeriscaping, sand-capped lawn, and artificial turf due to the lower runoff volume. For the rest of the study period (staring from November 2018), while concentration of PO_4-P for mulch was still significantly higher than other three landscapes for most cases (Figure 5.14), export of mulch dropped to the lowest level as xeriscaping, artificial turf, and sand-capped lawn due to its great runoff volume control.. In the meantime, St. Augustinegrass lawn stand-alone released significantly greater amount of PO_4-P than other landscapes mainly due to the high PO_4-P concentration.

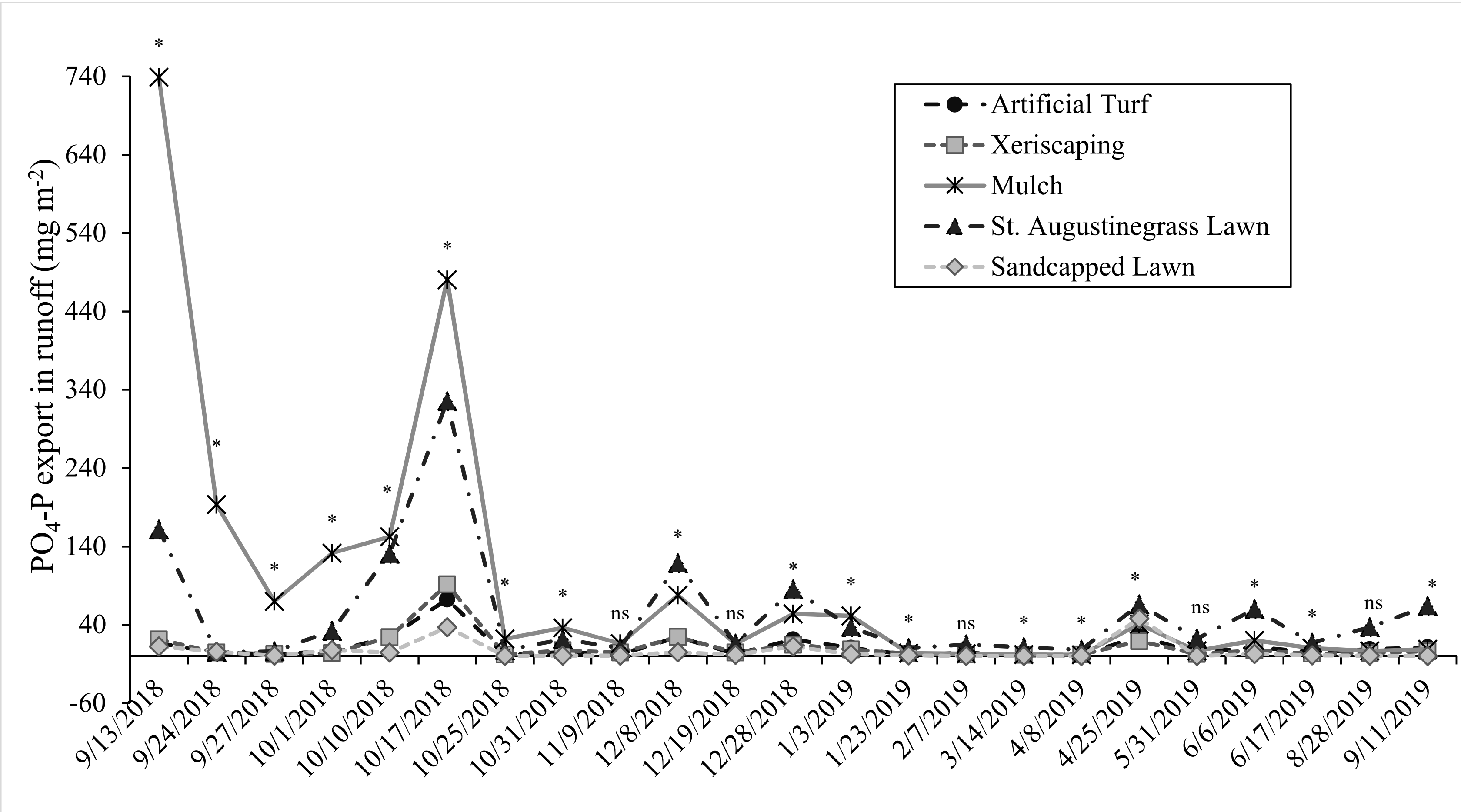

Figure 5.20. Effect of landscape and date on runoff PO_4-P export per event (mg m^{-2}). ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

The effect of landscape treatment on runoff water quality and quantity can be used as a useful reference for landscape design that can be used for both municipal purpose and watershed management. The performance of each landscape tested in this study were significantly different on different nutrient parameters. Thus, this study illustrated that there is no specific landscape to be used under all scenarios for mitigating runoff volumes and quality and alternative landscapes should be selecting based on environmental needs. For example, artificial turf and xeriscaping could be a better choice for a watershed where concern of river or stream contamination that was derived from the chemical offload of shoreside soil. On the contrary, if flood is a major concern, these two relatively impervious landscapes turn out to be unwise choice. Instead, lawn systems are more effective on flood water control.

5.3.7. Surface Temperature

Surface temperature was significantly different among landscapes over the study period, and an interaction of landscape and date was also observed (Table 5.3). Overall, the surface temperature was always highest for artificial turf, followed by mulch for most of the dates (Figure 5.21).

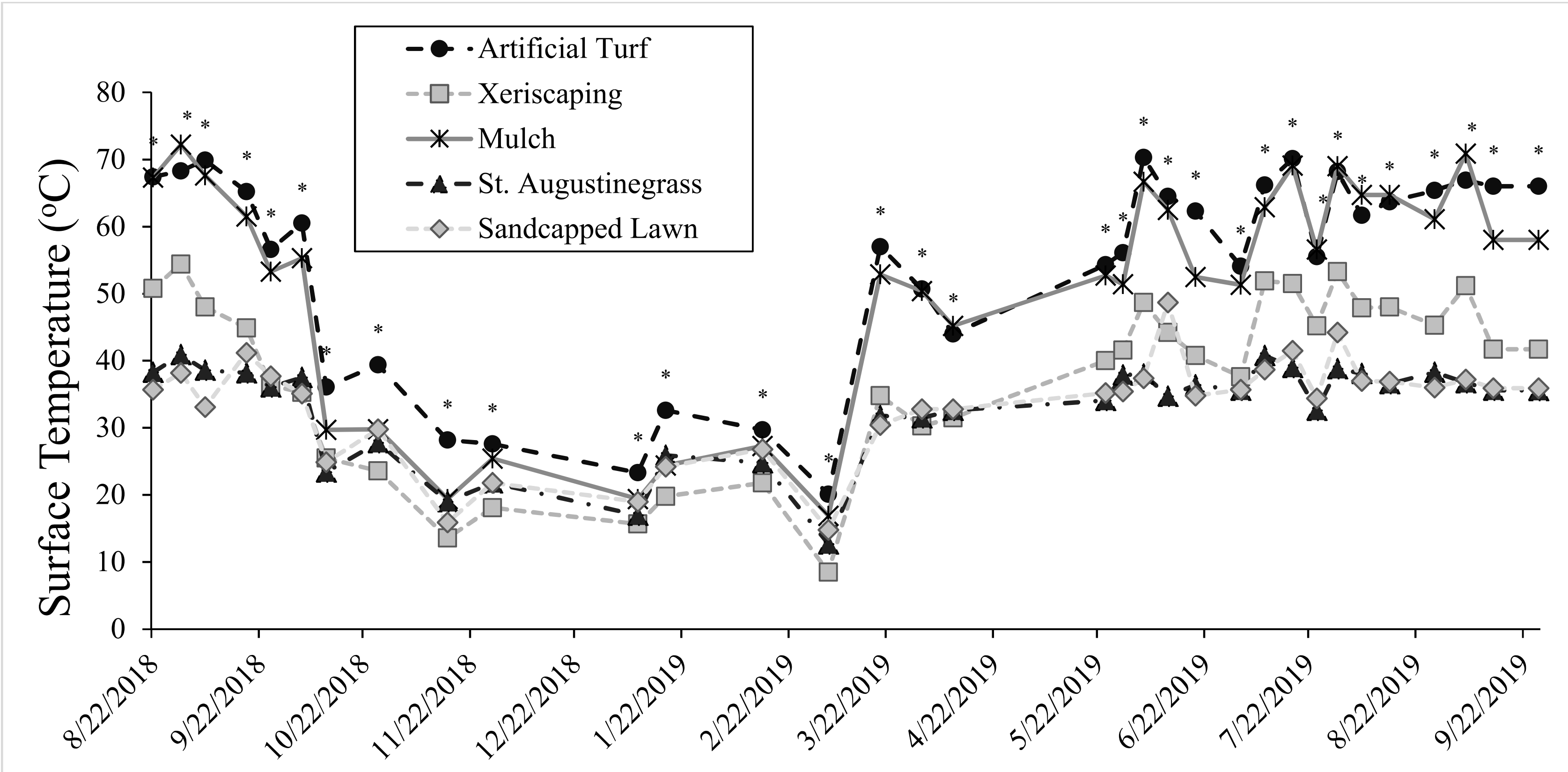

Figure 5.21 Infrared reflected surface temperature of all landscapes over the study period. Measurements were taken once a week during 12:00 pm to 2:00 pm on each measuring day. ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

A seasonal variation of difference of surface temperature among landscapes is observed during growing season (April to October) and non-growing season (November to March). As such, during the growing season, St. Augustinegrass lawn and sand-capped lawn maintained the lowest surface temperature (35 ± 4^{o} C), which was significantly lower than that of xeriscaping, mulch and artificial turf. This may be partially due to the energy liberation by turfgrasses through transpiration and high reflection of solar radiation. Surface temperature of xeriscaping was also significantly lower than that of mulch and artificial turf during the growing season, mainly because of its highest reflected solar radiation or in other words, highest albedo. However, limited energy losses through transpiration of native water efficient plants still result in a higher surface temperature when compare to lawns. Extremely high surface temperature was measured for mulch and artificial turf during the growing season, with a range of 44 to 70^{o}C for both landscapes. Radiation measurements revealed that this was because the relatively high net radiation and low reflected solar radiation of these two landscapes, especially for artificial turf (data not shown). During non-growing seasons, transpiration of turfgrasses was limited, and thus the surface temperature of St. Augustinegrass lawn and sand-capped lawn was within the similar range as xeriscaping (between 10 to 30^{o} C). In addition, when air temperature was low, the lowest surface temperature was found for xeriscaping due to the highest albedo, and it was sometimes significantly lower than that of St. Augustinegrass lawn and sand-capped lawn, such as for dates 10/26/2018, 12/3/2019, and 2/28/2020. A similar effect was found for mulch and artificial turf during the non-growing season when compared to the growing season, as the highest surface temperature was always found for between these two landscapes, with a range of 15 to 45^{o} C.

My results for landscape surface temperature are in the agreement with previous studies that evaluate the benefit of turfgrass on temperature mitigation. For example, Takebayashi and Moriyama (2012) studied the surface heat budget of various pavements and grasses and found that sensible heat flux is significantly reduced by grass surfaces due to evaporation as compared to other impervious pavement such as asphalt and cement. Surface temperature measured in their study showed that the maximum difference in daytime temperature were between asphalt and grass, which was about 20^{o} C, and the difference between these two land covers during the nighttime was still about 4^{o} C. Jim (2016) evaluated several components of radiant-energy environment of real turfgrass and artificial turf in an urban city and found a significant difference in surface temperature when comparing the real and the artificial turfgrasses, with 70^{o} C and < 40 ºC for artificial turf and real turfgrass, respectively. My results and those of other studies demonstrate the exceptional cooling capacity turfgrass provided to an urban ecosystem.

5.3.8. Weed Density

Turf replacement is always voluntary, and one of the driving forces is maintenance requirement of landscape (Hayden et al., 2015). It is a preconceived idea that alternative landscapes required less maintenance than turfgrasses. Regular maintenance such as mowing and fertilization of turfgrass are not necessary for xeriscaping, artificial turf and other alternative landscapes. However, some maintenance is always overlooked. For example, refilling infill material and straightening leaf blades are needed for artificial turf, but not required by real home lawns. No matter if mowing or fertilization is needed, weed control is related to most residential landscapes, and thus weed density was measured to document the maintenance requirement for all landscapes included in this study. Total amount of weeds, no matter what species grew in the plots were measured weekly were found to be significantly affected by date, landscape, and their interaction (Table 5.3). The worst weed problem was observed for xeriscaping and mulch, and there was a wide-ranging fluctuation of weekly weed counts for the entire study period, with a range of 10 to 400 and 5 to 125 for xeriscaping and mulch, respectively (Figure 5.22).

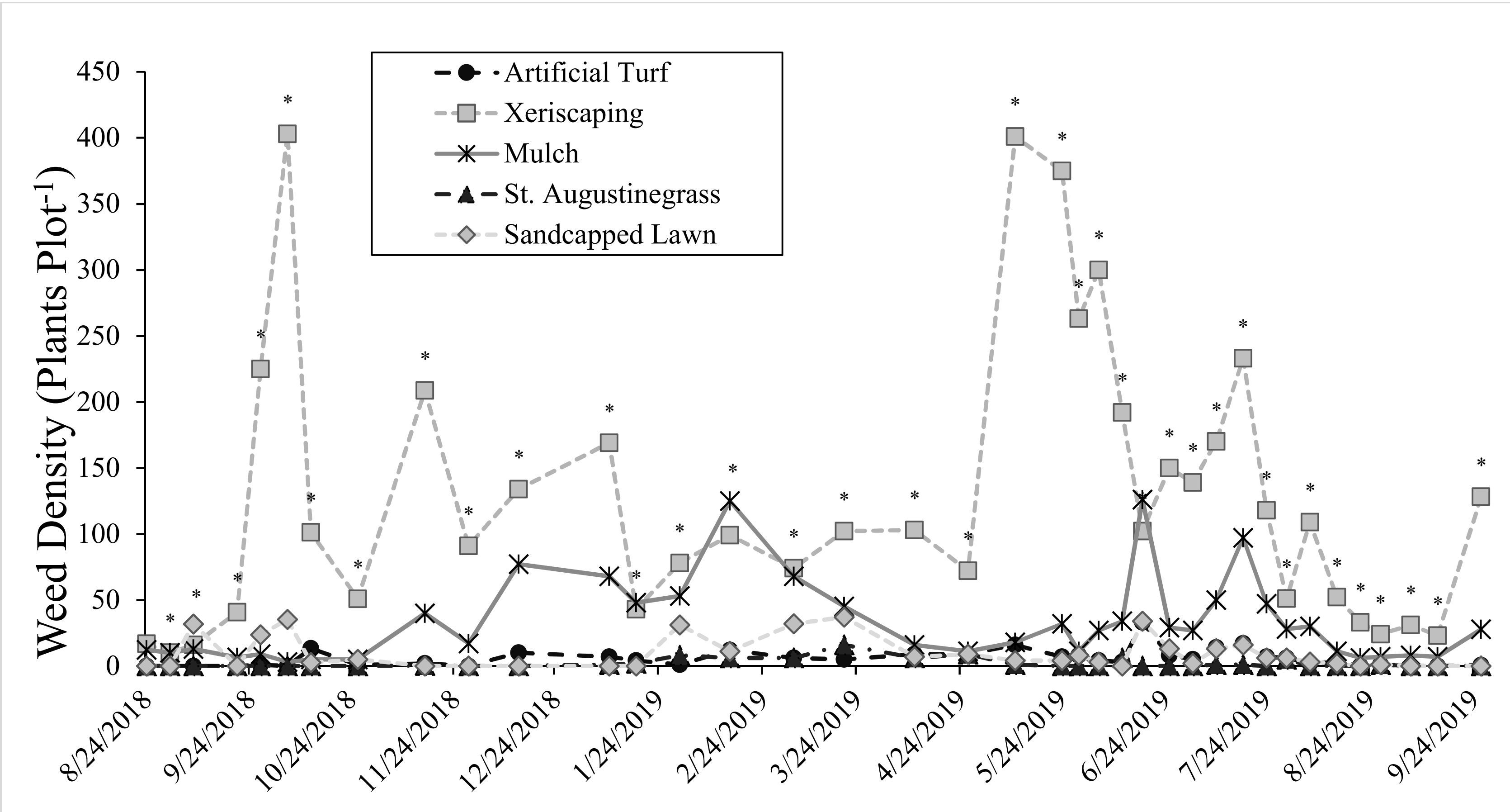

Figure 5.22 Weed pressure of each landscape during the study period, evaluated as cumulative weekly weed account. ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

The fluctuation of weed numbers during the study was related to the growing pattern of different weed species, as certain weed species only thrive in summer, while others only emerge when temperature was low. For example, the most common weeds found in summer include Horsenettle (*Solanum carolinense L.*), purple nutsedge (*Cyperus rotundus L.*), and spotted spurge (*Euphorbia maculata L.*). Bristly mallow (*Modiola caroliniana (L.) G. Don*) and annual ryegrass (*Lolium perenne L. ssp. multiflorum*) were found in fall, and bur clover (*Medicago polymorpha L.*), annual bluegrass (*Poa annua L.*), and henbit (*Lamium amplexicaule L.*) were found in winter. Weed problem was almost nonexistent for St. Augustinegrass lawn, sand-capped lawn, and artificial lawn, during the study period, especially when grasses were actively growing. When turfgrasses were dormant, the competition between turfgrass and weed for nutrient and water was low, and thus a mild weed emergence was found for sand-capped lawn, as shown on date 1/3/2019 to 3/20/2019 (Figure 5.22). Few weeds were found for sand-capped lawn on the late summer of 2018, and those weeds were introduced to the plot with sod that were purchased from a sod farm, used to cover the plots after the construction.

It has been found that insecticides and herbicides were used less on grass yards than rock yards (Larson et al., 2010). Our results confirmed the high requirement of herbicides for weed control for water efficient landscapes. This revealed that less maintenance requirement should not be advertised as an advantage of water efficient landscapes. Also, the higher dose of herbicides required for alternative landscapes could cause potential water contamination and concomitant safety issues.

5.3.9. Landscape Aesthetics

Landscape aesthetics were evaluated with a modified visual quality rating system. Based on the results, the visual quality score was significantly affected by landscape, date, and their interaction (Table 5.3). Not surprisingly, artificial turf maintained a high score of 9 for the entire study period, as it was unaffected by the seasonal climate change, which provided a benefit of providing a favorable green color all season long, even during the non-growing season (Figure 5.23).

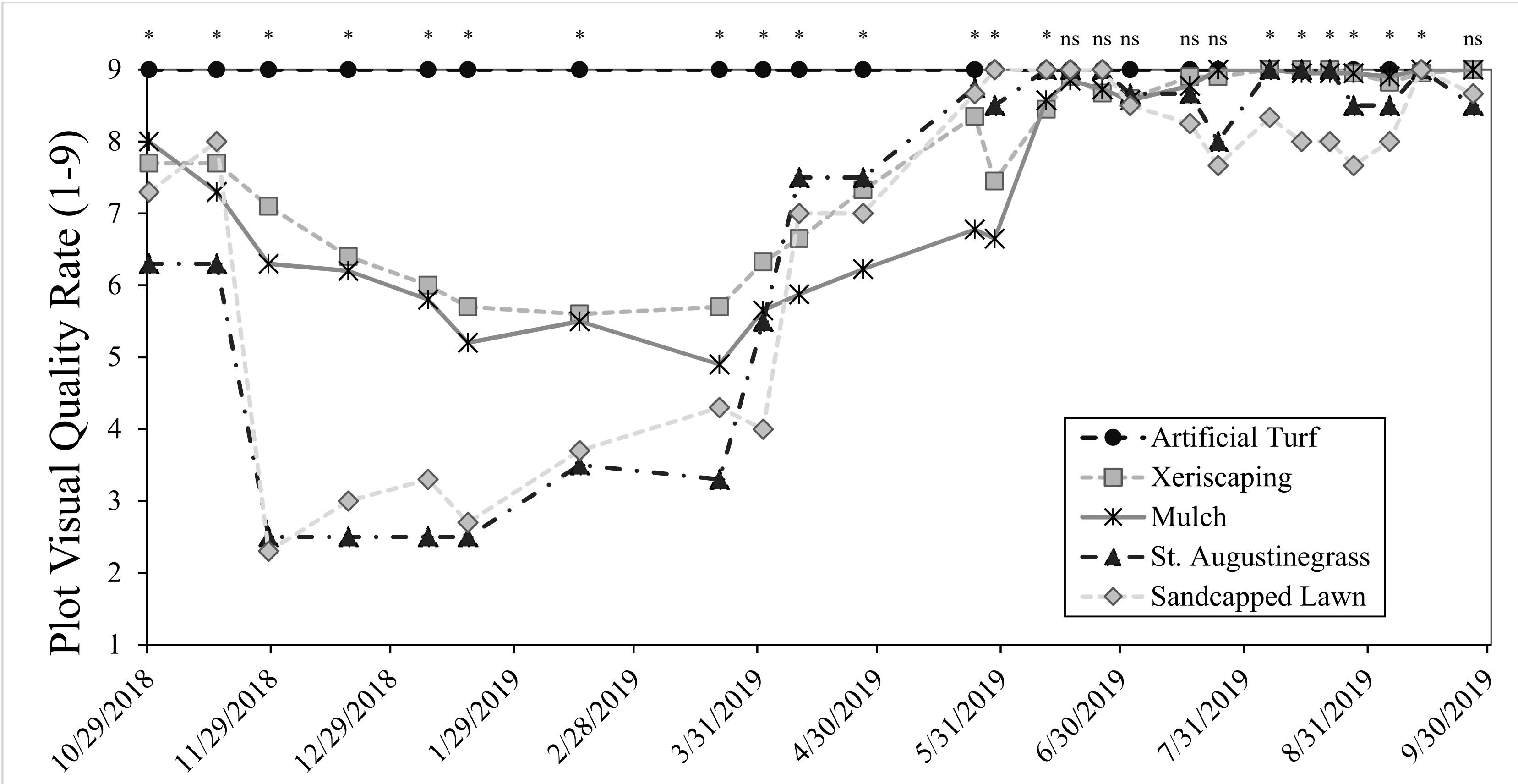

Figure 5.23 Visual grade of plant quality over the study period as an evaluation of landscape aesthetics. The grading standard was revised based on a commonly used scoring system for turfgrass science, with a scale of 1 to 9, and 6 as the minimal acceptable quality. For artificial turf and two lawns, rating was given to turfgrass, while the final score was an average of four plants that was grown in the plot for xeriscaping and mulch. ns and * respectively indicate that no statistically different and statistically different were detected between treatments on each date, based on Tukey's HSD at P = 0.05.

A seasonal pattern was found for St. Augustinegrass lawn and sand-capped lawn as expected. Under appropriate management including recommended fertilization and irrigation, a great visual quality (7 to 9) can be obtained for St. Augustinegrass lawn and sand-capped lawn during the growing season. However the plot quality was significantly lower for lawns when comparing to other alternative landscapes during the non-growing season (Figure 5.23). When just comparing two lawns, sometimes St. Augustinegrass had a greater quality than sand-capped lawn when temperature was high, which is because that sand-capped lawn might show symptoms of drought as a result of higher water shortage due to greater drainage. However, a greater quality was found for sand-capped lawn over St. Augustinegrass lawn during the non-growing season, which is also might be due to the better drainage of sand-capped lawn. Fungal related disease could be less likely under a lower soil moisture content. A similar pattern was found for xeriscaping and mulch in terms of plot visual quality rate as plot quality reached to the same level as artificial turf during the growing season and dropped during the non-growing season. Their quality plunged to an unacceptable level in the winter is because that during the acclimation period when native water efficient plants were just transferred to the plots, an extended raining season was experienced (referring to figure 5.2), and Texas sage (*Leucophyllum frutescens*) was sensitive to high water input, and thus pulled down the average of the plot quality for xeriscaping and mulch.

Landscape aesthetic assessment is a complicated subject that involve with many indicators such as complexity, coherence, and historicity, and a more detailed description can be found in Ode et al. (2008). In this study, aesthetic is mainly evaluated by plants growth condition, and it serve as a supportive information to show the quality of ecoservice provided by plants of each landscape during different seasons. As such, based on the results, turfgrass lawns offer the most eco-benefits during their growing seasons, and the impact of 3 alternative landscapes on environment is relatively stable over the year.

5.4. Conclusions

This study evaluated several environmental impacts as affected by transformation of home lawns to water efficient landscapes in south Texas. Over the study period, xeriscaping and water efficient landscape could reduce irrigation cost, however, their impact on surface runoff and extra cost on maintenance also need to be considered. Artificial turf showed a lot advantage, including all year long green color and low maintenance requirement, but its extremely high surface temperature makes it a bad choice for warm areas. Traditional home lawn and sand-capped lawn can reduce runoff and weed emergence, and moderate surface temperature, so as long as a proper management can be given, we believe lawns, to an extent, still has irreplaceability in urban ecosystem. More studies are still needed to investigate the real role of such landscapes at different locations, as climate and concerns are varied significantly in different regions. Overall, the information gained from this research will benefit municipalities, water purveyors, and homeowner associations as they weigh the long-term consequences and impacts of lawn removal and landscape conversion programs.

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6. CONCLUSIONS

Due to the growth of population in modern urban areas, limitation in high quality water is becoming a more prevalent issue for turf managers. In this dissertation, we investigated 1. the relationship between increasing irrigation EC and turfgrass nutrient uptake efficiency, 2. Evaluated potential for weeting agents to improve turf performance as well as to reduce runoff losses of water and nutrients from St. Augustinegrass lawns, and 3. Evaluated several environmental impacts as affected by transformation of home lawns to water efficient landscapes in south Texas. Our results demonstrated that 1. Tifway bermudagrass was capable of maintaining acceptable quality and N uptake efficiency with irrigation EC levels up to 5 dS m^{-1}, and with saline irrigation (2.5 to 10 dS m^{-1} salinity levels), urea produced superior turf quality to ammonium sulfate under root fertilization. 2. For foliar fertilized Champion bermudagrass, when water sources containing moderately high salinity levels (2.5 dS m^{-1}) are used, KNO_3 may provide the greatest turfgrass quality, however, its uptake efficiency may be lower than other N sources, which could result in potential for greater environmental losses. 3. wetting agents provided mild improvements in turfgrass quality and percent green cover in plots and no negative effects on runoff and nutrient movement. However, their benefits did not extend to significant reductions in runoff water volumes or nutrient exports during precipitation events. 4. Traditional home lawn and sand-capped lawn can reduce runoff and weed emergence, and moderate surface temperature, so as long as a proper management can be given, we believe lawns, to an extent, still has irreplaceability in urban ecosystem. Overall, the information gained from this research will benefit municipalities, water purveyors, and turfgrass managers as they weigh the long-term consequences and impacts of lawn removal and landscape conversion programs, as well as enrich the information of current turfgrass management.

APPENDIX A

COMPELETE DATASET – LANDSCAPE CONVERSION STUDY

Table A.1 Runoff nutirent concentrations and runoff volume.

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
9/13/2018	1	SC	0	0	.	.	.	.	.	.	.	.
9/13/2018	2	DG	1572	13	8.2	528	2.0	0.2	0.7	12.9	3.3	1.1
9/13/2018	3	SC	2246	19	8.2	908	3.5	0.3	1.6	36.3	7.1	3.3
9/13/2018	4	M	1115	9	8.3	905	0.2	0.5	5.3	169.2	8.2	7.5
9/13/2018	6	SA	562	5	8.0	785	0.2	0.7	8.8	75.5	5.6	4.7
9/13/2018	7	M	5876	50	7.8	803	0.5	0.2	6.1	241.9	9.4	8.6
9/13/2018	8	AT	1257	11	7.8	220	2.7	0.0	0.3	8.7	7.1	4.4
9/13/2018	9	SA	713	6	7.9	903	0.4	0.6	7.3	80.2	5.9	4.9
9/13/2018	11	AT	1318	11	8.5	491	1.0	0.1	0.7	8.8	1.6	0.5
9/13/2018	15	M	3364	29	8.0	791	0.2	0.2	10.0	172.3	6.1	5.7
9/13/2018	16	SA	976	8	8.1	260	0.2	0.4	6.5	59.9	3.7	3.1
9/13/2018	17	SA	4300	37	8.1	1579	1.2	0.9	13.9	197.0	12.1	10.1
9/13/2018	18	AT	1017	9	8.6	199	0.9	0.1	0.5	5.3	2.3	1.3
9/13/2018	19	DG	1926	16	8.3	253	0.4	0.1	0.3	5.9	0.9	0.4
9/13/2018	20	SC	1416	12	8.3	542	0.3	0.1	1.2	19.4	2.2	1.8
9/13/2018	22	DG	1245	11	9.2	134	0.4	0.1	0.5	4.8	0.7	0.2
9/13/2018	23	DG	4740	40	8.6	116	0.5	0.1	0.1	2.9	0.7	0.1
9/13/2018	24	M	639	5	7.9	335	0.1	0.1	3.2	113.5	4.0	3.8
9/24/2018	1	SC	0	0	.	.	.	.	.	.	.	.
9/24/2018	2	DG	220	5	7.2	795	2.7	0.5	0.5	21.7	4.5	1.4
9/24/2018	3	SC	451	10	6.7	1196	0.7	0.5	0.8	34.3	4.4	3.3
9/24/2018	4	M	62	1	.	.	.	.	.	.	.	.
9/24/2018	6	SA	23	1	8.3	1161	1.1	0.3	4.3	66.8	5.5	4.1
9/24/2018	7	M	2167	49	.	.	.	.	.	.	.	.
9/24/2018	8	AT	567	13	.	.	.	.	.	.	.	.
9/24/2018	9	SA	42	1	8.2	1255	1.1	0.3	4.3	73.3	6.2	4.8
9/24/2018	11	AT	231	5	8.1	693	3.5	0.3	1.2	21.6	5.4	1.6
9/24/2018	15	M	926	21	8.1	1233	0.4	0.5	7.1	216.7	9.7	8.7
9/24/2018	16	SA	56	1	8.2	1192	0.4	0.2	4.9	70.9	4.4	3.8
9/24/2018	17	SA	1899	43	8.6	1137	1.6	0.3	4.6	57.0	5.0	3.0
9/24/2018	18	AT	58	1	8.6	335	1.7	0.4	0.4	13.6	3.6	1.4
9/24/2018	19	DG	383	9	8.9	430	0.8	0.6	0.8	18.2	2.5	1.1

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
9/24/2018	20	SC	730	17	8.6	946	1.8	0.2	1.3	15.1	3.2	1.1
9/24/2018	22	DG	96	2	8.9	361	1.1	0.1	0.6	22.3	2.8	1.6
9/24/2018	23	DG	1611	36	8.9	316	2.7	0.3	0.4	22.0	5.2	2.1
9/24/2018	24	M	0	0	.	.	.	.	.	.	.	.
9/27/2018	1	SC	0	0	.	.	.	.	.	.	.	.
9/27/2018	2	DG	184	34	8.3	436	1.0	0.2	0.4	14.5	2.3	1.1
9/27/2018	3	SC	290	54	.	.	.	.	.	.	.	.
9/27/2018	4	M	63	12	.	.	.	.	.	.	.	.
9/27/2018	6	SA	18	3	7.8	1083	1.0	0.3	7.7	89.6	6.5	5.2
9/27/2018	7	M	226	42	.	.	.	.	.	.	.	.
9/27/2018	8	AT	221	41	7.8	210	2.9	0.2	0.5	8.4	3.5	0.4
9/27/2018	9	SA	33	6	7.2	1100	0.7	0.2	5.6	72.4	5.3	4.5
9/27/2018	11	AT	120	22	7.2	692	2.8	0.1	1.3	17.5	4.1	1.2
9/27/2018	15	M	256	48	7.9	1055	0.5	0.3	9.3	260.4	9.4	8.6
9/27/2018	16	SA	39	7	7.9	1124	0.4	0.2	6.7	71.5	4.2	3.6
9/27/2018	17	SA	535	100	.	.	.	.	.	.	.	.
9/27/2018	18	AT	58	11	7.6	218	1.4	0.0	0.4	7.2	2.1	0.7
9/27/2018	19	DG	233	44	7.1	244	0.3	0.3	0.4	9.1	1.1	0.5
9/27/2018	20	SC	182	34	7.1	541	0.7	0.1	1.5	14.0	1.9	1.1
9/27/2018	22	DG	123	23	7.3	316	0.2	0.1	0.8	14.7	1.2	0.9
9/27/2018	23	DG	535	100	6.8	147	0.4	0.1	0.2	10.9	1.2	0.7
9/27/2018	24	M	3	1	.	.	.	.	.	.	.	.
10/1/2018	1	SC	808	96	7.9	330	0.6	0.5	1.0	14.8	2.2	1.2
10/1/2018	2	DG	361	43	8.4	267	0.6	0.3	0.4	12.5	2.1	1.2
10/1/2018	3	SC	648	77	7.9	715	0.7	0.5	1.1	25.8	3.7	2.5
10/1/2018	4	M	271	32	7.8	855	0.3	0.5	6.7	278.8	10.8	10.0
10/1/2018	6	SA	122	15	7.4	755	1.9	1.4	8.0	110.3	10.5	7.2
10/1/2018	7	M	821	98	7.6	831	0.3	3.3	9.6	341.3	14.7	11.1
10/1/2018	8	AT	732	87	8.1	175	1.8	0.1	0.3	8.0	2.3	0.4
10/1/2018	9	SA	159	19	7.9	801	1.0	1.3	7.1	101.1	8.5	6.2
10/1/2018	11	AT	338	40	8.0	403	2.5	0.2	0.9	14.0	3.1	0.3
10/1/2018	15	M	856	838	8.2	838	0.5	0.6	8.0	267.8	9.7	8.6
10/1/2018	16	SA	176	21	8.1	795	0.4	0.9	6.7	82.0	5.7	4.4
10/1/2018	17	SA	503	60	.	.	.	.	.	.	.	.
10/1/2018	18	AT	200	24	8.1	214	0.9	0.3	0.4	6.4	1.7	0.5
10/1/2018	19	DG	564	67	8.3	212	0.2	0.2	0.3	6.2	0.8	0.3

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
10/1/2018	20	SC	386	46	8.2	594	1.0	0.3	1.3	18.0	2.6	1.3
10/1/2018	22	DG	447	53	8.4	152	0.2	0.3	0.3	7.4	0.8	0.3
10/1/2018	23	DG	614	73	8.0	121	0.2	0.2	0.1	5.4	0.6	0.2
10/1/2018	24	M	164	20	8.2	739	0.5	2.3	8.1	352.4	15.3	12.5
10/10/2018	1	SC	781	46	8.2	174	0.3	0.3	1.0	9.0	1.4	0.8
10/10/2018	2	DG	1695	100	8.4	188	0.8	0.2	0.6	9.1	1.5	0.5
10/10/2018	3	SC	449	26	7.7	182	0.4	0.2	3.1	11.0	1.4	0.9
10/10/2018	4	M	516	30	7.9	379	0.2	0.4	3.6	149.8	5.5	4.9
10/10/2018	6	SA	1063	63	8.0	249	1.0	0.6	4.4	29.2	3.6	2.1
10/10/2018	7	M	1422	84	7.6	454	0.3	0.5	5.6	211.8	7.5	6.7
10/10/2018	8	AT	1020	60	7.8	98	0.5	0.2	0.7	10.3	1.4	0.7
10/10/2018	9	SA	1695	100	7.8	325	1.0	0.8	4.7	44.6	4.3	2.5
10/10/2018	11	AT	1586	94	7.9	135	1.4	0.2	0.8	9.0	2.3	0.7
10/10/2018	15	M	1281	79	7.6	455	0.4	0.5	5.4	207.1	7.2	6.3
10/10/2018	16	SA	675	42	7.9	298	0.2	0.4	2.8	42.5	2.9	2.2
10/10/2018	17	SA	824	51	7.9	337	0.4	0.5	4.0	51.6	3.5	2.7
10/10/2018	18	AT	1626	100	7.9	131	0.8	0.1	0.3	4.7	1.2	0.3
10/10/2018	19	DG	726	45	8.0	107	0.3	0.2	0.4	5.4	0.8	0.4
10/10/2018	20	SC	1113	68	7.7	237	0.3	0.2	0.8	13.4	1.2	0.8
10/10/2018	22	DG	1212	75	9.1	165	0.5	0.3	1.4	11.0	1.7	0.8
10/10/2018	23	DG	1507	93	8.1	68	0.2	0.2	0.2	6.1	0.8	0.4
10/10/2018	24	M	944	58	7.7	324	0.2	0.4	4.2	213.2	7.3	6.6
10/17/2018	1	SC	3439	55	9.2	86	0.3	0.3	0.3	5.2	0.9	0.4
10/17/2018	2	DG	6304	100	8.1	211	2.0	0.5	0.9	12.2	3.1	0.6
10/17/2018	3	SC	.	.	.	.	.	.	.	.	.	.
10/17/2018	4	M	5512	87	7.7	145	0.5	0.4	1.8	53.9	2.8	1.9
10/17/2018	6	SA	6304	100	7.5	159	1.3	0.6	1.5	18.3	3.2	1.4
10/17/2018	7	M	6304	100	7.2	189	0.3	0.6	2.5	72.9	3.6	2.7
10/17/2018	8	AT	6304	100	7.4	68	0.4	0.3	0.4	8.6	1.2	0.5
10/17/2018	9	SA	6304	100	7.2	209	2.0	0.7	2.1	24.3	4.4	1.7
10/17/2018	11	AT	6304	100	7.3	115	1.4	0.2	0.5	8.6	2.3	0.7
10/17/2018	15	M	7306	100	7.3	262	0.3	0.9	2.8	129.8	5.2	4.0
10/17/2018	16	SA	7306	100	7.5	146	0.6	0.4	1.5	18.1	2.2	1.1
10/17/2018	17	SA	7306	100	7.5	135	0.6	0.5	1.5	15.2	2.0	1.0
10/17/2018	18	AT	7306	100	7.5	67	0.5	0.2	0.2	3.6	0.9	0.2
10/17/2018	19	DG	6525	89	7.3	99	0.5	0.2	0.4	4.4	1.0	0.2

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
10/17/2018	20	SC	7306	100	7.2	115	0.4	0.2	0.4	5.6	1.0	0.4
10/17/2018	23	DG	5820	80	7.4	85	0.2	0.1	0.2	4.3	0.6	0.2
10/17/2018	24	M	7306	100	7.2	185	0.1	0.7	2.7	108.5	4.3	3.5
10/20/2018	1	SC	106	26	8.7	310	0.4	0.2	0.6	13.5	2.0	1.4
10/20/2018	2	DG	406	100	8.1	200	0.4	0.2	0.5	7.3	1.5	0.9
10/20/2018	3	SC	.	.	.	.	.	.	.	.	.	.
10/20/2018	4	M	96	24	.	.	.	.	.	.	.	.
10/20/2018	6	SA	209	51	8.0	245	0.8	0.3	1.7	26.9	3.3	2.1
10/20/2018	7	M	406	100	.	.	.	.	.	.	.	.
10/20/2018	8	AT	86	21	.	.	.	.	.	.	.	.
10/20/2018	9	SA	104	26	8.0	320	0.4	0.6	2.0	33.1	3.5	2.4
10/20/2018	11	AT	97	24	8.0	200	0.8	0.1	0.4	6.6	1.7	0.8
10/20/2018	15	M	458	100	.	.	.	.	.	.	.	.
10/20/2018	16	SA	90	20	8.1	350	0.2	0.2	1.9	25.9	2.5	2.0
10/20/2018	17	SA	199	43	7.9	220	0.2	0.2	1.4	27.0	2.3	1.8
10/20/2018	18	AT	163	36	7.8	115	0.5	0.2	0.2	5.1	1.4	0.7
10/20/2018	19	DG	248	54	7.8	95	0.2	0.1	0.2	4.5	1.0	0.6
10/20/2018	20	SC	99	22	.	.	.	.	.	.	.	.
10/20/2018	22	DG	458	100	7.8	45	0.2	0.2	0.2	4.6	1.0	0.6
10/20/2018	23	DG	458	100	7.7	47	0.2	0.2	0.1	4.3	0.9	0.6
10/20/2018	24	M	135	29	.	.	.	.	.	.	.	.
10/25/2018	1	SC	147	26	7.9	275	0.2	0.1	0.7	9.6	1.0	0.7
10/25/2018	2	DG	413	74	8.1	163	0.2	0.0	0.4	5.8	0.6	0.4
10/25/2018	3	SC	.	.	.	.	.	.	.	.	.	.
10/25/2018	4	M	97	17	7.6	310	0.0	0.0	1.7	44.2	1.6	1.5
10/25/2018	6	SA	188	33	8.0	310	0.5	0.2	1.8	26.0	2.5	1.8
10/25/2018	7	M	561	100	7.8	303	0.1	0.2	2.4	64.3	2.5	2.2
10/25/2018	8	AT	125	22	8.1	120	0.4	0.0	0.3	5.0	0.7	0.2
10/25/2018	9	SA	118	21	8.0	390	0.4	0.1	2.0	28.7	2.5	2.0
10/25/2018	11	AT	126	22	8.2	150	0.6	0.0	0.2	4.6	0.9	0.3
10/25/2018	15	M	477	99	8.1	340	0.2	0.1	1.7	76.4	2.6	2.3
10/25/2018	16	SA	123	25	8.1	450	0.1	0.1	1.9	32.2	2.2	2.0
10/25/2018	17	SA	164	34	8.2	293	0.1	0.1	1.3	23.0	1.5	1.4
10/25/2018	18	AT	483	100	8.1	108	0.4	0.1	0.2	3.2	0.6	0.2
10/25/2018	19	DG	207	43	8.1	83	0.2	0.0	0.2	2.9	0.3	0.1
10/25/2018	20	SC	82	17	7.9	240	0.1	0.1	0.4	5.4	0.5	0.4

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
10/25/2018	22	DG	483	100	.	.	.	.	.	.	.	.
10/25/2018	23	DG	214	44	7.8	60	0.1	0.1	0.1	4.4	0.6	0.4
10/25/2018	24	M	252	52	7.8	280	0.1	0.1	2.5	81.1	2.9	2.7
10/31/2018	1	SC	351	51	7.7	133	0.3	0.1	1.0	9.2	1.3	0.9
10/31/2018	2	DG	816	120	8.2	100	0.3	0.3	0.5	4.4	0.8	0.2
10/31/2018	3	SC	.	0	.	.	.	.	.	.	.	.
10/31/2018	4	M	370	54	7.5	193	0.1	0.5	1.4	47.5	2.4	1.8
10/31/2018	6	SA	414	61	7.5	215	0.6	0.4	1.7	24.4	2.5	1.4
10/31/2018	7	M	682	100	7.2	220	0.2	0.6	2.1	65.7	2.8	2.1
10/31/2018	8	AT	514	75	7.7	83	0.6	0.1	0.5	7.1	1.0	0.3
10/31/2018	9	SA	410	60	7.5	308	0.6	0.3	2.1	28.0	3.3	2.4
10/31/2018	11	AT	505	74	7.9	85	0.4	0.1	0.3	4.6	1.3	0.8
10/31/2018	15	M	967	100	7.5	230	0.1	1.5	2.1	70.1	3.8	2.3
10/31/2018	16	SA	442	46	7.6	295	0.4	0.2	1.7	24.4	2.0	1.5
10/31/2018	17	SA	568	59	7.6	185	0.4	0.1	1.2	16.0	1.4	0.9
10/31/2018	18	AT	967	100	7.9	63	0.8	0.1	0.2	2.7	0.8	0.0
10/31/2018	19	DG	712	74	8.2	55	0.4	0.1	0.3	3.0	0.5	0.1
10/31/2018	20	SC	265	27	7.8	160	0.4	0.1	0.4	5.7	0.8	0.2
10/31/2018	22	DG	967	100	.	.	.	.	.	.	.	.
10/31/2018	23	DG	535	55	7.6	45	0.3	0.1	0.3	3.6	0.6	0.1
10/31/2018	24	M	521	54	7.3	185	0.2	0.5	1.7	75.0	3.1	2.3
11/9/2018	1	SC	192	42	8.0	390	0.3	0.2	0.9	13.5	1.5	1.0
11/9/2018	2	DG	458	100	8.2	280	0.4	0.1	0.4	8.2	1.2	0.7
11/9/2018	3	SC	.	0	.	.	.	.	.	.	.	.
11/9/2018	4	M	107	23	7.7	390	0.1	0.2	1.1	43.9	2.2	1.8
11/9/2018	6	SA	258	56	8.1	573	0.5	0.2	1.3	39.4	3.2	2.6
11/9/2018	7	M	458	100	7.7	400	0.2	0.1	1.5	56.1	2.3	2.0
11/9/2018	8	AT	112	24	8.1	130	0.5	0.0	0.4	8.2	1.2	0.6
11/9/2018	9	SA	241	53	7.9	693	0.5	0.1	2.1	36.8	3.2	2.6
11/9/2018	11	AT	153	33	8.3	330	1.6	0.1	0.4	8.6	2.7	1.0
11/9/2018	15	M	501	100	8.3	380	0.2	0.2	1.6	63.4	2.3	2.0
11/9/2018	16	SA	175	35	8.3	657	0.2	0.1	1.6	32.2	2.2	1.9
11/9/2018	17	SA	294	59	8.2	528	0.2	0.1	1.0	23.5	1.7	1.4
11/9/2018	18	AT	501	100	7.9	183	0.7	0.1	0.2	4.2	1.3	0.5
11/9/2018	19	DG	298	59	7.4	130	0.4	0.1	0.3	4.6	0.8	0.3
11/9/2018	20	SC	119	24	8.0	450	0.5	0.1	0.5	9.8	1.1	0.6
11/9/2018	22	DG	501	100	8.3	168	0.6	0.1	0.4	7.2	1.3	0.6

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
11/9/2018	23	DG	166	33	7.6	70	0.4	0.2	0.3	4.6	0.9	0.4
11/9/2018	24	M	46	9	.	.	.	.	.	.	.	.
12/8/2018	1	SC	1237	39	7.7	110	0.3	0.1	0.9	7.3	1.2	0.8
12/8/2018	2	DG	3195	100	7.9	84	0.3	0.1	0.6	8.4	1.0	0.6
12/8/2018	3	SC	3195	100	7.7	117	0.2	0.1	0.6	8.1	1.1	0.8
12/8/2018	4	M	1679	53	7.6	129	0.1	0.2	1.0	25.5	1.3	1.1
12/8/2018	6	SA	1953	61	7.8	195	0.8	0.2	1.7	19.5	2.4	1.4
12/8/2018	7	M	1208	38	7.5	130	0.1	0.2	1.5	35.6	1.5	1.2
12/8/2018	8	AT	2077	65	7.8	66	0.5	0.1	0.4	5.9	0.7	0.2
12/8/2018	9	SA	3195	100	7.7	234	1.7	0.3	2.1	20.4	3.1	1.1
12/8/2018	11	AT	3195	100	7.7	61	0.5	0.1	0.4	5.5	1.6	1.0
12/8/2018	15	M	3195	100	7.6	196	0.2	0.2	1.7	70.6	2.9	2.5
12/8/2018	16	SA	1933	60	7.8	147	0.2	0.2	1.3	15.6	1.7	1.4
12/8/2018	17	SA	2132	67	7.8	182	0.3	0.1	1.7	17.9	1.9	1.5
12/8/2018	18	AT	3195	100	7.9	79	0.6	0.1	0.2	3.1	1.2	0.5
12/8/2018	19	DG	2214	69	7.7	36	0.2	0.0	0.2	3.7	0.7	0.5
12/8/2018	20	SC	1033	32	7.8	92	0.2	0.1	0.6	7.3	1.0	0.8
12/8/2018	22	DG	3149	99	7.5	44	0.2	0.0	0.2	4.3	0.7	0.5
12/8/2018	23	DG	1952	61	7.5	29	0.2	0.1	0.2	3.5	0.8	0.5
12/8/2018	24	M	1390	44	7.3	106	0.1	0.1	1.2	34.1	1.6	1.4
12/19/2018	1	SC	287	34	7.8	92	0.3	0.2	0.6	8.1	1.5	1.0
12/19/2018	2	DG	769	91	8.1	70	0.2	0.1	0.3	4.8	0.9	0.6
12/19/2018	3	SC	846	100	7.8	126	0.2	0.2	0.4	7.5	1.2	0.8
12/19/2018	4	M	253	30	7.7	157	0.1	0.1	0.8	29.0	1.5	1.3
12/19/2018	6	SA	372	44	7.8	180	1.2	0.2	1.6	24.6	3.5	2.0
12/19/2018	7	M	195	23	7.6	151	0.1	0.1	1.5	43.9	2.0	1.7
12/19/2018	8	AT	392	46	7.9	64	0.6	0.1	0.3	6.2	0.9	0.2
12/19/2018	9	SA	331	39	7.9	315	2.6	0.2	1.9	31.1	5.0	2.2
12/19/2018	11	AT	331	39	7.9	59	0.5	0.1	0.2	3.2	0.6	0.0
12/19/2018	15	M	846	100	7.7	157	0.2	0.2	1.5	62.8	2.3	2.0
12/19/2018	16	SA	333	39	7.9	314	0.3	0.2	1.4	32.8	2.9	2.4
12/19/2018	17	SA	412	49	7.9	244	0.3	0.3	1.1	31.2	2.5	1.9
12/19/2018	18	AT	846	100	8.0	72	0.3	0.1	0.1	2.3	0.7	0.3
12/19/2018	19	DG	477	56	8.0	54	0.1	0.0	0.2	4.1	0.5	0.3
12/19/2018	20	SC	154	18	8.0	124	0.2	0.1	0.4	6.1	0.7	0.4
12/19/2018	22	DG	761	90	7.8	73	0.2	0.1	0.3	5.3	0.6	0.3
12/19/2018	23	DG	354	42	7.8	42	0.2	0.0	0.2	3.9	0.3	0.1

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
12/19/2018	24	M	220	26	7.7	117	0.3	0.1	1.6	50.9	1.8	1.3
12/28/2018	1	SC	2751	89	7.3	54	0.1	0.1	0.4	16.0	0.9	0.6
12/28/2018	2	DG	3097	100	7.9	72	0.2	0.1	0.3	6.8	0.7	0.5
12/28/2018	3	SC	3097	100	7.6	60	0.1	0.2	0.3	5.3	0.7	0.4
12/28/2018	4	M	1703	55	7.5	96	0.0	0.1	0.6	17.9	0.8	0.7
12/28/2018	6	SA	3097	100	7.7	107	0.3	0.2	0.6	12.0	1.4	0.9
12/28/2018	7	M	2689	87	7.4	117	0.0	0.1	1.0	28.6	1.2	1.1
12/28/2018	8	AT	2392	77	7.5	47	0.3	0.1	0.3	5.5	0.9	0.4
12/28/2018	9	SA	3097	100	7.5	150	0.7	0.2	1.0	15.4	2.3	1.3
12/28/2018	11	AT	3097	100	7.6	59	0.3	0.1	0.4	5.3	0.9	0.5
12/28/2018	15	M	3097	100	7.3	66	0.1	0.1	0.7	17.6	1.0	0.8
12/28/2018	16	SA	3097	100	7.7	146	0.2	0.1	0.8	16.3	1.5	1.2
12/28/2018	17	SA	3097	100	7.8	314	0.2	0.2	1.3	32.7	2.7	2.3
12/28/2018	18	AT	3097	100	7.6	57	0.4	0.1	0.1	2.5	0.5	0.1
12/28/2018	19	DG	1974	64	7.7	33	0.1	0.0	0.1	2.4	0.1	0.0
12/28/2018	20	SC	912	29	7.5	65	0.1	0.1	0.3	4.4	0.3	0.1
12/28/2018	22	DG	2106	68	7.4	113	0.2	0.1	0.2	3.6	0.4	0.1
12/28/2018	23	DG	1644	53	7.5	33	0.1	0.1	0.1	2.7	0.2	0.0
12/28/2018	24	M	1644	53	7.5	66	0.0	0.1	0.9	20.2	0.6	0.5
1/3/2019	1	SC	751	35	6.8	79	0.1	0.1	0.3	4.4	0.8	0.6
1/3/2019	2	DG	2133	100	7.0	99	0.2	0.2	0.2	4.3	0.7	0.3
1/3/2019	3	SC	2133	100	.	.	.	.	.	.	.	.
1/3/2019	4	M	944	44	7.4	88	0.0	0.1	0.6	15.6	0.8	0.7
1/3/2019	6	SA	949	44	7.6	83	0.3	0.2	0.5	10.0	1.2	0.8
1/3/2019	7	M	2133	100	7.6	142	0.1	0.3	1.1	45.9	2.1	1.8
1/3/2019	8	AT	1302	61	7.4	57	0.3	0.1	0.2	3.9	0.8	0.3
1/3/2019	9	SA	2133	100	7.6	107	0.7	0.2	0.8	10.9	1.9	1.0
1/3/2019	11	AT	2133	100	7.4	42	0.3	0.1	0.3	4.0	0.8	0.4
1/3/2019	15	M	2133	100	7.7	131	0.1	0.1	1.0	44.6	1.7	1.5
1/3/2019	16	SA	1193	56	7.9	170	0.2	0.1	0.7	17.6	1.6	1.3
1/3/2019	17	SA	2133	100	7.5	264	0.2	0.1	0.9	25.0	2.1	1.8
1/3/2019	18	AT	2133	100	7.9	63	0.5	0.1	0.1	2.1	0.8	0.2
1/3/2019	19	DG	1538	72	6.9	43	0.2	0.1	0.1	2.2	0.3	0.1
1/3/2019	20	SC	721	34	7.4	71	0.1	0.1	0.2	2.6	0.3	0.1
1/3/2019	22	DG	1683	79	7.5	66	0.2	0.1	0.2	4.5	0.6	0.3
1/3/2019	23	DG	1229	58	7.6	36	0.1	0.1	0.1	2.6	0.3	0.1
1/3/2019	24	M	2133	100	7.4	84	0.0	0.1	0.9	23.6	0.9	0.7

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
1/23/2019	1	SC	133	14	7.8	115	0.4	0.2	0.7	8.7	1.4	0.7
1/23/2019	2	DG	413	43	8.2	56	0.2	0.2	0.2	3.7	0.5	0.1
1/23/2019	3	SC	10	1	.	.	.	.	.	.	.	.
1/23/2019	4	M	135	14	7.8	138	0.1	0.2	0.7	28.3	1.4	1.1
1/23/2019	6	SA	165	17	7.8	185	0.6	0.1	1.1	15.3	1.9	1.2
1/23/2019	7	M	227	23	7.7	142	0.1	0.2	1.1	43.9	1.6	1.4
1/23/2019	8	AT	252	26	7.8	74	0.7	0.2	0.3	6.1	1.0	0.1
1/23/2019	9	SA	250	26	8.0	290	2.0	0.1	2.1	22.5	3.7	1.6
1/23/2019	11	AT	222	23	7.8	72	0.8	0.1	0.2	3.6	1.1	0.2
1/23/2019	15	M	139	14	8.0	167	0.1	0.2	1.1	58.6	2.2	1.9
1/23/2019	16	SA	780	81	8.0	309	0.4	0.2	1.4	29.3	2.6	2.0
1/23/2019	17	SA	884	91	7.8	239	0.4	0.2	1.2	22.3	2.1	1.5
1/23/2019	18	AT	592	61	7.8	65	0.6	0.1	0.1	2.7	0.8	0.1
1/23/2019	19	DG	520	54	7.8	42	0.2	0.2	0.2	3.4	0.6	0.1
1/23/2019	20	SC	182	19	7.8	118	0.2	0.2	0.4	6.4	0.8	0.4
1/23/2019	22	DG	590	61	7.8	67	0.4	0.2	0.3	5.9	0.9	0.3
1/23/2019	23	DG	386	40	7.5	47	0.3	0.3	0.2	4.8	0.7	0.2
1/23/2019	24	M	134	14	7.5	102	0.3	0.2	0.3	6.1	0.8	0.3
2/7/2019	1	SC	118	22	9.1	99	0.5	0.2	0.5	10.7	1.8	1.1
2/7/2019	2	DG	1042	192	8.2	98	0.8	0.2	0.8	11.2	2.0	1.0
2/7/2019	3	SC	41	8	.	.	.	.	.	.	.	.
2/7/2019	4	M	138	25	7.7	125	0.1	0.1	0.7	34.6	1.8	1.5
2/7/2019	6	SA	169	31	7.5	197	0.7	0.2	0.9	16.0	2.2	1.3
2/7/2019	7	M	101	19	7.5	143	0.1	0.1	1.0	49.9	2.2	2.0
2/7/2019	8	AT	218	40	7.5	57	0.8	0.2	0.2	6.9	1.5	0.5
2/7/2019	9	SA	527	97	7.7	193	1.9	0.3	2.3	19.4	3.6	1.5
2/7/2019	11	AT	565	86	7.6	79	1.0	0.2	0.6	10.6	2.2	0.9
2/7/2019	15	M	133	20	6.9	152	0.1	0.1	1.0	54.4	2.2	1.9
2/7/2019	16	SA	349	53	6.9	259	0.5	0.1	1.1	28.8	2.8	2.2
2/7/2019	17	SA	275	42	7.6	184	0.4	0.1	1.0	21.9	2.4	1.9
2/7/2019	18	AT	380	58	8.5	61	0.9	0.2	0.1	4.5	1.7	0.6
2/7/2019	19	DG	327	50	8.6	38	0.2	0.2	0.1	3.4	0.8	0.4
2/7/2019	20	SC	102	16	8.0	98	0.4	0.1	0.3	7.4	1.2	0.7
2/7/2019	22	DG	551	84	6.9	67	0.3	0.3	0.2	5.4	1.1	0.5
2/7/2019	23	DG	300	46	7.6	49	0.3	0.2	0.1	4.4	1.0	0.5
2/7/2019	24	M	42	6	7.4	91	0.1	0.1	0.9	47.2	2.0	1.8
3/14/2019	1	SC	60	13	7.6	140	0.4	0.3	0.8	14.8	1.8	1.1

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
3/14/2019	2	DG	181	39	8.1	82	0.4	0.1	0.2	5.7	0.9	0.4
3/14/2019	3	SC	28	6	7.7	146	0.3	0.5	0.4	12.4	2.2	1.4
3/14/2019	6	SA	131	28	7.9	288	0.5	0.2	1.6	31.5	3.1	2.3
3/14/2019	7	M	71	15	7.8	239	0.1	0.2	1.3	75.2	3.0	2.7
3/14/2019	8	AT	164	35	8.0	95	1.2	0.1	0.2	7.1	1.6	0.3
3/14/2019	9	SA	182	39	7.9	471	3.4	0.5	3.5	53.7	7.5	3.6
3/14/2019	11	AT	189	41	8.2	94	0.9	0.1	0.3	6.6	1.5	0.5
3/14/2019	15	M	71	15	7.9	259	0.3	0.2	1.2	100.2	3.8	3.3
3/14/2019	16	SA	164	35	8.0	340	0.5	0.2	2.0	53.9	4.2	3.5
3/14/2019	17	SA	466	100	7.9	302	0.5	0.2	1.9	45.1	3.7	3.0
3/14/2019	18	AT	277	59	8.2	89	1.2	0.2	0.1	5.0	1.7	0.3
3/14/2019	19	DG	212	45	8.3	83	0.4	0.1	0.2	6.7	1.0	0.5
3/14/2019	20	SC	59	13	7.9	230	0.3	0.1	0.4	16.6	1.6	1.1
3/14/2019	22	DG	335	72	7.9	83	0.4	0.1	0.3	8.2	1.0	0.5
3/14/2019	23	DG	244	52	7.9	60	0.3	0.1	0.2	6.4	0.7	0.3
3/14/2019	24	M	27	6	7.5	258	0.1	0.0	1.5	92.4	3.1	2.9
4/8/2019	1	SC	33	2	7.4	168	0.6	0.1	0.9	17.3	1.7	1.1
4/8/2019	2	DG	101	8	7.9	111	0.5	0.0	0.3	7.7	1.1	0.6
4/8/2019	3	SC	3	0	.	.	.	.	.	.	.	.
4/8/2019	4	M	14	1	7.5	310	0.3	0.1	1.7	134.4	4.7	4.2
4/8/2019	6	SA	43	3	7.6	264	0.3	0.1	1.9	39.9	3.1	2.7
4/8/2019	7	M	49	4	7.4	279	0.2	0.0	1.3	115.3	3.8	3.5
4/8/2019	8	AT	67	5	7.6	85	1.3	0.1	0.2	8.6	1.8	0.3
4/8/2019	9	SA	103	8	7.8	412	0.7	0.1	3.3	67.9	5.6	4.9
4/8/2019	11	AT	74	6	7.9	108	1.1	0.1	0.3	6.8	1.6	0.4
4/8/2019	15	M	42	3	7.6	334	0.4	0.1	1.7	136.7	4.0	3.5
4/8/2019	16	SA	87	7	7.8	472	0.5	0.2	2.9	76.8	5.5	4.7
4/8/2019	17	SA	196	15	8.1	512	0.6	0.1	2.1	45.4	3.5	2.8
4/8/2019	18	AT	360	27	8.0	110	1.7	0.1	0.2	5.1	2.1	0.3
4/8/2019	19	DG	144	11	7.8	93	0.6	0.1	0.3	5.9	1.1	0.4
4/8/2019	20	SC	107	8	7.8	249	0.4	0.2	0.6	17.4	1.7	1.1
4/8/2019	22	DG	400	30	7.7	104	0.7	0.2	0.4	8.7	1.5	0.6
4/8/2019	23	DG	200	15	7.6	62	0.5	0.1	0.2	6.6	1.0	0.4
4/8/2019	24	M	58	4	7.2	227	0.4	0.1	1.7	143.7	4.9	4.3
4/18/2019	1	SC	106	7	.	.	.	.	.	.	.	.
4/18/2019	2	DG	556	39	8.6	125	0.8	0.3	0.4	8.4	1.6	0.5
4/18/2019	3	SC	34	2	.	.	.	.	.	.	.	.

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
4/18/2019	4	M	221	15	7.5	253	0.4	0.3	1.6	118.0	4.0	3.3
4/18/2019	6	SA	225	16	7.9	305	0.5	0.3	2.5	44.7	4.1	3.4
4/18/2019	7	M	309	21	7.4	229	0.3	0.2	1.3	107.2	3.5	3.1
4/18/2019	8	AT	655	45	7.8	95	1.5	0.4	0.3	9.4	1.9	0.1
4/18/2019	9	SA	462	32	8.2	427	1.4	0.3	2.7	50.1	5.2	3.5
4/18/2019	11	AT	573	40	8.6	282	1.4	0.2	0.5	8.1	2.1	0.5
4/18/2019	15	M	305	21	7.5	267	0.8	0.2	2.5	133.3	4.5	3.4
4/18/2019	16	SA	359	25	7.7	310	0.9	0.7	2.8	57.7	5.7	4.1
4/18/2019	17	SA	405	28	7.6	286	0.5	0.4	2.6	46.1	4.4	3.4
4/18/2019	18	AT	959	66	7.8	84	1.5	0.2	0.2	4.7	1.9	0.3
4/18/2019	19	DG	637	44	8.1	101	1.0	0.2	0.4	7.6	1.7	0.5
4/18/2019	20	SC	161	11	.	.	.	.	.	.	.	.
4/18/2019	22	DG	1067	74	7.8	100	1.0	0.3	0.4	7.6	1.5	0.2
4/18/2019	23	DG	700	49	7.8	83	0.8	0.2	0.3	6.1	1.2	0.2
4/18/2019	24	M	450	31	7.4	215	0.6	0.3	1.8	123.2	4.1	3.3
4/25/2019	1	SC	546	31	7.5	175	0.8	3.3	0.7	15.3	10.9	6.8
4/25/2019	2	DG	1788	100	7.4	103	0.6	0.8	1.0	15.6	2.6	1.2
4/25/2019	3	SC	530	30	6.7	546	0.8	2.8	1.0	12.7	9.2	5.6
4/25/2019	4	M	699	39	7.3	192	0.2	0.3	1.3	58.2	3.0	2.5
4/25/2019	6	SA	966	54	7.4	252	1.1	5.6	1.7	22.4	16.0	9.3
4/25/2019	7	M	558	31	7.5	184	0.3	0.2	1.3	79.5	2.9	2.4
4/25/2019	8	AT	1285	72	7.1	80	0.7	0.5	0.3	10.8	2.1	0.8
4/25/2019	9	SA	1788	100	6.8	176	1.5	3.8	2.0	15.4	9.2	3.9
4/25/2019	11	AT	1788	100	7.1	144	1.4	1.1	1.1	10.8	4.3	1.8
4/25/2019	15	M	722	40	7.4	176	0.4	0.1	1.4	84.0	3.3	2.7
4/25/2019	16	SA	1284	72	7.5	264	1.3	0.3	1.5	29.3	16.6	15.0
4/25/2019	17	SA	1043	58	7.6	314	1.8	0.3	1.7	28.6	19.3	17.3
4/25/2019	18	AT	1563	87	7.2	73	1.2	0.2	0.2	4.4	2.0	0.7
4/25/2019	19	DG	1066	60	6.2	91	0.6	0.3	0.2	4.3	1.5	0.6
4/25/2019	20	SC	486	27	7.4	192	0.9	3.3	0.4	13.1	12.5	7.6
4/25/2019	22	DG	1788	100	6.9	55	0.6	0.3	0.2	9.4	1.6	0.4
4/25/2019	23	DG	1273	71	7.2	43	0.6	0.3	0.2	4.4	1.2	0.4
4/25/2019	24	M	1788	100	7.2	182	0.4	0.2	1.7	104.7	3.5	3.0
5/31/2019	1	SC	66	6	7.1	141	0.3	0.1	0.8	12.1	1.3	0.9
5/31/2019	2	DG	284	26	7.4	63	0.5	0.1	0.2	5.5	1.0	0.4
5/31/2019	3	SC	14	1	7.5	146	0.2	0.5	0.6	12.2	1.7	0.9
5/31/2019	4	M	103	9	7.0	145	0.0	0.0	1.4	58.5	1.9	1.8

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
5/31/2019	6	SA	180	17	7.2	258	0.2	0.4	3.0	23.2	2.3	1.7
5/31/2019	8	AT	274	25	7.0	52	1.1	0.1	0.4	11.5	1.8	0.6
5/31/2019	9	SA	249	23	7.3	318	0.5	0.4	2.4	28.8	3.1	2.2
5/31/2019	11	AT	363	33	7.7	126	1.3	0.1	0.6	8.2	2.2	0.7
5/31/2019	15	M	197	18	7.1	188	0.2	0.2	1.4	79.3	2.5	2.2
5/31/2019	16	SA	392	36	7.1	250	1.3	0.3	2.7	19.9	1.8	0.5
5/31/2019	17	SA	361	33	7.2	230	0.2	0.2	2.3	16.8	1.5	1.1
5/31/2019	18	AT	557	51	7.4	81	1.4	0.1	0.2	5.3	1.9	0.4
5/31/2019	19	DG	479	44	7.3	63	0.6	0.1	0.3	5.6	1.1	0.5
5/31/2019	20	SC	141	13	7.4	186	0.4	0.1	0.8	12.1	1.3	0.8
5/31/2019	22	DG	613	56	7.1	48	0.6	0.2	0.2	5.4	1.3	0.5
5/31/2019	23	DG	435	40	6.9	35	0.4	0.1	0.1	5.0	0.8	0.3
5/31/2019	24	M	78	7	6.7	107	0.1	0.0	1.5	59.8	2.1	2.0
6/6/2019	1	SC	250	13	7.5	163	0.0	0.2	0.7	13.5	1.0	0.8
6/6/2019	2	DG	755	38	7.7	103	0.5	0.0	0.4	6.7	1.0	0.4
6/6/2019	3	SC	75	4	7.7	138	0.1	0.1	0.6	14.7	1.1	0.9
6/6/2019	4	M	413	21	7.4	183	0.1	0.2	1.3	73.0	2.5	2.2
6/6/2019	6	SA	756	38	7.6	273	0.1	0.2	2.7	31.4	2.4	2.1
6/6/2019	7	M	401	20	7.0	179	0.1	0.3	1.4	84.4	3.0	2.6
6/6/2019	8	AT	985	50	7.4	74	0.8	0.1	0.4	9.6	1.2	0.3
6/6/2019	9	SA	888	45	7.6	381	0.1	0.2	1.9	38.8	3.0	2.7
6/6/2019	11	AT	1033	52	7.7	89	0.6	0.0	0.4	5.4	1.0	0.4
6/6/2019	15	M	459	23	7.1	207	0.1	0.2	1.4	89.0	3.0	2.6
6/6/2019	16	SA	894	45	7.5	287	0.1	0.2	2.4	25.1	1.8	1.6
6/6/2019	17	SA	876	44	7.7	305	0.0	0.1	2.6	24.7	1.7	1.5
6/6/2019	18	AT	1270	64	7.8	91	1.1	0.1	0.3	4.0	1.3	0.2
6/6/2019	19	DG	855	43	7.5	79	0.5	0.0	0.3	5.5	0.9	0.3
6/6/2019	20	SC	384	19	7.8	387	0.0	0.6	0.7	13.2	1.5	0.8
6/6/2019	22	DG	1286	65	7.4	45	0.2	0.0	0.2	4.2	0.5	0.2
6/6/2019	23	DG	966	49	7.2	37	0.2	0.1	0.2	4.7	0.5	0.3
6/6/2019	24	M	509	26	7.1	167	0.1	0.3	1.9	105.0	3.4	3.0
6/17/2019	1	SC	225	16	7.4	177	0.5	0.1	0.9	14.3	1.6	1.0
6/17/2019	2	DG	1396	100	6.7	148	1.2	0.1	0.9	26.3	2.5	1.3
6/17/2019	3	SC	874	62	7.2	148	1.2	0.1	1.1	30.8	2.8	1.5
6/17/2019	4	M	425	30	7.2	142	0.1	0.2	1.4	63.9	2.3	2.0
6/17/2019	6	SA	159	11	7.4	222	0.2	0.1	2.4	31.0	2.2	1.9

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
6/17/2019	7	M	168	12	7.1	154	0.1	0.2	1.7	84.4	2.9	2.6
6/17/2019	8	AT	447	32	7.2	50	0.7	0.1	0.4	11.4	1.2	0.4
6/17/2019	9	SA	195	14	7.4	253	0.4	0.2	2.3	29.7	2.8	2.2
6/17/2019	11	AT	511	37	7.0	54	0.7	0.1	0.4	5.5	1.2	0.4
6/17/2019	15	M	211	15	6.8	138	0.1	0.1	1.4	63.0	2.1	1.9
6/17/2019	16	SA	355	25	7.1	190	0.3	0.2	2.5	20.5	1.8	1.3
6/17/2019	17	SA	203	15	7.8	356	0.1	0.1	3.0	24.0	1.7	1.5
6/17/2019	18	AT	615	44	7.8	69	0.8	0.1	0.2	4.4	1.2	0.2
6/17/2019	19	DG	303	22	6.8	54	0.3	0.1	0.3	4.2	0.7	0.2
6/17/2019	20	SC	66	5	7.3	137	0.2	0.1	0.9	12.7	1.2	0.9
6/17/2019	22	DG	686	49	6.8	58	0.4	0.1	0.2	5.7	0.9	0.4
6/17/2019	23	DG	456	33	6.7	27	0.2	0.0	0.2	4.7	0.5	0.2
6/17/2019	24	M	104	7	6.0	139	0.1	0.3	2.0	83.9	3.1	2.6
8/28/2019	1	SC	12	3	7.8	461	0.4	1.6	5.6	70.4	9.5	7.4
8/28/2019	2	DG	152	43	7.5	171	1.0	0.1	1.1	18.4	3.0	1.9
8/28/2019	3	SC	1	0	.	.	.	.	.	.	.	.
8/28/2019	4	M	69	19	7.0	311	0.0	0.0	3.3	126.6	4.9	4.8
8/28/2019	6	SA	177	50	8.5	991	1.8	3.8	6.1	95.9	23.3	17.7
8/28/2019	7	M	68	19	7.0	280	0.1	0.2	2.8	116.1	5.7	5.4
8/28/2019	8	AT	113	32	7.1	190	2.5	0.0	1.6	20.6	4.6	2.1
8/28/2019	9	SA	188	53	8.7	1091	1.8	2.3	4.4	66.9	15.8	11.6
8/28/2019	11	AT	253	71	7.3	267	2.7	0.5	2.3	21.1	8.6	5.4
8/28/2019	15	M	99	28	7.3	374	0.2	0.1	2.8	160.4	6.8	6.5
8/28/2019	16	SA	316	89	8.6	993	1.6	6.9	5.0	78.2	27.1	18.6
8/28/2019	17	SA	294	83	8.6	916	1.0	15.6	5.3	78.9	35.0	18.5
8/28/2019	18	AT	271	77	7.4	151	2.7	0.2	0.4	11.9	4.3	1.4
8/28/2019	19	DG	193	55	7.4	111	0.6	0.1	0.5	10.5	2.1	1.4
8/28/2019	20	SC	60	17	8.8	956	0.1	0.5	1.6	34.1	4.4	3.8
8/28/2019	22	DG	195	55	6.7	75	0.4	0.1	0.6	12.7	1.1	0.7
8/28/2019	23	DG	0	0	.	.	.	.	.	.	.	.
8/28/2019	24	M	66	19	.	.	.	.	.	.	.	.
9/11/2019	1	SC	21	3	7.8	385	0.4	0.2	10.0	64.7	4.3	3.7
9/11/2019	2	DG	122	18	7.6	138	1.0	0.1	1.9	17.7	2.4	1.3
9/11/2019	3	SC	7	1	9.0	1084	0.4	0.1	2.8	33.6	2.6	2.2
9/11/2019	4	M	10	1	7.3	345	0.2	0.2	5.8	134.4	5.8	5.3
9/11/2019	6	SA	187	28	7.8	684	0.8	0.4	12.5	84.9	7.2	5.9
9/11/2019	7	M	86	13	7.2	294	0.4	0.1	4.9	110.4	4.8	4.3

Table A.1 Continued

Date	Plot	Trt	Runoff	Runoff	pH	EC	NO_3N	NH_4N	PO_4P	DOC	TDN	DON
			L	%			mg L^{-1}					
9/11/2019	8	AT	195	29	7.2	103	1.8	0.1	1.6	14.7	2.8	0.9
9/11/2019	9	SA	223	33	8.2	923	2.0	0.4	10.4	81.6	8.5	6.2
9/11/2019	11	AT	309	46	7.4	118	1.9	0.6	1.7	15.2	3.1	0.6
9/11/2019	15	M	102	15	7.4	299	0.2	0.1	4.1	131.7	4.8	4.4
9/11/2019	16	SA	263	39	7.7	467	0.5	0.7	10.2	70.1	5.7	4.6
9/11/2019	17	SA	275	41	8.0	650	0.3	0.4	4.9	65.9	4.8	4.1
9/11/2019	18	AT	411	61	7.5	94	1.4	0.2	0.8	10.4	2.1	0.5
9/11/2019	19	DG	222	33	7.6	94	1.0	0.1	0.8	9.2	1.6	0.5
9/11/2019	20	SC	113	17	8.1	712	0.2	0.1	1.5	59.2	3.4	3.2
9/11/2019	22	DG	316	47	6.7	61	1.3	0.1	0.8	10.6	1.8	0.4
9/11/2019	23	DG	229	34	.	.	.	.	.	.	.	.
9/11/2019	24	M	101	15	.	.	.	.	.	.	.	.

Table A.2 Surface temperature of all landscapes over the study period.

Date	Plot	Trt	Temperature (°C)
8/22/2018	1	SC	36.4
8/22/2018	2	DG	51.6
8/22/2018	3	SC	37.7
8/22/2018	4	Mulch	64.2
8/22/2018	6	SA	35
8/22/2018	7	Mulch	69.3
8/22/2018	8	AT	68.8
8/22/2018	9	SA	37.2
8/22/2018	11	AT	65.7
8/22/2018	15	Mulch	68.5
8/22/2018	16	SA	42.3
8/22/2018	17	SA	38.7
8/22/2018	18	AT	67.6
8/22/2018	19	DG	51.7
8/22/2018	20	SC	33.1
8/22/2018	22	DG	50.1
8/22/2018	23	DG	49.7
8/22/2018	24	Mulch	67.3
8/30/2018	1	SC	35.5
8/30/2018	2	DG	51.9
8/30/2018	3	SC	42.2
8/30/2018	4	Mulch	74.8
8/30/2018	6	SA	39.1
8/30/2018	7	Mulch	77.1
8/30/2018	8	AT	71.5
8/30/2018	9	SA	41.1
8/30/2018	11	AT	63.7
8/30/2018	15	Mulch	65.3
8/30/2018	16	SA	37.5
8/30/2018	17	SA	45.9
8/30/2018	18	AT	69.8
8/30/2018	19	DG	52.9
8/30/2018	20	SC	36.8
8/30/2018	22	DG	56.3
8/30/2018	23	DG	56.5
8/30/2018	24	Mulch	71.7
9/6/2018	1	SC	33.5

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
9/6/2018	2	DG	40.7
9/6/2018	3	SC	32.2
9/6/2018	4	Mulch	68.3
9/6/2018	6	SA	40.8
9/6/2018	7	Mulch	71.1
9/6/2018	8	AT	70.2
9/6/2018	9	SA	35.3
9/6/2018	11	AT	68.2
9/6/2018	15	Mulch	66.5
9/6/2018	16	SA	38.6
9/6/2018	17	SA	39.6
9/6/2018	18	AT	71.3
9/6/2018	19	DG	48.1
9/6/2018	20	SC	33.7
9/6/2018	22	DG	50.1
9/6/2018	23	DG	52.9
9/6/2018	24	Mulch	64.3
9/18/2018	1	SC	40.9
9/18/2018	2	DG	41.1
9/18/2018	3	SC	43.7
9/18/2018	4	Mulch	64.8
9/18/2018	6	SA	36.6
9/18/2018	7	Mulch	58.1
9/18/2018	8	AT	63.6
9/18/2018	9	SA	32.9
9/18/2018	11	AT	64.6
9/18/2018	15	Mulch	60.2
9/18/2018	16	SA	40.5
9/18/2018	17	SA	42.8
9/18/2018	18	AT	67.3
9/18/2018	19	DG	45.6
9/18/2018	20	SC	38.9
9/18/2018	22	DG	45.5
9/18/2018	23	DG	47.2
9/18/2018	24	Mulch	62.8
9/25/2018	1	SC	34.8
9/25/2018	2	DG	34.6
9/25/2018	3	SC	39.6

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
9/25/2018	4	Mulch	48.6
9/25/2018	6	SA	37.9
9/25/2018	7	Mulch	57.8
9/25/2018	8	AT	60.5
9/25/2018	9	SA	36.8
9/25/2018	11	AT	54.1
9/25/2018	15	Mulch	55.4
9/25/2018	16	SA	33.8
9/25/2018	17	SA	35.9
9/25/2018	18	AT	55.3
9/25/2018	19	DG	38.6
9/25/2018	20	SC	38.6
9/25/2018	22	DG	36.5
9/25/2018	23	DG	35.4
9/25/2018	24	Mulch	51.5
10/4/2018	1	SC	35.3
10/4/2018	2	DG	33.7
10/4/2018	3	SC	34.7
10/4/2018	4	Mulch	50.5
10/4/2018	6	SA	36.5
10/4/2018	7	Mulch	55.9
10/4/2018	8	AT	59.9
10/4/2018	9	SA	38.4
10/4/2018	11	AT	61.3
10/4/2018	15	Mulch	55.1
10/4/2018	16	SA	37.3
10/4/2018	17	SA	37.7
10/4/2018	18	AT	60.2
10/4/2018	19	DG	35.8
10/4/2018	20	SC	35.3
10/4/2018	22	DG	36.1
10/4/2018	23	DG	35.7
10/4/2018	24	Mulch	59.8
10/11/2018	1	SC	26.1
10/11/2018	2	DG	26.5
10/11/2018	3	SC	25.5
10/11/2018	4	Mulch	23.6
10/11/2018	6	SA	24.5

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
10/11/2018	7	Mulch	33.2
10/11/2018	8	AT	36.2
10/11/2018	9	SA	23.2
10/11/2018	11	AT	35.3
10/11/2018	15	Mulch	27.9
10/11/2018	16	SA	23
10/11/2018	17	SA	22.8
10/11/2018	18	AT	36.7
10/11/2018	19	DG	24.4
10/11/2018	20	SC	23.2
10/11/2018	22	DG	25.4
10/11/2018	23	DG	25.5
10/11/2018	24	Mulch	33.9
10/26/2018	1	SC	31.3
10/26/2018	2	DG	24.2
10/26/2018	3	SC	29.6
10/26/2018	4	Mulch	28
10/26/2018	6	SA	25.7
10/26/2018	7	Mulch	31.3
10/26/2018	8	AT	43.4
10/26/2018	9	SA	30
10/26/2018	11	AT	35.6
10/26/2018	15	Mulch	29.4
10/26/2018	16	SA	27.7
10/26/2018	17	SA	27.9
10/26/2018	18	AT	39.3
10/26/2018	19	DG	23.5
10/26/2018	20	SC	28.5
10/26/2018	22	DG	24.5
10/26/2018	23	DG	22
10/26/2018	24	Mulch	30.6
11/15/2018	1	SC	12.8
11/15/2018	2	DG	11
11/15/2018	3	SC	13.7
11/15/2018	4	Mulch	11.7
11/15/2018	6	SA	18.9
11/15/2018	7	Mulch	21.4
11/15/2018	8	AT	29

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
11/15/2018	9	SA	16.5
11/15/2018	11	AT	23.6
11/15/2018	15	Mulch	22.9
11/15/2018	16	SA	19.3
11/15/2018	17	SA	21.4
11/15/2018	18	AT	32.1
11/15/2018	19	DG	13.6
11/15/2018	20	SC	21.3
11/15/2018	22	DG	15.2
11/15/2018	23	DG	14.4
11/15/2018	24	Mulch	21.6
11/28/2018	1	SC	20.8
11/28/2018	2	DG	19.1
11/28/2018	3	SC	23.6
11/28/2018	4	Mulch	26.4
11/28/2018	6	SA	23.5
11/28/2018	7	Mulch	25.9
11/28/2018	8	AT	28.3
11/28/2018	9	SA	20.8
11/28/2018	11	AT	27.9
11/28/2018	15	Mulch	26.4
11/28/2018	16	SA	21.3
11/28/2018	17	SA	21.7
11/28/2018	18	AT	26.6
11/28/2018	19	DG	18.9
11/28/2018	20	SC	21.1
11/28/2018	22	DG	17.6
11/28/2018	23	DG	16.9
11/28/2018	24	Mulch	23
1/9/2019	1	SC	18.6
1/9/2019	2	DG	15.2
1/9/2019	3	SC	20.7
1/9/2019	4	Mulch	18.2
1/9/2019	6	SA	18.3
1/9/2019	7	Mulch	18
1/9/2019	8	AT	23.3
1/9/2019	9	SA	17.3
1/9/2019	11	AT	22.1

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
1/9/2019	15	Mulch	22.9
1/9/2019	16	SA	16.7
1/9/2019	17	SA	15.5
1/9/2019	18	AT	24.6
1/9/2019	19	DG	16.3
1/9/2019	20	SC	17.8
1/9/2019	22	DG	15.7
1/9/2019	23	DG	15.6
1/9/2019	24	Mulch	18.6
1/17/2019	1	SC	22.8
1/17/2019	2	DG	21.6
1/17/2019	3	SC	26.3
1/17/2019	4	Mulch	24.6
1/17/2019	6	SA	24.1
1/17/2019	7	Mulch	24.8
1/17/2019	8	AT	35.3
1/17/2019	9	SA	27.4
1/17/2019	11	AT	29.5
1/17/2019	15	Mulch	23.5
1/17/2019	16	SA	25.6
1/17/2019	17	SA	26.6
1/17/2019	18	AT	33.1
1/17/2019	19	DG	19.9
1/17/2019	20	SC	23.5
1/17/2019	22	DG	18.4
1/17/2019	23	DG	19.4
1/17/2019	24	Mulch	24.5
2/14/2019	1	SC	26.2
2/14/2019	2	DG	23.2
2/14/2019	3	SC	28.7
2/14/2019	4	Mulch	27.3
2/14/2019	6	SA	24.8
2/14/2019	7	Mulch	25.6
2/14/2019	8	AT	29.6
2/14/2019	9	SA	25.7
2/14/2019	11	AT	30.2
2/14/2019	15	Mulch	28.8
2/14/2019	16	SA	24.2

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
2/14/2019	17	SA	24.5
2/14/2019	18	AT	29.2
2/14/2019	19	DG	21.2
2/14/2019	20	SC	25.6
2/14/2019	22	DG	21.1
2/14/2019	23	DG	21.5
2/14/2019	24	Mulch	27.4
3/5/2019	1	SC	13.2
3/5/2019	2	DG	8.7
3/5/2019	3	SC	16.5
3/5/2019	4	Mulch	16.7
3/5/2019	6	SA	12.4
3/5/2019	7	Mulch	14.3
3/5/2019	8	AT	23.9
3/5/2019	9	SA	12.9
3/5/2019	11	AT	14.9
3/5/2019	15	Mulch	18.3
3/5/2019	16	SA	11.9
3/5/2019	17	SA	13.7
3/5/2019	18	AT	21.7
3/5/2019	19	DG	7.3
3/5/2019	20	SC	14.6
3/5/2019	22	DG	8.9
3/5/2019	23	DG	9.1
3/5/2019	24	Mulch	18.1
3/20/2019	1	SC	30.7
3/20/2019	2	DG	33.5
3/20/2019	3	SC	30.7
3/20/2019	4	Mulch	48.8
3/20/2019	6	SA	29.6
3/20/2019	7	Mulch	45.8
3/20/2019	8	AT	57.5
3/20/2019	9	SA	30.6
3/20/2019	11	AT	55.3
3/20/2019	15	Mulch	57.7
3/20/2019	16	SA	32.1
3/20/2019	17	SA	34.7
3/20/2019	18	AT	58.4

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
3/20/2019	19	DG	34.5
3/20/2019	20	SC	29.8
3/20/2019	22	DG	35.2
3/20/2019	23	DG	36.1
3/20/2019	24	Mulch	59.6
4/1/2019	1	SC	34.3
4/1/2019	2	DG	28.5
4/1/2019	3	SC	31.9
4/1/2019	4	Mulch	53.3
4/1/2019	6	SA	33.2
4/1/2019	7	Mulch	47.5
4/1/2019	8	AT	53.2
4/1/2019	9	SA	31.8
4/1/2019	11	AT	46.1
4/1/2019	15	Mulch	51.4
4/1/2019	16	SA	29.9
4/1/2019	17	SA	31.2
4/1/2019	18	AT	52.8
4/1/2019	19	DG	31.8
4/1/2019	20	SC	32.1
4/1/2019	22	DG	30.9
4/1/2019	23	DG	30.1
4/1/2019	24	Mulch	49.2
4/10/2019	1	SC	33.4
4/10/2019	2	DG	32.5
4/10/2019	3	SC	33.5
4/10/2019	4	Mulch	44.1
4/10/2019	6	SA	31.2
4/10/2019	7	Mulch	43.7
4/10/2019	8	AT	43.5
4/10/2019	9	SA	32.3
4/10/2019	11	AT	43.3
4/10/2019	15	Mulch	46.4
4/10/2019	16	SA	34.7
4/10/2019	17	SA	32.3
4/10/2019	18	AT	45.2
4/10/2019	19	DG	30.8
4/10/2019	20	SC	31.6

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
4/10/2019	22	DG	31.5
4/10/2019	23	DG	31
4/10/2019	24	Mulch	46.5
4/26/2019	1	SC	35.6
4/26/2019	2	DG	29.4
4/26/2019	3	SC	31.3
4/26/2019	4	Mulch	31.5
4/26/2019	6	SA	29.3
4/26/2019	7	Mulch	36.1
4/26/2019	8	AT	59.2
4/26/2019	9	SA	32.2
4/26/2019	11	AT	47.1
4/26/2019	15	Mulch	32.4
4/26/2019	16	SA	34.5
4/26/2019	17	SA	31.7
4/26/2019	18	AT	51.6
4/26/2019	19	DG	33.4
4/26/2019	20	SC	27.6
4/26/2019	22	DG	31.4
4/26/2019	23	DG	28.9
4/26/2019	24	Mulch	32.6
5/24/2019	1	SC	39.8
5/24/2019	2	DG	40.3
5/24/2019	3	SC	34.4
5/24/2019	4	Mulch	53.9
5/24/2019	6	SA	35.9
5/24/2019	7	Mulch	54.4
5/24/2019	8	AT	59.2
5/24/2019	9	SA	34.6
5/24/2019	11	AT	51.3
5/24/2019	15	Mulch	49.7
5/24/2019	16	SA	32.6
5/24/2019	17	SA	33.3
5/24/2019	18	AT	52.3
5/24/2019	19	DG	39.8
5/24/2019	20	SC	31.4
5/24/2019	22	DG	40.2
5/24/2019	23	DG	39.6

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
5/24/2019	24	Mulch	52.6
5/29/2019	1	SC	35.2
5/29/2019	2	DG	40.4
5/29/2019	3	SC	35.4
5/29/2019	4	Mulch	51.2
5/29/2019	6	SA	38.9
5/29/2019	7	Mulch	54.2
5/29/2019	8	AT	55.3
5/29/2019	9	SA	37.8
5/29/2019	11	AT	56.9
5/29/2019	15	Mulch	48.8
5/29/2019	16	SA	39.2
5/29/2019	17	SA	35.8
5/29/2019	18	AT	56.3
5/29/2019	19	DG	41.2
5/29/2019	20	SC	35.6
5/29/2019	22	DG	41.8
5/29/2019	23	DG	43.1
5/29/2019	24	Mulch	51.3
6/4/2019	1	SC	38.5
6/4/2019	2	DG	47.7
6/4/2019	3	SC	37.2
6/4/2019	4	Mulch	68.3
6/4/2019	6	SA	38.8
6/4/2019	7	Mulch	66.3
6/4/2019	8	AT	75.2
6/4/2019	9	SA	39.2
6/4/2019	11	AT	64.8
6/4/2019	15	Mulch	67.4
6/4/2019	16	SA	35.8
6/4/2019	17	SA	38.1
6/4/2019	18	AT	71
6/4/2019	19	DG	48.7
6/4/2019	20	SC	36.4
6/4/2019	22	DG	49.4
6/4/2019	23	DG	49.1
6/4/2019	24	Mulch	64.8
6/11/2019	1	SC	32.7

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
6/11/2019	2	DG	44.4
6/11/2019	3	SC	34.1
6/11/2019	4	Mulch	60.2
6/11/2019	6	SA	32.9
6/11/2019	7	Mulch	65.9
6/11/2019	8	AT	70.3
6/11/2019	9	SA	34.7
6/11/2019	11	AT	59
6/11/2019	15	Mulch	65.7
6/11/2019	16	SA	35.3
6/11/2019	17	SA	35.8
6/11/2019	18	AT	64.1
6/11/2019	19	DG	43.7
6/11/2019	20	SC	79.4
6/11/2019	22	DG	42.7
6/11/2019	23	DG	45.8
6/11/2019	24	Mulch	58
6/19/2019	1	SC	35.1
6/19/2019	2	DG	37.1
6/19/2019	3	SC	34.5
6/19/2019	4	Mulch	47.2
6/19/2019	6	SA	35.2
6/19/2019	7	Mulch	51.3
6/19/2019	8	AT	62.8
6/19/2019	9	SA	38.3
6/19/2019	11	AT	62.1
6/19/2019	15	Mulch	52.2
6/19/2019	16	SA	36.9
6/19/2019	17	SA	35.3
6/19/2019	18	AT	61.9
6/19/2019	19	DG	37.9
6/19/2019	20	SC	34.8
6/19/2019	22	DG	44
6/19/2019	23	DG	44.2
6/19/2019	24	Mulch	59.3
7/2/2019	1	SC	36.5
7/2/2019	2	DG	35.8
7/2/2019	3	SC	35.7

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
7/2/2019	4	Mulch	53.3
7/2/2019	6	SA	37.2
7/2/2019	7	Mulch	54.3
7/2/2019	8	AT	57.4
7/2/2019	9	SA	35.4
7/2/2019	11	AT	46.5
7/2/2019	15	Mulch	46.6
7/2/2019	16	SA	36.4
7/2/2019	17	SA	33.5
7/2/2019	18	AT	58.5
7/2/2019	19	DG	37.4
7/2/2019	20	SC	34.9
7/2/2019	22	DG	38.2
7/2/2019	23	DG	39.1
7/2/2019	24	Mulch	51.1
7/9/2019	1	SC	37.4
7/9/2019	2	DG	50.3
7/9/2019	3	SC	40.4
7/9/2019	4	Mulch	53.3
7/9/2019	6	SA	39.6
7/9/2019	7	Mulch	62.8
7/9/2019	8	AT	67.1
7/9/2019	9	SA	39.5
7/9/2019	11	AT	64.3
7/9/2019	15	Mulch	65.5
7/9/2019	16	SA	45.5
7/9/2019	17	SA	38.7
7/9/2019	18	AT	67.1
7/9/2019	19	DG	53.8
7/9/2019	20	SC	38.4
7/9/2019	22	DG	52.3
7/9/2019	23	DG	51.3
7/9/2019	24	Mulch	69.9
7/17/2019	1	SC	41.8
7/17/2019	2	DG	51.5
7/17/2019	3	SC	44.9
7/17/2019	4	Mulch	71.3
7/17/2019	6	SA	40.2

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
7/17/2019	7	Mulch	68.6
7/17/2019	8	AT	72.7
7/17/2019	9	SA	38.6
7/17/2019	11	AT	65.7
7/17/2019	15	Mulch	65.9
7/17/2019	16	SA	39.4
7/17/2019	17	SA	37.9
7/17/2019	18	AT	71.9
7/17/2019	19	DG	51.8
7/17/2019	20	SC	37.9
7/17/2019	22	DG	50.6
7/17/2019	23	DG	52.1
7/17/2019	24	Mulch	70.5
7/24/2019	1	SC	32.7
7/24/2019	2	DG	44.9
7/24/2019	3	SC	37.7
7/24/2019	4	Mulch	62.1
7/24/2019	6	SA	31.4
7/24/2019	7	Mulch	53.6
7/24/2019	8	AT	57.2
7/24/2019	9	SA	31.2
7/24/2019	11	AT	55.6
7/24/2019	15	Mulch	57.7
7/24/2019	16	SA	36.3
7/24/2019	17	SA	31.4
7/24/2019	18	AT	53.6
7/24/2019	19	DG	45
7/24/2019	20	SC	32.7
7/24/2019	22	DG	44.5
7/24/2019	23	DG	46.3
7/24/2019	24	Mulch	53.2
7/30/2019	1	SC	42.7
7/30/2019	2	DG	52.5
7/30/2019	3	SC	49.1
7/30/2019	4	Mulch	69.9
7/30/2019	6	SA	38.9
7/30/2019	7	Mulch	65.7
7/30/2019	8	AT	69.3

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
7/30/2019	9	SA	39.1
7/30/2019	11	AT	66.1
7/30/2019	15	Mulch	69.7
7/30/2019	16	SA	39.2
7/30/2019	17	SA	37.8
7/30/2019	18	AT	69.3
7/30/2019	19	DG	52.2
7/30/2019	20	SC	40.7
7/30/2019	22	DG	53.9
7/30/2019	23	DG	54.3
7/30/2019	24	Mulch	70.6
8/6/2019	1	SC	35.4
8/6/2019	2	DG	51.1
8/6/2019	3	SC	38.9
8/6/2019	4	Mulch	70.2
8/6/2019	6	SA	38.2
8/6/2019	7	Mulch	68.1
8/6/2019	8	AT	59.7
8/6/2019	9	SA	39.6
8/6/2019	11	AT	63.4
8/6/2019	15	Mulch	58.7
8/6/2019	16	SA	36.8
8/6/2019	17	SA	37.8
8/6/2019	18	AT	62.1
8/6/2019	19	DG	44.6
8/6/2019	20	SC	36.8
8/6/2019	22	DG	45.9
8/6/2019	23	DG	49.8
8/6/2019	24	Mulch	61.8
8/14/2019	1	SC	36.8
8/14/2019	2	DG	50.1
8/14/2019	3	SC	35.9
8/14/2019	4	Mulch	69.1
8/14/2019	6	SA	36.4
8/14/2019	7	Mulch	63.9
8/14/2019	8	AT	63.3
8/14/2019	9	SA	37
8/14/2019	11	AT	66.4

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
8/14/2019	15	Mulch	64.6
8/14/2019	16	SA	36.9
8/14/2019	17	SA	36.1
8/14/2019	18	AT	61.3
8/14/2019	19	DG	44.3
8/14/2019	20	SC	37.9
8/14/2019	22	DG	49.7
8/14/2019	23	DG	47.7
8/14/2019	24	Mulch	61.1
8/21/2019	1	SC	.
8/21/2019	2	DG	.
8/21/2019	3	SC	.
8/21/2019	4	Mulch	.
8/21/2019	6	SA	.
8/21/2019	7	Mulch	.
8/21/2019	8	AT	.
8/21/2019	9	SA	.
8/21/2019	11	AT	.
8/21/2019	15	Mulch	.
8/21/2019	16	SA	.
8/21/2019	17	SA	.
8/21/2019	18	AT	.
8/21/2019	19	DG	.
8/21/2019	20	SC	.
8/21/2019	22	DG	.
8/21/2019	23	DG	.
8/21/2019	24	Mulch	.
8/27/2019	1	SC	35.7
8/27/2019	2	DG	44.4
8/27/2019	3	SC	35.5
8/27/2019	4	Mulch	62.2
8/27/2019	6	SA	37.1
8/27/2019	7	Mulch	62.4
8/27/2019	8	AT	64.6
8/27/2019	9	SA	38.3
8/27/2019	11	AT	67.8
8/27/2019	15	Mulch	59.1
8/27/2019	16	SA	39.2

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
8/27/2019	17	SA	38.5
8/27/2019	18	AT	63.7
8/27/2019	19	DG	44.5
8/27/2019	20	SC	36.7
8/27/2019	22	DG	47
8/27/2019	23	DG	45.3
8/27/2019	24	Mulch	60.8
9/5/2019	1	SC	36.1
9/5/2019	2	DG	51.1
9/5/2019	3	SC	37.3
9/5/2019	4	Mulch	73.8
9/5/2019	6	SA	37.3
9/5/2019	7	Mulch	72.4
9/5/2019	8	AT	67.8
9/5/2019	9	SA	35.4
9/5/2019	11	AT	66.4
9/5/2019	15	Mulch	68.5
9/5/2019	16	SA	35.7
9/5/2019	17	SA	38.2
9/5/2019	18	AT	66.6
9/5/2019	19	DG	50.3
9/5/2019	20	SC	38.3
9/5/2019	22	DG	51.6
9/5/2019	23	DG	51.8
9/5/2019	24	Mulch	68.8
9/13/2019	1	SC	34.5
9/13/2019	2	DG	42.6
9/13/2019	3	SC	35.5
9/13/2019	4	Mulch	54.8
9/13/2019	6	SA	34.4
9/13/2019	7	Mulch	51.7
9/13/2019	8	AT	67.5
9/13/2019	9	SA	36.4
9/13/2019	11	AT	62.3
9/13/2019	15	Mulch	62.5
9/13/2019	16	SA	34.2
9/13/2019	17	SA	37.2
9/13/2019	18	AT	68.2

Table A.2 Continued

Date	Plot	Trt	Temperature (°C)
9/13/2019	19	DG	41.1
9/13/2019	20	SC	37.8
9/13/2019	22	DG	41.4
9/13/2019	23	DG	41.8
9/13/2019	24	Mulch	63.1
9/26/2019	1	SC	33.5
9/26/2019	2	DG	43.1
9/26/2019	3	SC	32.6
9/26/2019	4	Mulch	58.5
9/26/2019	6	SA	33.6
9/26/2019	7	Mulch	57.1
9/26/2019	8	AT	58.1
9/26/2019	9	SA	34.7
9/26/2019	11	AT	53.8
9/26/2019	15	Mulch	58.9
9/26/2019	16	SA	31.4
9/26/2019	17	SA	31.8
9/26/2019	18	AT	56.5
9/26/2019	19	DG	38
9/26/2019	20	SC	32.7
9/26/2019	22	DG	38.4
9/26/2019	23	DG	38.2
9/26/2019	24	Mulch	54.5

Table A.3 Visual grade of plant quality over the study period.

Date	Plot	Trt	Plant Quality
10/29/2018	1	SC	8
10/29/2018	2	DG	7.75
10/29/2018	3	SC	7
10/29/2018	4	Mulch	7.5
10/29/2018	6	SA	8
10/29/2018	7	Mulch	8.25
10/29/2018	8	AT	9
10/29/2018	9	SA	6
10/29/2018	11	AT	9
10/29/2018	15	Mulch	7.75
10/29/2018	16	SA	5
10/29/2018	17	SA	6
10/29/2018	18	AT	9
10/29/2018	19	DG	7.25
10/29/2018	20	SC	7
10/29/2018	22	DG	7.5
10/29/2018	23	DG	8.25
10/29/2018	24	Mulch	8.25
11/15/2018	1	SC	8
11/15/2018	2	DG	7.75
11/15/2018	3	SC	8
11/15/2018	4	Mulch	6.75
11/15/2018	6	SA	9
11/15/2018	7	Mulch	7.5
11/15/2018	8	AT	9
11/15/2018	9	SA	6
11/15/2018	11	AT	9
11/15/2018	15	Mulch	7.25
11/15/2018	16	SA	5
11/15/2018	17	SA	5
11/15/2018	18	AT	9
11/15/2018	19	DG	7.25
11/15/2018	20	SC	8
11/15/2018	22	DG	7.5
11/15/2018	23	DG	8.25
11/15/2018	24	Mulch	7.5
11/28/2018	1	SC	3

Table A.3 Continued

Date	Plot	Trt	Plant Quality
11/28/2018	2	DG	6.75
11/28/2018	3	SC	2
11/28/2018	4	Mulch	6.25
11/28/2018	6	SA	3
11/28/2018	7	Mulch	6
11/28/2018	8	AT	9
11/28/2018	9	SA	3
11/28/2018	11	AT	9
11/28/2018	15	Mulch	6.25
11/28/2018	16	SA	2
11/28/2018	17	SA	2
11/28/2018	18	AT	9
11/28/2018	19	DG	6.75
11/28/2018	20	SC	2
11/28/2018	22	DG	7
11/28/2018	23	DG	7.75
11/28/2018	24	Mulch	6.5
12/18/2018	1	SC	3
12/18/2018	2	DG	6.5
12/18/2018	3	SC	3
12/18/2018	4	Mulch	6.25
12/18/2018	6	SA	3
12/18/2018	7	Mulch	6.25
12/18/2018	8	AT	9
12/18/2018	9	SA	3
12/18/2018	11	AT	9
12/18/2018	15	Mulch	6
12/18/2018	16	SA	2
12/18/2018	17	SA	2
12/18/2018	18	AT	9
12/18/2018	19	DG	5.75
12/18/2018	20	SC	3
12/18/2018	22	DG	6.25
12/18/2018	23	DG	7
12/18/2018	24	Mulch	6
1/7/2019	1	SC	4
1/7/2019	2	DG	6
1/7/2019	3	SC	3

Table A.3 Continued

Date	Plot	Trt	Plant Quality
1/7/2019	4	Mulch	6
1/7/2019	6	SA	3
1/7/2019	7	Mulch	5.75
1/7/2019	8	AT	9
1/7/2019	9	SA	3
1/7/2019	11	AT	9
1/7/2019	15	Mulch	6
1/7/2019	16	SA	2
1/7/2019	17	SA	2
1/7/2019	18	AT	9
1/7/2019	19	DG	5.5
1/7/2019	20	SC	3
1/7/2019	22	DG	5.75
1/7/2019	23	DG	6.5
1/7/2019	24	Mulch	5.5
1/17/2019	1	SC	3
1/17/2019	2	DG	5.25
1/17/2019	3	SC	2
1/17/2019	4	Mulch	5
1/17/2019	6	SA	3
1/17/2019	7	Mulch	4.75
1/17/2019	8	AT	9
1/17/2019	9	SA	3
1/17/2019	11	AT	9
1/17/2019	15	Mulch	5.75
1/17/2019	16	SA	2
1/17/2019	17	SA	2
1/17/2019	18	AT	9
1/17/2019	19	DG	5
1/17/2019	20	SC	3
1/17/2019	22	DG	6
1/17/2019	23	DG	6.5
1/17/2019	24	Mulch	5
2/14/2019	1	SC	4
2/14/2019	2	DG	6
2/14/2019	3	SC	4
2/14/2019	4	Mulch	5
2/14/2019	6	SA	6

Table A.3 Continued

Date	Plot	Trt	Plant Quality
2/14/2019	7	Mulch	5.75
2/14/2019	8	AT	9
2/14/2019	9	SA	3
2/14/2019	11	AT	9
2/14/2019	15	Mulch	5.5
2/14/2019	16	SA	3
2/14/2019	17	SA	2
2/14/2019	18	AT	9
2/14/2019	19	DG	4.75
2/14/2019	20	SC	3
2/14/2019	22	DG	5.25
2/14/2019	23	DG	6.25
2/14/2019	24	Mulch	5.5
3/21/2019	1	SC	4
3/21/2019	2	DG	5.75
3/21/2019	3	SC	5
3/21/2019	4	Mulch	4.75
3/21/2019	6	SA	4
3/21/2019	7	Mulch	4.75
3/21/2019	8	AT	9
3/21/2019	9	SA	3
3/21/2019	11	AT	9
3/21/2019	15	Mulch	4.75
3/21/2019	16	SA	3
3/21/2019	17	SA	3
3/21/2019	18	AT	9
3/21/2019	19	DG	5
3/21/2019	20	SC	4
3/21/2019	22	DG	5.75
3/21/2019	23	DG	6.25
3/21/2019	24	Mulch	5
4/1/2019	1	SC	4
4/1/2019	2	DG	6.5
4/1/2019	3	SC	4
4/1/2019	4	Mulch	5.5
4/1/2019	6	SA	7
4/1/2019	7	Mulch	5.75
4/1/2019	8	AT	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
4/1/2019	9	SA	4
4/1/2019	11	AT	9
4/1/2019	15	Mulch	5.75
4/1/2019	16	SA	6
4/1/2019	17	SA	5
4/1/2019	18	AT	9
4/1/2019	19	DG	5.5
4/1/2019	20	SC	4
4/1/2019	22	DG	6.25
4/1/2019	23	DG	7
4/1/2019	24	Mulch	5.5
4/10/2019	1	SC	7
4/10/2019	2	DG	6.5
4/10/2019	3	SC	7
4/10/2019	4	Mulch	5.5
4/10/2019	6	SA	8
4/10/2019	7	Mulch	6
4/10/2019	8	AT	9
4/10/2019	9	SA	7
4/10/2019	11	AT	9
4/10/2019	15	Mulch	6
4/10/2019	16	SA	8
4/10/2019	17	SA	7
4/10/2019	18	AT	9
4/10/2019	19	DG	5.75
4/10/2019	20	SC	7
4/10/2019	22	DG	6.75
4/10/2019	23	DG	7.5
4/10/2019	24	Mulch	6
4/26/2019	1	SC	8
4/26/2019	2	DG	7.5
4/26/2019	3	SC	7
4/26/2019	4	Mulch	6.25
4/26/2019	6	SA	9
4/26/2019	7	Mulch	6.25
4/26/2019	8	AT	9
4/26/2019	9	SA	8
4/26/2019	11	AT	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
4/26/2019	15	Mulch	6
4/26/2019	16	SA	7
4/26/2019	17	SA	6
4/26/2019	18	AT	9
4/26/2019	19	DG	6.5
4/26/2019	20	SC	6
4/26/2019	22	DG	7.5
4/26/2019	23	DG	7.75
4/26/2019	24	Mulch	6.25
5/24/2019	1	SC	9
5/24/2019	2	DG	8.25
5/24/2019	3	SC	8
5/24/2019	4	Mulch	7
5/24/2019	6	SA	9
5/24/2019	7	Mulch	6.5
5/24/2019	8	AT	9
5/24/2019	9	SA	9
5/24/2019	11	AT	9
5/24/2019	15	Mulch	6.75
5/24/2019	16	SA	8
5/24/2019	17	SA	9
5/24/2019	18	AT	9
5/24/2019	19	DG	8
5/24/2019	20	SC	9
5/24/2019	22	DG	8.25
5/24/2019	23	DG	8.75
5/24/2019	24	Mulch	6.75
5/29/2019	1	SC	9
5/29/2019	2	DG	8
5/29/2019	3	SC	9
5/29/2019	4	Mulch	7
5/29/2019	6	SA	9
5/29/2019	7	Mulch	6.75
5/29/2019	8	AT	9
5/29/2019	9	SA	9
5/29/2019	11	AT	9
5/29/2019	15	Mulch	6.25
5/29/2019	16	SA	8

Table A.3 Continued

Date	Plot	Trt	Plant Quality
5/29/2019	17	SA	8
5/29/2019	18	AT	9
5/29/2019	19	DG	6.75
5/29/2019	20	SC	9
5/29/2019	22	DG	7
5/29/2019	23	DG	8
5/29/2019	24	Mulch	6.5
6/11/2019	1	SC	9
6/11/2019	2	DG	8
6/11/2019	3	SC	9
6/11/2019	4	Mulch	8.5
6/11/2019	6	SA	9
6/11/2019	7	Mulch	8.5
6/11/2019	8	AT	9
6/11/2019	9	SA	9
6/11/2019	11	AT	9
6/11/2019	15	Mulch	8.25
6/11/2019	16	SA	9
6/11/2019	17	SA	9
6/11/2019	18	AT	9
6/11/2019	19	DG	8.25
6/11/2019	20	SC	9
6/11/2019	22	DG	8.5
6/11/2019	23	DG	9
6/11/2019	24	Mulch	9
6/17/2019	1	SC	9
6/17/2019	2	DG	9
6/17/2019	3	SC	9
6/17/2019	4	Mulch	8.75
6/17/2019	6	SA	9
6/17/2019	7	Mulch	8.75
6/17/2019	8	AT	9
6/17/2019	9	SA	9
6/17/2019	11	AT	9
6/17/2019	15	Mulch	8.75
6/17/2019	16	SA	9
6/17/2019	17	SA	9
6/17/2019	18	AT	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
6/17/2019	19	DG	8.75
6/17/2019	20	SC	9
6/17/2019	22	DG	8.75
6/17/2019	23	DG	9
6/17/2019	24	Mulch	9
6/25/2019	1	SC	9
6/25/2019	2	DG	8.75
6/25/2019	3	SC	9
6/25/2019	4	Mulch	8.75
6/25/2019	6	SA	9
6/25/2019	7	Mulch	8.75
6/25/2019	8	AT	9
6/25/2019	9	SA	9
6/25/2019	11	AT	9
6/25/2019	15	Mulch	8.5
6/25/2019	16	SA	9
6/25/2019	17	SA	9
6/25/2019	18	AT	9
6/25/2019	19	DG	8.25
6/25/2019	20	SC	9
6/25/2019	22	DG	8.75
6/25/2019	23	DG	8.75
6/25/2019	24	Mulch	8.75
7/2/2019	1	SC	8
7/2/2019	2	DG	8.25
7/2/2019	3	SC	9
7/2/2019	4	Mulch	8
7/2/2019	6	SA	8
7/2/2019	7	Mulch	8.75
7/2/2019	8	AT	9
7/2/2019	9	SA	9
7/2/2019	11	AT	9
7/2/2019	15	Mulch	8.5
7/2/2019	16	SA	9
7/2/2019	17	SA	8
7/2/2019	18	AT	9
7/2/2019	19	DG	8.25
7/2/2019	20	SC	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
7/2/2019	22	DG	8.75
7/2/2019	23	DG	9
7/2/2019	24	Mulch	9
7/9/2019	1	SC	9
7/9/2019	2	DG	8.25
7/9/2019	3	SC	9
7/9/2019	4	Mulch	9
7/9/2019	6	SA	9
7/9/2019	7	Mulch	9
7/9/2019	8	AT	9
7/9/2019	9	SA	9
7/9/2019	11	AT	9
7/9/2019	15	Mulch	9
7/9/2019	16	SA	8
7/9/2019	17	SA	8
7/9/2019	18	AT	9
7/9/2019	19	DG	8.75
7/9/2019	20	SC	8
7/9/2019	22	DG	9
7/9/2019	23	DG	9
7/9/2019	24	Mulch	9
7/17/2019	1	SC	9
7/17/2019	2	DG	8.75
7/17/2019	3	SC	8
7/17/2019	4	Mulch	8.5
7/17/2019	6	SA	9
7/17/2019	7	Mulch	8.75
7/17/2019	8	AT	9
7/17/2019	9	SA	8
7/17/2019	11	AT	9
7/17/2019	15	Mulch	8.75
7/17/2019	16	SA	8
7/17/2019	17	SA	8
7/17/2019	18	AT	9
7/17/2019	19	DG	8.75
7/17/2019	20	SC	9
7/17/2019	22	DG	9
7/17/2019	23	DG	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
7/17/2019	24	Mulch	9
7/24/2019	1	SC	8
7/24/2019	2	DG	8.75
7/24/2019	3	SC	7
7/24/2019	4	Mulch	9
7/24/2019	6	SA	9
7/24/2019	7	Mulch	9
7/24/2019	8	AT	9
7/24/2019	9	SA	8
7/24/2019	11	AT	9
7/24/2019	15	Mulch	9
7/24/2019	16	SA	7
7/24/2019	17	SA	8
7/24/2019	18	AT	9
7/24/2019	19	DG	8.75
7/24/2019	20	SC	8
7/24/2019	22	DG	9
7/24/2019	23	DG	9
7/24/2019	24	Mulch	9
8/6/2019	1	SC	9
8/6/2019	2	DG	9
8/6/2019	3	SC	7
8/6/2019	4	Mulch	9
8/6/2019	6	SA	9
8/6/2019	7	Mulch	9
8/6/2019	8	AT	9
8/6/2019	9	SA	9
8/6/2019	11	AT	9
8/6/2019	15	Mulch	9
8/6/2019	16	SA	9
8/6/2019	17	SA	9
8/6/2019	18	AT	9
8/6/2019	19	DG	9
8/6/2019	20	SC	9
8/6/2019	22	DG	9
8/6/2019	23	DG	9
8/6/2019	24	Mulch	9
8/14/2019	1	SC	8

Table A.3 Continued

Date	Plot	Trt	Plant Quality
8/14/2019	2	DG	9
8/14/2019	3	SC	.
8/14/2019	4	Mulch	8.75
8/14/2019	6	SA	9
8/14/2019	7	Mulch	9
8/14/2019	8	AT	9
8/14/2019	9	SA	9
8/14/2019	11	AT	9
8/14/2019	15	Mulch	9
8/14/2019	16	SA	9
8/14/2019	17	SA	9
8/14/2019	18	AT	9
8/14/2019	19	DG	9
8/14/2019	20	SC	8
8/14/2019	22	DG	9
8/14/2019	23	DG	9
8/14/2019	24	Mulch	9
8/21/2019	1	SC	8
8/21/2019	2	DG	9
8/21/2019	3	SC	7
8/21/2019	4	Mulch	8.75
8/21/2019	6	SA	9
8/21/2019	7	Mulch	9
8/21/2019	8	AT	9
8/21/2019	9	SA	9
8/21/2019	11	AT	9
8/21/2019	15	Mulch	9
8/21/2019	16	SA	9
8/21/2019	17	SA	9
8/21/2019	18	AT	9
8/21/2019	19	DG	9
8/21/2019	20	SC	9
8/21/2019	22	DG	9
8/21/2019	23	DG	9
8/21/2019	24	Mulch	9
8/27/2019	1	SC	8
8/27/2019	2	DG	9
8/27/2019	3	SC	7

Table A.3 Continued

Date	Plot	Trt	Plant Quality
8/27/2019	4	Mulch	9
8/27/2019	6	SA	8
8/27/2019	7	Mulch	9
8/27/2019	8	AT	9
8/27/2019	9	SA	9
8/27/2019	11	AT	9
8/27/2019	15	Mulch	8.75
8/27/2019	16	SA	9
8/27/2019	17	SA	8
8/27/2019	18	AT	9
8/27/2019	19	DG	9
8/27/2019	20	SC	8
8/27/2019	22	DG	9
8/27/2019	23	DG	8.75
8/27/2019	24	Mulch	9
9/5/2019	1	SC	8
9/5/2019	2	DG	8.5
9/5/2019	3	SC	8
9/5/2019	4	Mulch	8.75
9/5/2019	6	SA	9
9/5/2019	7	Mulch	9
9/5/2019	8	AT	9
9/5/2019	9	SA	9
9/5/2019	11	AT	9
9/5/2019	15	Mulch	8.75
9/5/2019	16	SA	8
9/5/2019	17	SA	8
9/5/2019	18	AT	9
9/5/2019	19	DG	8.75
9/5/2019	20	SC	8
9/5/2019	22	DG	9
9/5/2019	23	DG	9
9/5/2019	24	Mulch	9
9/13/2019	1	SC	9
9/13/2019	2	DG	8.75
9/13/2019	3	SC	9
9/13/2019	4	Mulch	9
9/13/2019	6	SA	9

Table A.3 Continued

Date	Plot	Trt	Plant Quality
9/13/2019	7	Mulch	9
9/13/2019	8	AT	9
9/13/2019	9	SA	9
9/13/2019	11	AT	9
9/13/2019	15	Mulch	9
9/13/2019	16	SA	9
9/13/2019	17	SA	9
9/13/2019	18	AT	9
9/13/2019	19	DG	9
9/13/2019	20	SC	9
9/13/2019	22	DG	9
9/13/2019	23	DG	9
9/13/2019	24	Mulch	9
9/26/2019	1	SC	9
9/26/2019	2	DG	9
9/26/2019	3	SC	8
9/26/2019	4	Mulch	9
9/26/2019	6	SA	9
9/26/2019	7	Mulch	9
9/26/2019	8	AT	9
9/26/2019	9	SA	8
9/26/2019	11	AT	9
9/26/2019	15	Mulch	9
9/26/2019	16	SA	8
9/26/2019	17	SA	9
9/26/2019	18	AT	9
9/26/2019	19	DG	9
9/26/2019	20	SC	9
9/26/2019	22	DG	9
9/26/2019	23	DG	9
9/26/2019	24	Mulch	9

Table A.4 Weed pressure of each landscape during the study period.

Date	Plot	Trt	Count
8/24/2018	1	SC	0
8/24/2018	2	DG	9
8/24/2018	3	SC	0
8/24/2018	4	Mulch	13
8/24/2018	6	SA	0
8/24/2018	7	Mulch	10
8/24/2018	8	AT	0
8/24/2018	9	SA	.
8/24/2018	11	AT	0
8/24/2018	15	Mulch	19
8/24/2018	16	SA	0
8/24/2018	17	SA	.
8/24/2018	18	AT	0
8/24/2018	19	DG	0
8/24/2018	20	SC	0
8/24/2018	22	DG	27
8/24/2018	23	DG	31
8/24/2018	24	Mulch	7
8/31/2018	1	SC	0
8/31/2018	2	DG	7
8/31/2018	3	SC	0
8/31/2018	4	Mulch	16
8/31/2018	6	SA	0
8/31/2018	7	Mulch	4
8/31/2018	8	AT	0
8/31/2018	9	SA	.
8/31/2018	11	AT	0
8/31/2018	15	Mulch	14
8/31/2018	16	SA	0
8/31/2018	17	SA	.
8/31/2018	18	AT	0
8/31/2018	19	DG	7
8/31/2018	20	SC	0
8/31/2018	22	DG	15
8/31/2018	23	DG	11
8/31/2018	24	Mulch	6
9/7/2018	1	SC	40

Table A.4 Continued

Date	Plot	Trt	Count
9/7/2018	2	DG	5
9/7/2018	3	SC	36
9/7/2018	4	Mulch	15
9/7/2018	6	SA	0
9/7/2018	7	Mulch	10
9/7/2018	8	AT	0
9/7/2018	9	SA	.
9/7/2018	11	AT	0
9/7/2018	15	Mulch	23
9/7/2018	16	SA	0
9/7/2018	17	SA	.
9/7/2018	18	AT	0
9/7/2018	19	DG	23
9/7/2018	20	SC	19
9/7/2018	22	DG	20
9/7/2018	23	DG	17
9/7/2018	24	Mulch	3
9/20/2018	1	SC	.
9/20/2018	2	DG	12
9/20/2018	3	SC	.
9/20/2018	4	Mulch	13
9/20/2018	6	SA	0
9/20/2018	7	Mulch	7
9/20/2018	8	AT	0
9/20/2018	9	SA	0
9/20/2018	11	AT	0
9/20/2018	15	Mulch	3
9/20/2018	16	SA	0
9/20/2018	17	SA	.
9/20/2018	18	AT	0
9/20/2018	19	DG	70
9/20/2018	20	SC	.
9/20/2018	22	DG	38
9/20/2018	23	DG	43
9/20/2018	24	Mulch	3
9/27/2018	1	SC	31
9/27/2018	2	DG	17
9/27/2018	3	SC	40

Table A.4 Continued

Date	Plot	Trt	Count
9/27/2018	4	Mulch	18
9/27/2018	6	SA	0
9/27/2018	7	Mulch	6
9/27/2018	8	AT	1
9/27/2018	9	SA	0
9/27/2018	11	AT	0
9/27/2018	15	Mulch	5
9/27/2018	16	SA	0
9/27/2018	17	SA	0
9/27/2018	18	AT	1
9/27/2018	19	DG	303
9/27/2018	20	SC	0
9/27/2018	22	DG	157
9/27/2018	23	DG	423
9/27/2018	24	Mulch	7
10/5/2018	1	SC	43
10/5/2018	2	DG	45
10/5/2018	3	SC	24
10/5/2018	4	Mulch	11
10/5/2018	6	SA	0
10/5/2018	7	Mulch	1
10/5/2018	8	AT	0
10/5/2018	9	SA	0
10/5/2018	11	AT	0
10/5/2018	15	Mulch	0
10/5/2018	16	SA	0
10/5/2018	17	SA	0
10/5/2018	18	AT	0
10/5/2018	19	DG	218
10/5/2018	20	SC	39
10/5/2018	22	DG	349
10/5/2018	23	DG	1000
10/5/2018	24	Mulch	0
10/12/2018	1	SC	3
10/12/2018	2	DG	22
10/12/2018	3	SC	5
10/12/2018	4	Mulch	15
10/12/2018	6	SA	0

Table A.4 Continued

Date	Plot	Trt	Count
10/12/2018	7	Mulch	3
10/12/2018	8	AT	6
10/12/2018	9	SA	0
10/12/2018	11	AT	10
10/12/2018	15	Mulch	0
10/12/2018	16	SA	0
10/12/2018	17	SA	0
10/12/2018	18	AT	24
10/12/2018	19	DG	58
10/12/2018	20	SC	0
10/12/2018	22	DG	120
10/12/2018	23	DG	205
10/12/2018	24	Mulch	2
10/26/2018	1	SC	4
10/26/2018	2	DG	22
10/26/2018	3	SC	9
10/26/2018	4	Mulch	9
10/26/2018	6	SA	0
10/26/2018	7	Mulch	4
10/26/2018	8	AT	0
10/26/2018	9	SA	0
10/26/2018	11	AT	1
10/26/2018	15	Mulch	1
10/26/2018	16	SA	0
10/26/2018	17	SA	0
10/26/2018	18	AT	1
10/26/2018	19	DG	64
10/26/2018	20	SC	3
10/26/2018	22	DG	73
10/26/2018	23	DG	44
10/26/2018	24	Mulch	5
11/15/2018	1	SC	0
11/15/2018	2	DG	83
11/15/2018	3	SC	0
11/15/2018	4	Mulch	71
11/15/2018	6	SA	0
11/15/2018	7	Mulch	9
11/15/2018	8	AT	0

Table A.4 Continued

Date	Plot	Trt	Count
11/15/2018	9	SA	0
11/15/2018	11	AT	6
11/15/2018	15	Mulch	39
11/15/2018	16	SA	0
11/15/2018	17	SA	1
11/15/2018	18	AT	0
11/15/2018	19	DG	289
11/15/2018	20	SC	0
11/15/2018	22	DG	283
11/15/2018	23	DG	180
11/15/2018	24	Mulch	40
11/28/2018	1	SC	0
11/28/2018	2	DG	95
11/28/2018	3	SC	0
11/28/2018	4	Mulch	21
11/28/2018	6	SA	1
11/28/2018	7	Mulch	16
11/28/2018	8	AT	0
11/28/2018	9	SA	0
11/28/2018	11	AT	0
11/28/2018	15	Mulch	19
11/28/2018	16	SA	0
11/28/2018	17	SA	0
11/28/2018	18	AT	1
11/28/2018	19	DG	85
11/28/2018	20	SC	0
11/28/2018	22	DG	82
11/28/2018	23	DG	102
11/28/2018	24	Mulch	12
12/13/2018	1	SC	0
12/13/2018	2	DG	87
12/13/2018	3	SC	0
12/13/2018	4	Mulch	96
12/13/2018	6	SA	0
12/13/2018	7	Mulch	54
12/13/2018	8	AT	11
12/13/2018	9	SA	0
12/13/2018	11	AT	4

Table A.4 Continued

Date	Plot	Trt	Count
12/13/2018	15	Mulch	79
12/13/2018	16	SA	0
12/13/2018	17	SA	0
12/13/2018	18	AT	14
12/13/2018	19	DG	136
12/13/2018	20	SC	0
12/13/2018	22	DG	193
12/13/2018	23	DG	119
12/13/2018	24	Mulch	79
1/9/2019	1	SC	0
1/9/2019	2	DG	115
1/9/2019	3	SC	1
1/9/2019	4	Mulch	150
1/9/2019	6	SA	1
1/9/2019	7	Mulch	32
1/9/2019	8	AT	6
1/9/2019	9	SA	0
1/9/2019	11	AT	9
1/9/2019	15	Mulch	51
1/9/2019	16	SA	0
1/9/2019	17	SA	1
1/9/2019	18	AT	6
1/9/2019	19	DG	184
1/9/2019	20	SC	0
1/9/2019	22	DG	190
1/9/2019	23	DG	187
1/9/2019	24	Mulch	38
1/17/2019	1	SC	0
1/17/2019	2	DG	39
1/17/2019	3	SC	0
1/17/2019	4	Mulch	67
1/17/2019	6	SA	5
1/17/2019	7	Mulch	30
1/17/2019	8	AT	4
1/17/2019	9	SA	0
1/17/2019	11	AT	5
1/17/2019	15	Mulch	70
1/17/2019	16	SA	0

Table A.4 Continued

Date	Plot	Trt	Count
1/17/2019	17	SA	2
1/17/2019	18	AT	2
1/17/2019	19	DG	42
1/17/2019	20	SC	0
1/17/2019	22	DG	56
1/17/2019	23	DG	36
1/17/2019	24	Mulch	26
1/30/2019	1	SC	6
1/30/2019	2	DG	46
1/30/2019	3	SC	74
1/30/2019	4	Mulch	70
1/30/2019	6	SA	5
1/30/2019	7	Mulch	45
1/30/2019	8	AT	2
1/30/2019	9	SA	13
1/30/2019	11	AT	0
1/30/2019	15	Mulch	63
1/30/2019	16	SA	4
1/30/2019	17	SA	10
1/30/2019	18	AT	1
1/30/2019	19	DG	103
1/30/2019	20	SC	12
1/30/2019	22	DG	86
1/30/2019	23	DG	76
1/30/2019	24	Mulch	33
2/14/2019	1	SC	2
2/14/2019	2	DG	96
2/14/2019	3	SC	17
2/14/2019	4	Mulch	194
2/14/2019	6	SA	7
2/14/2019	7	Mulch	78
2/14/2019	8	AT	7
2/14/2019	9	SA	1
2/14/2019	11	AT	20
2/14/2019	15	Mulch	152
2/14/2019	16	SA	3
2/14/2019	17	SA	11
2/14/2019	18	AT	10

Table A.4 Continued

Date	Plot	Trt	Count
2/14/2019	19	DG	134
2/14/2019	20	SC	14
2/14/2019	22	DG	90
2/14/2019	23	DG	76
2/14/2019	24	Mulch	74
3/5/2019	1	SC	27
3/5/2019	2	DG	99
3/5/2019	3	SC	51
3/5/2019	4	Mulch	93
3/5/2019	6	SA	5
3/5/2019	7	Mulch	43
3/5/2019	8	AT	2
3/5/2019	9	SA	4
3/5/2019	11	AT	6
3/5/2019	15	Mulch	82
3/5/2019	16	SA	7
3/5/2019	17	SA	9
3/5/2019	18	AT	11
3/5/2019	19	DG	92
3/5/2019	20	SC	18
3/5/2019	22	DG	49
3/5/2019	23	DG	56
3/5/2019	24	Mulch	52
3/20/2019	1	SC	3
3/20/2019	2	DG	132
3/20/2019	3	SC	71
3/20/2019	4	Mulch	26
3/20/2019	6	SA	16
3/20/2019	7	Mulch	59
3/20/2019	8	AT	4
3/20/2019	9	SA	.
3/20/2019	11	AT	7
3/20/2019	15	Mulch	53
3/20/2019	16	SA	12
3/20/2019	17	SA	20
3/20/2019	18	AT	3
3/20/2019	19	DG	91
3/20/2019	20	SC	36

Table A.4 Continued

Date	Plot	Trt	Count
3/20/2019	22	DG	104
3/20/2019	23	DG	81
3/20/2019	24	Mulch	41
4/1/2019	1	SC	12
4/1/2019	2	DG	39
4/1/2019	3	SC	28
4/1/2019	4	Mulch	18
4/1/2019	6	SA	17
4/1/2019	7	Mulch	32
4/1/2019	8	AT	3
4/1/2019	9	SA	35
4/1/2019	11	AT	2
4/1/2019	15	Mulch	45
4/1/2019	16	SA	21
4/1/2019	17	SA	69
4/1/2019	18	AT	16
4/1/2019	19	DG	89
4/1/2019	20	SC	42
4/1/2019	22	DG	94
4/1/2019	23	DG	117
4/1/2019	24	Mulch	26
4/10/2019	1	SC	3
4/10/2019	2	DG	26
4/10/2019	3	SC	7
4/10/2019	4	Mulch	15
4/10/2019	6	SA	1
4/10/2019	7	Mulch	15
4/10/2019	8	AT	1
4/10/2019	9	SA	3
4/10/2019	11	AT	4
4/10/2019	15	Mulch	21
4/10/2019	16	SA	3
4/10/2019	17	SA	.
4/10/2019	18	AT	14
4/10/2019	19	DG	146
4/10/2019	20	SC	1
4/10/2019	22	DG	104
4/10/2019	23	DG	136

Table A.4 Continued

Date	Plot	Trt	Count
4/10/2019	24	Mulch	12
4/26/2019	1	SC	1
4/26/2019	2	DG	42
4/26/2019	3	SC	7
4/26/2019	4	Mulch	9
4/26/2019	6	SA	0
4/26/2019	7	Mulch	9
4/26/2019	8	AT	0
4/26/2019	9	SA	6
4/26/2019	11	AT	5
4/26/2019	15	Mulch	7
4/26/2019	16	SA	6
4/26/2019	17	SA	23
4/26/2019	18	AT	7
4/26/2019	19	DG	68
4/26/2019	20	SC	3
4/26/2019	22	DG	67
4/26/2019	23	DG	112
4/26/2019	24	Mulch	17
5/10/2019	1	SC	0
5/10/2019	2	DG	33
5/10/2019	3	SC	0
5/10/2019	4	Mulch	18
5/10/2019	6	SA	0
5/10/2019	7	Mulch	9
5/10/2019	8	AT	0
5/10/2019	9	SA	0
5/10/2019	11	AT	4
5/10/2019	15	Mulch	17
5/10/2019	16	SA	0
5/10/2019	17	SA	3
5/10/2019	18	AT	32
5/10/2019	19	DG	597
5/10/2019	20	SC	1
5/10/2019	22	DG	551
5/10/2019	23	DG	423
5/10/2019	24	Mulch	29
5/24/2019	1	SC	0

Table A.4 Continued

Date	Plot	Trt	Count
5/24/2019	2	DG	69
5/24/2019	3	SC	0
5/24/2019	4	Mulch	44
5/24/2019	6	SA	0
5/24/2019	7	Mulch	22
5/24/2019	8	AT	0
5/24/2019	9	SA	0
5/24/2019	11	AT	0
5/24/2019	15	Mulch	43
5/24/2019	16	SA	0
5/24/2019	17	SA	0
5/24/2019	18	AT	10
5/24/2019	19	DG	461
5/24/2019	20	SC	0
5/24/2019	22	DG	545
5/24/2019	23	DG	424
5/24/2019	24	Mulch	18
5/29/2019	1	SC	0
5/29/2019	2	DG	48
5/29/2019	3	SC	0
5/29/2019	4	Mulch	14
5/29/2019	6	SA	0
5/29/2019	7	Mulch	11
5/29/2019	8	AT	0
5/29/2019	9	SA	0
5/29/2019	11	AT	1
5/29/2019	15	Mulch	6
5/29/2019	16	SA	0
5/29/2019	17	SA	0
5/29/2019	18	AT	1
5/29/2019	19	DG	190
5/29/2019	20	SC	0
5/29/2019	22	DG	485
5/29/2019	23	DG	330
5/29/2019	24	Mulch	14
6/4/2019	1	SC	0
6/4/2019	2	DG	55
6/4/2019	3	SC	0

Table A.4 Continued

Date	Plot	Trt	Count
6/4/2019	4	Mulch	35
6/4/2019	6	SA	0
6/4/2019	7	Mulch	11
6/4/2019	8	AT	2
6/4/2019	9	SA	0
6/4/2019	11	AT	0
6/4/2019	15	Mulch	35
6/4/2019	16	SA	0
6/4/2019	17	SA	0
6/4/2019	18	AT	3
6/4/2019	19	DG	345
6/4/2019	20	SC	0
6/4/2019	22	DG	471
6/4/2019	23	DG	329
6/4/2019	24	Mulch	25
6/11/2019	1	SC	0
6/11/2019	2	DG	89
6/11/2019	3	SC	0
6/11/2019	4	Mulch	57
6/11/2019	6	SA	0
6/11/2019	7	Mulch	30
6/11/2019	8	AT	0
6/11/2019	9	SA	20
6/11/2019	11	AT	1
6/11/2019	15	Mulch	35
6/11/2019	16	SA	1
6/11/2019	17	SA	2
6/11/2019	18	AT	9
6/11/2019	19	DG	180
6/11/2019	20	SC	0
6/11/2019	22	DG	322
6/11/2019	23	DG	177
6/11/2019	24	Mulch	12
6/17/2019	1	SC	0
6/17/2019	2	DG	25
6/17/2019	3	SC	0
6/17/2019	4	Mulch	54
6/17/2019	6	SA	0

Table A.4 Continued

Date	Plot	Trt	Count
6/17/2019	7	Mulch	30
6/17/2019	8	AT	0
6/17/2019	9	SA	0
6/17/2019	11	AT	0
6/17/2019	15	Mulch	42
6/17/2019	16	SA	0
6/17/2019	17	SA	1
6/17/2019	18	AT	0
6/17/2019	19	DG	103
6/17/2019	20	SC	2
6/17/2019	22	DG	129
6/17/2019	23	DG	149
6/17/2019	24	Mulch	379
6/25/2019	1	SC	5
6/25/2019	2	DG	57
6/25/2019	3	SC	8
6/25/2019	4	Mulch	48
6/25/2019	6	SA	0
6/25/2019	7	Mulch	21
6/25/2019	8	AT	1
6/25/2019	9	SA	0
6/25/2019	11	AT	0
6/25/2019	15	Mulch	14
6/25/2019	16	SA	0
6/25/2019	17	SA	0
6/25/2019	18	AT	0
6/25/2019	19	DG	112
6/25/2019	20	SC	3
6/25/2019	22	DG	215
6/25/2019	23	DG	214
6/25/2019	24	Mulch	31
7/2/2019	1	SC	0
7/2/2019	2	DG	54
7/2/2019	3	SC	0
7/2/2019	4	Mulch	25
7/2/2019	6	SA	0
7/2/2019	7	Mulch	33
7/2/2019	8	AT	0

Table A.4 Continued

Date	Plot	Trt	Count
7/2/2019	9	SA	0
7/2/2019	11	AT	0
7/2/2019	15	Mulch	24
7/2/2019	16	SA	0
7/2/2019	17	SA	0
7/2/2019	18	AT	7
7/2/2019	19	DG	157
7/2/2019	20	SC	0
7/2/2019	22	DG	185
7/2/2019	23	DG	161
7/2/2019	24	Mulch	24
7/9/2019	1	SC	0
7/9/2019	2	DG	101
7/9/2019	3	SC	0
7/9/2019	4	Mulch	60
7/9/2019	6	SA	0
7/9/2019	7	Mulch	32
7/9/2019	8	AT	0
7/9/2019	9	SA	0
7/9/2019	11	AT	0
7/9/2019	15	Mulch	28
7/9/2019	16	SA	5
7/9/2019	17	SA	0
7/9/2019	18	AT	2
7/9/2019	19	DG	104
7/9/2019	20	SC	0
7/9/2019	22	DG	220
7/9/2019	23	DG	257
7/9/2019	24	Mulch	79
7/17/2019	1	SC	0
7/17/2019	2	DG	147
7/17/2019	3	SC	0
7/17/2019	4	Mulch	79
7/17/2019	6	SA	0
7/17/2019	7	Mulch	68
7/17/2019	8	AT	1
7/17/2019	9	SA	0
7/17/2019	11	AT	0

Table A.4 Continued

Date	Plot	Trt	Count
7/17/2019	15	Mulch	62
7/17/2019	16	SA	4
7/17/2019	17	SA	0
7/17/2019	18	AT	0
7/17/2019	19	DG	208
7/17/2019	20	SC	0
7/17/2019	22	DG	282
7/17/2019	23	DG	295
7/17/2019	24	Mulch	178
7/24/2019	1	SC	0
7/24/2019	2	DG	83
7/24/2019	3	SC	0
7/24/2019	4	Mulch	42
7/24/2019	6	SA	0
7/24/2019	7	Mulch	32
7/24/2019	8	AT	0
7/24/2019	9	SA	0
7/24/2019	11	AT	0
7/24/2019	15	Mulch	13
7/24/2019	16	SA	0
7/24/2019	17	SA	1
7/24/2019	18	AT	2
7/24/2019	19	DG	113
7/24/2019	20	SC	0
7/24/2019	22	DG	157
7/24/2019	23	DG	117
7/24/2019	24	Mulch	100
7/30/2019	1	SC	0
7/30/2019	2	DG	42
7/30/2019	3	SC	0
7/30/2019	4	Mulch	36
7/30/2019	6	SA	0
7/30/2019	7	Mulch	22
7/30/2019	8	AT	0
7/30/2019	9	SA	0
7/30/2019	11	AT	0
7/30/2019	15	Mulch	0
7/30/2019	16	SA	21

Table A.4 Continued

Date	Plot	Trt	Count
7/30/2019	17	SA	0
7/30/2019	18	AT	0
7/30/2019	19	DG	54
7/30/2019	20	SC	0
7/30/2019	22	DG	46
7/30/2019	23	DG	61
7/30/2019	24	Mulch	52
8/6/2019	1	SC	0
8/6/2019	2	DG	71
8/6/2019	3	SC	2
8/6/2019	4	Mulch	47
8/6/2019	6	SA	0
8/6/2019	7	Mulch	30
8/6/2019	8	AT	0
8/6/2019	9	SA	0
8/6/2019	11	AT	0
8/6/2019	15	Mulch	25
8/6/2019	16	SA	1
8/6/2019	17	SA	0
8/6/2019	18	AT	0
8/6/2019	19	DG	90
8/6/2019	20	SC	0
8/6/2019	22	DG	132
8/6/2019	23	DG	142
8/6/2019	24	Mulch	18
8/14/2019	1	SC	0
8/14/2019	2	DG	21
8/14/2019	3	SC	0
8/14/2019	4	Mulch	9
8/14/2019	6	SA	0
8/14/2019	7	Mulch	9
8/14/2019	8	AT	0
8/14/2019	9	SA	0
8/14/2019	11	AT	2
8/14/2019	15	Mulch	11
8/14/2019	16	SA	0
8/14/2019	17	SA	0
8/14/2019	18	AT	1

Table A.4 Continued

Date	Plot	Trt	Count
8/14/2019	19	DG	39
8/14/2019	20	SC	0
8/14/2019	22	DG	82
8/14/2019	23	DG	67
8/14/2019	24	Mulch	16
8/21/2019	1	SC	0
8/21/2019	2	DG	10
8/21/2019	3	SC	0
8/21/2019	4	Mulch	9
8/21/2019	6	SA	0
8/21/2019	7	Mulch	5
8/21/2019	8	AT	0
8/21/2019	9	SA	0
8/21/2019	11	AT	0
8/21/2019	15	Mulch	3
8/21/2019	16	SA	0
8/21/2019	17	SA	0
8/21/2019	18	AT	0
8/21/2019	19	DG	45
8/21/2019	20	SC	0
8/21/2019	22	DG	46
8/21/2019	23	DG	32
8/21/2019	24	Mulch	5
8/27/2019	1	SC	0
8/27/2019	2	DG	18
8/27/2019	3	SC	0
8/27/2019	4	Mulch	8
8/27/2019	6	SA	0
8/27/2019	7	Mulch	1
8/27/2019	8	AT	0
8/27/2019	9	SA	0
8/27/2019	11	AT	0
8/27/2019	15	Mulch	16
8/27/2019	16	SA	0
8/27/2019	17	SA	2
8/27/2019	18	AT	0
8/27/2019	19	DG	17
8/27/2019	20	SC	0

Table A.4 Continued

Date	Plot	Trt	Count
8/27/2019	22	DG	24
8/27/2019	23	DG	37
8/27/2019	24	Mulch	3
9/5/2019	1	SC	0
9/5/2019	2	DG	28
9/5/2019	3	SC	0
9/5/2019	4	Mulch	14
9/5/2019	6	SA	0
9/5/2019	7	Mulch	5
9/5/2019	8	AT	0
9/5/2019	9	SA	0
9/5/2019	11	AT	0
9/5/2019	15	Mulch	12
9/5/2019	16	SA	1
9/5/2019	17	SA	0
9/5/2019	18	AT	1
9/5/2019	19	DG	26
9/5/2019	20	SC	0
9/5/2019	22	DG	37
9/5/2019	23	DG	31
9/5/2019	24	Mulch	2
9/13/2019	1	SC	0
9/13/2019	2	DG	13
9/13/2019	3	SC	0
9/13/2019	4	Mulch	7
9/13/2019	6	SA	0
9/13/2019	7	Mulch	6
9/13/2019	8	AT	0
9/13/2019	9	SA	0
9/13/2019	11	AT	0
9/13/2019	15	Mulch	13
9/13/2019	16	SA	0
9/13/2019	17	SA	0
9/13/2019	18	AT	0
9/13/2019	19	DG	32
9/13/2019	20	SC	0
9/13/2019	22	DG	18
9/13/2019	23	DG	29

Table A.4 Continued

Date	Plot	Trt	Count
9/13/2019	24	Mulch	1
9/26/2019	1	SC	0
9/26/2019	2	DG	55
9/26/2019	3	SC	0
9/26/2019	4	Mulch	25
9/26/2019	6	SA	0
9/26/2019	7	Mulch	21
9/26/2019	8	AT	1
9/26/2019	9	SA	0
9/26/2019	11	AT	1
9/26/2019	15	Mulch	43
9/26/2019	16	SA	0
9/26/2019	17	SA	0
9/26/2019	18	AT	0
9/26/2019	19	DG	102
9/26/2019	20	SC	0
9/26/2019	22	DG	154
9/26/2019	23	DG	202
9/26/2019	24	Mulch	22

Table A.5 Total suspend solids of the first runoff sample and the last runoff sample for all landscapes.

Date	Plot	Trt	Sample	TSS (mg L^{-1})
10/10/2018	1	SC	First	107.0
10/10/2018	2	DG	First	1045.0
10/10/2018	3	SC	First	78.1
10/10/2018	4	Mulch	First	115.8
10/10/2018	6	SA	First	36.4
10/10/2018	7	Mulch	First	163.6
10/10/2018	8	AT	First	14.8
10/10/2018	9	SA	First	210.8
10/10/2018	11	AT	First	45.6
10/10/2018	15	Mulch	First	164.5
10/10/2018	16	SA	First	57.6
10/10/2018	17	SA	First	51.0
10/10/2018	18	AT	First	40.5
10/10/2018	19	DG	First	547.1
10/10/2018	20	SC	First	57.3
10/10/2018	22	DG	First	1038.9
10/10/2018	23	DG	First	585.7
10/10/2018	24	Mulch	First	143.2
10/17/2018	1	SC	First	34.8
10/17/2018	2	DG	First	2463.6
10/17/2018	3	SC	First	.
10/17/2018	4	Mulch	First	150.0
10/17/2018	6	SA	First	48.5
10/17/2018	7	Mulch	First	144.6
10/17/2018	8	AT	First	19.3
10/17/2018	9	SA	First	44.1
10/17/2018	11	AT	First	97.3
10/17/2018	15	Mulch	First	173.8
10/17/2018	16	SA	First	56.3
10/17/2018	17	SA	First	72.2
10/17/2018	18	AT	First	55.2
10/17/2018	19	DG	First	1065.0
10/17/2018	20	SC	First	213.6
10/17/2018	22	DG	First	.
10/17/2018	23	DG	First	930.3

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
10/17/2018	24	Mulch	First	146.5
11/1/2018	1	SC	First	17.5
11/1/2018	2	DG	First	315.0
11/1/2018	3	SC	First	.
11/1/2018	4	Mulch	First	102.0
11/1/2018	6	SA	First	68.0
11/1/2018	7	Mulch	First	57.1
11/1/2018	8	AT	First	10.7
11/1/2018	9	SA	First	50.0
11/1/2018	11	AT	First	52.8
11/1/2018	15	Mulch	First	142.0
11/1/2018	16	SA	First	34.0
11/1/2018	17	SA	First	20.0
11/1/2018	18	AT	First	15.3
11/1/2018	19	DG	First	237.7
11/1/2018	20	SC	First	75.0
11/1/2018	22	DG	First	.
11/1/2018	23	DG	First	202.0
11/1/2018	24	Mulch	First	120.0
12/8/2018	1	SC	First	41.0
12/8/2018	2	DG	First	119.0
12/8/2018	3	SC	First	23.0
12/8/2018	4	Mulch	First	42.0
12/8/2018	6	SA	First	55.0
12/8/2018	7	Mulch	First	61.0
12/8/2018	8	AT	First	23.0
12/8/2018	9	SA	First	44.0
12/8/2018	11	AT	First	29.0
12/8/2018	15	Mulch	First	90.0
12/8/2018	16	SA	First	39.0
12/8/2018	17	SA	First	29.0
12/8/2018	18	AT	First	23.0
12/8/2018	19	DG	First	76.0
12/8/2018	20	SC	First	83.0
12/8/2018	22	DG	First	51.0
12/8/2018	23	DG	First	83.0
12/8/2018	24	Mulch	First	48.0
3/14/2019	1	SC	First	21.0

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
3/14/2019	2	DG	First	62.0
3/14/2019	3	SC	First	64.5
3/14/2019	4	Mulch	First	104.6
3/14/2019	6	SA	First	97.3
3/14/2019	7	Mulch	First	64.3
3/14/2019	8	AT	First	25.6
3/14/2019	9	SA	First	76.8
3/14/2019	11	AT	First	35.3
3/14/2019	15	Mulch	First	170.8
3/14/2019	16	SA	First	95.7
3/14/2019	17	SA	First	65.1
3/14/2019	18	AT	First	9.6
3/14/2019	19	DG	First	288.9
3/14/2019	20	SC	First	270.8
3/14/2019	22	DG	First	55.6
3/14/2019	23	DG	First	92.3
3/14/2019	24	Mulch	First	160.9
4/8/2019	1	SC	First	42.2
4/8/2019	2	DG	First	272.7
4/8/2019	3	SC	First	.
4/8/2019	4	Mulch	First	56.7
4/8/2019	6	SA	First	55.1
4/8/2019	7	Mulch	First	41.4
4/8/2019	8	AT	First	22.4
4/8/2019	9	SA	First	100.0
4/8/2019	11	AT	First	31.2
4/8/2019	15	Mulch	First	80.6
4/8/2019	16	SA	First	60.0
4/8/2019	17	SA	First	24.3
4/8/2019	18	AT	First	4.8
4/8/2019	19	DG	First	195.7
4/8/2019	20	SC	First	116.5
4/8/2019	22	DG	First	214.5
4/8/2019	23	DG	First	370.6
4/8/2019	24	Mulch	First	63.1
4/25/2019	1	SC	First	19.8
4/25/2019	2	DG	First	77.1
4/25/2019	3	SC	First	26.7

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
4/25/2019	4	Mulch	First	34.1
4/25/2019	6	SA	First	24.3
4/25/2019	7	Mulch	First	41.6
4/25/2019	8	AT	First	42.3
4/25/2019	9	SA	First	15.1
4/25/2019	11	AT	First	21.3
4/25/2019	15	Mulch	First	72.0
4/25/2019	16	SA	First	37.8
4/25/2019	17	SA	First	37.0
4/25/2019	18	AT	First	22.5
4/25/2019	19	DG	First	86.7
4/25/2019	20	SC	First	36.2
4/25/2019	22	DG	First	100.0
4/25/2019	23	DG	First	65.5
4/25/2019	24	Mulch	First	71.8
6/1/2019	1	SC	First	35.0
6/1/2019	2	DG	First	391.1
6/1/2019	3	SC	First	110.5
6/1/2019	4	Mulch	First	57.1
6/1/2019	6	SA	First	39.0
6/1/2019	7	Mulch	First	54.4
6/1/2019	8	AT	First	12.5
6/1/2019	9	SA	First	48.2
6/1/2019	11	AT	First	62.7
6/1/2019	15	Mulch	First	187.5
6/1/2019	16	SA	First	38.5
6/1/2019	17	SA	First	97.9
6/1/2019	18	AT	First	25.8
6/1/2019	19	DG	First	137.8
6/1/2019	20	SC	First	86.0
6/1/2019	22	DG	First	90.6
6/1/2019	23	DG	First	66.3
6/1/2019	24	Mulch	First	47.8
6/6/2019	1	SC	First	29.2
6/6/2019	2	DG	First	74.2
6/6/2019	3	SC	First	30.3
6/6/2019	4	Mulch	First	41.9
6/6/2019	6	SA	First	19.3

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
6/6/2019	7	Mulch	First	41.1
6/6/2019	8	AT	First	10.8
6/6/2019	9	SA	First	22.6
6/6/2019	11	AT	First	3.2
6/6/2019	15	Mulch	First	66.7
6/6/2019	16	SA	First	16.0
6/6/2019	17	SA	First	18.4
6/6/2019	18	AT	First	25.6
6/6/2019	19	DG	First	47.6
6/6/2019	20	SC	First	30.6
6/6/2019	22	DG	First	20.7
6/6/2019	23	DG	First	14.9
6/6/2019	24	Mulch	First	40.4
6/17/2019	1	SC	First	71.6
6/17/2019	2	DG	First	.
6/17/2019	3	SC	First	.
6/17/2019	4	Mulch	First	57.5
6/17/2019	6	SA	First	38.6
6/17/2019	7	Mulch	First	36.8
6/17/2019	8	AT	First	21.9
6/17/2019	9	SA	First	34.8
6/17/2019	11	AT	First	5.7
6/17/2019	15	Mulch	First	33.0
6/17/2019	16	SA	First	23.8
6/17/2019	17	SA	First	30.0
6/17/2019	18	AT	First	17.2
6/17/2019	19	DG	First	135.4
6/17/2019	20	SC	First	56.3
6/17/2019	22	DG	First	155.2
6/17/2019	23	DG	First	98.8
6/17/2019	24	Mulch	First	46.5
8/29/2019	1	SC	First	395.5
8/29/2019	2	DG	First	274.5
8/29/2019	3	SC	First	.
8/29/2019	4	Mulch	First	53.2
8/29/2019	6	SA	First	45.3
8/29/2019	7	Mulch	First	62.9
8/29/2019	8	AT	First	23.5

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
8/29/2019	9	SA	First	31.7
8/29/2019	11	AT	First	44.3
8/29/2019	15	Mulch	First	121.7
8/29/2019	16	SA	First	47.5
8/29/2019	17	SA	First	44.8
8/29/2019	18	AT	First	29.5
8/29/2019	19	DG	First	132.2
8/29/2019	20	SC	First	50.6
8/29/2019	22	DG	First	47.4
8/29/2019	23	DG	First	.
8/29/2019	24	Mulch	First	.
9/11/2019	1	SC	First	72.0
9/11/2019	2	DG	First	167.1
9/11/2019	3	SC	First	316.2
9/11/2019	4	Mulch	First	53.8
9/11/2019	6	SA	First	11.6
9/11/2019	7	Mulch	First	31.6
9/11/2019	8	AT	First	8.6
9/11/2019	9	SA	First	7.1
9/11/2019	11	AT	First	32.1
9/11/2019	15	Mulch	First	114.9
9/11/2019	16	SA	First	35.4
9/11/2019	17	SA	First	5.2
9/11/2019	18	AT	First	32.5
9/11/2019	19	DG	First	97.1
9/11/2019	20	SC	First	44.2
9/11/2019	22	DG	First	89.6
9/11/2019	23	DG	First	.
9/11/2019	24	Mulch	First	.
10/10/2018	1	SC	Last	28.5
10/10/2018	2	DG	Last	554.5
10/10/2018	3	SC	Last	410.7
10/10/2018	4	Mulch	Last	92.9
10/10/2018	6	SA	Last	231.0
10/10/2018	7	Mulch	Last	95.3
10/10/2018	8	AT	Last	54.8
10/10/2018	9	SA	Last	455.6
10/10/2018	11	AT	Last	335.3

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
10/10/2018	15	Mulch	Last	92.9
10/10/2018	16	SA	Last	25.2
10/10/2018	17	SA	Last	31.1
10/10/2018	18	AT	Last	30.7
10/10/2018	19	DG	Last	213.8
10/10/2018	20	SC	Last	46.2
10/10/2018	22	DG	Last	188.9
10/10/2018	23	DG	Last	533.3
10/10/2018	24	Mulch	Last	101.5
10/17/2018	1	SC	Last	13.8
10/17/2018	2	DG	Last	737.5
10/17/2018	3	SC	Last	.
10/17/2018	4	Mulch	Last	366.7
10/17/2018	6	SA	Last	421.7
10/17/2018	7	Mulch	Last	95.8
10/17/2018	8	AT	Last	129.5
10/17/2018	9	SA	Last	446.3
10/17/2018	11	AT	Last	705.3
10/17/2018	15	Mulch	Last	179.7
10/17/2018	16	SA	Last	386.2
10/17/2018	17	SA	Last	66.1
10/17/2018	18	AT	Last	86.9
10/17/2018	19	DG	Last	229.1
10/17/2018	20	SC	Last	77.7
10/17/2018	22	DG	Last	.
10/17/2018	23	DG	Last	896.3
10/17/2018	24	Mulch	Last	71.0
11/1/2018	1	SC	Last	10.7
11/1/2018	2	DG	Last	95.6
11/1/2018	3	SC	Last	.
11/1/2018	4	Mulch	Last	46.0
11/1/2018	6	SA	Last	29.0
11/1/2018	7	Mulch	Last	30.0
11/1/2018	8	AT	Last	10.7
11/1/2018	9	SA	Last	42.0
11/1/2018	11	AT	Last	23.3
11/1/2018	15	Mulch	Last	57.1
11/1/2018	16	SA	Last	32.0

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
11/1/2018	17	SA	Last	6.0
11/1/2018	18	AT	Last	2.0
11/1/2018	19	DG	Last	87.0
11/1/2018	20	SC	Last	18.0
11/1/2018	22	DG	Last	.
11/1/2018	23	DG	Last	52.0
11/1/2018	24	Mulch	Last	45.0
12/8/2018	1	SC	Last	12.0
12/8/2018	2	DG	Last	89.0
12/8/2018	3	SC	Last	24.0
12/8/2018	4	Mulch	Last	23.0
12/8/2018	6	SA	Last	44.0
12/8/2018	7	Mulch	Last	34.0
12/8/2018	8	AT	Last	7.0
12/8/2018	9	SA	Last	60.0
12/8/2018	11	AT	Last	41.0
12/8/2018	15	Mulch	Last	44.0
12/8/2018	16	SA	Last	29.0
12/8/2018	17	SA	Last	21.0
12/8/2018	18	AT	Last	13.0
12/8/2018	19	DG	Last	30.0
12/8/2018	20	SC	Last	33.0
12/8/2018	22	DG	Last	35.0
12/8/2018	23	DG	Last	67.0
12/8/2018	24	Mulch	Last	43.0
3/14/2019	1	SC	Last	.
3/14/2019	2	DG	Last	117.5
3/14/2019	3	SC	Last	.
3/14/2019	4	Mulch	Last	.
3/14/2019	6	SA	Last	35.1
3/14/2019	7	Mulch	Last	.
3/14/2019	8	AT	Last	13.7
3/14/2019	9	SA	Last	40.5
3/14/2019	11	AT	Last	38.3
3/14/2019	15	Mulch	Last	.
3/14/2019	16	SA	Last	59.7
3/14/2019	17	SA	Last	53.1
3/14/2019	18	AT	Last	11.2

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
3/14/2019	19	DG	Last	101.4
3/14/2019	20	SC	Last	.
3/14/2019	22	DG	Last	118.9
3/14/2019	23	DG	Last	186.7
3/14/2019	24	Mulch	Last	.
4/8/2019	1	SC	Last	16.9
4/8/2019	2	DG	Last	22.9
4/8/2019	3	SC	Last	.
4/8/2019	4	Mulch	Last	72.2
4/8/2019	6	SA	Last	22.4
4/8/2019	7	Mulch	Last	36.9
4/8/2019	8	AT	Last	1.2
4/8/2019	9	SA	Last	24.7
4/8/2019	11	AT	Last	5.0
4/8/2019	15	Mulch	Last	45.8
4/8/2019	16	SA	Last	21.2
4/8/2019	17	SA	Last	24.3
4/8/2019	18	AT	Last	3.9
4/8/2019	19	DG	Last	5.3
4/8/2019	20	SC	Last	20.0
4/8/2019	22	DG	Last	9.6
4/8/2019	23	DG	Last	5.7
4/8/2019	24	Mulch	Last	37.1
4/25/2019	1	SC	Last	9.5
4/25/2019	2	DG	Last	205.3
4/25/2019	3	SC	Last	86.6
4/25/2019	4	Mulch	Last	18.3
4/25/2019	6	SA	Last	16.9
4/25/2019	7	Mulch	Last	23.0
4/25/2019	8	AT	Last	4.7
4/25/2019	9	SA	Last	79.0
4/25/2019	11	AT	Last	87.8
4/25/2019	15	Mulch	Last	43.2
4/25/2019	16	SA	Last	17.1
4/25/2019	17	SA	Last	13.8
4/25/2019	18	AT	Last	9.5
4/25/2019	19	DG	Last	74.1
4/25/2019	20	SC	Last	13.5

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
4/25/2019	22	DG	Last	96.6
4/25/2019	23	DG	Last	64.0
4/25/2019	24	Mulch	Last	38.0
6/1/2019	1	SC	Last	.
6/1/2019	2	DG	Last	154.8
6/1/2019	3	SC	Last	.
6/1/2019	4	Mulch	Last	.
6/1/2019	6	SA	Last	24.1
6/1/2019	7	Mulch	Last	36.5
6/1/2019	8	AT	Last	6.9
6/1/2019	9	SA	Last	25.5
6/1/2019	11	AT	Last	21.6
6/1/2019	15	Mulch	Last	47.5
6/1/2019	16	SA	Last	26.9
6/1/2019	17	SA	Last	11.0
6/1/2019	18	AT	Last	16.0
6/1/2019	19	DG	Last	35.4
6/1/2019	20	SC	Last	39.5
6/1/2019	22	DG	Last	31.0
6/1/2019	23	DG	Last	26.0
6/1/2019	24	Mulch	Last	.
6/6/2019	1	SC	Last	28.6
6/6/2019	2	DG	Last	45.9
6/6/2019	3	SC	Last	.
6/6/2019	4	Mulch	Last	12.8
6/6/2019	6	SA	Last	21.8
6/6/2019	7	Mulch	Last	22.5
6/6/2019	8	AT	Last	5.4
6/6/2019	9	SA	Last	11.0
6/6/2019	11	AT	Last	5.8
6/6/2019	15	Mulch	Last	29.3
6/6/2019	16	SA	Last	6.5
6/6/2019	17	SA	Last	4.6
6/6/2019	18	AT	Last	1.1
6/6/2019	19	DG	Last	21.4
6/6/2019	20	SC	Last	10.4
6/6/2019	22	DG	Last	12.4
6/6/2019	23	DG	Last	11.1

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
6/6/2019	24	Mulch	Last	19.6
6/17/2019	1	SC	Last	.
6/17/2019	2	DG	Last	145.5
6/17/2019	3	SC	Last	208.2
6/17/2019	4	Mulch	Last	36.4
6/17/2019	6	SA	Last	22.9
6/17/2019	7	Mulch	Last	41.9
6/17/2019	8	AT	Last	30.7
6/17/2019	9	SA	Last	77.4
6/17/2019	11	AT	Last	116.2
6/17/2019	15	Mulch	Last	38.0
6/17/2019	16	SA	Last	97.6
6/17/2019	17	SA	Last	31.8
6/17/2019	18	AT	Last	12.8
6/17/2019	19	DG	Last	48.2
6/17/2019	20	SC	Last	.
6/17/2019	22	DG	Last	25.5
6/17/2019	23	DG	Last	31.0
6/17/2019	24	Mulch	Last	42.1
8/29/2019	1	SC	Last	.
8/29/2019	2	DG	Last	127.9
8/29/2019	3	SC	Last	.
8/29/2019	4	Mulch	Last	.
8/29/2019	6	SA	Last	53.6
8/29/2019	7	Mulch	Last	.
8/29/2019	8	AT	Last	24.2
8/29/2019	9	SA	Last	58.4
8/29/2019	11	AT	Last	16.8
8/29/2019	15	Mulch	Last	.
8/29/2019	16	SA	Last	57.0
8/29/2019	17	SA	Last	45.7
8/29/2019	18	AT	Last	11.9
8/29/2019	19	DG	Last	28.7
8/29/2019	20	SC	Last	32.6
8/29/2019	22	DG	Last	17.5
8/29/2019	23	DG	Last	.
8/29/2019	24	Mulch	Last	.
9/11/2019	1	SC	Last	.

Table A.5 Continued

Date	Plot	Trt	Sample	TSS (mg L^{-1})
9/11/2019	2	DG	Last	73.6
9/11/2019	3	SC	Last	.
9/11/2019	4	Mulch	Last	23.7
9/11/2019	6	SA	Last	22.1
9/11/2019	7	Mulch	Last	.
9/11/2019	8	AT	Last	5.6
9/11/2019	9	SA	Last	41.2
9/11/2019	11	AT	Last	1.1
9/11/2019	15	Mulch	Last	61.3
9/11/2019	16	SA	Last	27.8
9/11/2019	17	SA	Last	28.7
9/11/2019	18	AT	Last	2.5
9/11/2019	19	DG	Last	11.9
9/11/2019	20	SC	Last	.
9/11/2019	22	DG	Last	7.1
9/11/2019	23	DG	Last	.
9/11/2019	24	Mulch	Last	.

Table A.6 Soil volumetric water content.

Date	Plot	Trt	VMC (%)
10/11/2018	1	SC	15
10/11/2018	2	DG	19.65
10/11/2018	3	SC	13
10/11/2018	4	Mulch	25.7
10/11/2018	6	SA	54.2
10/11/2018	7	Mulch	31.35
10/11/2018	8	AT	8.5
10/11/2018	9	SA	53.8
10/11/2018	11	AT	9.6
10/11/2018	15	Mulch	29.8
10/11/2018	16	SA	52.2
10/11/2018	17	SA	44.4
10/11/2018	18	AT	9.4
10/11/2018	19	DG	16.5
10/11/2018	20	SC	15.5
10/11/2018	22	DG	20.25
10/11/2018	23	DG	18.85
10/11/2018	24	Mulch	23.85
11/15/2018	1	SC	11.2
11/15/2018	2	DG	16.35
11/15/2018	3	SC	14
11/15/2018	4	Mulch	25.8
11/15/2018	6	SA	43.4
11/15/2018	7	Mulch	29.45
11/15/2018	8	AT	4.4
11/15/2018	9	SA	42.4
11/15/2018	11	AT	3.7
11/15/2018	15	Mulch	33.65
11/15/2018	16	SA	42.6
11/15/2018	17	SA	38.7
11/15/2018	18	AT	7.2
11/15/2018	19	DG	19.85
11/15/2018	20	SC	15
11/15/2018	22	DG	17.3
11/15/2018	23	DG	20.15
11/15/2018	24	Mulch	32.45
11/28/2018	1	SC	9.2

Table A.6 Continued

Date	Plot	Trt	VMC (%)
11/28/2018	2	DG	16.4
11/28/2018	3	SC	10.1
11/28/2018	4	Mulch	24.3
11/28/2018	6	SA	36
11/28/2018	7	Mulch	26.4
11/28/2018	8	AT	4.1
11/28/2018	9	SA	36.8
11/28/2018	11	AT	5.2
11/28/2018	15	Mulch	27.4
11/28/2018	16	SA	36.9
11/28/2018	17	SA	37.8
11/28/2018	18	AT	4.5
11/28/2018	19	DG	12.35
11/28/2018	20	SC	11.7
11/28/2018	22	DG	13.85
11/28/2018	23	DG	14.7
11/28/2018	24	Mulch	26.7
12/13/2018	1	SC	12.7
12/13/2018	2	DG	17
12/13/2018	3	SC	11.6
12/13/2018	4	Mulch	23.2
12/13/2018	6	SA	38.2
12/13/2018	7	Mulch	25.75
12/13/2018	8	AT	2.1
12/13/2018	9	SA	36
12/13/2018	11	AT	2.5
12/13/2018	15	Mulch	27.15
12/13/2018	16	SA	34.9
12/13/2018	17	SA	35.6
12/13/2018	18	AT	4
12/13/2018	19	DG	13.55
12/13/2018	20	SC	12.3
12/13/2018	22	DG	15.6
12/13/2018	23	DG	16.1
12/13/2018	24	Mulch	28.8
1/9/2019	1	SC	14.6
1/9/2019	2	DG	18.6
1/9/2019	3	SC	11.9

Table A.6 Continued

Date	Plot	Trt	VMC (%)
1/9/2019	4	Mulch	31.95
1/9/2019	6	SA	38.7
1/9/2019	7	Mulch	30.45
1/9/2019	8	AT	2
1/9/2019	9	SA	40.2
1/9/2019	11	AT	4.4
1/9/2019	15	Mulch	29.8
1/9/2019	16	SA	42.7
1/9/2019	17	SA	39.8
1/9/2019	18	AT	5.1
1/9/2019	19	DG	15.3
1/9/2019	20	SC	11.7
1/9/2019	22	DG	17.65
1/9/2019	23	DG	19.4
1/9/2019	24	Mulch	34.2
1/17/2019	1	SC	14.1
1/17/2019	2	DG	18.05
1/17/2019	3	SC	16.7
1/17/2019	4	Mulch	29.95
1/17/2019	6	SA	41.2
1/17/2019	7	Mulch	33.45
1/17/2019	8	AT	4.9
1/17/2019	9	SA	41.9
1/17/2019	11	AT	7.5
1/17/2019	15	Mulch	33.15
1/17/2019	16	SA	41.9
1/17/2019	17	SA	41.4
1/17/2019	18	AT	5.9
1/17/2019	19	DG	18.15
1/17/2019	20	SC	16.5
1/17/2019	22	DG	20.7
1/17/2019	23	DG	21.55
1/17/2019	24	Mulch	34
1/30/2019	1	SC	11.3
1/30/2019	2	DG	19.85
1/30/2019	3	SC	13.7
1/30/2019	4	Mulch	30.45
1/30/2019	6	SA	40.1

Table A.6 Continued

Date	Plot	Trt	VMC (%)
1/30/2019	7	Mulch	31.45
1/30/2019	8	AT	2.5
1/30/2019	9	SA	40.7
1/30/2019	11	AT	5.3
1/30/2019	15	Mulch	27.45
1/30/2019	16	SA	40.3
1/30/2019	17	SA	37.9
1/30/2019	18	AT	5.1
1/30/2019	19	DG	15.3
1/30/2019	20	SC	13.4
1/30/2019	22	DG	17.7
1/30/2019	23	DG	18.8
1/30/2019	24	Mulch	30.75
2/14/2019	1	SC	10.2
2/14/2019	2	DG	15.95
2/14/2019	3	SC	10.4
2/14/2019	4	Mulch	28.9
2/14/2019	6	SA	38.9
2/14/2019	7	Mulch	28.65
2/14/2019	8	AT	2.8
2/14/2019	9	SA	39.5
2/14/2019	11	AT	6
2/14/2019	15	Mulch	29.9
2/14/2019	16	SA	39.5
2/14/2019	17	SA	39.5
2/14/2019	18	AT	4.3
2/14/2019	19	DG	17.35
2/14/2019	20	SC	13.9
2/14/2019	22	DG	16.65
2/14/2019	23	DG	18.4
2/14/2019	24	Mulch	33.35
3/5/2019	1	SC	9.8
3/5/2019	2	DG	15.8
3/5/2019	3	SC	10.8
3/5/2019	4	Mulch	27.65
3/5/2019	6	SA	33.4
3/5/2019	7	Mulch	25.8
3/5/2019	8	AT	2.6

Table A.6 Continued

Date	Plot	Trt	VMC (%)
3/5/2019	9	SA	37.2
3/5/2019	11	AT	2.7
3/5/2019	15	Mulch	23.15
3/5/2019	16	SA	40.2
3/5/2019	17	SA	37.6
3/5/2019	18	AT	2.9
3/5/2019	19	DG	13.6
3/5/2019	20	SC	10.1
3/5/2019	22	DG	12.4
3/5/2019	23	DG	14.4
3/5/2019	24	Mulch	24.4
3/20/2019	1	SC	5.3
3/20/2019	2	DG	14.3
3/20/2019	3	SC	6.6
3/20/2019	4	Mulch	24.75
3/20/2019	6	SA	30.6
3/20/2019	7	Mulch	25.35
3/20/2019	8	AT	1.4
3/20/2019	9	SA	31.7
3/20/2019	11	AT	3.1
3/20/2019	15	Mulch	21.8
3/20/2019	16	SA	26.4
3/20/2019	17	SA	26.3
3/20/2019	18	AT	3.3
3/20/2019	19	DG	10.35
3/20/2019	20	SC	10.5
3/20/2019	22	DG	11.3
3/20/2019	23	DG	13.3
3/20/2019	24	Mulch	23.15
4/1/2019	1	SC	9.7
4/1/2019	2	DG	12.95
4/1/2019	3	SC	8.5
4/1/2019	4	Mulch	19.95
4/1/2019	6	SA	29.2
4/1/2019	7	Mulch	20.65
4/1/2019	8	AT	1.8
4/1/2019	9	SA	30.1
4/1/2019	11	AT	1.6

Table A.6 Continued

Date	Plot	Trt	VMC (%)
4/1/2019	15	Mulch	24.65
4/1/2019	16	SA	30
4/1/2019	17	SA	28
4/1/2019	18	AT	2.6
4/1/2019	19	DG	10.95
4/1/2019	20	SC	10.3
4/1/2019	22	DG	9.15
4/1/2019	23	DG	8.3
4/1/2019	24	Mulch	18.45
4/10/2019	1	SC	11.7
4/10/2019	2	DG	16.45
4/10/2019	3	SC	10.5
4/10/2019	4	Mulch	28.95
4/10/2019	6	SA	32
4/10/2019	7	Mulch	31
4/10/2019	8	AT	7
4/10/2019	9	SA	34.8
4/10/2019	11	AT	3.5
4/10/2019	15	Mulch	27.65
4/10/2019	16	SA	29.3
4/10/2019	17	SA	30.8
4/10/2019	18	AT	4.1
4/10/2019	19	DG	13.85
4/10/2019	20	SC	9.8
4/10/2019	22	DG	13.5
4/10/2019	23	DG	14.8
4/10/2019	24	Mulch	31.1
4/26/2019	1	SC	16.1
4/26/2019	2	DG	19.05
4/26/2019	3	SC	17.7
4/26/2019	4	Mulch	36.95
4/26/2019	6	SA	38.4
4/26/2019	7	Mulch	35.2
4/26/2019	8	AT	8.1
4/26/2019	9	SA	35.1
4/26/2019	11	AT	8.3
4/26/2019	15	Mulch	34.5
4/26/2019	16	SA	34.7

Table A.6 Continued

Date	Plot	Trt	VMC (%)
4/26/2019	17	SA	36.8
4/26/2019	18	AT	6.8
4/26/2019	19	DG	17.45
4/26/2019	20	SC	18
4/26/2019	22	DG	16.85
4/26/2019	23	DG	17.85
4/26/2019	24	Mulch	30.1
5/29/2019	1	SC	13.9
5/29/2019	2	DG	14.55
5/29/2019	3	SC	12.8
5/29/2019	4	Mulch	27
5/29/2019	6	SA	22.4
5/29/2019	7	Mulch	25.7
5/29/2019	8	AT	8.6
5/29/2019	9	SA	23.2
5/29/2019	11	AT	8.4
5/29/2019	15	Mulch	24.2
5/29/2019	16	SA	21.3
5/29/2019	17	SA	18.4
5/29/2019	18	AT	6.7
5/29/2019	19	DG	10.4
5/29/2019	20	SC	17
5/29/2019	22	DG	11.3
5/29/2019	23	DG	11.65
5/29/2019	24	Mulch	22.55
6/4/2019	1	SC	13.9
6/4/2019	2	DG	15.7
6/4/2019	3	SC	13.5
6/4/2019	4	Mulch	30.75
6/4/2019	6	SA	37.2
6/4/2019	7	Mulch	33.25
6/4/2019	8	AT	9.3
6/4/2019	9	SA	36.1
6/4/2019	11	AT	8.7
6/4/2019	15	Mulch	33.65
6/4/2019	16	SA	37.1
6/4/2019	17	SA	37
6/4/2019	18	AT	8

Table A.6 Continued

Date	Plot	Trt	VMC (%)
6/4/2019	19	DG	14.05
6/4/2019	20	SC	17.8
6/4/2019	22	DG	10.55
6/4/2019	23	DG	10.9
6/4/2019	24	Mulch	33.65
6/11/2019	1	SC	12.7
6/11/2019	2	DG	14.8
6/11/2019	3	SC	12.7
6/11/2019	4	Mulch	30.9
6/11/2019	6	SA	33.5
6/11/2019	7	Mulch	31.9
6/11/2019	8	AT	9.8
6/11/2019	9	SA	24.3
6/11/2019	11	AT	7.6
6/11/2019	15	Mulch	32.6
6/11/2019	16	SA	18.7
6/11/2019	17	SA	21.7
6/11/2019	18	AT	7.7
6/11/2019	19	DG	6.05
6/11/2019	20	SC	13.8
6/11/2019	22	DG	11.55
6/11/2019	23	DG	12.15
6/11/2019	24	Mulch	29.15
6/25/2019	1	SC	22.6
6/25/2019	2	DG	19.3
6/25/2019	3	SC	17.4
6/25/2019	4	Mulch	36.8
6/25/2019	6	SA	41.2
6/25/2019	7	Mulch	40.7
6/25/2019	8	AT	10.1
6/25/2019	9	SA	37.7
6/25/2019	11	AT	8.8
6/25/2019	15	Mulch	40.25
6/25/2019	16	SA	41.6
6/25/2019	17	SA	37.8
6/25/2019	18	AT	8.4
6/25/2019	19	DG	16.8
6/25/2019	20	SC	21.6

Table A.6 Continued

Date	Plot	Trt	VMC (%)
6/25/2019	22	DG	16.1
6/25/2019	23	DG	17.45
6/25/2019	24	Mulch	40.55
7/2/2019	1	SC	20.6
7/2/2019	2	DG	17
7/2/2019	3	SC	18.6
7/2/2019	4	Mulch	33.8
7/2/2019	6	SA	41.5
7/2/2019	7	Mulch	35.55
7/2/2019	8	AT	11.1
7/2/2019	9	SA	35.8
7/2/2019	11	AT	8.2
7/2/2019	15	Mulch	33.65
7/2/2019	16	SA	27.5
7/2/2019	17	SA	25
7/2/2019	18	AT	9.1
7/2/2019	19	DG	14.6
7/2/2019	20	SC	18.7
7/2/2019	22	DG	15.3
7/2/2019	23	DG	14.8
7/2/2019	24	Mulch	35.65
7/9/2019	1	SC	18.1
7/9/2019	2	DG	13.5
7/9/2019	3	SC	19.9
7/9/2019	4	Mulch	28.05
7/9/2019	6	SA	36.2
7/9/2019	7	Mulch	29.75
7/9/2019	8	AT	9.8
7/9/2019	9	SA	28
7/9/2019	11	AT	8.1
7/9/2019	15	Mulch	26.2
7/9/2019	16	SA	24.9
7/9/2019	17	SA	24.5
7/9/2019	18	AT	7.4
7/9/2019	19	DG	10.95
7/9/2019	20	SC	18.6
7/9/2019	22	DG	10.65
7/9/2019	23	DG	12.15

Table A.6 Continued

Date	Plot	Trt	VMC (%)
7/9/2019	24	Mulch	30
7/17/2019	1	SC	19.1
7/17/2019	2	DG	10.15
7/17/2019	3	SC	15.3
7/17/2019	4	Mulch	20.4
7/17/2019	6	SA	35.8
7/17/2019	7	Mulch	21.8
7/17/2019	8	AT	8.2
7/17/2019	9	SA	21.1
7/17/2019	11	AT	7.4
7/17/2019	15	Mulch	18.6
7/17/2019	16	SA	24.1
7/17/2019	17	SA	19.9
7/17/2019	18	AT	7.7
7/17/2019	19	DG	9.35
7/17/2019	20	SC	17.1
7/17/2019	22	DG	9.4
7/17/2019	23	DG	10.35
7/17/2019	24	Mulch	19.6
7/24/2019	1	SC	11.8
7/24/2019	2	DG	11.55
7/24/2019	3	SC	9.5
7/24/2019	4	Mulch	19.05
7/24/2019	6	SA	26.9
7/24/2019	7	Mulch	22.7
7/24/2019	8	AT	9.7
7/24/2019	9	SA	23
7/24/2019	11	AT	7.9
7/24/2019	15	Mulch	19.35
7/24/2019	16	SA	18.1
7/24/2019	17	SA	17.7
7/24/2019	18	AT	5.9
7/24/2019	19	DG	7.9
7/24/2019	20	SC	15.7
7/24/2019	22	DG	8.4
7/24/2019	23	DG	10.15
7/24/2019	24	Mulch	17.5
7/30/2019	1	SC	15.9

Table A.6 Continued

Date	Plot	Trt	VMC (%)
7/30/2019	2	DG	11.65
7/30/2019	3	SC	13.6
7/30/2019	4	Mulch	19.55
7/30/2019	6	SA	32.2
7/30/2019	7	Mulch	19.05
7/30/2019	8	AT	8.8
7/30/2019	9	SA	33.3
7/30/2019	11	AT	6.1
7/30/2019	15	Mulch	14.9
7/30/2019	16	SA	31.4
7/30/2019	17	SA	29.7
7/30/2019	18	AT	6.3
7/30/2019	19	DG	8.85
7/30/2019	20	SC	16.9
7/30/2019	22	DG	7.4
7/30/2019	23	DG	8.6
7/30/2019	24	Mulch	14.7
8/6/2019	1	SC	25.4
8/6/2019	2	DG	14.4
8/6/2019	3	SC	22.5
8/6/2019	4	Mulch	18.95
8/6/2019	6	SA	42.2
8/6/2019	7	Mulch	22.45
8/6/2019	8	AT	15
8/6/2019	9	SA	47.2
8/6/2019	11	AT	7.2
8/6/2019	15	Mulch	19.75
8/6/2019	16	SA	44.4
8/6/2019	17	SA	46.8
8/6/2019	18	AT	6.9
8/6/2019	19	DG	11.15
8/6/2019	20	SC	27
8/6/2019	22	DG	10.85
8/6/2019	23	DG	14.05
8/6/2019	24	Mulch	18.7
8/14/2019	1	SC	16.9
8/14/2019	2	DG	11.2
8/14/2019	3	SC	16.8

Table A.6 Continued

Date	Plot	Trt	VMC (%)
8/14/2019	4	Mulch	15.7
8/14/2019	6	SA	36.9
8/14/2019	7	Mulch	15.25
8/14/2019	8	AT	8.7
8/14/2019	9	SA	37.2
8/14/2019	11	AT	7.5
8/14/2019	15	Mulch	15.1
8/14/2019	16	SA	34.6
8/14/2019	17	SA	33.7
8/14/2019	18	AT	6.9
8/14/2019	19	DG	8.3
8/14/2019	20	SC	18.1
8/14/2019	22	DG	9.25
8/14/2019	23	DG	5.3
8/14/2019	24	Mulch	13.75
8/21/2019	1	SC	17.8
8/21/2019	2	DG	8.2
8/21/2019	3	SC	11.3
8/21/2019	4	Mulch	13.55
8/21/2019	6	SA	37.4
8/21/2019	7	Mulch	16.45
8/21/2019	8	AT	9.6
8/21/2019	9	SA	34.9
8/21/2019	11	AT	9.1
8/21/2019	15	Mulch	15
8/21/2019	16	SA	33.5
8/21/2019	17	SA	31
8/21/2019	18	AT	7.5
8/21/2019	19	DG	8.1
8/21/2019	20	SC	21.9
8/21/2019	22	DG	8.55
8/21/2019	23	DG	8.95
8/21/2019	24	Mulch	12.8
8/27/2019	1	SC	20.9
8/27/2019	2	DG	14.55
8/27/2019	3	SC	20.8
8/27/2019	4	Mulch	22.05
8/27/2019	6	SA	37.1

Table A.6 Continued

Date	Plot	Trt	VMC (%)
8/27/2019	7	Mulch	16.85
8/27/2019	8	AT	8.8
8/27/2019	9	SA	38.4
8/27/2019	11	AT	7.4
8/27/2019	15	Mulch	17.9
8/27/2019	16	SA	39.5
8/27/2019	17	SA	37.3
8/27/2019	18	AT	6.6
8/27/2019	19	DG	10.5
8/27/2019	20	SC	28.9
8/27/2019	22	DG	8.75
8/27/2019	23	DG	9.2
8/27/2019	24	Mulch	11.7
9/5/2019	1	SC	19.2
9/5/2019	2	DG	12.5
9/5/2019	3	SC	21.1
9/5/2019	4	Mulch	13.65
9/5/2019	6	SA	36.3
9/5/2019	7	Mulch	20.15
9/5/2019	8	AT	9.3
9/5/2019	9	SA	31.3
9/5/2019	11	AT	7.1
9/5/2019	15	Mulch	19.95
9/5/2019	16	SA	27.7
9/5/2019	17	SA	30
9/5/2019	18	AT	8.1
9/5/2019	19	DG	9
9/5/2019	20	SC	20.5
9/5/2019	22	DG	12.7
9/5/2019	23	DG	12.2
9/5/2019	24	Mulch	17.05
9/13/2019	1	SC	25.5
9/13/2019	2	DG	15.8
9/13/2019	3	SC	28.6
9/13/2019	4	Mulch	33.85
9/13/2019	6	SA	46.4
9/13/2019	7	Mulch	34.15
9/13/2019	8	AT	9.3

Table A.6 Continued

Date	Plot	Trt	VMC (%)
9/13/2019	9	SA	43.2
9/13/2019	11	AT	7.9
9/13/2019	15	Mulch	32.5
9/13/2019	16	SA	43.9
9/13/2019	17	SA	45.6
9/13/2019	18	AT	8.9
9/13/2019	19	DG	15.85
9/13/2019	20	SC	30.8
9/13/2019	22	DG	16.15
9/13/2019	23	DG	14.55
9/13/2019	24	Mulch	24.35
9/20/2019	1	SC	19.3
9/20/2019	2	DG	14.35
9/20/2019	3	SC	18.4
9/20/2019	4	Mulch	30.1
9/20/2019	6	SA	39.8
9/20/2019	7	Mulch	25.9
9/20/2019	8	AT	9.5
9/20/2019	9	SA	34.7
9/20/2019	11	AT	9
9/20/2019	15	Mulch	25.95
9/20/2019	16	SA	31.1
9/20/2019	17	SA	34.4
9/20/2019	18	AT	8.6
9/20/2019	19	DG	13.85
9/20/2019	20	SC	27.1
9/20/2019	22	DG	12.75
9/20/2019	23	DG	13.9
9/20/2019	24	Mulch	25.3