MULTI-YEAR EFFECTS OF GRANULAR AND FOLIAR NITROGEN FERTILIZERS ON PENN 'A-4' CREEPING BENTGRASS (*AGROSTIS PALUSTRIS* HUDS.) GROWN ON THREE ROOTZONES

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE

Crop and Soil Sciences

2012

ABSTRACT

MULTI-YEAR EFFECTS OF GRANULAR AND FOLIAR NITROGEN FERTILIZERS ON PENN 'A-4' CREEPING BENTGRASS (*AGROSTIS PALUSTRIS* HUDS.) GROWN ON THREE ROOTZONES

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Research on the multi-year effects of foliar and granular nitrogen fertilizers alone or in combination on turfgrass tissue and soil nutrient concentrations is limited. The research objective was to determine the effect of different foliar and granular nitrogen fertilizers on Penn 'A-4' creeping bentgrass (*Agrostis palustris* Huds.) grown on three putting green rootzones. The fertilizer treatments were urea, methylene urea, natural organic, foliar alone, foliar + granular, and an untreated control. The three rootzones were a United States Golf Association specification rootzone (80:20, v:v), sand/peat/soil rootzone (80-10-10, v:v:v) and a sandy clay loam. The urea, methylene urea, and natural organic fertilizer treatments were applied at 24.4 kg N $ha^{-1}month^{-1}$. The foliar treatment was applied at two rates, 12.2 kg N $ha^{-1}month^{-1}$ and 24.4 kg N $ha^{-1}month^{-1}$. Soil and tissue samples were collected in October 2009, June 2010, October 2010, June 2011, and October 2011. Turfgrass color, quality and chlorophyll ratings were measured weekly for 2009 - 2011. Ball roll distance was measured in July and August in 2010 and 2011 using a Pelzmeter. Dollar spot (*Sclerotinia homeocarpa*) and worm casting mounds were counted throughout the season when present. Results indicate that higher soil N, P, and K values did not result in higher tissue N, P, and K values among rootzones. Granular fertilizers had better color and quality in the late fall and faster green up in the spring. Foliar applications result in better turfgrass color and quality under summer stress. The natural organic treatment had the shortest ball roll distance, and the largest percentage of annual bluegrass invasion.

To Kuo-Hsien and Emma, for your love and support.

ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor, Dr. Kevin Frank, for his support, patience, and friendship throughout my graduate life. I appreciate his guidance through many of my anxieties for my research and future steps. I feel very fortunate to have him as my advisor. I would like to thank Dr. Thom Nikolai, for his encouragement and humor, and for introducing me to the world of research when I was an intern student. I would also like to thank Dr. Joe Vargas for his encouragement and insight on my research, and for giving me the opportunity of being his teaching assistant. I would like to acknowledge Jeff Bryan and Aaron Hathaway, for their help and support in my research and their valuable friendship in my life. I would also like to thank Diana Frank and Kim Bryan, who treat me as one of their family members. As an international student, I could not have enjoyed my stay here without their love and support.

I specially thank my mother, Lixia Xiao for coming all the way from China to take care of my baby. This thesis could not have been completed without her support and love. Last but not least, I thank my husband, Kuo-Hsien and my daughter, Emma for making my life complete. They are the best gifts in my life.

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INTRODUCTION

Different types and forms of fertilizers have been widely used in the golf industry. Granular fertilizers such as urea are most commonly used (Carrow et al., 2001). There is an increasing use of foliar fertilizers because it results in faster plant response, uniform coverage (Marschner, 1995), reduction of nutrient losses through runoff and leaching, and better turf growth when under summer stress (Liu et al., 2008). However, the time of year affects foliar nitrogen absorption efficiency, with the cooler temperatures showing lower N uptake (Stiegler et al., 2011). Slow release fertilizers have been researched to overcome the drawbacks of urea. However, it is a challenging task to match the N release rate with plant N demand, because the N release from slow-release fertilizers are strongly dependent on environmental conditions, such as soil temperature, moisture level and microbial activities (Wu et al., 2010).

Totten et al. (2008) compared foliar and/or granular N fertilization on 'L-93' creeping bentgrass. Their treatments included 100% granular urea fertilizer, 50% granular urea + 50% liquid urea fertilizer, and 100% liquid urea fertilizer at two annual N rates: 127 and 190 kg ha^{-1}. They concluded that combining both liquid and granular methods resulted in better turfgrass quality, more clipping yield, and root biomass compared to relying on one method exclusively.

Soil nutrient analysis is the primary means of assessing available nutrients for turfgrass and is primarily used in developing guidelines for fertilization programs (Carrow et al., 2001). However, tissue test provides the nutrient concentration in the plant at the sampling day. Petrovic et al. (2005) researched the relationship between extractable soil and tissue P and K concentrations with turfgrass quality and shoot growth. They concluded that N, P, and K tissue levels were not well correlated with turfgrass quality, and N application amount may affect P and K recommendations.

There is limiting research on the multi-year effects of foliar and granular nitrogen fertilizers on turfgrass tissue and soil nutrient concentrations. Objectives of this research were to evaluate soil and tissue nutrient status in turfgrass, and to determine the effects of different forms of fertilizers on Penn 'A-4' creeping bentgrass (*Agrostis palustris* Huds.) grown on three putting green rootzones.

LITERATURE REVIEW

Turfgrass Fertilizers

Fertilization is one of the important turfgrass management practices to improve soil nitrogen (Walker et al., 2007), and therefore to maintain turfgrass playable, aesthetic, and functioning. Turfgrass requires a more frequent fertilization program than crops and other plants because of regular mowing. Selection of turfgrass fertilizers is based on the quickness of response desired, application rates, and other economic and environmental factors (Landschoot and Waddington, 1987). Most turfgrass fertilizers are solid, granular products (Carrow et al., 2001). Recently, liquid and foliar products have been applied and studied frequently.

Granular, liquid, and foliar fertilizers

Fertilizers can be absorbed by turfgrass through roots and turf tissue. Granular fertilizers such as urea, methylene urea, and natural organic are targeted at root absorption. Liquid fertilizers can be clear liquids or in suspension or slurry form (Carrow et al., 2001). About 30 - 60% of liquid nitrogen fertilizer applied is absorbed by turfgrass tissue (Rieke, 1982; Bowman and Paul, 1989, 1990, 1992; Liu, 2005; Totten, 2006b). The rest may be left in the turf-soil system, which still has a better chance of being taken up by roots than granular fertilizers (Liu et al., 2008). Foliar fertilizers are a dilute solution of plant nutrients that are sprayed onto plant foliage with the objective of being absorbed through the plant tissue (Beard, 2005). Many research use the term liquid fertilization for foliar fertilization, especially when describing liquid urea, because a certain amount of liquid urea goes into the foliage as well as the roots (Bowman and Paul, 1990, 1992; Marschner, 1995; Hull and Liu, 2005).

Major advantages of foliar fertilization compared to granular fertilizers include faster plant response and rapidly correcting nutrient deficiencies (Marschner, 1995). Foliar fertilization provides more uniform coverage than granular fertilization, and does not have the issues of possibly collecting granules when mowing (Mancino et al., 2001). The proper rate of foliar application will reduce nutrient losses through runoff and leaching (Liu et al., 2008). In summer time for cool season turfgrasses, foliar fertilization is a good option to overcome root stress and unfavorable soil conditions. However, foliar fertilization with low nitrogen rates requires frequent applications, which increase labor costs, and could potentially increase unwanted weeds (Stiegler et al., 2003). Also, high volatilization rates (Wesly, 1985) and foliar burn (Johnson and Christians, 1984) are concerns for turfgrass managers.

Stiegler et al. (2011) evaluated the efficiency of foliar fertilization of liquid urea with the rate of 0.5 and 1.25 g N m^{-2} $month^{-1}$. Their results showed that the time of year affects foliar nitrogen (N) absorption efficiency, with the cooler season showing lower N uptake. The authors also found that the higher N rate resulted in the significantly lower N uptake efficiency. Pease et al. (2011) compared the effects of liquid forms of ammonium sulfate, urea, ammonium nitrate, and calcium nitrate at the N rate of 49, 146, 244 kg ha^{-1} yr^{-1} on velvet bentgrass (*Agrostis canina* L.) grown on two putting green rootzones (sand/peat 80:20, v:v and Troxel silt loam). Their results showed that higher N rates treatments increased clipping yield, shoot density, and chlorophyll index, and decreased ball roll distances. For the silt loam rootzone, 146 kg N ha^{-1} yr^{-1} is usually regarded as the rate for maintaining an acceptable turf quality. Higher N rate better alleviated velvet bentgrass mid-summer stress than lower N rate. Totten et al. (2008) compared liquid and/or granular N fertilization on 'L-93' creeping bentgrass. Their treatments included 100% granular urea fertilizer, 50% granular urea + 50% liquid urea fertilizer, and 100% liquid urea fertilizer at two annual N rates: 127 and 190 kg ha^{-1}. They concluded that combining both liquid and granular methods resulted in better turfgrass quality, more clipping yield, and root biomass compared to relying on one method exclusively.

Slow-release N vs. quick-release N fertilizers

There are two forms of N fertilizers according to the water soluble and N release rate: quick-release N and slow-release N. Application of quick-release N (nitrate and ammonia based fertilizers) often leads to rapid greening, improved turfgrass quality, and higher N uptake by turfgrass (Landschoot and Waddington, 1987). Urea is the most widely used quick-release N fertilizer that can be applied either as liquid or as granular. However, liquid urea application might injure foliage (Beard, 1973) and might cause nitrate leaching and ground water pollution (Saha et al., 2007).

Alternative N sources for turfgrass fertilizers have been studied to overcome the drawbacks of urea. Research has focused on slow-release N fertilizers such as polymer-coated sulfur-coated urea (PCSCU), ureaformaldehyde (UF), isobutylidene diurea (IBDU), and natural organics (Landschoot and Waddington, 1987; Quiroga-Garza et al., 2001). Guillard and Kopp (2004) recommended that a larger fraction of slow-release N than quick-release N should be formulated in turfgrass fertilizers, as a way to reduce NO_3-N leaching in the southern New England environment. Petrovic (2004) indicated that using slow-release N sources such as PCSCU and natural organics is one of the solutions to reduce nitrate leaching from turfgrass rootzones. Wu et al. (2010) compared different N sources and rates on Tall Fescue [*Schedonorus phoenix* (Scop.) Holub], and also concluded that slow-release N had less nitrate leaching than fast-release N among all the N sources they applied. However, it is a challenging task to match the N release rate with plant N demand, because the N release from slow-release fertilizers are strongly dependent on environmental conditions, such as soil temperature, moisture level and microbial activities (Wu et al., 2010).

Turfgrass species have different responses to N source. Steinke et al. (2003) concluded that liquid urea absorbed by turfgrass tissue significantly improved color and quality of creeping bentgrass (*Agrostis stolonifera* L.), while Kentucky bluegrass (*Poa pratensis* L.) responded better to granular urea taken up by roots. Moreover, Carrow (1997) observed a great diversity in N-release patterns for slow-release fertilizers across N carrier classes and within a class. Variation within an N carrier class indicated each fertilizer carrier requires a further study for an effective N uptake.

Turfgrass Phosphorous fertilization

Phosphorous (P) plays an important role in forming high-energy bond in adenosine diphosphate (ADP) and adenosine triphosphate (ATP) for storing and transferring energy in the plant. P is also an important structural constituent in nucleic acids, lipids, phosphoproteins, and a number of other biochemicals (Hopkins, 1995). A starter fertilizer high in P content for initial turfgrass establishment is often used to support root and tiller growth (Frank et al., 2002). Phosphorous is often limited in the sand-based rootzone turfgrass system, because many fertilizers for mature turfgrasses have a low P analysis (Carrow et al., 2001)

P leaching and runoff cause an economic loss to homeowners and a nutritional loss to turfgrass. Excessive P concentration is the most common cause of eutrophication in freshwater (Correll, 1998; Noe et al., 2001). PO_4^{3-}–P concentration in excess of 0.024 mg L^{-1} are favorable for eutrophication in the temperate northeast America (Owens, 1998). Easton and Petrovic (2004) compared natural organic and synthetic organic nutrient sources applied at rates of 50 and 100 kg N ha^{-1} per application (200 kg ha^{-1} yr^{-1}). The authors observed that fertilizers with higher P content had higher P losses. However, very little of the applied P was recovered in clippings, runoff, or leachate, suggesting much of the applied P remains in the soil, roots, and/or plant tissue. They also observed an equal or higher amount of N and P losses in runoff and leachate from the untreated control, supporting that establishment fertilization can reduce water contamination from N and P. For urban landscape system, the cumulative mean of P leached from St. Augustinegrass [*Stenotaphrum secundatum* (Wait.) Kuntze] urban lawn was 22.9 kg ha^{-1} during 45 months, which is high enough to raise concern on ecological impacts on urban landscape systems (Erickson et al., 2005). Leaching losses were high during establishment and following intense precipitation, and were also affected by species type and fertilizer protocols (Erickson et al., 2005). Runoff loss of P from turfgrass shortly after P application ranges from < 1% to 18% of P fertilizer applied (Soldat and Petrovic, 2008). Turfgrasses grown on low Cation Exchange Capacity (CEC), acid sands are susceptible to P leaching. Therefore, the use of a spoon-feeding method of 12.2–24.4 kg P_2O_5 ha^{-1} with two to six applications per year is recommended for this condition (Hull, 1997).

For a mature turfgrass stand, P fertilizer should be applied less than 48.8 kg P_2O_5 ha^{-1} to minimize the possibility of leaching and runoff (Hull, 1997). Bierman et al. (2010) studied on P fertilization and clipping management on P runoff on Kentucky bluegrass (*Poa pratensis* L.). The authors concluded that reduced turfgrass quality will result in greater runoff depth for the no fertilizer treatment than P fertilizer treatments, and P runoff can be reduced by not applying P to high testing soils (27 mg kg^{-1} Bray P) and by avoiding fall applications. The addition of ferrous sulfate as soil amendment may greatly reduce reactive phosphorus (< 0.45) runoff losses from manure applications through a sod surface and has great potential to be used on turfgrass (Torbert et al., 2005). There is limited research on the long-term effect of fertilization on P leaching from turfgrass (Easton and Petrovic, 2004; Soldat and Petrovic, 2008).

Turfgrass Potassium fertilization

Potassium (K) is usually considered the second most important nutrient behind N in turfgrass (Carrow et al., 2001). It increases turfgrass tolerance to drought, wear, disease, salinity, cold (Turner, 1992), and heat (Beard, 1973) stresses. K does not directly affect turfgrass clipping yield, and quality. However, higher K rates (162 and 243 kg ha^{-1} yr^{-1}) increase N recovery and use efficiency (Fitzpatrick and Guillard, 2004). Increasing N:K ratio beyond 1:0.5 did not result in better turfgrass growth, appearance, or root weight, and did not increase K in turfgrass tissue (Snyder and Cisar, 2000). N:K ratio higher than 1:1 will result in excess soluble salts in the sandy soils. This salinity buildup will cause physiological drought and wear stress, especially when rainfall or irrigation is limited (Carrow et al., 2001)

High K application may reduce soil and turfgrass calcium (Ca) and magnesium (Mg) levels on hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. x C. *transvaalensis* Burtt Davy], as the Ca and Mg cation exchange sites in soil are replaced by K (Miller, 1999). For calcareous soils with a low CEC, high rates of K application can also reduce plant available Ca and Mg in leaf tissue, and in extractable soil Ca and Mg when using 1:5 H_2O and 0.01 *M* $SrCl_2$ extractions (Woods et al., 2005).

Snyder and Cisar (2005) studied on K fertilization responses as affected by sodium (Na) in Florida, indicates that the Na fertilizer application at the rate of 5.0 g m^{-2} on a molar adjusted basis generally has no effect on bermudagrass quality and growth. Tissue Na concentration increased with decreasing K fertilizer application (0, 1.25, 2.5 and 5.0 g m^{-2}), and was markedly greater in the no K fertilizer treatment.

Soil and Tissue Nutrient Analysis

Soil and tissue nutrient status are two key factors in diagnosing turfgrass problems. Soil nutrient analysis is the primary means of assessing available nutrients for turfgrass and is primarily used in developing guidelines for fertilization programs (Carrow et al., 2001). Tissue analysis is used as a diagnostic tool. Soil test calibrations used for crops are fairly reliable, which is based largely on yield response and crop quality. However, very little research on turfgrass has been conducted for precise calibration and interpretation (Shuman, 2002; Petrovic et al., 2005). Petrovic et al. (2005) researched the relationship between extractable soil and tissue P and K concentrations with turfgrass quality and shoot growth at three sites in the New York. The authors concluded that N, P, and K tissue levels were not well correlated with turfgrass quality, and the application of K alone did not increase tissue K content. Additionally, they pointed out that current soil K interpretations are too high, which needs to be reevaluated, and N application amount may affect P and K recommendations.

Calcium (Ca), Magnesium (Mg) and Sulfur (S) are secondary nutrients behind N, P, K. Ca is an important element in plant cell wall structure, and in membrane system inside cells. Ca deficiency is rare on turfgrass, and there is no need to apply extra Ca to creeping bentgrass grown on calcareous sands (St John et al., 2003). Mg and S deficiencies are sometimes observed on turfgrass grown on high sand based rootzones. Tissue and soil extractable Ca and Mg can be reduced by high rates of K fertilizer in sand-peat (390 kg K ha^{-1} $month^{-1}$) and loamy sand (195 kg K $ha^{-1}month^{-1}$) rootzones (Miller, 1999), as well as in calcareous sand rootzone (6 g K m^{-2} 14 d^{-1}) (Woods et al., 2005). Mg is the central atom in the chlorophyll molecule, and plays a crucial role in plant photosynthesis. Soluble salt forms of Mg can be applied if detecting Mg deficiency. However, excess Mg levels can induce K or Ca deficiencies, especially on low CEC rootzones (Carrow et al., 2001). S is an essential element for many proteins and plant synthesis precursor. Turfgrass sites often receive S additions in uptake of SO_4^{2-} from other fertilizers. S^0 is also recommended for turfgrass (Beard, 1973; Vargas, 2005). However, Berndt and Vargas Jr. (2008) identified that adding S^0 to greens with low redox may result in a rapid formation of S^{2-} ,and thereby an accelerated rate of black layer development. The authors suggested that either limiting the input of S^0 or encouraging high soil redox through fertilizing with nitrate (NO^{3-}) and aerifying.

Micronutrients required for turfgrass are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni). Sodium (Na) and silicon (Si), which are nonessential elements, also influence turfgrass growth under some conditions. Levels of these nutrients are interacting to each other. For example, high soil levels of Fe, Cu, Zn or Na can inhibit Mn uptake, while high Mn can reduce uptake of Fe, Mg, and Ca (Carrow et al., 2001). McCrimmon et al. (1992) found that NO_3^- form application had higher concentrations of most macro- and micronutrients and greater nutrient uptake in turfgrass shoot and root tissue compared to the NH_4^+ treated plants. Nitrogen and potassium applications affect most macronutrient and micronutrient content in zoysiagrasses (McCrimmon, 2000). Especially K, Ca, and Mg concentrations were below sufficiency level, which indicates that these nutrients may require supplemental fertilizers applications. Previous research have been conducted on turfgrass micronutrient fertilization. Foliar Fe applications can improve annual bluegrass persistence in shade (Stiegler et al., 2003). Xu and Mancino (2001a) identified that Fe fertilization levels produced the higher color ratings did not result in higher shoot and root production in creeping bentgrass (*Agrostis palustris* Huds.) and annual bluegrass (*Poa annua* L.). Mn fertilization ($MnSO_4$) effectively reduced take-all patch [*Gaeumannomyces graminis* (Sacc.) Arx. & D. Olivier var. *avenae* (E.M. Turner) Dennis] severity when applied in April or in October (Heckman et al., 2003). Mancino et al. (1999) identified that application of Mn and Zn can reduce dollar spot (*Sclerotinia homoeocarpa*), and red leaf spot (*Drechslera erythrospila*) infection. Increased Zn fertilization levels (0, 2.5, 5.0, or 40 mg L^{-1} Zn from $ZnSO_4$) resulted in increased shoot dry weight of creeping bentgrass and annual bluegrass, and shoot Zn concentrations were higher in annual bluegrass than in creeping bentgrass at each Zn level (Xu and Mancino, 2001b). Guertal et al. (2004) researched on B fertilization of turfgrass, and concluded that dry weight of clippings, thatch depth, shoot density, and turf color were unaffected by B fertilization in the loamy sand soil. However, B fertilization of bentgrass in sand-based greens might be warranted. Silicon fertilizers may increase the P adsorption capacity of sandy soil, and also transform plant-unavailable P into available forms (Matichenkov et al., 2001). The authors observed the promoted bahiagrass (*Paspalum notatum* Fluegge) growth by 20-100% and reduced P leaching by 40-70% in cultivated spodosols, alfisols, and entisols in Florida.

Soil analysis

Different laboratories may have different soil test results because of different methods used to measure pH and lime requirements, and different extracting solutions to extract available nutrients (Brown, 1987). As a result of the ever-changing forms of N in soil, routine soil testing does not include soil N (Carrow et al., 2001). However, it is still important to understand the effects of N fertilization when soil and tissue test calibrations are being made (Petrovic et al., 2005), because N fertilization on turfgrass is known to significantly affect turfgrass growth, shoot density, color, and stress tolerance (Beard, 1973; Turner and Hummel, 1992). A normal soil test will include pH and extractable P, K, Mg, and Ca.

"Sufficiency level of available nutrients" (SLAN) and "Basic cation saturation ratio" (BCSR) are two concepts for soil testing (Carrow et al., 2001). SLAN, which measures the amount of available nutrient in ppm to determine fertilization needs, is the traditional way of predicting the total amount of available nutrients. BCSR uses the percentage saturation of basic cations (K, Mg, and Ca) as a guide to determine the rates of fertilization. Arguments on which method is more effective and accurate exist among scientists (Liebhardt, 1981). The BCSR theory tends to be more misleading on low CEC soils, such as calcareous or silica sand-based rootzone (St.John, 2007). Nutrient deficiency may still exist even if the BCSR theory identifies a rootzone containing exchangeable cations in the correct proportions. St. John and Christians (2007) observed K saturation percentage of silica sand samples were > 28%, yet the leaf and soil extractable K were <21 g kg^{-1} and <1.6 mg kg^{-1}, which are deficient.

An extracting solution removes exchangeable cations on CEC sites. The Bray P1 extractant (0.03 M NH_4F + 0.025 M HCl) and Mehlich III extractant (0.015 M NH_4F + 0.2 M NH_4NO_3 + 0.013 M HNO_3 + EDTA) are widely used for assessing plant available P (Plank, 2001). In addition, Olsen extractant (0.5 M $NaHCO_3$ at pH 8.5) is mostly used for P in calcareous and alkaline soils. For soil K, 1M ammonium acetate (NH_4OAc) is the mostly used (Haby, 1990; Plank, 2001), with various other extractants available, such as Mehlich I (0.05 M H_2SO_4 + 0.05 HCl), Mehlich III, and Morgan (0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA) extractants. Extracting solutions for Ca and Mg are commonly Mehlich III, Morgan, and NH_4OAc (Carrow, 2004).

Tissue analysis

Turfgrass tissue testing can be used as a tool to evaluate nutrient levels in plant and relate them to fertilization recommendations (Duble, 1977). Tissue test is useful for perennials, because it might be too late to take actions for annual crops when symptoms occur after tissue analysis (Carrow, 2000). Contrast to soil test, tissue test values should be the same regardless of the method used, because it measures the total plant nutrient content by percentage. However, limited research has been focused on the relationship between tissue analysis values and density, color and growth on turfgrass (Carrow et al., 2001). Data for tissue interpretation can be referred to forage and crops, which recommendation would be more affected by animal health and yield productivity. Common sufficiency range for turfgrass tissue N is 2.8-3.5% dry weight; for tissue P: 0.2-0.5%; tissue K: 1.5-3.0% (Carrow et al., 2001). These values vary with different turfgrass species and cultivars and require further research for specific ranges.

Turfgrass Rootzone and Soil Property

Maintaining sufficient nutrient in the rootzone is one of the principals for a healthy turf (Happ, 1995). Recreational turfgrass sites, such as golf course putting green or athletic fields, usually adopt the United States Golf Association (USGA) specification rootzone, which is sand-based, well-drained, and has less potential for compaction (Green section stuff, 2004). However, its high macroporosity leads to easy nutrient loss through leaching (Bigelow et al., 2001; Petri and Petrovic, 2001), and therefore pose a significant problem of nutrient retention, especially for the establishment year (Carrow et al., 2001). Organic matter then accumulates overtime leading to the loss of macropores in the rootzone (Davis, 1990; Duble, 1996; Heback, 2000; Curtis, 2001), which reduces water infiltration, leaching, and improves CEC and nutrient retention. There is a limited research on nutrient dynamics in sand-based rootzones with time (McClellan et al., 2007).

Soil amendments

The sand is usually amended with organic matter to improve moisture and nutrient retention, as well as maintaining rootzone drainage and compaction resistance (Waltz and McCarty, 2005). However, particulate organic matter is associated with soil water repellency (SWR) in the turfgrass system (Moody et al., 2009). The organic coatings on mineral constituents are considered as the cause of hydrophobicity (Doerr, 2000). In maturing turfgrass system, microbial decomposition of plant residues may facilitate the hydrophobic process and enhance organic matter adsorption onto mineral surfaces (Hallett et al., 2001). Soil organisms such as basidiomycete fungi may cause severe SWR by producing hydrophobic fungi (Fidanza et al., 2007); and then SWR would reduce irrigation and fertilizer efficiency, seed germination, and pesticide response (Doerr, 2000).

There is a trend of replacing organic matter with inorganic soil amendments, such as zeolite and polypropylene fibers, in golf course putting greens and athletic fields. Several studies (Horn, 1969; Minner et al., 1997; Bigelow, 1999) were conducted on calcined clay as a sole amendment on sandy soil, yet poor turfgrass performances were reported. The reason is that calcined clay amended sand caused water bound at high tension and therefore unavailable to the plant. Additionally, Waltz Jr et al. (2005) compared soil and turfgrass performance on rootzones amended with Canadian sphagnum peat (organic CSP), calcined clay, and diatomaceous earth, concluding the organic CSP was the best amendment for a better turfgrass cover and quality, the earliest turf establishment, and reduced bulk density.

<u>Playability</u>

Ball Roll Distance

Ball roll distance (BRD) is a key factor of identifying putting green smoothness and playability (Salaiz et al., 1995). Increased N rate application would decrease BRD because of the excessive turf growth (Pease et al., 2011). However, Kopec et al (2007) determined that the BRD was largely unaffected by N fertilization with the rate ranging from 12, 18, 24, and 36 kg N $ha^{-1}month^{-1}$, but was consistently affected by mowing height and rolling. Nikolai et al (2001) also suggested lightweight green rolling would significantly increase ball roll distance, as well as reduce dollar spot (*Sclerotinia homoeocarpa*), moss growth, and bird activity. Moreover, lower soil P values on calcareous sand greens resulted in longer ball roll distance (Johnson et al., 2003).

Wear Tolerance

Traffic on turfgrass surface can cause wear and soil compaction (Carrow, 1992), and turfgrass wear accounts for 90% of injury compared with soil compaction (Dest, 2009). Fertility is one of the management strategies to improve wear tolerance (Hoffman et al., 2010). A number of studies have evaluated wear tolerance in creeping bentgrass, and previous studies have found that velvet bentgrass has better wear tolerance than creeping bentgrass and other *Agrostis* species (Dowgiewicz et al., 2011).

Increased N fertilization (96, 192, 392 kg N $ha^{-1}yr^{-1}$) increases wear tolerance in creeping bentgrass (Carroll, 1991; Trenholm et al., 2001a). High level of K (392 kg K $ha^{-1}yr^{-1}$) increase wear tolerance because of the increased turgidity and reduced tissue succulence (Beard, 1973). However, research also shows no influence of K on wear tolerance in both cool season and warm season grasses (Carroll, 1991; Trenholm et al., 2001a).

Silicon (Si) could also improve wear tolerance. Si deposition in the cuticle and lignin polymers improves leaf and stem strength (Takahashi et al., 1990; Hull, 2004). However, Trenholm et al. (2001b) pointed out that increasing Si level would reduce turfgrass quality score. The authors also indentified that K alone fertilizer application had the same or better effect on wear tolerance than Si applied as foliar potassium silicate on seashore paspalum (*Paspalum vaginatum* Swartz).

Dollar Spot Suppression

Dollar spot (DS), caused by *Slerotinia homoeocapa* F.T. Bennett, is a widespread disease that affects all turfgrasses from home lawns to putting greens (Vargas, 2005). DS has been reported as more severe under low N fertility (Smiley, 2005; Vargas, 2005).

There were inconsistent results on DS suppression by using organic fertilizers. Liu et al (1995) found that organic fertilizers reduce DS severity on creeping bentgrass similarly to chlorothalonil. However, the authors did not apply the fertilizers at a uniform rate (50-260 kg N ha^{-1}). As a result, their observation of dollar spot suppression might have been influenced by the increasinged N rates of fertiliers applied, which might allow the turf to recover more rapidly from the disease.

Landschoot and McNitt (Landchoot, 1997) compared the effects of natural organic fertilizers, urea, and ureaform on dollar spot suppression, showing that creeping bentgrass fertilized with urea had equal or better dollar spot suppression than that of receiving natural organic fertilizers. Davis and Dernoeden (2002) compared nine N sources by using the recommended N rate (200 kg N ha^{-1} yr^{-1}) on southshore creeping bentgrass fairway for seven years. Their results showed that the Ringer Lawn Restore (Ringer LR, Ringer Corporation, Minneapolis, MN) and urea treatments suppressed DS, while the Com-Pro (Blue Plains Sanitation Commission, Silver Spring, MD) enhanced it. Boulter et al (2002) identified that application of compost products on creeping bentgrass reduced DS incidence to a level similar to conventional fungicides. However, Lee et al (2003) indicated that it is less likely to maintain good bentgrass putting green quality without fungicides at the place where DS pressure is significant in Kansas.

Annual Bluegrass Invasion

Annual bluegrass (*Poa annua*) invasion of bentgrass greens is a universal problem for golf course superintendents. Currently, no products available can completely prevent annual bluegrass from invading newly seeded bentgrass greens. Herbicides and plant growth regulators are the commonly used methods for regional annual bluegrass control (Beard, 1978; McCullough, 2005).

There were a few studies on turfgrass fertilizer effects on annual bluegrass invasion. Hardt and Schulz (1995) found that ureaform-fertilized bentgrass was more susceptible to annual bluegrass invasion than IBDU and natural organic N applications. Low level of soil P might contribute limiting annual bluegrass invasion, because bentgrass was able to fix P from deep soil where annual bluegrass roots could not reach (Stowell, 2005).

MATERIALS AND METHODS

Research was conducted at the Hancock Turfgrass Research Center at Michigan State University on a putting green measuring 36 x 36 m with three rootzones. Each rootzone had three greens measuring 11 x 11 m, and an 11 x 1.8 m buffer area between them. The three rootzone mixes were (1) 80:20 (sand:peat, v/v) mixture constructed to USGA specification, (2) 80:10:10 (sand:peat:soil, v/v) mixture with subsurface tile drainage, and (3) undisturbed sandy clay loam (58% sand, 20.5% silt, and 21.5% clay) native soil.

The rootzones were constructed in 1993. In 2007, Glyphosate was applied, sod was stripped and 5 cm of topdressing was removed. In 2008, the site was seeded with Penn A-4 creeping bentgrass (*Agrostis palustris* Huds.). In June 2009, fertilizer treatments were initiated.

Experimental design of the research was a Randomized Complete Block Design with three replications. Treatment design was a split-plot. Data were analyzed through mixed effects analysis of variance using PROC MIXED in SAS (SAS Institute, 2002). Fertilizer treatments and rootzones were the two factors. Analysis of Variance was used to determine significant effects. When significant differences were detected ($P < 0.05$), the least square means were separated using LSMEANS procedure.

Each rootzone was split into nine 11 x 1.2 m plots for nine fertilizer treatments (Table 1). The nine fertilizer treatments were: an all natural organic (Organic) (10N-2P-4K), a methylene urea (MU) (40N-0P-0K), a urea (46N-0P-0K), a urea with phosphorous (P) soil test recommendation (calcium phosphate 100%, $CaHPO_4$), a urea with potassium (K) soil test recommendation [Pro Turf Super K (0N-0P-45K)], Grigg Bros. Gary's Green (18N-3P-4K) foliar at two rates (1xF and 2xF), Grigg Bros. Gary's Green (18N-3P-4K) foliar with Grigg Bros. Turf Rally (16N-4P-8K)

Table 1. Treatment design and research plot map.

Rep3	7	9	6	5	1	3	4	2	8		3	6	9	1	4	2	5	8	7		2	7	3	4	6	5	1	9	8
					USGA										**Native**										**80-10-10**				
Rep2	6	3	2	9	8	1	4	7	5		8	1	4	7	2	3	6	9	5		4	5	2	3	7	8	1	6	9
					80-10-10										**Native**										**USGA**				
Rep1	5	8	6	1	3	2	9	4	7		5	4	6	3	9	7	2	1	8		5	6	8	9	7	2	4	3	1
					USGA										**80-10-10**										**Native**				

1 Untreated control
2 Grigg Bros. all natural organic (10-2-4)
3 Methylene urea (40-0-0)
4 Urea (46-0-0)
5 Urea+ P soil test recommendation ($CaHPO_4$)
6 Urea + K soil test recommendation [Pro Turf Super K (0-0-45)]
7 Grigg Bros. Gary's Green (1xF) (18-3-4)
8 Grigg Bros. Gary's Green (1xF) (18-3-4) + Grigg Bros. Turf Rally (16-4-8)
9 Grigg Bros. Gary’s Green (2xF) (18-3-4)

granular (Combination), and an untreated control (UC). The organic fertilizer is derived from soy protein and blood meal.

The organic, MU, and urea were applied at the rate of 24.4 kg N ha^{-1} per application at the beginning of each month from May through October. The 1xF was sprayed at the rate of 6.1 kg N ha^{-1} and 2xF 12.2 kg N ha^{-1} per application biweekly from May through October. The Turf Rally granular was applied at the rate of 12.2 kg N ha^{-1} per month. All the treatments received the same amount of total annual N of 146.4 kg N ha^{-1}, except the 1xF treatment, which received 73.2 kg N ha^{-1} (Table 2).

$CaHPO_4$ as P source and Pro Turf Super K as K source were added accordingly to the urea+P and urea+K treatments in 2010 and 2011 based on the soil P and K test recommendations from October 2009 and 2010 (Tables 3 and 4). $CaHPO_4$ was sprayed once a month at the beginning of June, July, August, and September at the rate of 13.4 kg P_2O_5 ha^{-1} in 2010, and 19.5 kg P_2O_5 ha^{-1} in 2011. Granular Pro Turf Super K was applied monthly from June through September at the rate of 69.5 kg K_2O ha^{-1} in 2010 and 67.1 kg K_2O ha^{-1} in 2011.

Turfgrass color and quality were rated visually every week from May through October on a scale of 1 to 9 (1-poor, 6-acceptable, 9-best for quality) (1-straw brown, 6-acceptable, 9-dark green for color). Chlorophyll ratings were taken weekly using the Field Scout TCM 500 Turf Color Meter (Spectrum Technologies Inc.), which measures light reflectance in the red and near-infrared spectral bands to calculate an objective color evaluation of turf. Chlorophyll indexes were expressed as 3 digit numbers, where a higher number indicates a relatively greener color, and a lower number indicates a relatively yellower color. The use of the TCM 500 Color Meter for chlorophyll readings provides a quantitative measurement of turfgrass color.

Ball roll distance was measured from July through September by rolling three golf balls from a Pelzmeter (Pelz Golf Institute). The bubble-level system implemented on the Pelzmeter ensures that the ball is released from a consistent height, therefore reducing variability. The tapered ramp minimizes ball bounce where the ramp meets the turf. The Pelzmeter's three side-by-side grooves allow rolling three balls at a time and help to minimize ball-tracking effects (Pelzmeter User Mannual, 2004). In this study, three golf balls were rolled at the same time from the Pelzmeter on one end of the plot, and then rolled again from the other end of the plot so as to avoid slope effect within a plot. The six distances were averaged to obtain one ball roll distance for each plot, and reported in cm.

Water infiltration tests were conducted in October using double-ring infiltrometers. The inner ring was 12.7 cm and the outer ring was 21.3 cm in diameter. The water level in the outer ring was maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring. The water level in the inner ring was also kept at a fixed level, and the volume of water needed to maintain this level was measured. Water level was recorded every five minutes for an hour and results reported in cm hr^{-1} (Gregory et al., 2005).

Turfgrass diseases and weed occurrence were also rated. Dollar spot (*Sclerotinia homeocarpa*) was visually assessed as number of dollar spot infection centers per plot from July through September. Worm castings were counted when observed before mowing from July through September. Annual bluegrass (*Poa annua*) was counted on May 20, 2011.

Table 2. Fertilizer treatments.

Name	Nigrogen rate (kg N ha^{-1})		
	Per application	Per month	Annual total
Untreated control	NA†	NA	NA
All natural organic	24.4	24.4	146.4
Methylene urea	24.4	24.4	146.4
Urea	24.4	24.4	146.4
Urea+phosphorous	24.4	24.4	146.4
Urea+potassium	24.4	24.4	146.4
1xF‡	6.1	12.2	73.2
Combination	6.1(Foliar)+12.2(Granular)	24.4	146.4
2xF§	12.2	24.4	146.4

† No fertilizer application.

‡ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Table 3. Phosphorous (P_2O_5) recommendation for the Urea+phophorous treatment from soil test results of October 2009 and 2010.

		Recommend phosphorous (P_2O_5) kg ha^{-1}	
Replication	Soil type	2009	2010
1	USGA	NR†	39.0
1	80-10-10	NR	NR
1	Native	NR	NR
2	USGA	53.7	78.0
2	80-10-10	NR	NR
2	Native	NR	NR
3	USGA	NR	83.0
3	80-10-10	NR	NR
3	Native	NR	NR

† No recommendation, P levels from soil test were at or above optimum

Table 4. Potassium (K_2O) recommendation for the Urea+K treatment from soil test results of October 2009 and 2010.

		Recommend potassium (K_2O) kg ha^{-1}	
Replication	Soil type	2009	2010
1	USGA	278.2	268.4
1	80-10-10	263.5	258.6
1	Native	180.6	190.3
2	USGA	278.2	248.9
2	80-10-10	258.6	170.8
2	Native	122.0	263.5
3	USGA	273.3	258.6
3	80-10-10	273.3	141.5
3	Native	165.9	253.8

Turfgrass soil and tissue samples were collected on the same days in June and October from 2009 to 2011. Samples were dried in a convention oven for 72 h at 60 °C. Oven-dried tissue samples were then weighed before a complete nutrient analysis. Soil samples were collected to a depth of 10 cm, and verdure and thatch were removed. Each plot was split into five equal sections, one section for each year to avoid soil sampling from a previously disturbed area. All the samples were sent to the Soil and Plant Nutrient Laboratory at the Department of Crop and Soil Sciences, Michigan State University (East Lansing, MI).

Soil P was measured by using Bray P1 extractant (0.03 M NH_4F + 0.025 M HCl) when pH equals or less than 7.4, or Olsen extractant solution (0.5 M $NaHCO_3$) when pH is greater than 7.4. Soil K, Ca, and Mg were tested by using 1M ammonium acetate (NH_4OAc). Soil total N (not including nitrates) was determined with the LaChat Rapid Flow Injection Unit using the ammonia-salicylate method after going through the Micro-Kjeldahl Block Digestion process. Soil nitrate-N was extracted by 1 M KCl (Manual of Laboratory Procedures).

Tissue analysis was conducted in the A&L Great Lakes Laboratories Inc. (Fort Wayne, Indiana). Tissue total N was measured using the Dumas Method (nitrogen by combustion or nitrogen by thermal conductance). Mineral nutrients were analyzed using the Inductively Coupled Argon Plasma (ICAP) after going through Mineral Digestion (Open Vessel Microwave) (Plant Tissue Analysis Method Summary).

The plots were mowed at a height of 35 mm five days a week with a walk-behind Toro Greensmaster 1000 (Toro Co., Bloomington, MN). Topdressing with fine sand (>60% 0.25-1.0 mm) was applied weekly from June through September.

RESULTS AND DISCUSSION

Soil Nutrient Analysis

Nitrate Nitrogen

There was a significant rootzone x sampling date interaction for NO_3-N soil test values (Table 5). The native soil rootzone had higher soil NO_3-N concentration than the USGA and 80-10-10 rootzones at all sampling dates, except for June 2010 when there were no significant differences (Table 6). The largest amount of soil NO_3-N for rootzones was detected at the October 2011 sampling date, with 2.29 ppm for the USGA rootzone, 2.31 ppm for the 80-10-10 rootzone, and 4.33 ppm for the native soil (Table 6). The native soil rootzone resulted in high soil nutrient values because of its high water and nutrient retention ability. Clay particles (colloids) in the native soil also attribute to high soil nutrient because of its high CEC (Carrow et al., 2001).

There was a significant fertilizer treatment effect for soil NO_3-N (Table 7). The granular fertilizer treatments (natural organic, methylene urea, urea, urea+P, and urea+K) had the highest soil NO_3-N content. The untreated control had the lowest NO_3-N concentration but was not significantly different from the foliar and combination treatments (1xF, 1xF+ granular, and 2xF). Foliar application of nitrogen fertilizers results in lower soil nutrient concentration because research has shown that 30 - 60% of applied fertilizer is absorbed by turfgrass tissue (Liu, 2005; Totten, 2006a).

Total Nitrogen

There was a significant rootzone effect across all sampling dates for soil total nitrogen (Table 5). The native soil rootzone had the largest amount of total nitrogen of 0.09%, following with 0.05% and 0.03% for the 80-10-10 and USGA rootzones, respectively (Table 8). The native soil has 21.5% clay content. Therefore the CEC associated with the clay, and organic matter bound to the clay result in higher soil NO_3-N and total N values. There was no difference among fertilizer treatments for soil total N content for all sampling dates (Table 5).

Phosphorus

There was a significant rootzone x sampling date interaction for soil P test values (Table 5). The USGA rootzone had a smaller amount of soil P than the 80-10-10 and the native soil rootzones (Table 9). Soil P content for the USGA rootzone was below sufficiency level based on turfgrass soil P recommendation (Soil and Plant Nutrient Laboratory, MSU). For the USGA rootzone, soil P decreased from October 2009 to October 2011. Soil P values for the 80-10-10 and native soil rootzones were generally consistent throughout the sampling dates. Easton and Petrovic (2004) concluded that very little of fertilizer applied P was recovered in clippings, runoff, or leachate, and much of the applied P remains in the soil, roots, and/or plant tissue. In this research, the USGA rootzone had decreasing soil P concentration (Table 9), and consistent tissue P concentration over sampling dates (Table 16). Phosphorous is often limited in the sand-based rootzone turfgrass system, because many fertilizers for mature turfgrasses have a low P analysis (Carrow et al., 2001). However, there was no significant difference among fertilizer treatments for soil P content (Table 5), which implies the urea+P treatment did not result in a higher soil P content than other fertilizer treatments. Easton and Petrovic (2004) observed less

Table 5. Analysis of variance for soil nitrate nitrogen (NO_3-N), total nitrogen (Total N), phosphorus (P), and potassium (K) of Penn 'A-4' creeping bentgrass in 2009, 2010, and 2011.

	Soil nutrient test			
Contrasts	NO_3-N	Total N	P	K
		Pr>F		
Rootzone (R)	*	*	*	*
Fertilizer treatment (F)	*	NS	NS	*
R x F	NS	NS	NS	*
Sampling date (S)	*	*	*	*
R x S	*	NS	*	*
F x S	NS	NS	NS	NS
R x F x S	NS	NS	NS	NS

* and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 6. Lsmean soil nitrate nitrogen (NO_3-N) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Soil NO_3-N (ppm)				
Rootzone					
USGA	0.59c†C‡	1.26B	0.41dD	0.51dD	2.29bA
80-10-10	1.03bC	1.73B	0.61abC	0.81bC	2.31bA
Native	1.92aB	1.40BC	0.97aC	1.21aC	4.33aA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 7. Lsmean soil nitrate nitrogen (NO_3-N) for the fertilizer treatment effect of Penn 'A-4' creeping bentgrass.

	Soil NO_3-N
Fertilizer treatments	ppm
Untreated control	1.22b†
Natural organic	1.69a
Methylene urea	1.64a
Urea	1.54ab
Urea+phosphorous	1.45ab
Urea+potassium	1.49ab
1xF‡	1.23b
1xF+granular	1.29b
2xF§	1.29b
P value	0.03

† Letters represent significant differences at the 0.05 probability level.

‡ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

§ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

soil N and P concentration on the untreated control from a Arkport sandy loam soil. However, in this research, the untreated control did not result in lower soil P concentration than other fertilizer treatments on any of the rootzones.

Potassium

There was a significant rootzone x sampling date interaction for soil potassium test values (Table 5). The native soil rootzone had the highest soil potassium values for all sampling dates (Table 10), and the USGA rootzone had the smallest amount of soil K. For the USGA rootzone, the October 2011 sampling date had the lowest soil K value compared with other dates. The June 2011 sampling date had the largest concentration of soil K for the 80-10-10 and the native soil rootzones (Table 10).

There was a significant fertilizer treatment x rootzone interaction for soil K (Table 5). The native soil had higher K concentration than the USGA and 80-10-10 rootzones across all fertilizer treatments (Table 11). For the Urea+K treatment among the rootzone, the USGA rootzone had the lowest soil K value (Table 11). Potassium moves more readily in sandy soils with lower CEC than finer-textured soils (Carl J. Rosen, 2008). Therefore, turfgrass grown on the USGA rootzone tends to absorb K easier from the soil, resulting in lower K concentration on the USGA rootzone for the urea+K treatment. Moreover, high macroporosity of the USGA rootzone leads to easy K loss through leaching (Bigelow et al., 2001; Petri and Petrovic, 2001).

There were no significant differences among fertilizer treatments for the USGA and 80-10-10 rootzones. For the native soil rootzone, the natural organic, methylene urea, urea, 2xF, and the untreated control had the highest soil K values, and the urea+P treatment had the lowest concentration of soil K. The native soil with 21.5% clay content had higher Cation Exchange

Table 8. Lsmean soil total nitrogen (N) for the rootzone effect of Penn 'A-4' creeping bentgrass.

Rootzone	Soil total N %
USGA	0.03b[†]
80-10-10	0.05b
Native	0.09a
P value	<0.01

[†] Lower case letters represent significant differences at the 0.05 probability level.

Table 9. Lsmean bentgrass soil phosphorus (P) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Soil P (ppm)				
Rootzone					
USGA	19.43b[†]A[‡]	17.18bB	14.66bC	16.04BcC	14.52cC
80-10-10	48.33aA	43.41aAB	45.70aAB	44.67bAB	39.96bB
Native	54.76aA	51.33aC	51.89aB	57.48aAB	54.33aAB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Capacity (CEC), resulting in higher K levels. A high soil K concentration for the untreated control could be caused by less turfgrass growth, thereby less tissue K absorption.

Tissue Nutrient Analysis

Nitrogen

There was a significant fertilizer treatment x sampling date interaction for tissue total nitrogen (Table 12). The urea, urea+P, and urea+K treatments had the largest amount of tissue total N for the October 2010 and the October 2011 sampling dates (Table 13). The untreated control had the lowest amount of tissue total N for all sampling dates (Table 13). Application of quick-release nitrogen often leads to higher N uptake by turfgrass (Landschoot and Waddington, 1987). In October when weather condition is more favorable for the root growth of creeping bentgrass, root absorption of nutrient is more effective than foliar absorption, thus quick-release N fertilizer resulted in higher N concentration than foliar N application.

There was a significant rootzone x sampling date interaction for tissue total nitrogen values (Table 12). The native soil rootzone had the lowest tissue total N values for the October 2010, June 2011, and October 2011 sampling dates (Table 14). These tissue N values (1.23, 2.11, 1.63%) were below turfgrass common sufficiency range of 2.8-3.5% (Carrow et al., 2001). This result is contrary to soil N test results, that the native soil rootzone had the largest soil NO_3-N and soil total N concentration (Tables 6 and 8). These results suggest that the concentration of soil nitrogen is not reflected in tissue nitrogen. However, soil N tests are not usually used to recommend N application rates for turfgrass.

Table 10. Lsmean soil potassium (K) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Soil K (ppm)				
Rootzone					
USGA	16.67c† AB‡	17.78cA	19.33cA	18.33bA	13.18bB
80-10-10	21.86bB	25.29bAB	22.33bB	27.11bA	17.63bC
Native	86.57aA	75.15aB	76.89aB	88.92aA	75.29aB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 11. Lsmean soil potassium (K) for the rootzone x fertilizer treatment interaction.

	Rootzone		
	USGA	80-10-10	Native
Fertilizer treatment	Soil K (ppm)		
Untreated control	16.53B‡	22.40B	84ab†A
Natural organic	17.73B	24.86B	89.66aA
Methylene urea	17.20B	21.13B	84.66abA
Urea	15.93B	19.86B	84.00abA
Urea+phosphorous	14.53B	19.80B	63.53dA
Urea+potassium	17.33C	27.53B	77.46bcA
1xF§	18.73B	23.93B	80.33bcA
1xF+granular	19.06B	24.33B	72.06cdA
2xF¶	16.06B	21.73B	82.60abA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Phosphorous

There was a significant fertilizer treatment x sampling date interaction for tissue phosphorous (Table 12). The methylene urea, urea, urea+P, urea+K, and 2xF had the highest tissue P values for the Ocotober 2010 sampling date (Table 15). The urea+P, 1xF+granular, and 2xF treatments had the highest amount of tissue P for the October 2011 sampling date. The urea+P and 2xF treatments maintained the high P concentration on both October 2010 and October 2011 sampling dates. This result suggests that the 2xF treatment had similar effects in improving tissue P content as P supplement in the Urea+P fertilizer treatment.

There was a significant rootzone x sampling date interaction for tissue phosphorous values (Table 12). The native soil rootzone had the lowest tissue P values for the October 2010 and October 2011 sampling dates (Table 16). This result suggests that high soil P does not result in high turfgrass tissue P concentration, especially on the native soil (Tables 9 and 16). Plant available P in the forms of $H_2PO_4^-$ and HPO_4^- in the soil solution can be utilized by microbial activities and bound with Fe, Al, Mn, and Ca to cause insoluble P forms (Carrow et al., 2001). The native soil rootzone with high Ca content could attribute to the low turfgrass tissue P, which were below the sufficiency range of 0.2-0.5% (Carrow et al., 2001) on the October 2010 and October 2011 sampling dates.

Potassium

There was a significant fertilizer treatment x sampling date interaction for tissue K (Table 12). The urea+K treatment had the highest tissue K concentration for the October 2010, June 2011, and October 2011 sampling dates (Table 17). This result suggests that additional K

Table 12. Analysis of variance for tissue nitrogen (N), phosphorus (P), and potassium (K) of Penn 'A-4' creeping bentgrass in 2009, 2010, and 2011.

	Tissue nutrient test		
Contrasts	Total N	P	K
		%	
Rootzone (R)	*	NS	*
Fertilizer treatment (F)	*	*	*
R x F	NS	NS	NS
Sampling date (S)	*	*	*
R x S	*	*	*
F x S	*	*	*
R x F x S	NS	NS	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 13. Lsmean creeping bentgrass tissue total nitrogen (N) for the fertilizer treatment x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue total N (%)				
Fertilizer treatment					
Untreated control	3.08c[†]B[‡]	3.65bA	1.45eC	1.79bC	1.44eC
Natural organic	3.37bB	3.95aA	2.10bcC	2.93aB	2.20cdC
Methylene urea	3.63aA	3.88aA	2.17bcC	3.01aB	2.69bB
Urea	3.45abA	3.06dAB	2.62aC	3.17aAB	2.95abBC
Urea+phosphorous	3.45abA	2.96dA	2.49abB	3.01aA	2.99aA
Urea+potassium	3.45abA	3.18dA	2.64aB	3.22aA	3.01aA
1xF[§]	3.36bA	3.55bcA	1.51deC	2.68aB	2.02dB
1xF+granular	3.46abA	3.47cdA	1.88cdC	2.96aB	2.36cB
2xF[¶]	3.51abA	3.67bA	2.18bcD	3.20aC	2.68bB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 14. Lsmean bentgrass tissue total nitrogen (N) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue total N (%)				
Rootzone					
USGA	2.91B‡	3.44A	2.85a†B	3.33aA	2.95aB
80-10-10	3.64A	3.52A	2.27bD	3.22aB	2.86aC
Native	3.68A	3.51A	1.23cD	2.11bB	1.63bC

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

applications are effective in improving turfgrass tissue K across rootzones over time. The untreated control had the lowest tissue K values across all sampling dates.

There was a significant rootzone x sampling date interaction for tissue potassium values (Table 12). The native soil rootzone had higher tissue K content for the October 2009 and June 2010 sampling dates, but the lowest tissue K values for the October 2010, June 2011, and October 2011 sampling dates (Table 18). Similar to tissue N and P results, high soil K does not result in high turfgrass tissue K. These results suggest that tissue and soil analysis can not predict each other, thus tissue test should be considered in making fertilization recommendations, especially for critical areas such as golf greens.

Table 15. Lsmean tissue phosphorous (P) for the fertilizer treatment x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue P (%)				
Fertilizer treatment					
Untreated control	0.39B‡	0.51a†A	0.20cC	0.24C	0.19eC
Natural organic	0.44A	0.51aA	0.27bcB	0.42A	0.28bcdB
Methylene urea	0.45A	0.49abA	0.29abCD	0.38B	0.27bcdC
Urea	0.44A	0.40cAB	0.30abCD	0.36BC	0.27bcdD
Urea+phosphorous	0.44A	0.37cB	0.30abCD	0.37BC	0.29abD
Urea+potassium	0.44A	0.40cA	0.32aB	0.38AB	0.26dC
1xF§	0.43AB	0.51aA	0.21cD	0.37B	0.26dC
1xF+granular	0.43AB	0.46bA	0.27bcC	0.41B	0.29abC
2xF¶	0.43AB	0.50abA	0.30abC	0.41B	0.31aC

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 16. Lsmean tissue phophorous (P) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue P (%)				
Rootzone					
USGA	0.39A‡	0.40b†A	0.32aB	0.38A	0.29aC
80-10-10	0.46A	0.47aA	0.31aC	0.42B	0.32aC
Native	0.44B	0.51aA	0.19bD	0.31C	0.19bD

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 17. Lsmean tissue potassium (K) for the fertilizer treatment x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue K (%)				
Fertilizer treatment					
Untreated control	1.34c†A‡	1.21A	0.85cB	0.79eB	0.94eB
Natural organic	1.56abA	1.23BC	1.14bC	1.43bcdAB	1.30cdBC
Methylene urea	1.70aA	1.38B	1.24bB	1.35cdB	1.42bcB
Urea	1.68aA	1.08C	1.28bC	1.46bcB	1.45bB
Urea+phosphorous	1.68aA	1.00C	1.31bB	1.41bcdB	1.40bcB
Urea+potassium	1.68aB	1.21C	1.70aB	2.07aA	1.60aB
1xF§	1.50bA	1.24B	0.83cC	1.27dB	1.22dBC
1xF+granular	1.59abA	1.27B	1.17bB	1.44bcdA	1.43bcA
2xF¶	1.66aA	1.20B	1.27bB	1.47bA	1.51abA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

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Table 18. Lsmean creeping bentgrass tissue potassium (K) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue K (%)				
Rootzone					
USGA	1.41B‡	1.07b†C	1.57aAB	1.50B	1.59aA
80-10-10	1.63A	1.24abB	1.34bB	1.58A	1.63aA
Native	1.69A	1.30aB	0.68cD	1.15B	0.87bC

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Color, Quality, and Chlorophyll

There was a significant fertilizer treatment x rootzone x sampling date x year interaction for turfgrass color, quality and chlorophyll ratings (Table 19). Therefore, these results are discussed by each year. The turfgrass color, quality, and chlorophyll were rated 4 weeks after fertilizer application, except for the foliar treatments, which were 2 weeks after the second application.

Within years

2009

There was a significant fertilizer treatment x sampling date interaction for the 2009 turfgrass color ratings (Table 20). The urea treatment had the highest and the untreated control had the lowest color rating for all sampling dates in 2009 (Table 21). All the color ratings were above the acceptable level (>6), except for the untreated control in June and October (Table 21).

There was a significant rootzone x sampling date interaction for the 2009 turfgrass color ratings (Table 20). In August and October, the native soil rootzone had higher color ratings than the USGA and 80-10-10 rootzones (Table 22). All the rootzones had the lowest color ratings for the June sampling date. The reason could be that the first fertilizer application was made in June.

There was a significant fertilizer treatment x sampling date interaction for the 2009 turfgrass quality ratings (Table 20). The urea treatment had the highest quality rating in June and October 2009 (Table 23). This result is similar to the 2009 color rating except for the August sampling date, which had no difference in quality rating among fertilized treatments (Table 23).

There was a significant rootzone x sampling date interaction for the 2009 turfgrass quality ratings (Table 20). The 80-10-10 rootzone had the highest quality rating in August, while the native soil had the highest quality rating in October 2009 (Table 24).

There was a significant fertilizer treatment effect for the chlorophyll ratings for 2009 (Table 20). The urea, 2xF, and methylene urea treatments had the highest chlorophyll ratings for 2009, and the untreated control had the lowest chlorophyll ratings (Table 25).

The 2009 results suggest that the urea treatment had the best turf color and quality for all sampling dates in 2009. The double-rate foliar treatment had equal color and quality ratings with the slow-release fertilizer treatments (natural organic and methylene urea). The combination and single-rate foliar treatments had the lowest turfgrass color ratings among fertilized treatments in 2009.

2010

There was a significant fertilizer treatment x sampling date interaction for the 2010 turfgrass color ratings (Table 20). The granular fertilizer treatments had the highest color ratings in April (Table 26). In May and June, the natural organic and methylene urea treatments had the highest color ratings. For July and August sampling dates, the 2xF and 1xF+Granular treatments had the highest ratings. The urea, urea+P, and urea+K treatments had the highest color ratings in September and Ocotber 2010 (Table 26). These results suggest that granular fertilizer treatments had better turfgrass color in late fall and faster green up in the spring. Foliar applications result in better turfgrass color and quality for the summer time.

Table 19. Analysis of variance for color, quality, and chlorophyll ratings of Penn 'A-4' creeping bentgrass.

Contrasts	Turfgrass color, quality, and chlorophyll ratings		
	Color	Quality	Chlorophyll
		Pr>F	
Rootzone (R)	*	NS	NS
Fertilizer treatment (F)	*	*	*
R x F	NS	NS	NS
Sampling date (S)	*	*	*
R x S	*	*	NS
F x S	*	*	NS
R x F x S	NS	NS	NS
Year (Y)	*	*	*
R x Y	*	NS	NS
F x Y	*	*	*
S x Y	*	*	*
R x F x S x Y	*	*	*

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level.

Table 20. Analysis of variance for color, quality, and chlorophyll ratings of Penn ‘A-4’ creeping bentgrass by year.

	Turfgrass color, quality, and chlorophyll rating								
	2009			2010			2011		
Contrasts	Color	Quality	Chlorophyll	Color	Quality	Chlorophyll	Color	Quality	Chlorophyll
	Pr>F								
Rootzone (R)	*	NS	NS	*	NS	NS	NS	NS	NS
Fertilizer treatment (F)	*	*	*	*	*	*	*	*	*
R x F	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sampling date (S)	*	*	*	*	*	*	*	*	*
R x S	*	*	NS	*	*	NS	*	*	*
F x S	*	*	NS	*	*	*	*	*	*
R x F x S	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level.

Table 21. Lsmean creeping bentgrass color rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2009.

	Sampling date				
	June	July	August	September	October
	Color†				
Fertilizer treatment					
Untreated control	5.5e‡C§	6.8cA	6.4cB	6.5eB	5.9eC
Natural organic	6.2cdC	7.6bA	7.2bB	7.8abcA	7.4bcB
Methylene urea	6.9bC	8.1aA	7.5abB	8.0abA	7.7bB
Urea	7.5aC	8.2aB	7.7aC	8.1aB	8.5aA
Urea+phosphorous	7.5aC	8.2aB	7.7aC	8.0aB	8.5aA
Urea+potassium	7.5aC	8.2aB	7.7aC	8.0aB	8.5aA
1xF¶	6.1dC	7.4bcA	7.1bB	7.5dA	7.1cdB
1xF+granular	5.7deC	7.8abA	7.2bB	7.8bcA	7.0dB
2xF#	6.5bcC	7.8abA	7.3bB	7.6cdAB	7.5bB

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 22. Lsmean creeping bentgrass color rating for the rootzone x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2009.

	Sampling date				
	June	July	August	September	October
			Color†		
Rootzone					
USGA	5.9D‡	7.7A	6.9b§C	7.3bB	6.9C
80-10-10	6.6D	7.7A	7.3aC	7.5abB	7.2C
Native	6.4C	7.9A	7.4aB	8.0aA	7.8AB

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

§ Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 23. Lsmean creeping bentgrass quality rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2009.

	Sampling date				
	June	July	August	September	October
	Quality†				
Fertilizer treatment					
Untreated control	5.5c†C‡	6.6eA	6.3bB	6.2cB	5.5eC
Natural organic	6.3bC	7.6cA	7.1aB	7.6abA	7.3cB
Methylene urea	7.1aB	8.0abA	7.6aAB	7.7aAB	7.8bA
Urea	7.6aC	8.2aA	7.5aC	7.8aB	8.4aA
Urea+phosphorous	7.6aB	7.1dC	7.5aB	7.3bC	8.4aA
Urea+potassium	7.6aB	7.1dC	7.5aB	7.3bC	8.4aA
1xF¶	6.4bB	7.1dAB	7.1aAB	7.3bA	6.7dB
1xF+granular	6.3bD	7.8bcA	7.2aB	7.6abA	6.8dC
2xF#	6.1bcC	7.9abcA	7.5aB	7.7abA	7.2cB

† Turfgrass color rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 24. Lsmean creeping bentgrass quality rating for the rootzone x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2009.

	Sampling date				
	June	July	August	September	October
	Quality†				
Rootzone					
USGA	6.6C‡	7.4A	6.9b§C	7.1B	6.7cC
80-10-10	6.6B	7.7A	7.5aA	7.6A	7.0bB
Native	6.2C	7.7A	7.2abB	7.5A	7.6aA

† Turfgrass quality rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

§ Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 25. Lsmean chlorophyll rating for the fertilizer treatment effect of Penn 'A-4' creeping bentgrass in 2009.

Fertilizer treatment	Chlorophyll
Untreated control	0.602d†
Natural organic	0.645bc
Methylene urea	0.655ab
Urea	0.671a
Urea+phosphorous	0.676a
Urea+potassium	0.662ab
1xF‡	0.644bc
1xF+granular	0.632c
2xF§	0.666ab
P value	<0.01

† Lower case letters represent significant differences at the 0.05 probability level.

‡ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

§ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

There was a significant rootzone x sampling date interaction for the 2010 turfgrass color ratings (Table 20). The USGA rootzone had the lowest turfgrass color ratings in April, May, September, and Ocotber. However, there were no differences among rootzones for June, July, and August (Table 27).

There was a significant fertilizer treatment x sampling date interaction for the 2010 turfgrass quality ratings (Table 20). The urea, urea+P, urea+K, and methylene urea treatments had the highest quality ratings in April. However, in August, September, and October, the 2xF and 1xF+granular treatments resulted in higher quality ratings than other fertilizer treatments (Table 28). These results suggest that foliar application is more effective than granular fertilizers for creeping bentgrass under summer stress. The reason for these results could be that root growth is more sensitive to heat and drought stress than shoots, and root dieback would decline bentgrass quality (Beard and Daniel, 1966; Xu and Huang, 2000).

There was a significant rootzone x sampling date interaction for the 2010 turfgrass quality ratings (Table 20). The USGA rootzone had the lowest quality ratings for the April, June, July, September, and October sampling dates (Table 29). The April sampling date had lower quality ratings for the USGA and 80-10-10 rootzones (Table 29).

There was a significant fertilizer treatment x sampling date interaction for the 2010 turfgrass chlorophyll ratings (Table 20). The urea, urea+P, urea+K, and natural organic treatments had the highest chlorophyll ratings in June (Table 30). The 2xF and 1xF+granular treatments had the highest chlorophyll ratings in August and October. The 1xF treatment had higher chlorophyll ratings than the urea treatment in August. The reason could be that the second application (in the middle of the month) of 1xF was made two weeks after the urea application

Table 26. Lsmean creeping bentgrass color rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2010.

	Sampling date						
	April	May	June	July	August	September	October
	Color†						
Fertilizer treatment							
Untreated control	6.2c‡B§	6.0dB	6.3dB	7.2deA	6.3dB	6.0eB	6.1eB
Natural organic	7.1abC	8.2aA	7.9aA	7.3cdC	7.7abB	7.7abB	7.8bAB
Methylene urea	7.2aB	7.0cC	7.6abA	7.4cAB	7.8aA	7.5bcAB	7.8bcA
Urea	7.5aBC	7.4bC	7.3bcC	7.0efD	7.3cC	7.7abB	8.2aA
Urea+phosphorous	7.3aBC	7.4bC	7.4bcC	7.0fC	7.3cB	7.8aB	8.4aA
Urea+potassium	7.1abC	7.5bB	7.3bcC	6.8fD	7.5bcB	7.7abB	8.4aA
1xF¶	6.4cD	7.0cB	7.0cB	8.0bA	7.3cB	6.9dC	7.2dB
1xF+granular	6.9bC	7.3bcB	7.6bAB	8.1abA	7.8abA	7.3cB	7.6cAB
2xF#	6.7bC	7.2bcB	7.2cB	8.3aA	7.9aA	7.6bAB	7.9bA

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 27. Lsmean creeping bentgrass color rating for the rootzone x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2010.

	Sampling date						
	April	May	June	July	August	September	October
	Color†						
Rootzone							
USGA	6.3c‡C§	7.0A	7.0bA	7.2A	7.2A	6.9B	7.1bA
80-10-10	6.8bB	7.2AB	7.2aAB	7.3A	7.3A	7.4A	7.3aA
Native	7.2aB	7.1B	7.3aB	7.5A	7.2B	7.5A	7.3aB

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 28. Lsmean creeping bentgrass quality rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2010.

	Sampling date						
	April	May	June	July	August	September	October
	Quality†						
Fertilizer treatment							
Untreated control	5.8d‡	5.8d	6.2d	6.1d	6.1d	6.0d	5.9c
Natural organic	6.8bC§	7.9aA	7.5aB	7.2cBC	7.4bcB	7.5aB	7.4bB
Methylene urea	7.0abB	6.9cB	7.3abAB	7.3cAB	7.5bcA	7.4abA	7.4bA
Urea	7.3a	7.3b	7.3ab	7.0c	7.3c	7.3b	7.3b
Urea+phosphorous	7.1aB	7.3bAB	7.4aA	7.1cB	7.3cAB	7.5aA	7.2bAB
Urea+potassium	7.2aB	7.5bA	7.5aA	7.0cB	7.2cB	7.4abA	7.3bAB
1xF¶	6.3dD	6.7cC	6.8cC	7.8bA	7.3cB	7.1cB	7.3bB
1xF+granular	6.6cD	7.3bC	7.4aC	8.1abA	7.6abB	7.6aB	7.7aB
2xF#	6.6cD	6.9cC	7.1bcC	8.2aA	7.7aB	7.5aB	7.6aB

† Turfgrass color rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

(at the beginning of the month), and the rating date was at the end of the month. In contrast to color ratings, the June sampling date had the highest chlorophyll ratings. This is probably because the TCM500 turf color meter measures light reflected from the turfgrass canopy with sensors specific for red, green, or blue wavelengths. It then provides an NDVI (Normalized Difference Vegetation Index), which assess whether the target being observed contains live green vegetation or not. Therefore, in addition to color, turfgrass density may also attribute to the rating results.

2011

There was a significant fertilizer treatment x sampling date interaction for the 2011 turfgrass color ratings (Table 20). The urea treatments and methylene urea had the highest quality ratings in April (Table 31). This result is similar to the color ratings in 2010. The 2xF and 1xF+granular treatments had the highest color ratings in June and August 2011, which was different from 2010 (Table 31). The urea treatments had the highest color ratings again in October 2011. These results show a clearer trend of granular and foliar fertilizers than previous years, that granular fertilizer treatments had better turfgrass color in late fall and faster green up in the spring. Foliar applications may have better turfgrass color and quality in the summer time.

There was a significant rootzone x sampling date interaction for the 2011 turfgrass color ratings (Table 20). The native soil had the highest color ratings in April, June, and August. The August sampling date had the highest color rating for all rootzones (Table 32).

There was a significant fertilizer treatment x sampling date interaction for the 2011 turfgrass quality ratings (Table 20). The untreated control had the lowest quality ratings below acceptable level (<6) for all sampling dates (Table 33). All the fertilizer treatments had higher

Table 29. Lsmean bentgrass quality rating for the rootzone x sampling date interaction in at four weeks after fertilizer application for each month from April to October in 2010.

	Sampling date						
	April	May	June	July	August	September	October
	Quality†						
Rootzone							
USGA	6.3c‡C§	7.0A	7.0bA	7.2bA	7.2A	6.9bB	7.1bA
80-10-10	6.8bB	7.2AB	7.2aAB	7.3abA	7.3A	7.4aA	7.3aA
Native	7.2aB	7.1B	7.3aB	7.5aA	7.2B	7.5aA	7.3aB

† Turfgrass quality rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 30. Lsmean creeping bentgrass chlorophyll rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2010.

	Sampling date				
	2010 Jun	July	2010 Aug	September	2010 Oct
	Chlorophyll				
Fertilizer treatment					
Untreated control	0.652e†	0.641e	0.644d	0.647d	0.666d
Natural organic	0.753aA‡	0.683cB	0.672cB	0.719aA	0.691bB
Methylene urea	0.744bA	0.683cB	0.683bcB	0.713abAB	0.693bB
Urea	0.752aA	0.664dC	0.675cBC	0.715abB	0.682cB
Urea+phosphorous	0.753aA	0.660dB	0.674cB	0.725aA	0.684cB
Urea+potassium	0.757aA	0.659dC	0.673cB	0.726aA	0.683bcB
1xF§	0.699d	0.689c	0.681abc	0.690c	0.697b
1xF+granular	0.742bcA	0.694bB	0.696abB	0.699bcB	0.709aB
2xF¶	0.711c	0.702a	0.702a	0.714ab	0.711a

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

quality ratings in August compared with other sampling dates. There was a significant rootzone x sampling date interaction for the 2011 turfgrass quality ratings (Table 20). There was no difference in quality rating among rootzones for all the sampling dates.

There was a significant fertilizer treatment x sampling date interaction for the 2011 turfgrass chlorophyll ratings (Table 20). The 2xF treatment had the highest chlorophyll ratings in June and August. The urea and urea+K treatments had the highest chlorophyll ratings in October (Table 35). All the fertilizer treatments had the highest chlorophyll ratings in July and September compared with other sampling dates (Table 35).

There was a significant rootzone x sampling date interaction for the 2011 turfgrass chlorophyll ratings (Table 20). The USGA rootzone had the lowest chlorophyll ratings in June (Table 36). The July sampling date had the highest chlorophyll ratings for all the rootzones (Table 36).

Within month

April 2010 and 2011

There was a significant fertilizer treatment x sampling date interaction for turfgrass color in April (Table 37). The natural organic, methylene urea, urea, urea+P, and urea+K treatments had the best color ratings in April 2010 (Table 38). The urea+P and urea+K treatments had the best color ratings for April 2011. These results suggest that phosphorus and potassium addition in urea may attribute to faster green up of bentgrass in the spring. All the fertilizer treatments had higher April color ratings in 2010 than in 2011 (Table 38). The reason for this result could be that the average temperature for April 2011 in Lansing was 45.3 F, compared with 52.4 F in April 2010 (HTRC weather station).

Table 31. Lsmean creeping bentgrass color rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2011.

	Sampling date						
	April	May	June	July	August	September	October
	Color†						
Fertilizer treatment							
Untreated control	4.2c‡B§	5.2cA	5.1cA	5.4eA	5.3eA	5.1eA	4.3eB
Natural organic	6.4aC	7.7bAB	7.2bB	7.7aAB	8.0bcA	7.5bcdB	7.1cB
Methylene urea	6.4aC	7.5bAB	7.1bB	7.6abA	7.8cdA	7.3cdB	7.2bcB
Urea	6.4aC	7.5b	7.1bB	7.2bc	7.72cdA	7.4cd	7.9aA
Urea+phosphorous	6.5aC	7.6bAB	7.1bB	7.2cB	7.7cdA	7.5bcdAB	7.8aA
Urea+potassium	6.6aD	7.7bA	7.1bC	7.2cB	7.6dAB	7.5bcAB	7.8aA
1xF¶	5.3bD	7.6bA	7.0bB	6.6dC	7.7cdA	7.2dB	6.5dC
1xF+granular	5.1bD	8.2aA	7.7aB	7.0cC	8.3aA	7.8abAB	7.2bcC
2xF#	5.6bC	8.2aA	7.9aA	7.6abAB	8.2abA	7.9aA	7.5bB

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 32. Lsmean creeping bentgrass color rating for the rootzone x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2011.

	Sampling date						
	April	May	June	July	August	September	October
	Color[†]						
Rootzone							
USGA	5.4b[‡]C[§]	7.2bAB	6.6cB	6.8B	7.5bA	6.9B	6.9B
80-10-10	6.0aC	7.5a	7.1bB	7.2AB	7.4bA	7.3A	6.9B
Native	6.1aC	7.7aA	7.4aB	7.2B	7.8aA	7.5B	7.2B

[†] Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

[‡] Lower case letters represent significant differences at the 0.05 probability level in columns.

[§] Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 33. Lsmean creeping bentgrass quality rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2011.

	Sampling date						
	April	May	June	July	August	September	October
	Quality†						
Fertilizer treatment							
Untreated control	4.1d‡C§	4.8dB	5.1dA	5.1dA	5.2A	4.8eB	5.0dA
Natural organic	6.4aC	7.0cB	7.6aA	7.6aA	7.5A	7.1cdB	7.4cA
Methylene urea	6.0abC	7.0cB	7.6aA	7.6aA	7.5A	6.8dB	7.6bcA
Urea	5.7bC	6.9cB	7.3abB	7.3abB	7.7A	7.0cdB	7.7abcA
Urea+phosphorous	5.8abD	7.0bcC	7.2bB	7.2bB	7.5AB	7.0cdC	7.8abA
Urea+potassium	6.2abC	7.2bcB	7.2bB	7.2abB	7.4A	7.2bcB	7.5bcA
1xF¶	4.8cC	6.8cB	6.6cB	6.6cB	7.3A	6.8dB	7.5bcA
1xF+granular	5.8abC	7.6aAB	7.1bB	7.1bB	8.1A	7.5aAB	7.8aA
2xF#	5.6bC	7.4abB	7.5abB	7.5abB	7.7A	7.4abB	7.8aA

† Turfgrass color rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 34. Lsmean creeping bentgrass quality rating for the rootozone x sampling date interaction at four weeks after fertilizer application for each month from April to October in 2011.

	Sampling date						
	April	May	June	July	August	September	October
	Quality†						
Rootzone							
USGA	5.3C‡	6.8B	6.8B	6.8B	7.3A	6.6B	7.2A
80-10-10	6.2D	6.8C	7.2B	7.2B	7.4A	6.9C	7.4A
Native	5.3C	7.0B	7.0B	7.0B	7.2AB	7.1B	7.4A

† Turfgrass quality rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 35. Lsmean creeping bentgrass chlorophyll rating for the fertilizer treatment x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2011.

	Sampling date				
	June	July	August	September	October
	Chlorophyll				
Fertilizer treatment					
Untreated control	0.570f†B‡	0.665dA	0.623dA	0.652eA	0.564eB
Natural organic	0.667bcdB	0.734aA	0.703aA	0.723aA	0.658bcB
Methylene urea	0.660cdB	0.730abA	0.694bB	0.719abAB	0.648cC
Urea	0.677abB	0.729abA	0.692bAB	0.718abA	0.666abB
Urea+phosphorous	0.666bcdB	0.719bcA	0.693bA	0.715bcA	0.659bcB
Urea+potassium	0.681aB	0.715cA	0.687bcB	0.709cdA	0.671aB
1xF§	0.639eC	0.712cA	0.676cB	0.700dA	0.624dC
1xF+granular	0.656dB	0.710cA	0.693bA	0.705dA	0.652cB
2xF¶	0.671abcB	0.723abcA	0.697abB	0.715bcA	0.655bcC

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 36. Lsmean creeping bentgrass chlorophyll rating for the rootzone x sampling date interaction at four weeks after fertilizer application for each month from June to October in 2011.

	Sampling date				
	June	July	August	September	October
	Chlorophyll				
Rootzone					
USGA	0.633b†B‡	0.714A	0.681AB	0.702A	0.628B
80-10-10	0.659abD	0.720A	0.683C	0.708B	0.647D
Native	0.670aB	0.711A	0.688B	0.709A	0.658B

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

There was a significant fertilizer treatment x sampling date interaction for turfgrass quality in April (Table 37). Granular form fertilizer treatments had the best quality ratings in April 2010 (Table 39), which is similar to the color rating results. For April 2011, the natural organic, methylene urea, and urea+K had the best quality ratings (Table 39). There was a significant rootzone x sampling date interaction for April turfgrass quality rating (Table 37). The native soil had the best quality rating in 2010, and the 80-10-10 rootzone had the best quality rating in 2011 (Table 40).

June 2009, 2010, and 2011

There was a significant fertilizer treatment x sampling date interaction for turfgrass color in June (Table 37). The urea, urea+P, and urea+K treatments had the highest color rating for June 2009 (Table 41). The natural organic and methylene urea treatments had the highest color ratings in June 2010. For June 2011, the 1xF+granular and the 2xF treatments had the highest color ratings (Table 41). These results suggest that the granular-foliar combination and foliar alone treatments started to have better June color ratings in the third year of the research. For June 2010 and 2011, the 1xF treatment had the same color ratings with urea treatment (Table 41).

There was a significant rootzone x sampling date interaction (Table 37). The highest turfgrass color rating was 7.4 for the native soil rootzone in June 2011 (Table 42) All the rootzones had higher color ratings in 2010 than in 2009 and 2011 (Table 42), for the reason of a higher June temperature in 2010 compared with 2009 and 2011.

Table 37. Analysis of variance for color, quality, and chlorophyll ratings of Penn ‘A-4’ creeping bentgrass in April, June, August, and October in 2009, 2010, and 2011.

	Turfgrass color, quality, and chlorophyll rating										
	April		June			August			October		
Contrasts	Color	Quality	Color	Quality	Chlorophyll	Color	Quality	Chlorophyll	Color	Quality	Chlorophyll
						Pr>F					
Rootzone (R)	NS	NS	*	NS	NS	*	NS	NS	NS	NS	*
Fertilizer treatment (F)	*	*	*	*	*	*	*	*	*	*	*
R x F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sampling date (S)	*	*	*	*	*	*	*	*	*	*	*
R x S	NS	*	*	*	*	NS	NS	*	*	*	*
F x S	*	*	*	*	*	*	*	*	*	*	*
R x F x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 38. Lsmean bentgrass color rating for the fertilizer treatment x sampling date interaction in April 2010 and 2011.

	Sampling date	
	2010	2011
	Color†	
Fertilizer treatment		
Untreated control	6.2c‡A§	4.2eB
Natural organic	7.1abA	6.4bB
Methylene urea	7.2aA	6.4bB
Urea	7.5aA	6.4bB
Urea+phosphorous	7.3aA	6.5aB
Urea+potassium	7.1ab	6.6a
1xF¶	6.4cA	5.3cdB
1xF+granular	6.9bA	5.1dB
2xF#	6.7bcA	5.6cB

† Turfgrass color rating scale: 1-9, 1 straw brown, 6 acceptable, 9 dark green.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 39. Lsmean bentgrass quality rating for the fertilizer treatment x sampling date interaction in April 2010 and 2011.

	sampling date	
	2010	2011
	Quality†	
Fertilizer treatment		
Untreated control	5.8d‡A§	4.1dB
Natural organic	6.8b	6.4a
Methylene urea	7.0aA	6.0abB
Urea	7.3aA	5.7bB
Urea+phosphorous	7.1aA	5.8bB
Urea+potassium	7.2aA	6.2aB
1xF¶	6.2cA	4.8cB
1xF+granular	6.6bA	5.8bB
2xF#	6.6bA	5.6bB

† Turfgrass color rating scale: 1-9, 1 poor, 6 acceptable, 9 best.

‡ Lower case letters represent significant differences at the 0.05 probability level in columns.

§ Capital letters indicate significant differences at the 0.05 probability level in rows.

¶ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 40. Lsmean bentgrass quality rating for the rootzone x sampling date interaction in April 2010 and 2011.

	Sampling date	
	2010	2011
	Quality	
Rootzone		
USGA	6.2c†A‡	5.3bB
80-10-10	6.8bA	6.2aB
Native	7.2aA	5.3bB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

There was a significant fertilizer treatment x sampling date interaction for turfgrass quality ratings in June (Table 37). The methylene urea, urea, urea+P, and urea+K treatments had high quality ratings consistently for the three years (Table 43). The 1xF treatment had a lower quality rating than the urea treatment, which is different from color rating results.

There was a significant rootzone x sampling date interaction for turfgrass quality in June (Table 37). There was no difference in turfgrass quality among rootzones for all the sampling dates (Table 44). The June 2010 sampling date had the highest quality rating for the native soil rootzone (Table 44).

There was a significant fertilizer treatment x sampling date interaction for turfgrass chlorophyll ratings in June (Table 37). The natural organic, urea, urea+P, and urea+K treatments had the highest chlorophyll values for the June 2010 sampling dates. The urea+K, urea, and 2xF treatments had the highest chlorophyll ratings in June 2011 (Table 45). For all fertilizer treatments, the June 2010 sampling date had the highest chlorophyll ratings (Table 45). There was a significant rootzone x sampling date interaction for June chlorophyll ratings (Table 37). The 80-10-10 and native soil had higher chlorophyll ratings than the USGA rootzone, and June 2010 had higher chlorophyll ratings than other sampling dates (Table 46).

Table 41. Lsmean bentgrass color rating for the fertilizer treatment x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Color		
Fertilizer treatment			
Untreated control	5.5e[†]B[‡]	6.2dA	5.1cB
Natural organic	6.2cdB	7.5aA	7.2bA
Methylene urea	6.9	7.3ab	7.1b
Urea	7.5a	7.3bc	7.1b
Urea+phosphorous	7.5a	7.4bc	7.1b
Urea+potassium	7.6a	7.5bc	7.1b
1xF[§]	6.1dB	6.8cA	7.0bA
1xF+granular	5.7deB	7.4bA	7.7aA
2xF[¶]	6.5bcC	7.1cB	7.9aA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 42. Lsmean bentgrass color rating for the rootzone x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Color		
Rootzone			
USGA	6.2C‡	7.0A	6.6c†B
80-10-10	6.9	7.2	7.1b
Native	6.7B	7.3A	7.4aA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 43. Lsmean bentgrass quality rating for the fertilizer treatment x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Quality		
Fertilizer treatment			
Untreated control	5.5c†B‡	6.2dA	5.1dB
Natural organic	6.3b	7.5a	7.6a
Methylene urea	7.1a	7.3ab	7.6a
Urea	7.6a	7.3ab	7.3ab
Urea+phosphorous	7.5a	7.4a	7.2b
Urea+potassium	7.6a	7.5a	7.2ab
1xF§	6.4b	6.8c	6.6c
1xF+granular	6.3bB	7.4aA	7.1bA
2xF¶	6.1bcB	7.1bcA	7.5abA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 44. Lsmean bentgrass quality rating for the rootzone x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Quality		
Rootzone			
USGA	6.7	7.1	6.8
80-10-10	6.6	7.2	7.3
Native	6.2B†	7.3A	7.0A

† Letters represent significant differences at the 0.05 probability level in rows.

August 2009, 2010, and 2011

There was a significant fertilizer treatment x sampling date interaction for turfgrass color in August (Table 37). In 2009 and 2010, the urea, urea+P, and urea+K treatments had the highest turfgrass color ratings. In 2011, the 2xF and 1xF+granular had the highest color ratings (Table 47). These results suggest that the combination and foliar treatments started to have better turfgrass color in the third year of research. In 2009 and 2010, the 1xF had a low color rating which was only higher than the untreated control. However, in 2011 the 1xF had a color rating equal to the methylene urea, urea, and urea+P treatments. There was a significant rootzone effect for the August color rating (Table 37). The native soil rootzone had the highest color rating for all years in August (Table 48).

Table 45. Lsmean bentgrass chlorophyll rating for the fertilizer treatment x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Chlorophyll		
Fertilizer treatment			
Untreated control	0.565B‡	0.656e†A	0.570fB
Natural organic	0.600C	0.759aA	0.667bcdB
Methylene urea	0.585C	0.742bA	0.660cdB
Urea	0.584C	0.756aA	0.677abB
Urea+phosphorous	0.584C	0.758aA	0.666bcdB
Urea+potassium	0.600C	0.758aA	0.681aB
1xF§	0.600B	0.692dA	0.639eB
1xF+granular	0.570C	0.742bcA	0.656dB
2xF¶	0.596C	0.718cA	0.671abcB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 46. Lsmean bentgrass chlorophyll rating for the rootzone x sampling date interaction in June 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Chlorophyll		
Rootzone			
USGA	0.584C‡	0.721b†A	0.633bB
80-10-10	0.597C	0.741aA	0.659abB
Native	0.577C	0.732abA	0.670aB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

There was a significant fertilizer treatment x sampling date for turfgrass quality for August ratings (Table 37). The 1xF+granular and 2xF treatments had the highest quality ratings for August 2010 and 2011 (Table 49). These results suggest that the combination and foliar applications are more effective than granular fertilizers for creeping bentgrass under summer stress. For all sampling dates, fertilized treatments had better turfgrass quality than the untreated control (Table 49).

There was a significant fertilizer treatment x sampling date interaction for turfgrass chlorophyll ratings for the August sampling dates (Table 37). In August 2010, the 1xF, 2xF, and 1xF+granular treatments had the highest chlorophyll ratings (Table 50). In August 2011, the 2xF and natural organic treatments had the best chlorophyll ratings (Table 50). There was a significant rootzone x sampling date interaction for the August chlorophyll rating (Table 51). No difference was revealed among rootzones for August for the three years. The August 2009 sampling date had the best chlorophyll rating for all the rootzones (Table 51).

October 2009, 2010 and 2011

There was a significant fertilizer treatment x sampling date interaction for turfgrass color in October (Table 37). The urea, urea+P, and urea+K treatments had the best turfgrass color for all the three years in October (Table 52). There was a significant rootzone x sampling date interaction for turfgrass color in October (Table 37). The native soil rootzone had the highest color ratings in 2009 and 2010 sampling dates (Table 53).

Table 47. Lsmean bentgrass color rating for the fertilizer treatment x sampling date interaction in August 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
		Color	
Fertilizer treatment			
Untreated control	6.4c†A‡	6.1eA	5.3eB
Natural organic	7.2bA	7.8bA	8.0bcA
Methylene urea	7.5abB	7.8bcA	7.8cdA
Urea	7.7aB	8.2aA	7.7cdB
Urea+phosphorous	7.7aB	8.4aA	7.7cdB
Urea+potassium	7.7aB	8.4aA	7.6dB
1xF§	7.1bB	7.2dB	7.7cdA
1xF+granular	7.2bC	7.6cB	8.3aA
2xF¶	7.3bB	7.9bA	8.2abA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 48. Lsmean bentgrass color rating for the rootzone effect in August 2009, 2010, and 2011.

	Sampling date
	August
	Color
Rootzone	
USGA	7.4b†
80-10-10	7.4b
Native	7.6a
P value	<0.01

† Lower case letters represent significant differences at the 0.05 probability level.

Table 49. Lsmean bentgrass quality rating for the fertilizer treatment x sampling date interaction in August 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Quality		
Fertilizer treatment			
Untreated control	6.3b†A‡	6.1dA	5.2cB
Natural organic	7.1a	7.4bc	7.5b
Methylene urea	7.6a	7.5bc	7.5b
Urea	7.5aAB	7.3dB	7.7abA
Urea+phosphorous	7.5a	7.3c	7.5b
Urea+potassium	7.5a	7.2c	7.4b
1xF§	7.5a	7.3c	7.3b
1xF+granular	7.5aB	7.6abB	8.1aA
2xF¶	7.5a	7.7a	7.7ab

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 50. Lsmean bentgrass chlorophyll rating for the fertilizer treatment x sampling date interaction in August 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Chlorophyll		
Fertilizer treatment			
Untreated control	0.682c[†]A[‡]	0.649dB	0.623dC
Natural organic	0.706bc	0.679c	0.703a
Methylene urea	0.730ab	0.683bc	0.694b
Urea	0.746aA	0.671cC	0.692bB
Urea+phosphorous	0.746aA	0.676cB	0.693bAB
Urea+potassium	0.746aA	0.673cB	0.687bcB
1xF[§]	0.707bcA	0.688abcB	0.676cB
1xF+granular	0.713bA	0.695abB	0.693bB
2xF[¶]	0.744aA	0.700aB	0.697abB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 51. Lsmean bentgrass chlorophyll rating for the rootzone x sampling date interaction in August 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Chlorophyll		
Rootzone			
USGA	0.706A†	0.671C	0.681B
80-10-10	0.724A	0.683B	0.683B
Native	0.725A	0.685B	0.689B

† Capital case letters represent significant differences at the 0.05 probability level in columns.

There was a fertilizer treatment x sampling date interaction for turfgrass quality in October (Table 37). The urea, urea+P, and urea+K treatments had the best turfgrass quality for October 2009 (Table 54), which was similar to the October color rating results. For October 2010, the 2xF and 1xF+granular treatments had the highest quality ratings. For October 2011, the urea, urea+P, 2xF, and 1xF+granular treatments had the best turfgrass quality (Table 54). There was a significant rootzone x sampling date interaction for quality rating in October (Table 37). The highest quality rating was 7.6 obtained on the native soil in October 2009. There was no difference among rootzones on turfgrass quality for the 2010 and 2011 sampling dates (Table 55). Results of color and quality rating from April to October suggest that different rootzone did not play an important role in determining turfgrass color and quality when comparing the same month for three years.

There was a significant fertilizer treatment x sampling date interaction for turfgrass chlorophyll rating in October (Table 37). The urea, urea+P, and urea+K treatments had the best chlorophyll rating results for October 2009 (Table 56). The 2xF and 1xF+granular treatments had the highest chlorophyll ratings for October 2010 (Table 56). The urea, urea+K treatments had the best chlorophyll ratings in October 2011 (Table 56). There was a significant rootzone x sampling date interaction for October chlorophyll ratings (Table 37). No significant difference was revealed among rootzones for chlorophyll ratings for all sampling dates (Table 57).

Table 52. Lsmean bentgrass color rating for the fertilizer treatment x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	October 2009	October 2010	October 2011
	Color		
Fertilizer treatment			
Untreated control	5.9e†A‡	6.1eA	4.3eB
Natural organic	7.3bcB	7.8bA	7.1cC
Methylene urea	7.7bA	7.8bcA	7.2bcB
Urea	8.5aA	8.2aA	7.9aB
Urea+phosphorous	8.5aA	8.4aA	7.8aB
Urea+potassium	8.5aA	8.4aA	7.8aB
1xF§	7.1cdA	7.2dA	6.5dB
1xF+granular	7.0dB	7.6cA	7.2bcB
2xF¶	7.5bB	7.9bA	7.5bB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 53. Lsmean bentgrass color rating for the rootzone x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Color		
Rootzone			
USGA	6.9c†B‡	7.4bA	6.9B
80-10-10	7.2bB	7.8aA	6.9C
Native	7.8aA	7.9aA	7.2B

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 54. Lsmean bentgrass quality rating for the fertilizer treatment x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Quality		
Fertilizer treatment			
Untreated control	5.5e†B‡	5.9cA	5.0dC
Natural organic	7.3c	7.4b	7.4c
Methylene urea	7.8bA	7.4bB	7.6bcAB
Urea	8.4aA	7.3bC	7.7abcB
Urea+phosphorous	8.5aA	7.2bC	7.8abB
Urea+potassium	8.4Aa	7.3bB	7.5bcB
1xF§	6.7dB	7.3bA	7.5bcA
1xF+granular	6.8dB	7.7aA	7.8abA
2xF¶	7.2cB	7.6aAB	7.8aA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

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Table 55. Lsmean bentgrass quality rating for the rootzone x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Quality		
Rootzone			
USGA	6.7b†	7.2	7.2
80-10-10	7.0b	7.4	7.4
Native	7.6aA‡	7.3B	7.4B

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Clipping Dry Weight

There was a significant fertilizer treatment x sampling date interaction for turfgrass clipping dry weight (Table 58). The urea treatments had consistently the highest clipping dry weight values, except for the June 2011 sampling date, which the natural organic and methylene urea treatments resulted in the highest clipping weight (Table 59). The untreated control had the smallest amount of clippings for all sampling dates, along with the foliar treatments on the June and October 2011 sampling dates (Table 59). There was a significant rootzone x sampling date interaction for turfgrass clipping dry weight (Table 58). The native soil had the largest amount of clipping for all sampling dates (Table 60). However, there was no important trend for rootzones overtime.

There was a significant rootzone x fertilizer treatment interaction for turfgrass clipping dry weight (Table 58). For the USGA rootzone, the urea, urea+P, and urea+K treatments had the highest clipping dry weight values (Table 61). For the 80-10-10 and native soil, all the granular fertilizer treatments (natural organic, methylene urea, urea, urea+P, and urea+K) had larger amount of clippings than the foliar and combination treatments. For the native soil rootzone, 1xF, 2xF, and the combination treatments had statistically the same clipping dry weight with the untreated control (Table 61). This may be explained by the fact that the native soil rootzone provided more nutrients for the untreated control turfgrass to grow and generate top-growth.

Table 56. Lsmean bentgrass chlorophyll rating for the fertilizer treatment x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	2009	2010	2011
	Chlorophyll		
Fertilizer treatment			
Untreated control	0.604d[†]B[‡]	0.660dA	0.564eC
Natural organic	0.694cA	0.695bA	0.658bcB
Methylene urea	0.718bA	0.696bA	0.648cB
Urea	0.751aA	0.683cB	0.666abC
Urea+phosphorous	0.747aA	0.685cB	0.659bcC
Urea+potassium	0.743aA	0.689bcB	0.671aB
1xF[§]	0.666cB	0.696bA	0.624dC
1xF+granular	0.670cB	0.706aA	0.652cC
2xF[¶]	0.699bA	0.710aA	0.655bcB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

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Table 57. Lsmean bentgrass chlorophyll rating for the rootzone x sampling date interaction in October 2009, 2010, and 2011.

	Sampling date		
	October 2009	October 2010	October 2011
	Chlorophyll		
Rootzone			
USGA	0.683A†	0.682A	0.628B
80-10-10	0.698A	0.695A	0.647B
Native	0.717A	0.697B	0.658C

† Letters represent significant differences at the 0.05 probability level in rows.

Ball Roll Distance

There was a significant fertilizer treatment effect for ball roll distance in 2010 and 2011 (Table 62). The untreated control had the longest ball roll distance of 242.9 cm (Table 63), and the natural organic treatment had the shortest ball roll distance of 221.0 cm. Organic fertilizers increase soil microbial and fungal activities, and keep a sustainable reservoir of nutrient by its nature of slow release fertilizer (Dorer and Peacock, 1997). However, the natural organic treatment did not result in better turfgrass color and quality, and the 20 cm difference between the untreated control and natural organic treatments would not raise concerns for 50% golfers (Karcher et al., 2001). There was a significant rootzone effect for ball roll distance for 2010 and 2011 (Table 62). The USGA and 80-10-10 rootzones had longer ball roll distance than the native soil (Table 64).

Water Infiltration Rate

There was a significant rootzone x sampling date interaction for water infiltration rate (Table 65). In October 2010, the USGA rootzone had the highest water infiltration rate followed with 80-10-10, and in October 2011, 80-10-10 and native soil had statistically the same low water infiltration rate compared to the USGA rootzone (Table 66).

Table 58. Analysis of variance results for bentgrass clipping dry weight for 2009, 2010, and 2011.

Contrasts	Clipping dry weight
	g
Rootzone (R)	*
Fertilizer treatment (F)	*
R x F	*
Sampling date (S)	*
R x S	*
F x S	*
R x F x S	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 59. Lsmean bentgrass clipping dry weight for the fertilizer treatment x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	g				
Fertilizer treatment					
Untreated control	15.9d[†]A[‡]	4.8cB	4.1bB	15.7bcA	12.2bcA
Natural organic	20.5bcB	16.6aB	8.6aC	27.0aA	17.1aB
Methylene urea	26.2aA	13.4aC	8.3aD	22.6abB	13.5bcC
Urea	25.4aA	15.4aB	5.6abC	20.5bA	15.9abB
Urea+phosphorous	25.4aA	16.3aB	5.3abC	21.4abA	15.7abB
Urea+potassium	25.4aA	16.3aB	5.4abC	20.0bA	14.9abB
1xF[§]	18.1cA	7.0bC	7.5abC	17.3bcA	10.7cB
1xF+granular	19.3cA	13.5aB	5.6abC	12.8cB	10.6cB
2xF[¶]	23.6abA	7.5bC	5.8abC	21.3abA	13.1bcB

[†] Lower case letters represent significant differences at the 0.05 probability level in columns.

[‡] Capital letters indicate significant differences at the 0.05 probability level in rows.

[§] Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

[¶] Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 60. Lsmean bentgrass clipping dry weight for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Clipping dry weight (g)				
Rootzone					
USGA	14.8b[†]A[‡]	8.8bB	2.5cC	11.1cAB	8.5cB
80-10-10	21.7aA	12.7aB	4.3Cb	17.5bAB	9.5bBC
Native	27.4aB	15.4aC	11.9aC	31.0aA	23.3aB

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

Table 61. Lsmean bentgrass clipping dry weight for the rootzone x fertilizer treatment interaction.

	Rootzone		
	USGA	80-10-10	Native
	g		
Fertilizer treatment			
Untreated control	5.4c[†]B[‡]	8.0cB	18.3bA
Natural organic	9.5bC	14.0abB	30.4aA
Methylene urea	9.6bC	14.4aB	26.4aA
Urea	11.5aB	16.6aB	21.6abA
Urea+phosphorous	12.2aB	15.7aB	21.3abA
Urea+potassium	11.4aB	13.3abB	22.0abA
1xF[§]	6.8cB	10.5bB	19.0bA
1xF+granular	7.8bcB	12.9bAB	16.3bA
2xF[¶]	9.3bB	12.8bB	20.7bA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 62. Analysis of variance results for bentgrass ball roll distance for 2010 and 2011.

Contrasts	Ball roll distance
	cm
Rootzone (R)	*
Fertilizer treatment (F)	*
R x F	NS
Sampling date (S)	*
R x S	NS
F x S	NS
R x F x S	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 63. Lsmean bentgrass ball roll distance for the fertilizer treatment effect for 2010 and 2011.

Contrasts	Ball roll distance
	cm
Fertilizer treatment	
Untreated control	242.9a[†]
Natural organic	221.0c
Methylene urea	227.8b
Urea	227.9b
Urea+phosphorous	230.4b
Urea+potassium	229.8b
1xF[‡]	230.8b
1xF+granular	227.0b
2xF[§]	229.3b
P value	<0.01

† Lower case letters represent significant differences at the 0.05 probability level.

‡ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

§ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 64. Lsmean bentgrass ball roll distance for the rootzone effect for 2010 and 2011.

	Ball roll distance
	cm
Rootzone	
USGA	236.2a†
80-10-10	230.3a
Native	222.5b
P value	0.01

† Lower case letters represent significant differences at the 0.05 probability level.

Table 65. Analysis of variance results for water infiltration rate for October 2010 and 2011.

Contrasts	Water infiltration rate
	cm/hr
Rootzone (R)	*
Fertilizer treatment (F)	NS
R x F	NS
Sampling date (S)	*
R x S	*
F x S	NS
R x F x S	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 66. Lsmean bentgrass water infiltration rate for the rootzone effect for October 2010 and 2011.

	Sampling date	
	2010	2011
	Water infiltration rate (cm/hr)	
Rootzone		
USGA	22.3a†	25.5a
80-10-10	12.0b	8.1b
Native	1.5c	1.1b

† Letters represent significant differences at the 0.05 probability level in coloum.

Dollar Spot Occurrence

Dollar spot occurrence was rated based on observation. Therefore results were reported for each sampling date. There was a significant fertilizer treatment effect for dollar spot occurrence on July 18, August 23, and September 7, 2010 (Table 67). On July 18, 2010, the natural organic, urea+P, urea+K, 1xF+granular, and 2xF treatments had the most dollar spot occurrence (Table 68). For the three sampling dates, the untreated control had the least dollar spot amount compared to the fertilized treatments. Previous research has observed that natural organic fertilizer suppresses dollar spot occurrence (Liu et al., 1995; Landchoot, 1997; Davis and Dernoeden, 2002). However, results from this research show that natural organic fertilizer did not reduce dollar spot occurrence. Instead of forms of fertilizer, the rates of nitrogen fertilizer may affect dollar spot occurrence, with lower N rates decreasing dollar spot.

There was a significant rootzone effect for dollar spot occurrence on July 18, 2010 and August 23, 2010 (Table 67). The USGA rootzone had the most dollar spot counts for both rating dates (Table 69). Low soil moisture and low nitrogen has been reported to enhance dollar spot severity (Vargas, 1994; Kaminski et al., 2004). The USGA rootzone, which has relatively low moisture and nutrient retention ability, is more favorable for dollar spot activity.

Table 67. Analysis of variance results for dollar spot occurrence for 2010 and 2011.

Contrasts	Date				
	7/18/2010	8/23/2010	9/7/2010	7/6/2011	8/29/2011
	Dollar spot occurance (count)				
Rootzone (R)	*	NS	*	NS	NS
Fertilizer treatment (F)	*	*	*	NS	NS
R x F	NS	NS	NS	NS	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 68. Lsmean bentgrass dollar spot occurance for the fertilizer treatment effect.

Fertilizer treatment	Date		
	7/18/2010	8/23/2010	9/7/2010
	Dollar spot occurance (count)		
Untreated control	1.3c†	7.0c	10.1b
Natural organic	13.2a	28.4ab	51.8a
Methylene urea	5.2b	24.2ab	50.3a
Urea	5.2b	21.5ab	43.6a
Urea+phosphorous	12.3ab	26.7ab	59.0a
Urea+potassium	8.6ab	33.0ab	59.7a
1xF‡	3.3bc	19.8b	40.2a
1xF+granular	10.0ab	36.7ab	61.7a
2xF§	6.5ab	41.7a	79.1a
P value	0.03	0.01	0.01

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

§ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 69. Lsmean bentgrass dollar spot occurance for the rootzone effect.

	Date	
	7/18/2010	9/7/2010
	Dollar spot occurance (count)	
Rootzone		
USGA	11.9a†	64.5a
80-10-10	5.0b	56.6a
Native	4.9b	30.8b
P value	0.02	0.01

† Lower case letters represent significant differences at the 0.05 probability level in columns.

Worm Casting Occurrence

Worm casting occurrence was rated based on observation. Therefore, results are reported for each sampling date. There was a significant fertilizer treatment x rootzone interaction for worm casting occurrence for all sampling dates in 2010 and 2011 (Table 70). The USGA rootzone had the least or no worm castings, and the native soil had the most worm casting counts for all sampling dates in 2010 and 2011 (Tables 71-76). For the 80-10-10 rootzone, the untreated control had the highest amount of worm castings for all sampling dates, along with the 1xF for the September 14, 2010 and July 29, 2010 sampling dates (Tables 71-76). For the native soil, the untreated control had the most worm castings for all sampling dates, along with natural organic and methylene urea for the July 30, 2010 and August 6, 2011 sampling dates. These results suggest that fertilization could reduce the severity of worm casts on the 80-10-10 and native soil rootzones. The most worm casting mounds on the native soil among the sampling dates was counted on August 6, 2011 (Table 75).

Table 70. Analysis of variance results for worm casting occurance for 2010 and 2011.

Contrasts	Date					
	7/30/2010	8/13/2010	9/14/2010	7/29/2011	8/6/2011	9/2/2011
	Worm casting occurance (count)					
Rootzone (R)	*	*	*	*	*	*
Fertilizer treatment (F)	*	*	*	*	*	*
R x F	*	*	*	*	*	*

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 71. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on July 30, 2010.

	Rootzone		
Fertilizer treatment	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	0B‡	35a†A	56aA
Natural organic	3C	27bB	67aA
Methylene urea	0C	23bB	48abA
Urea	3B	20bA	36abA
Urea+phosphorous	0B	28bA	20bA
Urea+potassium	0C	9cB	20bA
1xF§	1C	21bB	50aA
1xF+granular	2B	23bB	29abA
2xF¶	0C	14bcB	31abA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 72. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on August 13, 2010.

Fertilizer treatment	Rootzone		
	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	0C‡	52a†B	107aA
Natural organic	4B	29bB	45bcA
Methylene urea	0C	25bB	44bcA
Urea	2C	16bcB	35bcA
Urea+phosphorous	1B	23bA	18cA
Urea+potassium	0C	9cB	25cA
1xF§	2C	32bB	81bA
1xF+granular	2B	28bA	25cA
2xF¶	0C	17bcB	40bcA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 73. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on September 14, 2010.

Fertilizer treatment	Rootzone		
	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	1C[‡]	50a[†]B	154aA
Natural organic	2C	22bB	62bcA
Methylene urea	0C	19bcB	64bcA
Urea	0C	12cB	40cA
Urea+phosphorous	0B	12cB	21dA
Urea+potassium	0B	12cB	25dA
1xF[§]	1C	30abB	94bA
1xF+granular	6C	19bcB	51cA
2xF[¶]	0C	15bcB	44cA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 74. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on July 29, 2011.

Fertilizer treatment	Rootzone		
	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	0B‡	15a†B	89aA
Natural organic	0B	4bB	46bA
Methylene urea	0B	5bB	44bA
Urea	0B	6bB	33bcA
Urea+phosphorous	0B	10abB	26cA
Urea+potassium	0B	3bB	26cA
1xF§	0B	7abB	33bcA
1xF+granular	0B	1bB	25cA
2xF¶	0B	2bB	38bcA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 75. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on August 6, 2011.

Fertilizer treatment	Rootzone		
	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	0C‡	23a†B	223aA
Natural organic	0C	13abcB	214abA
Methylene urea	0C	14abcB	189abA
Urea	2C	12abcB	159abcA
Urea+phosphorous	0C	19abB	66dA
Urea+potassium	1B	7bcB	95cdA
1xF§	0C	13abcB	140bcdA
1xF+granular	0B	6cB	90cdA
2xF¶	0B	3cB	92cdA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table 76. Lsmean bentgrass worm casting occurance for the rootzone x fertilizer treatment interaction on September 2, 2011.

Fertilizer treatment	Rootzone		
	USGA	80-10-10	Native
	Worm casting (count)		
Untreated control	1B‡	15a†B	173aA
Natural organic	0B	5bcB	119bA
Methylene urea	0B	5bcB	103bcA
Urea	1B	7bcB	91cdA
Urea+phosphorous	0B	10abB	75dA
Urea+potassium	1B	4bcB	74dA
1xF§	0B	7bcB	97cA
1xF+granular	0B	4bcB	83cdA
2xF¶	0B	2cB	72cA

† Lower case letters represent significant differences at the 0.05 probability level in columns.

‡ Capital letters indicate significant differences at the 0.05 probability level in rows.

§ Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

¶ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Annual Bluegrass Invasion

There was a significant fertilizer treatment effect for *Poa annua* invasion (Table 77). The natural organic treatment had the largest percentage of *Poa annua* invasion (Table 78). The reason could be that the natural organic fertilizer had the largest percentage of water insoluble nitrogen given that all the granular fertilizers were applied at the same rate. Therefore, the natural organic treatment provides a more consistent nutrient reservoir favoring *Poa annua* invasion. The untreated control, urea, urea+P, and urea+K treatments had the smallest amount of annual bluegrass invasion. This result is in contrast to Hardt and Schulz (1995)'s conclusion that Ureaform-fertilized bentgrass was more susceptible to annual bluegrass invasion than IBDU, natural organic N (horn meal), and mineral N (ammonium nitrate) applications at the rate of 20, 40 or 80 g m^{-2} $year^{-1}$.

Table 77. Analysis of variance results for annual bluegrass invasion on May 20, 2011.

	Poa invasion
Contrasts	%
Rootzone (R)	NS
Fertilizer treatment (F)	*
R x F	NS

*, and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table 78. Lsmean annual bluegrass invasion for the fertilizer treatment effect on May 20, 2011.

	Date
	May 20, 2011
Fertilizer treatment	Poa invasion %
Untreated control	3.4d[†]
Natural organic	19.8a
Methylene urea	8.5b
Urea	3.1d
Urea+phosphorous	3.1d
Urea+potassium	3.8d
1xF[‡]	6.5bc
1xF+granular	4.6cd
2xF[§]	7.4bc
P value	<0.01

[†] Lower case letters represent significant differences at the 0.05 probability level.

[‡] Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

[§] Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

CONCLUSIONS

The native soil rootzone had the highest soil nitrogen, phosphorous, and potassium concentration compared with the 80-10-10 and USGA rootzones. The granular fertilizers (natural organic, methylene urea, urea, urea+K, and urea+P) tend to have higher soil nitrate nitrogen concentration than the foliar and combination treatments (1xF, 2xF, and 1xF+granular). The urea+P treatment did not result in a higher soil P content, and the untreated control did not result in lower soil P concentration than other fertilizer treatments on any of the rootzones. The urea+K treatment did not result in a higher soil K content. In addition, a high soil K concentration for the untreated control was observed, indicating less turfgrass growth for the untreated control, thereby less tissue K absorption from the soil.

In contrast to the soil N, P, and K analysis, tissue N, P, and K analysis revealed that the native soil rootzone had the lowest tissue N, P, and K concentration compared with the 80-10-10 and USGA rootzones. Tissue total N and P values for the native rootzone are under the turfgrass common sufficiency range of 2.8-3.5% and 0.2-0.5% (Carrow et al. 2001), respectively, for the October 2010, June 2011, and October 2011 sampling dates. These results suggest that soil nitrogen, phosphorous, and potassium test results could not reflect nitrogen, phosphorous, and potassium nutrient status in turfgrass tissue. Tissue analysis may need to be considered when assessing nutrient status and making recommendations.

The urea+P and 2xF treatments maintained high tissue P concentration on both October 2010 and October 2011 sampling dates, suggesting that the 2xF treatment may have similar effects in improving tissue P content as P supplement in the Urea+P fertilizer treatment. K supplement in the urea+K treatment is effective in improving turfgrass tissue K across rootzones overtime. Contrary to soil K result as previously discussed, the untreated control had the lowest tissue K values across all sampling dates.

For the first year of fertilizer application in 2009, the urea treatment had the best turf color and quality for all sampling dates. The double-rate foliar treatment was as effective as the slow-release fertilizer treatments (natural organic and methylene urea) for turfgrass color and quality in 2009. The combination and single-rate foliar treatments had the lowest turfgrass color ratings among fertilized treatments in 2009. For 2010 and 2011 sampling dates, the granular fertilizer treatments (natural organic, methylene urea, and urea) had better turfgrass color and quality in the late fall and faster green up speed in the spring. Foliar applications result in better turfgrass color and quality for the August sampling date, when creeping bentgrass is under summer stress. Root growth is limited and is more sensitive to heat and drought stress than shoots. In August 2010, the 1xF treatment had higher chlorophyll ratings than the urea treatment, suggesting that foliar application at half rate could be more effective in maintaining turfgrass color than the full rate urea treatment when bentgrass is under summer stress in August. The USGA rootzone usually has lower color and quality ratings in April and June sampling dates compared with the 80-10-10 and native soil rootzones.

The natural organic treatment had the shortest ball roll distance of 221.0 cm, yet it did not result in better turfgrass color and quality, and the 20 cm difference between the untreated control and natural organic treatments would not raise concerns for golf players. The natural organic treatment had the largest percentage of annual bluegrass invasion, which is contrary to Hardt and Schulz (1995)'s conclusion that Ureaform-fertilized bentgrass was more susceptible to annual bluegrass invasion than IBDU, natural organic N (horn meal), and mineral N (ammonium nitrate) applications at the rate of 20, 40 or 80 g m^{-2} $year^{-1}$. The natural organic fertilizer did not reduce dollar spot occurrence, which is contrary to some literature articles (Liu et al. 1995, Landchoot 1997, Davis and Dernoeden 2002). Additionally, instead of forms of fertilizer, the rates of nitrogen fertilizer may affect dollar spot occurrence, with lower rate decreasing dollar spot. The USGA rootzone had the most dollar spot counts, because of its relatively low moisture and nutrient retention ability, which is more favorable for dollar spot activity.

APPENDIX

Table A1. Analysis of variance for soil calcium (Ca) and magnesium (Mg) of Penn 'A-4' creeping bentgrass in 2009, 2010, and 2011.

	Soil nutrient test	
	Ca	Mg
Contrasts	Pr>F	
Rootzone (R)	*	*
Fertilizer treatment (F)	NS	NS
R x F	NS	NS
Sampling date (S)	*	*
R x S	*	*
F x S	NS	NS
R x F x S	NS	NS

* and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table A2. Lsmean bentgrass soil calcium (Ca) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Soil Ca (ppm)				
Rootzone					
USGA	1062.33	1016.63	1163.33	1277.85	1152.78
80-10-10	1093.48	1169.67	1118.93	1394.59	1259.26
Native	1421.95	1360.89	1436.26	1639.63	1533.81

Table A3. Lsmean bentgrass soil magnesium (Mg) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Soil Mg (ppm)				
Rootzone					
USGA	84.04	88.29	116.22	99.48	95.18
80-10-10	99.33	103.37	124.67	104.52	89.29
Native	219.24	218.33	241.48	233.44	237.74

Table A4. Analysis of variance for tissue nutrients of Penn ‘A-4’ creeping bentgrass in 2009, 2010, and 2011.

	Tissue nutrient test									
Contrasts	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Al	Na
	Pr>F									
Rootzone (R)	NS	NS	*	*	*	NS	*	*	*	NS
Fertilizer treatment (F)	*	*	*	*	*	*	*	*	*	NS
R x F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sampling date (S)	*	*	*	*	*	*	*	*	*	*
R x S	*	*	*	*	*	*	*	*	*	NS
F x S	*	*	*	*	*	*	*	*	*	NS
R x F x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* and NS indicate significance at P=0.05, and not significant at P=0.05 level, respectively.

Table A5. Lsmean creeping bentgrass tissue calcium (Ca) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Ca (%)				
Untreated control	2.36	1.12	2.25	3.08	2.68
Natural organic	1.96	1.14	1.67	1.61	1.60
Methylene urea	1.58	1.31	1.71	1.89	1.22
Urea	1.65	1.84	1.36	1.74	1.16
Urea+phosphorous	1.65	1.85	1.44	1.72	1.17
Urea+potassium	1.65	1.66	1.27	1.56	1.05
1xF†	1.81	1.17	2.00	1.76	1.72
1xF+granular	1.89	1.25	1.81	1.65	1.35
2xF‡	1.69	1.17	1.61	1.59	1.13

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A6. Lsmean bentgrass tissue calcium (Ca) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Rootzone	Tissue Ca (%)				
USGA	2.22	1.40	1.13	1.82	1.34
80-10-10	1.81	1.41	1.86	1.72	1.36
Native	1.50	1.36	2.03	2.00	1.67

Table A7. Lsmean creeping bentgrass tissue magnesium (Mg) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Mg (%)				
Untreated control	0.61	0.34	0.62	0.81	0.67
Natural organic	0.50	0.39	0.47	0.52	0.41
Methylene urea	0.43	0.36	0.48	0.57	0.34
Urea	0.44	0.44	0.39	0.54	0.32
Urea+phosphorous	0.44	0.45	0.43	0.53	0.33
Urea+potassium	0.44	0.42	0.38	0.49	0.30
1xF†	0.48	0.35	0.54	0.53	0.47
1xF+granular	0.51	0.35	0.47	0.52	0.37
2xF‡	0.45	0.33	0.46	0.52	0.31

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A8. Lsmean bentgrass tissue magnesium (Mg) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Mg (%)				
Rootzone					
USGA	0.55	0.38	0.33	0.55	0.36
80-10-10	0.50	0.39	0.53	0.54	0.38
Native	0.42	0.37	0.56	0.59	0.44

Table A9. Lsmean creeping bentgrass tissue sulfur (S) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue S (%)				
Untreated control	0.35	0.56	0.21	0.27	0.25
Natural organic	0.36	0.55	0.26	0.47	0.29
Methylene urea	0.37	0.51	0.27	0.45	0.33
Urea	0.36	0.44	0.29	0.46	0.33
Urea+phosphorous	0.36	0.42	0.29	0.44	0.32
Urea+potassium	0.36	0.44	0.37	0.68	0.35
1xF†	0.37	0.55	0.20	0.42	0.29
1xF+granular	0.37	0.49	0.24	0.46	0.31
2xF‡	0.36	0.52	0.28	0.47	0.33

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A10. Lsmean bentgrass tissue sulfur (S) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue S (%)				
Rootzone					
USGA	0.36	0.48	0.34	0.53	0.38
80-10-10	0.37	0.52	0.29	0.51	0.36
Native	0.35	0.50	0.17	0.33	0.20

Table A11. Lsmean creeping bentgrass tissue iron (Fe) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Fe (%)				
Untreated control	3380.33	1689.11	8379.89	5521.11	4228.89
Natural organic	2903.22	1674.33	5995.11	2939.67	2379.56
Methylene urea	2281.44	2418.33	5253.56	2863.89	1750.11
Urea	2420.11	4008.67	4666.56	2617.33	1747.11
Urea+phosphorous	2420.11	3375.78	5326.33	2645.56	2064.00
Urea+potassium	2420.11	3240.33	3868.44	2071.11	1861.22
1xF†	2546.67	1740.11	7362.22	3431.89	2742.00
1xF+granular	2751.44	2330.00	6564.78	2589.67	2507.89
2xF‡	2511.67	1573.33	4861.44	2708.56	1840.89

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A12. Lsmean bentgrass tissue iron (Fe) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Fe (%)				
Rootzone					
USGA	2498.29	2409.48	2727.70	2066.56	1512.81
80-10-10	2597.00	2455.63	6118.11	2285.56	1775.81
Native	2959.67	2484.89	8580.30	4777.48	3751.93

Table A13. Lsmean creeping bentgrass tissue manganese (Mn) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Mn (%)				
Untreated control	86.56	88.00	108.22	105.44	99.11
Natural organic	79.78	80.00	85.89	72.89	60.44
Methylene urea	69.56	75.11	80.11	73.00	50.22
Urea	68.44	88.11	70.44	70.44	49.89
Urea+phosphorous	68.44	87.33	75.89	70.56	54.44
Urea+potassium	68.44	85.44	69.78	70.89	51.33
1xF†	74.44	84.89	99.22	80.00	65.67
1xF+granular	79.11	82.89	90.33	73.33	61.22
2xF‡	70.33	77.00	81.56	69.78	50.78

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A14. Lsmean bentgrass tissue magnesium (Mn) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Mn (%)				
Rootzone					
USGA	70.76	78.67	53.70	59.81	49.04
80-10-10	77.10	80.48	84.22	65.70	48.70
Native	78.52	90.44	115.89	103.26	83.30

Table A15. Lsmean creeping bentgrass tissue zinc (Zn) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Zn (%)				
Untreated control	30.67	61.78	52.00	29.22	41.11
Natural organic	33.67	73.33	49.78	44.00	40.00
Methylene urea	34.33	66.78	49.11	41.33	36.44
Urea	32.56	74.00	46.78	40.22	39.00
Urea+phosphorous	35.44	79.22	48.11	39.00	37.33
Urea+potassium	34.56	72.00	44.56	40.44	35.89
1xF†	33.56	68.33	49.78	40.78	39.56
1xF+granular	36.67	68.67	50.44	46.89	41.11
2xF‡	35.44	66.44	53.11	43.67	43.11

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A16. Lsmean bentgrass tissue zinc (Zn) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Zn (%)				
Rootzone					
USGA	32.70	72.59	42.96	49.41	38.56
80-10-10	34.63	72.11	50.81	41.81	37.44
Native	34.96	65.48	54.11	30.63	41.85

Table A17. Lsmean creeping bentgrass tissue copper (Cu) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Cu (%)				
Untreated control	9.89	27.00	83.89	13.67	89.00
Natural organic	11.00	29.67	62.11	16.00	53.44
Methylene urea	11.11	38.56	56.22	14.78	42.00
Urea	10.56	59.56	49.22	15.22	46.56
Urea+phosphorous	10.56	50.89	61.11	14.11	44.22
Urea+potassium	10.56	51.11	44.22	14.33	39.67
1xF†	11.33	29.11	75.33	17.78	58.00
1xF+granular	11.89	34.11	67.67	18.44	51.78
2xF‡	12.33	28.00	52.11	21.00	45.89

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A18. Lsmean bentgrass tissue copper (Cu) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Cu (%)				
Rootzone					
USGA	10.10	27.23	33.04	18.11	32.67
80-10-10	11.71	29.66	63.33	16.41	37.30
Native	11.67	34.74	87.59	13.93	86.89

Table A19. Lsmean creeping bentgrass tissue boron (B) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue B (%)				
Untreated control	4.78	9.56	6.89	4.89	2.00
Natural organic	4.78	8.67	6.11	5.33	2.00
Methylene urea	4.78	8.56	5.78	5.33	2.56
Urea	4.67	8.33	6.56	5.67	2.44
Urea+phosphorous	4.67	7.78	5.67	5.33	2.56
Urea+potassium	4.67	9.11	5.00	6.44	2.11
1xF†	4.56	9.33	7.44	6.00	2.67
1xF+granular	5.22	9.11	6.56	6.67	2.33
2xF‡	4.33	9.44	6.00	5.89	2.56

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A 20. Lsmean bentgrass tissue boron (B) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue B (%)				
Rootzone					
USGA	5.05	9.26	5.56	6.52	3.22
80-10-10	4.71	8.30	6.52	5.96	2.44
Native	4.43	9.07	6.59	4.70	1.41

Table A21. Lsmean creeping bentgrass tissue aluminum (Al) for the rootzone x fertilizer treatment interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
Fertilizer treatment	Tissue Al (%)				
Untreated control	550.89	496.78	3018.78	961.00	2486.11
Natural organic	522.89	588.44	2270.44	683.11	1478.78
Methylene urea	431.67	929.00	2025.67	638.33	1148.78
Urea	439.89	1593.11	1705.56	560.67	1206.22
Urea+phosphorous	399.33	1396.33	1824.11	544.11	1126.33
Urea+potassium	403.44	1424.11	1483.33	467.00	988.56
1xF†	476.00	556.67	2719.89	666.89	1539.56
1xF+granular	473.00	804.22	2377.56	552.89	1276.22
2xF‡	398.33	505.44	1818.00	503.11	1080.22

† Gary's Green foliar fertilizer treatment at the rate of 6.1 kg N ha^{-1} per application.

‡ Gary's Green foliar fertilizer treatment at the rate of 12.2 kg N ha^{-1} per application.

Table A22. Lsmean bentgrass tissue aluminum (Al) for the rootzone x sampling date interaction.

	Sampling date				
	October 2009	June 2010	October 2010	June 2011	October 2011
	Tissue Al (%)				
Rootzone					
USGA	326.85	851.07	847.52	301.89	713.22
80-10-10	425.56	892.15	2030.89	408.81	854.37
Native	612.74	1021.48	3536.04	1148.33	2542.67

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