Foliar and Granular Nitrogen Fertilization of Bentgrass

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 14, 2013

Keywords: nitrogen, foliar, granular, urea, bentgrass, fertilizer

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Abstract

Creeping bentgrass, (*Agrostis stolenifera* L.), is the most widely used cool-season turfgrass for golf course putting greens. Creeping bentgrass is a fine-textured, stoloniferous, perennial with exceptional cold tolerance. Maintaining creeping bentgrass in the hot humid climate of the Southeast poses challenges for golf course superintendents in the summer, when drought, heavy traffic and low mowing height create stress. Although newer cultivars have been developed to cope with the climate in the South, maintenance of bentgrass still requires frequent and intensive inputs to maintain acceptable turf. Fertilization is a key cultural practice in order to promote a healthy turf. Foliar fertilization of turfgrass may provide advantages over granular application, including rapid turf response to the foliar nutrients, reduced fertilizer input, minimized potential losses by leaching and runoff, and the advantage of applying low rates of fertilizer when turf is under stress. Nitrogen is the main nutrient in a turfgrass fertilization program, and is responsible for maintaining turfgrass shoot density, recovery from stress, shoot growth rate, color and quality. Previous research has shown that foliar applied N is absorbed by transcuticular pores, has low volatility, and that time of day of application has little effect on N uptake. However, little is known about appropriate foliar rates of N for maintenance of bentgrass in the humid South, or timing of that N in conjunction with irrigation. The research objectives of this study were to examine the combined and separate effects of foliar N rate and timing of irrigation on the color, quality, shoot density, root growth and carbohydrate status of a creeping bentgrass putting green. The study was a two-year experiment conducted at the Auburn University Turfgrass Research Unit (TGRU), located in Auburn, AL. Treatments were 4 rates of N (0.5, 1.0, 2.0 and 4.0 g m^{-2}) and 3 methods of fertilizer application (granular watered in, foliar watered in, and foliar not watered in). In general, N rate most affected turf color and quality, with color typically increasing as N rate increased, regardless of the method of application. The only exception to this was in summer, when high rates of foliar N without a following irrigation created turf leaf-tip burn, lowering quality. Overall, N applied as a foliar treatment provided excellent turf quality, but the highest one time application of 4.0 g m^{-2} should be applied as a split application within the month.

Acknowledgments

First and foremost I would like to thank Dr. Guertal for everything she has done for me throughout my years here at Auburn University. I would also like to thank the members of my graduate committee, Dr. Han, Dr. Wood, and Dr. Higgins, for their guidance and cooperation. A special thanks to Jim Harris, Bill Bryce, and their staff for helping me with field work as well as work in the lab.

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Introduction

Creeping bentgrass (*Agrostis stolonifera* L.), is a fine-textured, stoloniferous, perennial with exceptional cold tolerance. It has become the most widely used cool-season turfgrass for golf course putting greens in the United States. In the Southeast however, maintaining creeping bentgrass in hot, humid climates poses challenges, especially when drought, heavy traffic and low mowing height create stress (Glinski et al., 1992). Superintendents in the Southeast find themselves applying frequent and intensive inputs (fertilizers, fungicides and irrigation) in order to maintain acceptable turf.

Summer quality decline or heat tolerance of creeping bentgrass varies between cultivars and could be due to changes in morphological and physiological factors (Beard, 1999; Xu and Huang, 2000). A random crossing of three vegetatively propagated clonal strains in 1954 produced the creeping bentgrass cultivar 'Penncross'. This cultivar became the most widely used cool season turfgrass on golf greens, providing a dense, smooth and uniform playing surface (Salaiz et al., 1995). However, creeping bentgrass growth in the transition zone and Southeast is limited due to heat stress (Xu and Huang, 2001a). In recent years researchers have developed other cultivars of creeping bentgrass, such as 'Penn A-4', providing new lines of bentgrass with heat and drought tolerance (Fraser, 1998). Newer varieties of creeping bentgrass are becoming more popular, offering significant improvements in turfgrass quality, putting characteristics, color and density (NTEP, 2008)

Once creeping bentgrass has established, mechanical practices such as vertical mowing, core cultivation, grooming and topdressing are all used to manage the thatch layer (McCarty et al., 2007). Excessive thatch is associated with negative physical and biological effects on the soil profile, including poor water infiltration (Murray and Juska, 1977), increases in localized dry spots (Cornman, 1952) and reduction in pesticide effectiveness (Cornman, 1952; Musser, 1960; Miller, 1965; Thompson, 1967).

Core cultivation provides benefits to the soil environment, such as reduced surface compaction, improved water infiltration, and increased surface aeration and rooting (Carrow et al., 1987; Dunn et al., 1995; White and Dickens, 1984). Eggens (1980) found that coring and vertical mowing (the use of a high-speed machine with vertically rotating blades that slice into the turf to reduce thatch and improve soil aeration) on creeping bentgrass, followed by topdressing, was more effective at controlling thatch than topdressing alone; coring also reduced thatch accumulation more than vertical mowing. Topdressing decreased thatch accumulation by improving the microenvironment for thatch decomposition (Thompson and Ward, 1966; Ledeboer and Skogley, 1967).

Management practices such as syringing (Dipaola, 1984), cooling fans (Guertal et al., 2005) and subsurface cooling aeration (Dodd et al., 1999; Camberato et al., 1999) are used to lower soil temperature in order to improve growth under heat stress. Syringing is the application of a fine spray of water to the leaf surface of stressed turf, and large fans (0.5 to 1 m diam.) are used to produce air movement across the surface of the green when vegetation and/or terrain impedes the flow of air (Guertal et al., 2005).

The most important component of a turfgrass management program is fertilization (Waddington et al., 1978). Turfgrasses are fertilized via soil application, targeting the roots (granular), liquid fertilization targeting the foliar part of the plant and/or roots (foliar), or a mixture of these two methods (Totten et al., 2008). The application of slow release granular fertilizer on golf greens provides nutrients for a longer period, while nutrients applied via foliar fertilizers have the risk of being removed with daily cutting (Bowman and Paul, 1990a; Mancino et al., 2001). A rapid turf response, reduced fertilizer input, advantages of applying low rates of fertilizer when turf is under stress, and minimized potential losses via leaching and runoff may be a few of the advantages of foliar fertilization (Liu et al., 2008).

Increased use of foliar fertilization on golf courses are partly due to the increasing diversity of foliar fertilizers. Foliar fertilizers are usually sold as liquids, and are typically a complete analysis (N-P-K). The ability to combine foliar fertilizers with other macronutrients, fungicides, and pesticides allows high-maintenance putting greens to be managed efficiently (Totten et al., 2008). Although superintendents have been using foliar fertilizers for years, some are concerned about converting solely to a foliar program from standard granular applications because nutrient uptake by leaves is often less than that via roots (Kopec, 2001). Limited research has been done on year-round N applications comparing granular and foliar applications on bentgrass greens in the southeast.

Leaf Structure and Uptake

Cool-season grasses are C_3 plants, due to their photosynthetic pathways (Fry and Huang, 2004). In this pathway, photosynthesis mainly takes place in leaf mesophyll cells containing chloroplasts, which are used for absorbing light for photosynthesis. Covered with a thin cuticular wax layer, the epidermis is the outermost cell layer (Fry and Huang, 2004). Small transcuticular pores in the wax layer are responsible for absorbing nutrients, while the stomates are used to take in CO_2 and dispel H_2O (Franke, 1967). The plant cuticle is the initial point of contact for foliar fertilizers, and serves as the barrier of penetration for the leaf blade. It also prevents uncontrolled water loss (Liu et al., 2008; Riederer and Müller, 2006). Plant species have leaves which vary in cuticular thickness, pore size and pore size distribution (ranging from 1nm to 10nm in length with a density of $10^6 – 10^9/mm^2$); therefore their efficiency of allowing solutes to penetrate varies amongst species (Riederer and Müller, 2006).

A three step process was proposed by Franke (1967) for ion uptake. First, the substance applied to the leaf penetrates the cuticle and cellulose via diffusion. Second, these substances are adsorbed to the surface of the plasma membrane by binding. Finally, the absorbed substances are taken into the cytoplasm of the plant. Calcium (Ca^{++}) and Manganese (Mn^{++}) penetrate more quickly because of their smaller ion radius and facilitate the passage of larger cationic molecules (Franke, 1967). The absorption of foliar fertilizers are influenced by numerous factors such as the quantity of liquid applied, surface moisture on the leaf blade, the moisture level in the air, and management practices like mowing, topdressing, irrigation and traffic (Liu et al., 2008).

Nutrient Transfer in the Leaf

The absorption of and transfer of N in the plant vary with fertilizer application method (Fry and Huang, 2004). When N is applied to roots, it is absorbed as ammonium (NH_4^+) and nitrate (NO_3^-) (Fry and Huang, 2004). For foliar fertilization, urea (NH_2-CO-NH_2) is commonly applied, but it must be catalyzed by the enzyme urease in order to be absorbed. Urease catalyzes the hydrolysis of urea to carbamate and NH_3. Carbamate is then broken down into NH_3 and carbonic acid. The NH_3 becomes protonated as NH_4^+, which is available in ready form for assimilation into the plant (Marschner, 1995).

The absorption of foliar urea-N was measured over a 48 hour period in Kentucky bluegrass (*Poa pratensis* L.). Urea was spray-applied at 5 g N m^{-2} in 200 ml m^{-2} of deionized water to turf. Over a 48 hour period uptake was estimated by the wash method (Stiegler et al., 2011a) to measure the urea left on the leaf and also by using ^{15}N analysis. The wash method significantly overestimated urea absorption at 59%, while the ^{15}N method estimated absorption at 43% of applied N. Approximately 40% of urea remained on the leaf blade 48 hours after application, a result that led the authors to conclude that N loss could occur from mowing and clipping removal (Bowman and Paul, 1989).

Absorption of foliar urea-N was also measured in tall fescue (*Festuca arundinaceae* Schreb.) and creeping bentgrass. Urea was dissolved in deionized water to a final concentration of 25 g N $liter^{-1}$ and spray-applied at a rate of 5 g N m^{-2}. Absorption was measured over 72 hours by ^{15}N analysis, and it averaged 55% for both tall fescue and creeping bentgrass. The wash method was also utilized to measure absorption, and no significant difference was found between the two methods. By 72 hours more than 90% of the N was hydrolyzed (Bowman and Paul, 1990a).

Research involving cuticular retention of Fe, Mn, and Zn was performed on tomatoes (*Lycopersicum esculentum*) in France. Although no significant differences were found in nutrient uptake between three sources of Fe, inorganic forms of Mn ($MnSO_4$ and $MnCl_2$) and Zn ($ZnSO_4$ and $ZnCl_2$) had significantly higher cutical sorption when compared to organic (EDTA) Mn and Zn forms (Ferrandon and Chamel, 1988). A second experiment using pea (*Piscum sativum* cv Douce Provence) demonstrated that sorption of foliarly applied inorganic forms was consistently higher than organic for all three elements due to the nature of the ligand associated with the metal cation and its ability to move across the cuticle and be absorbed by the vascular bundles (Ferrandon and Chamel, 1988).

Foliar N in Turf

Research regarding foliar applied N to turfgrasses is limited. Wesely et al. (1985) found that maximum N-uptake occurred within the first 24 hours after application for all turfgrasses studied. Time of year affected nutrient uptake, with higher uptake noted in the warm summer months as compared to the cool spring (Gaussoin et al., 2009). In some cases, nutrient uptake was also affected by foliar N source, with greater uptake of micronutrients from those in organic chelated form as compared to micronutrient uptake from synthetic chelated forms (Gaussoin et al., 2009). In other work, several N sources, including ureaform and urea, were foliarly applied and evaluated on Kentucky bluegrass turf. Color ratings were initially higher in KY bluegrass to which foliar urea had been applied, but turf burn was reduced in grass to which slow-release N had been applied (Spangenberg et al., 1986).

In work conducted exclusively on creeping bentgrass putting greens, it was found that turfgrass growth, color, N-uptake and leaf-N increased linearly with foliar N rate, (up to 244 kg ha^{-1} yr^{-1}) (Schlossberg and Schmidt, 2007). When urea was spray applied at 0.5 and 1.25 g N m^{-2} to creeping bentgrass or bermudagrass putting greens, peak N absorption was found to be 4 hours after application. Absorption of N was affected by species as well as time of year, with the higher N rate resulting in reduced N uptake within the plant (Stiegler et al., 2011a). Velvet bentgrass (*Agrostis canina* L.) was also evaluated for foliar N source and rate effects on putting greens. In that work, application of liquid forms of ammonium sulfate, urea, ammonium nitrate, and calcium nitrate had negligible divergent effects on turf characteristics. As N rate increased up to 244 kg ha^{-1} yr^{-1} so did clipping yield, shoot density and relative chlorophyll index. Ball roll distance decreased, regardless of N source (Pease et al., 2011)

Turf response to granular and foliar applications of fertilizer can vary widely with species. Foliar urea applied to creeping bentgrass provided the best quality, while granular urea provided highest quality on Kentucky bluegrass, when both were grown under 80% shade (Steinke and Stier, 2003). On creeping bentgrass in South Carolina, two annual rates of N (127 and 190 kg ha^{-1}), were applied as a 100% granular (18-3-18), 50% granular + 50% foliar and 100% foliar (combination of 10-3-5 and 5-0-7). Over two years the highest rate of 190 kg ha^{-1} N applied annually as a mixture of both granular and foliar applications provided acceptable bentgrass quality in the transition zone, but there were few significant differences due to N source over the two year study (Totten et al., 2008). Daily N addition (representing a fertigation program) and periodic N application (granular app) were studied on perennial ryegrass (*Lolium perenne* L.) in a greenhouse study. The daily addition of N resulted in stable growth and tissue N pools, compared to the wide fluctuations in the periodic applications. Daily applications, however, had little or no effect on long-term productivity and N use efficiency (Bowman, 2003).

Foliar application of nutrients has also been shown to improve heat tolerance of creeping bentgrass (Fu and Huang, 2003). Applications of $CaCl_2$, KH_2PO_4 or NH_4NO_3 slowed leaf senescence and maintained photosynthetic activities when applied to creeping bentgrass in stress (35/30^oC (day/night)). Calcium chloride and KH_2PO_4 applications produced turf with higher photochemical efficiency, shoot growth rate and turf quality, when compared to untreated plants that just received water. Foliar applications of NH_4NO_3 increased the canopy net photosynthetic rate, the chlorophyll content, photochemical efficiency, and turf quality while under heat stress (Fu and Huang, 2003). While not a foliar study, it has been shown that high rates of N (4.54 kg m^{-2} yr^{-1}) can reduce dollar spot (*Sclerotinia homoeocarpa* F. T. Bennett) in creeping bentgrass. Ammonium nitrate, especially, when combined with applications of activated sewage sludge, proved to be the most effective in producing disease resistant turf (Markland et al., 1969).

In other foliar work, the absorption of N (as $(NH_4)_2SO_4$ and KNO_3), was evaluated using ^{15}N labeled materials at 48 hours after application on perennial ryegrass turf. It was found that 32% of the applied N was absorbed in new leaves, 52% in old leaves and shoot tissue, and 16% in roots (Bowman and Paul, 1992). Research evaluating volatilization losses from foliar applied N treatments on Kentucky bluegrass has had variable results, with losses varying from a high of 35%, to a low of 5.3% (Wesely et al., 1987; Bowman and Paul, 1990b). Volatilization losses of foliar applied urea (at rates of 0.5 and 1.25 g N m^{-2}) were found to be 0.4 and 2.6% on creeping bentgrass and hybrid bermudagrass, respectively, maintained as putting greens. This low loss of N due to volatization (over 24 hr) was hypothesized to be due to the high amount of N absorbed by the turfgrass (Stiegler et al., 2011b).

Other Foliar-Applied Nutrients

Iron (Fe) is commonly foliarly applied to turfgrasses, and its use has been widely studied. Often, application of Fe will provide additional color when extra N is not needed. Iron chelate was applied at 2.2 kg ha^{-1} with urea at 25 kg N ha^{-1}, and this combination provided the same color as 49 kg N ha^{-1} alone (Yust et al., 1983), lessening the need for greater N applications. Foliar N was found to reduce the tolerance of centipedegrass (*Eremochloa Ophroides* Munro. Hack.) to high rates of iron. While Fe application improved turf color, centipedegrass was found to be very sensitive to phytotoxicity from Fe at high air temperatures (Carrow et al., 1988). Interactions between foliar applied N and potassium (K) were noted in creeping bentgrass; as K increased within the plant, less N was required to attain maximum quality (Christians et al., 1979).

Foliar iron applied as Fe citrate was applied at 1.5, 3.0, and 6.0 kg Fe/ha in May, July, and September each year over a two year period. On seven out of 11 sample dates, plots that received foliar Fe exhibited more growth than plots without iron. Phytotoxicity was noted at the 6.0 kg Fe ha^{-1} rate in some, but not all, applications (Cooper and Spokas, 1991). Foliar magnesium (Mg) in combination with Fe at 1.68 kg ha^{-1} increased annual bluegrass growth in creeping bentgrass putting greens that were in 80% shade. However, in full sun foliar Mg had no effect on the growth of annual bluegrass or bentgrass (Stiegler et al., 2003). Foliar boron (B) applied to bentgrass over a 2 year period increased tissue B as B rate increased, but turf color, quality, shoot density, and weight of clippings were unaffected (Guertal, 2004).

Foliar fertilizer programs have also been studied for agronomic crops. Urea applied foliarly to cotton plants (*Gossypium hirsutum* L.) that had low petiole N concentrations at fruiting was found to increase lint yields (Walker et al., 1987). Foliar applied potassium nitrate increased yield in cotton when applied during flowering and boll fill (Oosterhuis et al., 1994). Multiple studies have been done evaluating foliar N and P on cotton, with little research supporting an increase in yield from the applications of these nutrients (Edmisten et al., 1994; Bednarz et al., 1998). Soybean (*Glycine max* L.) to which foliar (3-8-15) and (10-4-8) fertilizers were applied (at the V5 leaf stage) had increased yield in 2 of 26 trials (Mallarino and Ul-Haq, 2000; Mallarino et al., 2001). However, when soybean was grown in sandy soils and irrigated frequently, foliar fertilizers applied at the R3-R5 growth stages caused an increase in yield (Gascho, 1991). When N-P-K-S fertilizers were sprayed at the R5 and R6 growth stages, yield increased 27 to 31% (Garcia and Hanway, 1976). Similarly, applications of N-P-K-S were found to increase yields when applied between the R4 and R7 stages in soybean (Poole et al., 1983). Wesley et al. (1998) found that ammonium nitrate foliarly applied at 22 kg N ha^{-1} increased soybean yield significantly, when applied at the R3 growth stage.

Summary

Creeping bentgrass, (*Agrostis palustris* ssp. *stolonifera* L.), is the most widely used cool-season turfgrass for golf course putting greens. Creeping bentgrass is a fine-textured, stoloniferous, perennial with exceptional cold tolerance. Maintaining creeping bentgrass in the hot humid climates of the Southeast poses challenges for superintendents in the summer, when drought, heavy traffic and low mowing height create stress. Although newer cultivars have been developed to cope with the climate in the South, maintenance of bentgrass still requires frequent and intensive inputs to maintain acceptable turf.

One of those intensive inputs is fertilization. Fertilization is a key cultural practice in order to promote a healthy turf, and N is especially important. Foliar fertilization of turfgrass may provide advantages over granular application, including rapid turf response to the foliar nutrients, reduced fertilizer input, minimized potential losses by leaching and runoff, and the advantage of applying low rates of fertilizer when turf is under stress. Nitrogen is the main nutrient in a turfgrass fertilization program, and is responsible for maintaining turfgrass shoot density, recovery from stress, shoot growth rate, color and quality. Previous research has shown that foliar applied N is absorbed by transcuticular pores, has low volatilization levels from the leaf, and that time of day of application has little effect on N uptake. However, little is known about appropriate foliar rates of N for maintenance of bentgrass in the humid south, or timing of that N in conjunction with irrigation.

The research objectives of this study were to examine the combined and separate effects of foliar N rate and method of application on the color, quality, shoot density, root growth and carbohydrate status of a creeping bentgrass putting green. The study was a two year experiment conducted at the Auburn University Turfgrass Research Unit (TGRU), located in Auburn, AL.

Materials and Methods

In August 2011 an existing 5-year old USGA-type (80% sand, 20% rice hulls) bentgrass putting green was selected for this study. The green was stripped of sod and Dazomet (Basamid) was applied at a rate of 391 kg ha^{-1} on September 28, 2011. On October 14, 2011 Penn-A4 creeping bentgrass was seeded at a rate of 98 kg ha^{-1} and granular urea (46-0-0) was applied at 6.1 kg ha^{-1}. Weekly applications of urea at 6.1 kg ha^{-1} were applied until November 21, 2011. This newly seeded green was then used for the N study, which was initiated on December 1, 2011 when the grow-in was 100%.

General management of the bentgrass green was as follows: the green was mowed 5 days a week with a walk behind Toro greens mower (Toro Co, 8111 Lyndale Ave S., Bloomington, MN 55420) at 0.3175 cm, with clippings removed. The green was aerified with a Hydroject (Toro Co, 8111 Lyndale Ave S., Bloomington, MN 55420) and topdressed lightly with sand roughly once a month. An initial soil test taken in 2011 indicated a soil pH of 6.1 and soil-test P and K of 17 g m^{-2} and 18 g m^{-2}, respectively. In March 2012 a blanket application of P_2O_5, K_2O and lime was made at 6.7 g m^{-2}, 13.5 g m^{-2} and 5.6 g m^{-2}, respectively, to meet soil-test recommendations. A second application of P (20.2 g m^{-2} P_2O_5) and K (20.2 g m^{-2} K_2O) was made in December, 2012, again applied to meet soil test recommendations for P and K. No additional lime was applied in the second application.Treatments were a 4 x 3 factorial of N rate and fertilizer application method, plus an unfertilized control. Treatments were arranged in a randomized complete block design with four replications. Nitrogen treatments were applied to each individual 1.5 x 2.1 m plot beginning in December 2011. Four N rates were used: 0.5, 1.0, 2.0, and 4.0 g m^{-2}, with urea (46-0-0) as the N source (SGN 150). The N rates were applied via three application methods: 1) granular, 2) foliar, with irrigation following ('foliar, watered-in', FWI), and, 3) foliar, with no irrigation following ('foliar, not watered-in', FNWI).

Nitrogen fertilizer application treatments were applied as follows. First, granular N treatments were hand applied to respective plots. Next, foliar N treatments that received irrigation were applied. After foliar N application, 0.3 cm of irrigation water was applied to the entire research green, ensuring that soil moisture was uniform across the entire green. Plots that were to receive foliar N, yet no subsequent irrigation, were then hand dried with towels to remove leaf moisture. These plots then received their foliar N treatment immediately after drying, and no further irrigation was applied. Foliar applications were made with a CO_2 backpack sprayer at 30 GPA with 8002 nozzles in the morning on the 1^{st} of each month, weather permitting (TeeJet, Spraying Systems Co. Wheaton Facility P.O. Box 7900 Wheaton, IL 60187 USA). Granular applications were also applied monthly at the same time as the foliar applications.

Data Collected

For Year 1 data collection, the experiment was conducted from December 5, 2011 to December 9, 2012. No data was collected nor treatments applied, from December 10, 2012 until January 5, 2013, after which the Year 2 study was initiated, with treatments applied to the same plots as in Year 1. In both years the following data was collected: 1) weekly color, quality and NDVI (Spectrum Technologies, 12360 S. Industrial Drive E., Plainfield, IL 60585), 2) dry weight of clippings at 1 and 3 weeks, and total N content of those clippings, 3) quarterly shoot and root density, and, 4) nonstructural carbohydrate content taken twice a year. Specific methods used to collect this data are as follows:

Color, Quality and NDVI

Relative color and quality were determined visually and rated on a 1-9 scale, with a minimum acceptable score of ‘6’. Color was rated with a ‘1’ being completely brown and ‘9’ being dark green. Quality was a ‘1’ for dead turf and ‘9’ for turf having the highest quality. The TCM 500 NDVI Turf Color Meter was used to measure the amount of reflected light in a 7.62 cm diameter section of turfgrass. The color meter uses an internal light source to negate the effect of sunny versus cloudy conditions and measures the reflectance in the red (660 nm) and near infrared (850 nm) spectral bands. Five readings were averaged together for each plot (Schiavon et al., 2011).

Clipping Dry Weight

Clippings were collected the first and the third week after each fertilizer application by harvesting a known area of each plot. A 2.3 m by 3.2 m plot area (two passes with a 55.8 cm reel mower) was harvested, and harvested clippings were dried in a plant drier at 60^{o}C for 48 hours. Once dried, dry weights were recorded and a sample (0.0995-0.1005g) was taken and weighed, and then analyzed for total N (Mulvaney et al., 2008). Total N of each sample was determined by dry combustion using a LECO TruSpec CN (Leco Corp, St. Joseph, MI).

Quarterly Shoot and Root Density

Quarterly shoot density was obtained in January, April, July and October of each year by taking three 1.9 cm (3/4 in) diameter cores 15.2 cm (6 in) deep from each plot. The thatch layer was removed and hand counts of individual shoots were made. The three shoot numbers were averaged together and reported as shoots per cm^2. Root density was measured quarterly in January, April, July, and October by using the remainder of the sample core (from above) and removing the soil by washing through an 18 mm sieve. After the roots had been washed and collected they were dyed with a neutral red (Certified Biological Stain by Harleco) in order to be visible on the scanner. The computer program WinRHIZO (Regent Instruments Inc., Quebec, Canada) was used to determine the total length of the roots in each plot in cm. These roots were then placed in a plant drier at 60^oC for 48 hours, and dry weights recorded.

Total Carbohydrates

Total carbohydrate content was determined by taking two 5.7 cm diameter cores at a depth of 5.1 cm from each plot in April 2012 and 2013, as well as in October 2012. In the field these samples were immediately put in a plastic bag and stored on ice. Once all samples were obtained they were immediately taken back to the lab where stolons and rhizomes were removed. Soil was separated from the roots without the use of water, roots collected and freeze-dried at -5^oC. These samples (0.20 to 0.25 g) were boiled in 50 mL of 0.05 *N* H_2SO_4 for 1 hour and placed in a shallow ice bath, after which 1.0 *N* NaOH was added to adjust the pH of the sample to 4.5. One mL of diluted amyloglucosidase (*Aspergillus niger*, Lot No. A 9913, Sigma-Aldrich Inc., St. Louis, MO) solution was added to samples, which were then covered and incubated at 60^oC for 1 hour. Samples were filtered and brought to volume in a 250-mL volumetric flask with 2 mL of 0.1 *N* NaOH and deionized water. Ten milliliters of Sheffer-Somogyi reagent (AOAC, 1995) were combined with a 10-mL aliquot of sample in a 25 x 200 mm capped test tube and boiled for 15 minutes. Tubes were then cooled in an ice bath, and 2 mL of potassium iodide-potassium oxalate solution was added to each sample. Next, 10 mL of 1.0 *N* H_2SO_4 and 1 mL of gelatinized starch solution were added to each tube before titration. Samples were titrated with 0.02 *N* sodium thiosulfate until the solution turned light blue. Concentration of TNC in samples was calculated as the amount of reducing sugar in the sample, multiplied by the dilution factor x 100, divided by the sample weight (Mullenix et al., 2012).

Results and Discussion

Color

In 2012 there were 53 rating dates for turfgrass color. In that year there were 13 rating dates in which the interaction of N rate and application method was significant (Table 1). If the interaction was not significant, the main effect of N rate was significant at 37 rating dates. In fact, the interaction of N rate or its main effect was significant in 50 of 53 ratings, with the only exceptions being early ratings (December, 2012), where N fertilization had not yet affected bentgrass color. Results for color (from January 1 to May 29) in 2013 were different from those of Year 1, as the N rate x method interaction was rarely significant (only March 13, 2013) and only N rate alone significantly affected turf color. Similarly to 2012, the main effect of N rate was significant at all 21 rating dates (Table 2).

Lower N rates of 0.5 and 1.0 g m^{-2} did not provide acceptable turf color, and were not able to maintain satisfactory color ratings throughout an entire month (Figures 1 and 2 (2012), 3 and 4 (2013)). Acceptable color was achieved with N rates of 2.0 and 4.0 g m^{-2}, with color maximized at the 4.0 g m^{-2} N rate (Figures 5 and 6 (2012), 7 and 8 (2013)). When N was applied at 4.0 g m^{-2}, plots maintained an acceptable color rating throughout the entire month. These results were similar to that found by Bilgili and Acikgoz (2005), who found that N applied at 5.0 g m^{-2} and 7.5 g m^{-2} (monthly) provided the best overall turf color on bentgrass. In work conducted exclusively on creeping bentgrass putting greens, it was found that turfgrass color increased linearly with foliar N rate, (up to 24 g m^{-1} yr^{-1}, applied at 2 g m^{-2} mo^{-1}) (Schlossberg and Schmidt, 2007). When examined over an entire month, N applied as a granular application sometimes provided better long-term color (Figure 9), but such a response to granular N was not always significantly different (Figures 10, 11 and 12). In many cases there was a linear color response to increasing N, especially in 2012 on the one-year old green (Figures 9-11). By 2013 turfgrass color often had a curvilinear response to increasing N, with turf color maximized at an N rate of 3.3 to 5.4 g m^{-2} mo^{-1} (Figure 12). Typically, foliar N followed by irrigation (FWI) and granular N applications produced bentgrass with a similar green color, and both were darker green than in plots which had received foliar N without subsequent irrigation (Figure 11). This was most often observed in the summer, when N at 2.0 and 4.0 g m^{-2} applied as a foliar material, without irrigation following (FNWI), caused tissue damage (burn), which decreased color ratings.

In 2012, the method of fertilizer application was significant in the spring and summer. In the spring the foliar treatments provided better color ratings compared to that of the granular treatment and the unfertilized control. In the summer the granular treatments provided better overall color compared to the two foliar methods, again a factor of burn and tissue damage from the foliar application at high N rates. These results were not observed in 2013. This is likely a result of the increasing age of the green, as it developed less succulent tissue and greater thatch that would provide mineralizable N over the year. In 2012, an establishment year, there was greater response to N rate.

Quality

In 2012 turfgrass quality ratings was sometimes affected by the interaction of N rate and method (significant on 7 of 41 rating dates), often by the main effect of method of application (16 times) and almost always by N rate (33 times) (Table 3). In 2013 the interaction was only significant once (January 9), and the main effect of method was only significant 3 times (in April and May) (Table 4). In 2012, N rate significantly affected bentgrass quality (with the exception on March 1) (Table 3). Similarly to 2012, N rate was significant at every rating date in 2013 (Table 4). Over the rating year turf quality in foliar treatments fluctuated widely within any given month, and this was especially evident at lower N rates (Figures 13 and 14). When applied at these low rates turf quality decreased within each month until the next application date, a function of insufficient N to maintain growth and quality throughout the month. When N was applied at 2.0 g m^{-2}, there was more consistent quality throughout the month in the spring and fall, but not during the summer (July – August) due to tissue damage in treatments that were not watered in (Figure 15). Quality ratings were maximized when N was applied at 4.0 g m^{-2}, in both years (Figure 16). In 2013 acceptable quality ratings were maintained throughout the entire month, regardless of application method. The exception was in the summer, when foliar applied N (without subsequent irrigation) caused tissue damage, and in turn caused quality ratings to drop (Figure 16). Previous research has found that urea, when spray applied at rates greater than 2.4 g m^{-2} has a high potential to burn turf and affect ratings (Johnson and Christians, 1984). Overall, there were very few differences in turf quality between the two foliar application methods, with the exception of those taken in summer. An examination of the use of split applications of that highest N rate within each month would be a useful next step for this research.

The application of granular N throughout the entire year at all rates (especially at rates of 0.5 and 1.0 g m^{-2}) created an undesirable ‘speckling’ of the turf, lowering quality (Figures 17, 18, 19 and 20). Reductions in quality were less frequent as more monthly applications of granular N were applied, and uniformity improved with each application. The turf that received lower N rates of 0.5 and 1.0 g m^{-2} also fought algae infestation throughout both years. As with color, turf quality often had a linear response to increasing N early in the study, but later in Year 1 (and Year 2) there were curvilinear responses. In those cases quality was maximized at an N rate of around 3.0 g N m^{-2} (Figures 18 and 19).

In 2013 bentgrass quality was very similar to that observed in 2012. N rate always significantly affected bentgrass quality (Table 4). Nitrogen applied at 0.5 and 1.0 g m^{-2} was not at a rate high enough to achieve an acceptable quality, and plots receiving granular N still had a ‘speckling’ effect from the distribution of the prills across the treated plots (Figures 21, 22, 23, 24 and 25). Quality ratings increased with increasing N rate with a maximum quality just at the maximum N rate of 4.0 g m^{-2}. Positive linear responses also occurred in previous research when N was applied (monthly) at 2.5, 5.0 and 7.5 g m^{-2}, with quality maximized at 7.5g m^{-2} (Bilgili and Acikgoz, 2005).

Foliarly applied N that was irrigated after application (FWI) had highest quality ratings at highest N rates, when compared to the other two fertilization methods (Figure 26), possibly due to more fertilizer being able to be absorbed through the roots. Previous work has shown that foliar-applied N uptake is governed by time and leaf structure features such as cuticle thickness, with substantial N entering into the leaf within 8 hours after application (Wesely et al., 1985;

Bowman and Paul, 1990a; Bowman and Paul, 1992; Gaussoin et al., 2009). In order to maximize foliar N-uptake on creeping bentgrass putting greens, it has been suggested that management practices such as syringing greens should be delayed 24 hours in order to obtain maximum foliar N uptake by the turfgrass (Stiegler et al., 2011a)

By 2013, repeated applications of granular N had uniformly fertilized the entire plot, causing turf 'speckle' to diminish. The 'speckling' effect on the turf was similar to that found by Howieson and Christians (2001) where Osmocote (14-14-14) (Scotts Miracle-Gro Company, 14111 Scottslawn Road, Marysville, OH 43041) was hand applied at 1.2 g m^{-2} (every 10 days) exhibited poor uniformity and 'speckling' of turf. Other researchers found that a rate of at least 19 g m^{-2} yr^{-1}, regardless of the foliar and granular application, was needed to attain acceptable bentgrass quality on bentgrass greens in the transition zone of the U.S. (Totten et al., 2008).

NDVI

NDVI readings were recorded as a newer quantitative check to the standard method of relative color ratings. Variability in NDVI readings was less than that in visual color ratings, a result similar to that found by previous researchers (Bell et al., 2002; Green, 2011). Out of 44 dates in which NDVI was recorded, there were 8 dates in which the N rate x method interaction was significant, while the main effects of N rate and method were significant on 36 and 11 dates, respectively (Table 5). In 2013, only the main effect of N rate ever affected NDVI readings (Table 6). When method of fertilizer application was significant, it occurred in the spring and summer, when spring foliar applications provided higher NDVI readings, as compared to readings obtained from bentgrass receiving granular fertilizer, or the control. In the summer granular applications of N produced higher NDVI readings as compared to the two foliar treatments, again due to the tissue damage that occurred from burn in the foliar treatments. Lower rates of 0.5 g m^{-2} and 1.0 g m^{-2} produced the lowest NDVI readings (Figures 27 and 28) compared to that of the two higher rates (Figures 29 and 30). When N was applied at 4.0 g m^{-2}, higher ratings were achieved in the months leading up to summer as compared to other rates. During August, N applied at 4.0 g m^{-2} as one application was at too high a rate, causing foliar burn, regardless of the method applied. After this, plots receiving N as a foliar application without subsequent irrigation, took longer to recover over the next few months, when compared to the other two application methods (Figure 30). Previous research has shown that slow-release methylene ureas caused minimal burn when applied at rates of 1.2, 2.4, and 4.9 g m^{-2}. This was in comparison to soluble urea, which caused unacceptable levels of burn when applied at amounts greater than 2.4 g m^{-2} (Johnson and Christians, 1984).

In 2013, N rate always significantly affected NDVI readings, regardless of the N application method, which was never significant (Table 6). In 2013, at a rate of 0.5 g m^{-2}, NDVI readings had higher initial readings which slowly began to decrease through the summer. Granular N applications still created a ‘speckling’ effect, although differences were not significant (Figure 31). When N was applied at 1.0 g m^{-2} there was also no significant difference in application method (Figure 32). Highest N rates of 2.0 g m^{-2} and 4.0 g m^{-2} maintained highest NDVI readings (Figures 33 and 34). Results involving NDVI could provide an unbiased estimate of turf ratings, but this method currently lacks calibration to justify discontinuing visual ratings (Schiavon et al., 2011). Visual ratings done by three different evaluators, with different turf rating experience, reduced the overall variability between NDVI and visual ratings (Bell et al., 2011)

Clipping Yield

In 2012, there were 23 clipping harvests taken at 1 and 3 weeks after fertilization. The N rate x method interaction was significant at 3 sampling dates, while the main effect of N rate was always significant (except for the first harvest on December 9) and the main effect of method was significant on 7 dates in which the interaction was not significant (Table 7). Clipping yield increased as N rate increased, usually maximizing at or near the highest N rate (Figure 35). The method by which fertilizer was applied was less likely to affect clipping yield, and if it was significant, clipping yield was greatest in plots that had granular N applied (Table 8). In 2012, there were 5 (of 10 total) harvest dates in which clipping yield was significantly greater from plots which had received granular N as compared to those which had foliar N applied, without subsequent irrigation. This was not the case when yield from granular plots was compared to that from foliar applications that were irrigated in. When comparing the two foliar methods in these months, plots receiving foliar N plus irrigation had greater clipping yield as compared to that from plots that were foliarly fertilized without irrigation. This was significant at 2 sampling dates. Out of 23 sampling dates in 2012, the N rate by method of application interaction was significant 6 times (Table 7). In 5 of these dates, (all spring or summer applications), granular application of N produced higher clipping yields at the highest N rate, as compared to either foliar N application. The only time granular application of N did not produce higher clipping yields was in fall (October). In other work, Totten et al. (2008) found mixed results when comparing granular and foliar applications (2008). In the first year of his study clipping yield was 25% greater from plots receiving foliar applications, compared to yield from those recieving granular applications. In the second year, however, granular applications of N produced clipping yields that were higher.

In 2013 (January 1 to May 29) only the main effect of N rate affected clipping yield (Table 9). Regardless of the method of application, as N rate increased there was a linear increase in clipping yield (Figure 36). There was no significant interaction between N rate and application method on clipping yield in 2013. The method of application was never significant at any sampling date. Application of N by any method produced greater clipping yield than from unfertilized plots, but there was never any differences in yield due to how that N was applied (Table 10). Researchers have found that an increase in annual N, from 13 to 19 g m^{-2} (applied in equal amounts every 2 weeks), produced an increase in clipping yield in two consecutive years (Totten et al., 2008). Also, a positive linear increase in clipping yield was reported with increasing N rates at 2.5, 5.0 and 7.5 g m^{-2} applied monthly (Bilgili and Acikgoz, 2005).

Nitrogen Content of Bentgrass Leaf Tissue

In 2012 there were only 3 sampling dates (out of 23 total) in which there was a significant N rate x method of application interaction (Table 11). In the first 6 months of the study the method of fertilizer application affected total N, but after May of 2012 that main effect was never significant again. The main effect of N rate always affected total N in clippings, in both years (Tables 11 and 12). As N rate increased there was a slight increase in tissue N

(Figure 37 and 38) with values ranging from 2.5 to 5 g kg^{-1} varying with sample month. In 2012, the method of application was often significant in the spring, because the application of granular N often produced clippings with a higher N content as compared to the other treatments (Table 13). Method of application was rarely significant in 2013 (Table 14).

Previous research has found that maximum N-uptake occurred within the first 24 hours after application for many turfgrass species, with peak absorption coming at the 4^{th} hour of measurement, with absorption of applied urea ranging from 38% to 62% (Stiegler et al., 2011a; Wesely et al. 1985). Time of year affected N nutrient uptake, with higher uptake noted in the warm summer months as compared to the cool spring (Gaussoin et al., 2009). Since tissue samples were not taken in this study until 24 hours and 3 weeks after application it was difficult to compare results, but total N found in the leaf tissue in our study as well as in previous research, was shown to range between 3% and 5% (Wesely et al., 1985).

Shoot Density

Over two years (6 sampling dates) there was one sampling date in which the N rate x method interaction significantly affected shoot density, and none in which the method of application was significant for shoot density (Table 15). In 4 of 6 sampling dates N rate was significant (Table 15) (Figure 39). In the sampling months in which the interaction was not significant there was a slight increase in shoot density as N rate increased (July and October, 2012) (Figure 39). In April 2012 there was no significant increase in shoot density as N increased. January, 2012, shoot density was affected by the interaction of N rate and method by which N was applied (Table 15). In that month, plots receiving granular N had a slight curvilinear response to increasing N, while those receiving foliar N were largely unaffected by the application of N (Figure 40). In other work shoot density was found to increase as N rate increased, when that N was applied every two weeks at rates of 0.75, 1.5, and 2.25 g m^{-2} (Schlossberg and Karnok, 2001).

Root Length Density

In 2012 the method of fertilizer application had no effect on root length density, and the interaction was never significant (Table 16). Nitrogen rate was only significant in January, when increasing the N rate caused a decrease in root length. In April, 2013 the interaction of N rate by method was significant, a function of decreased root length at highest N rates, but only in the granular treatment (Figure 41). In the winter and spring, root length was greater than that in the summer and fall, a function of southeastern heat and humidity (Figure 42). In a controlled environment, researchers found that decreasing the soil temperature from 35^{o}C to 32^{o}C, increased root growth in Penncross bentgrass (Xu and Huang, 2001b). Others have also found that increasing N fertility (0.75, 1.5, and 2.25 g m^{-2}) decreased total root length density on bentgrass (Schlossber and Karnok, 2001)

Root Dry Weight

In 2012 and 2013 the main effect of N rate affected the dry weight of bentgrass roots, but only in January, 2012 (Table 17). In that sampling month bentgrass receiving N at 0.5 g m^{-2} had higher root dry weights. The N rate by method interaction was significant in July, 2012, because any plot receiving granular N had increasing root dry weight up to 2.0 g m^{-2}, and decreasing thereafter. Plots receiving any foliar N were unaffected by N rate. In 2012 and 2013 there was no difference in method of application and its effect on root dry weight.

Total Carbohydrates

The main effect of N rate was the only factor that affected soluble carbohydrate content (Table 18). In both years, as N rate increased there was a decrease in soluble carbohydrates (Figure 43). In April, 2013 carbohydrate content was maximized at an N rate of 1.9 g m^{-2}, while in October, 2012 carbohydrate content was lowest at the highest N rate. Previous research found that increasing N during the growing season, starting in April and applying on 15 day intervals for 6 weeks, at rates totaling 0, 15, 29, 43 and 58 g m^{-2}, caused a decrease in total carbohydrates with increasing N rate (Green and Beard, 1968). Other work showed a decrease in TNC levels as N rate increased (from 0.3 up to 4.8 g m^{-2} wk^{-1}) in the first year, with TNC maximized at a rate of 2.4 g m^{-2} wk^{-1} (Guertal and Evans, 2006).

Summary

Highest rates of N were needed in order to maintain turfgrass color, quality, and NDVI readings throughout the sampling month. The application of high rates of foliar N in the summer created foliar burn of leaf tissue, which was the main source of differences in response to method of N application. Clipping yield was typically maximized at the highest N rate, while nitrogen content of the bentgrass leaf tissue only slightly increased with increasing N rate. Daily mowing and removal of clippings likely removed N that was applied via foliar applications. Granular application of N sometimes produced increased shoot density, when compared to foliar N applications. Root length density, as well as root dry weight, was mostly affected by sampling time. Last, total carbohydrates typically decreased with increasing N rate.

Conclusions

- The highest N rate of 4.0 g m^{-2} was often needed to achieve maximum color and quality of creeping bentgrass, although heat stress in the summer affected these ratings.
- In general, there were few significant differences between application Method over the course of the study. If present, it was because foliar N application at high rates, without a following irrigation, created foliar burn of leaf tissue.
- In the first year of the study the green was newly established, and thus was more sensitive to high rates of N via foliar application. Differences were less pronounced in Year 2.

- A monthly rate of 4.0 g m^{-2} could possibly maintain constant N levels within the plant if applied twice throughout the month at a rate of 2.0 g m^{-2}. This deserves further study.

Literature Cited

AOAC. 1995. Official Methods of Analysis. 6th ed. Assoc. Off. Anal. Chem., Washington, DC.

Beard, J.B. 1999. Bentgrass (*Agrostis*) cultivar botanical characteristics and culture. Proceeding of the 69th Annual Michigan Turfgrass Conf. 28:413-417.

Bednarz, C.W., Hopper, N.W. and Hickey, M.G. 1998. Effects of foliar fertilization of texas southern high plains cotton: leaf nitrogen and growth parameters. J. Prod. Agric. p. 80-84.

Bell, G.E., Martin, D.L., Wiese, S.G., Dobson, D.D., Smith, M.W., Stone, M.L and Solie, J.B. 2002. Vehicle-mounted optical sensing: an objective means for evaluating turf quality. Crop Sci. 42:197-201.

Bilgili, Ugur and Acikgoz, Esvet. 2005. Year-round nitrogen fertilization effects on growth and quality of sports turf mixtures. J. of Plant Nutr. 28: 299-307.

Bowman, D.C. 2003. Daily vs. periodic nitrogen addition affects growth and tissue nitrogen in perennial ryegrass turf. Crop Sci. 43:631-638.

Bowman, D.C. and Paul, J.L. 1992. Foliar absorption of urea, ammonium, and nitrate by perennial ryegrass turf. J. Amer. Soc. Hort. Sci. 117:75-79.

Bowman, D.C. and Paul, J.L. 1989. The foliar absorption of urea-N by Kentucky bluegrass turf. J. Plant Nutr. 12: 659-673.

Bowman, D.C. and Paul, J.L. 1990a. The foliar absoprtion of urea-N by tall fescue and creeping bentgrass turf. J. Plant Nutr. 13:1095-1113.

Bowman, D.C. and Paul, J.L. 1990b. Volatilization and rapid depletion of urea spray-applied to Kentucky bluegrass turf. J. Plant Nutr. 13(10):1335-1344.

Camberato, J., Martin, B. and Dodd, R. 1999. Surface cooling and aeration at Wildwing Plantation. Carolinas Green. 35:12-14.

Carrow, R.N., Johnson, B.J. and Burns, R.E. 1987. Thatch and quality of Tifway bermudagrass turf in relation to fertility and cultivation. Agron. J. 79:524-530.

Carrow, R.N., Johnson, B.J. and Landry, Jr. G.W. 1988. Centipedegrass response to foliar application of iron and nitrogen. Agron. J. 80:746-750.

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

Cooper, R.J. and Spokas, L.A. 1991. Growth, quality and foliar iron concentration of Kentucky bluegrass treated with chelated iron sources. J. Amer. Soc. Hort. Sci. 116:78-801

Cornman, J.F. 1952. Mat formation on putting greens. Golf Course Rep. 20:8-14.

Dipaola, J.M. 1984. Syringing effects on the canopy temperature of bentgrass greens. Agron. J. 76:951-953.

Dodd, R., Martin, B. and Camerato, J. 1999. Subsurface cooling and aeration. Golf Course Manage. 67:71-74.

Dunn, J.H., Minner, D.D., Fresenburg, B.F., Bughrara, S.S. and Hohnstrater, C.H. 1995. Influence of core aerification, topdressing, and nitrogen on mat, roots and quality of ‘Meyer’ zoysiagrass. Agron. J. 87:891-894.

Edmisten, K.L., Wood, C.W. and Burnmester, C.H. 1994. Effects of early-season fertilization on cotton growth, yield, and nutrient concentration. J. Plant Nutr. 17:683-692.

Eggens, J.L. 1980. Thatch control on creeping bentgrass turf. Can. J. Plant Sci. 60:1209-1213.

Ferrandon, M. and Chamel, A.R. 1988. Cuticular retention, foliar absorption and translocation of Fe, Mn, and Zn supplies in organic and inorganic form. J. Plant Nutr. 11: 247-263.

Franke, W. 1967. Mechanisms of foliar penetration of solutions. Annual Review of Plant Physiology. 18:281-300.

Fraser, Melodee L. 1998. Managing the new cultivars of creeping bentgrass. Golf Course Management. 8:53-56.

Fry, J. and Huang, B. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Inc., Hoboken, NJ.

Fu, J and Huang, B. 2003. Effects of foliar application of nutrients on heat tolerance of creeping bentgrass. J. Plant Nutr. 26:81-96.

Garcia, R.L. and Hanway, J.J. 1976. Foliar fertilization of soybean during the seed-filling period. Agron. J. 79:92-96.

Gascho, G.J. 1991. Late-season nitrogen for soybeans- Georgia studies show promise for increasing yields, quality. Solutions. 35:38-40.

Gaussoin, Roch, Schmid, C., Frank, K., Butler, T., Lui, H., Jarvis, W. and Baldwin, C. 2009. Foliar uptake of nutrients applied in solution to creeping bentgrass (*Agrostis palustris* Huds.), annual bluegrass (*Poa annua* var. *reptans* (Hausskn.) Timm) and ultra-dwarf bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy). The Proceedings of the International Plant Nutrition Colloquium XVI, Department of Plant Sciences. UC Davis, UC Davis.

Glinski, D.S., Carrow, R. N. and Karnok, K.J. 1992. Iron fertilization on shoot/root growth, water use, and drought stress of creeping bentgrass. Agron. J. 84:496-503

Green, B.D. 2011. Nitrogen release characteristics of commercial organic fertilizers in turfgrass. Master's Thesis. Auburn University. pg 27.

Green, D.G. and Beard, J.B. 1968. Seasonal relationships between nitrogen nutrition and soluble carbohydrates in the leaves of Agrostis palustris Huds., and Poa pratensis L. Agron. J. 61:107-111.

Guertal, E.A. 2004. Boron fertilization of bentgrass. Crop Sci. 44:204-208.

Guertal, E.A., Edzard van Santen, and D.Y. Han. 2005. Fan and syringe application for cooling bentgrass greens. Crop Sci. 45:245-250.

Guertal, E.A. and Evans, D.L. 2006. Nitrogen rate and moqing height effects on tifeagle berumudagrass establishment. Crop Sci. 46:1772-1778.

Howieson, M.J. and Christians, N.E. 2001. Spoon-feeding with granular materials? TurfGrass Trends. 10:7.

Johnson, S.J and Christians, N.E. 1984. Fertilizer burn comparisons on concentrated liquid fertilizers applied to Kentucky bluegrass turf. HortScience 109:890-893.

Kopec, David M. 2001. You get what you spray for foliar feeding: facts and fantasy! http://turf.arizona.edu/ccps101.htm.

Ledeboer, F.B. and Skogley, C.R. 1967. Investigations into the nature of thatch and methods for its decomposition. Agron. J. 59:320-323.

Liu, H., Baldwin, C.M., Totten, F.W. and McCarty, L.B. 2008. Foliar fertilization for turfgrasses. Acta Hort. 783:323-331.

Mallarino, Antonio P. and Ul-Haq, Mazhar. 2000. Soybean yield and nutrient composition as affected by early season foliar fertilization. Agron. J. 92:16-24.

Mallarino, A.P. Haq, M.U. Wittry, D. Bermudez, M. 2001. Variation in soybean response to early season foliar fertilization among and with fields. Agron. J. 93:1220-1226.

Mancino, C.F., Petrunak, D.M., and Wilkinson, D. 2001. Loss of putting-green grade fertilizer granules due to mowing. HortScience 36:1123-1126.

Markland, F.E., Roberts, E.C. and Frederick, L.R. 1969. Influence of nitrogen fertilizers on 'Washington' creeping bentgrass. (*Agrostis palustris* Huds). II. Incidence of Dollar Spot, *Sclerotinia homoeocarpa*, infection. Agron. J. 61:701-705.

Marschner, H. 1995. Mineral nutrition of higher plants. 2nd Edition. Academic Press, San Diego.

McCarty, L.B., Gregg, M.F. and Toler, J.E. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99:1530-1537.

Miller, R.W. 1965. The thatch problem. Weeds, Trees, and Turf 4:10-18.

Mullenix, M.K., E.J. Bungenstab, PAS, J.C. Lin, B.E. Gamble and R.B. Muntifering. 2012. Case study: productivity, quality characteristics, and beef cattle performance from cool-season annual forage mixtures. The Professional Animal Scientist. 28:379-386.

Mulvaney, M.J., C.W. Wood, and B.H. Wood. 2008. Carbon and nitrogen mineralization and persistence of organic residues under conservation and conventional tillage. Ag. J. 102:1425-1433.

Murray, J.J., and Juska, F.V. 1977. Effect of management practices on thatch accumulation, turf quality, and leaf spot damage in common Kentucky bluegrass. Agron. J. 69:365-369.

Musser, H.B. 1960. Topdressing-its preparation and use. Golf Course Rep. 28:16-22.

National Turfgrass Evaluation Program. 2008. National bentgrass putting green test. NTEP Progress Rep. 06-3. http://www.ntep.org/data/bt03g/bt03g_06-3/bt03g_06-3.pdf. NTEP, Beltsville, MD.

Oosterhuis, D.M. Abaye, O. Albers, D.W. Baker, W.H. Burnmester, C.H. Cothren, J.T. Ebelhar, M.W. Guthrie, D.S. Hickey, M.G. Hodges, S.C. 1994. A summary of a three-year beltwide study of soil and foliar fertilization with potassium nitrate in cotton. Proceedings of the Beltwide Cotton Conference. (3) p. 1532-1533.

Pease, B. W., Koeritz, E. J., Soldat, D. J. and Stier, J. C. 2011. Nitrogen source and rate effects on velvet bentgrass putting green turf. Crop Sci. 51:342-352.

Poole, W.D., Randall, G.W. and Ham, G.E. 1983. Foliar fertilization of soybean: I. effect of fertilizer sources, rates and frequency of application. Agron. J. 75:921-930.

Riederer, M. and Müller, C. 2006. Biology of the Plant Cuticle. Blackwell Pub., Oxford, Ames, Iowa.

Salaiz, T.A., Horst, G.L. and Sherman, R.C. 1995. Mowing height and vertical mowing frequency effects on putting green quality. Crop Sci. 35:1422-1425.

Schlossberg, M.J. and Karnok, K.J. 2001. Root and shoot performance of three creeping bentgrass cultivars as affected by nitrogen fertility. J. Plant Nutr. 24:535-548.

Schlossberg, M. J. and Schmidt, J. P. 2007. Influence of nitrogen rate and form on quality of putting greens cohabited by creeping bentgrass. Agron. J. 99:99-106.

Schiavon, M., B. Leinauer, E. Sevostianova, M. Serena, and B. Maier. 2011. Warm-season turfgrass quality, spring green-up, and fall color retention under drip irrigation. Appl. Turfgrass Sci. doi:10.1094/ATS-2011-0422-01-RS.

Spangenberg, B.G., Fermanian, T.W. and Wehner, D.J. 1986. Evaluation of liquid-applied nitrogen fertilizers on Kentucky bluegrass turf. Agron. J. 78:1002-1006.

Steinke, K. and Stier, J.C. 2003. Nitrogen selection and growth regulator applications for improving shaded turf performance. Crop Sci. 43:1399-1406.

Stiegler, J.C., Bell, G.E., and Martin D.L. 2003. Foliar applications of magnesium and iron encourage annual bluegrass in shaded creeping bentgrass putting greens. Crop Management.

Stiegler, J.C., Richardson, M. D. and Karcher, D. E. 2011a. Foliar nitogen uptake following urea application to putting green turfgrass species. Crop Sci. 51:1253-1260.

Stiegler, J.C., Richardson, M.D., Karcher, D.E., Roberts, T.L. and Norman, R.J. 2011b. Field-based measurement of ammonia volatilization following foliar applications of urea to putting green turf. Crop Sci. 51:1767-1773.

Thompson, W.R., Jr. 1967. Control of thatch in Tifgreen bermudagrass. Proc. Florida Turf Mgt. Conf. 15:53-55.

Thompson, W.R. and Ward, C.Y. 1966. Prevent thatch accumulation on Tifgreen bermudagrass greens. Golf Superintendent. 34:20-38.

Totten, F. W., Liu, H., McCarty, L.B., Baldwin, C.M., Bielenberg, D.G. and Toler, J.E. 2008. Efficiency of foliar versus granular fertilization: a field study of creeping bentgrass performance. J. Plant Nutr. 31:972-982.

Waddington, D.V., Turner, T.R., Duich, J.M. and Moberg, E.L. 1978. Effect of fertilization on penncross creeping bentgrass. Agron. J. 70:713-718.

Walker, M.E., Baker, S.H., Gaines, T.P. and Herzog, G.A. 1987. Response of cotton to soil and foliar applied nitrogen on two coastal plain soils. Proceedings of the Beltwide Cotton Conference. p. 478-489.

Wesley, T.L., Lamond, R.E., Martin, V.L. and Duncan, S.R. 1998. Effects of late-season nitrogen fertilizer on irrigated soybean yield and composition. J. of Prod. Agric. 11:331-336.

Wesely, R.W., Shearman, R.C. and Kinbacher E.J. 1985. Foliar N-uptake by eight turfgrasses grown in controlled environment. J. Amer. Soc. Hort. Sci. 110:612-614.

Wesely, R.W., Shearman, R.C., Kinbacher, E.J. and Lowry, S.R. 1987. Ammonia volatilization from foliar applied urea on field-grown Kentucky Bluegrass. HortScience 22:1278-1280.

White, R.H. and Dickens, R. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. Agron. J. 76:19-22.

Xu, Q. and Huang, B. 2000. Effects of differential air and soil temperature on carbohydrate metabolism in creeping bentgrass. Crop Sci. 40:1368-1374.

Xu, Q. and Huang, B. 2001a. Morphological and physiological characteristics associated with heat tolerance in creeping bentgrass. Crop Sci. 41:127-133.

Xu, Q. and Huang B. 2001b. Lowering soil temperatures improves creeping bentgrass growth under heat stress. Crop Sci. 41:1878-1883.

Yust, A.K., Wehner, D.J. and Fermanian, T.W. 1983. Foliar application of N and Fe to Kentucky bluegrass. Agron. J. 76:934-938.

Table 1. Analysis of variance for turfgrass color ratings, 2012, Auburn, AL.

Treatment	Date										
	Dec 3	Dec 5	Dec 7	Dec 9	Dec 16	Jan 6	Jan 12	Jan 19	Jan 26	Feb 2	Feb 9
	P > F										
N Rate	NS	NS	0.0001	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	0.0098	0.0001	0.0001	0.0001	0.0001	0.0011
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	0.0105	NS	0.0151
	Date										
	Feb 16	Feb 23	Mar 1	Mar 8	Mar 15	Mar 22	Mar 29	Apr 5	Apr 12	Apr 19	Apr 26
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0001	0.0021	NS	0.0001	0.0013	0.0418	0.0319	NS	NS	0.0499	NS
NR*M	0.0041	0.0353	NS	0.0197	0.0017	NS	NS	NS	NS	NS	NS
	Date										
	May 3	May 10	May 17	May 24	May 31	June 7	June 13	June 20	June 27	July 5	July 12
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	NS	0.0303	NS	NS	NS	0.0010
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Date										
	July 19	July 26	Aug 2	Aug 9	Aug 16	Aug 23	Aug 30	Sept 6	Sept 13	Sept 20	Sept 27
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0005	0.0001
Method	NS	NS	NS	0.0042	NS	0.0100	0.0074	NS	0.0035	NS	0.0357
NR*M	NS	0.0309	NS	NS	NS	NS	0.0335	NS	0.0174	0.0457	0.0131
	Date										
	Oct 4	Oct 11	Oct 18	Oct 25	Nov 1	Nov 8	Nov 15	Nov 22	Nov 29		
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		
Method	NS	NS	NS	0.0293	NS	NS	NS	0.0091	0.0151		
NR*M	0.0019	NS	0.0070	NS	NS	NS	NS	NS	NS		

Table 2. Analysis of variance for turfgrass color ratings, January 1, 2013 to May 29, 2013, Auburn, AL.

Treatment	Date										
	Jan9	Jan16	Jan23	Jan29	Feb6	Feb14	Feb20	Feb27	Mar6	Mar13	Mar20
	P > F										
N Rate	0.0002	0.0001	0.0001	0.0008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0479	NS
	Date										
	Mar27	Apr3	Apr10	Apr17	Apr24	May1	May8	May15	May22	May29	
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Method	NS	NS	NS	NS	NS	NS	NS	NS	0.0286	NS	
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Table 3. Analysis of variance for turfgrass quality ratings, 2012, Auburn, AL.

Treatment	Date										
	Feb 23	Mar 1	Mar 8	Mar 15	Mar 22	Mar 29	Apr 5	Apr 12	Apr 19	Apr 26	May 3
	P > F										
N Rate	0.0001	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0001	NS	0.0001	0.0001	NS	NS	NS	0.0333	NS	NS	0.0001
NR*M	NS	NS	0.0035	0.0027	NS	0.0376	NS	NS	NS	NS	0.0058
	Date										
	May 10	May 17	May 24	May 31	June 7	June 13	June 20	June 27	July 5	July 12	July 19
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0014	0.0394	0.0124	NS	0.0001	0.0051	NS	NS	0.0020	0.0001	NS
NR*M	NS	NS	NS	NS	0.0012	NS	NS	NS	NS	NS	NS
	Date										
	July 26	Aug 2	Aug 9	Aug 16	Aug 23	Aug 30	Sept 6	Sept 13	Sept 20	Sept 27	Oct 4
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0041	NS	NS	NS	NS	NS	0.0129	0.0010	NS	NS	0.0002
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	0.0459	NS	NS
	Date										
	Oct 11	Oct 18	Oct 25	Nov 1	Nov 8	Nov 15	Nov 22	Nov 29			
	P>F										
N Rate	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001			
Method	0.0116	NS	NS	NS	0.0069	0.0056	0.0019	0.0017			
NR*M	NS	NS	NS	NS	NS	NS	NS	0.0428			

Table 4. Analysis of variance for turfgrass quality ratings, January 1, 2013 to May 29, 2013, Auburn, AL.

Treatment	Date										
	Jan9	Jan16	Jan23	Jan29	Feb6	Feb14	Feb20	Feb27	Mar6	Mar13	Mar20
	P > F										
N Rate	0.0001	0.0438	0.0049	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	0.0115	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Date										
	Mar27	Apr3	Apr10	Apr17	Apr24	May1	May8	May15	May22	May29	
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Method	NS	NS	NS	0.0011	NS	NS	NS	0.0092	0.0007	NS	
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Table 5. Analysis of variance for turfgrass NDVI readings, 2012, Auburn, AL.

Treatment	Date										
	Feb 2	Feb 9	Feb 16	Feb 23	Mar 1	Mar 8	Mar 15	Mar 22	Mar 29	Apr 5	Apr 12
	P > F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0200	0.0018	NS	0.0193	NS	0.0089	NS	NS	NS	NS	NS
NR*M	0.0471	0.0022	NS	0.0090	NS	0.0344	0.0497	NS	NS	NS	NS
	Date										
	Apr 19	Apr 26	May 3	May 10	May 17	May 24	May 31	June 7	June 13	June 20	June 27
	P>F										
N Rate	0.0207	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	0.0127	NS	NS	0.0003	NS	NS	0.0201	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	0.0148	NS	NS	NS
	Date										
	July 5	July 12	July 19	July 26	Aug 2	Aug 9	Aug 16	Aug 23	Aug 30	Sept 6	Sept 13
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0448	0.0001	0.0001	0.0001	0.0001	0.0001	0.0012	0.0001
Method	NS	0.0012	0.0078	NS	NS	0.0198	0.0005	0.0016	0.0007	0.0178	0.0107
NR*M	NS	NS	NS	NS	NS	NS	NS	0.0174	0.0150	NS	NS
	Date										
	Sept 20	Sept 27	Oct 4	Oct 11	Oct 18	Oct 25	Nov 1	Nov 8	Nov 15	Nov 22	Nov 29
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0078	0.0029	NS	0.0045	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6. Analysis of variance for turfgrass NDVI readings, January 1, 2013 to May 29, 2013, Auburn, AL.

Treatment	Date										
	Jan9	Jan16	Jan23	Jan29	Feb6	Feb14	Feb20	Feb27	Mar6	Mar13	Mar20
	P > F										
N Rate	0.0058	0.0057	NS	0.0001	0.0311	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Date										
	Mar27	Apr3	Apr10	Apr17	Apr24	May1	May8	May15	May22	May29	
	P>F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Table 7. Analysis of variance for clipping dry weight, 2012, Auburn, AL.

Treatment	Date										
	Dec 9	Jan 12	Jan 26	Feb 9	Feb 23	Mar 12	Mar 26	Apr 2	Apr 16	May 2	May 17
	P > F										
N Rate	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	0.0301	NS	NS	NS	0.0045	0.0002	0.0318	0.0018	NS	0.0001
NR*M	NS	NS	NS	NS	NS	NS	0.0020	NS	0.0001	NS	0.0011
	Date										
	June 1	June 21	July 3	July 17	Aug 3	Aug 17	Sept 6	Sept 24	Oct 3	Oct 16	Nov 2
	P > F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0236	0.0001	0.0001	0.0001	0.0001
Method	NS	0.0182	NS	NS	NS	0.0115	NS	0.0026	0.0032	0.0053	0.0018
NR*M	NS	0.0096	NS	NS	NS	NS	NS	0.0285	NS	0.0033	NS
	Date										
	Nov 16										
	P > F										
N Rate	0.0001										
Method	0.0028										
NR*M	NS										

Table 8. Effect of method of fertilizer application on clipping dry weight from a Penn A-4 bentgrass putting green, 2012, Auburn, AL.

Method	Date									
	Feb 23	Mar 12	April 2	May 2	June 1	July 17	Aug 3	Sept 6	Oct 3	Nov 2
	Clipping Dry Weight (g m^{-2})									
GWI[ǂ]	5.8 a[†]	3.9 a	20.1 a	9.5 a	5.4 a	7.3 a	4.2 a	4.6 a	8.0 a	2.1 a
FWI	4.7 a	2.9 ab	17.8 a	9.0 a	5.6 a	6.5 a	4.2 a	4.4 a	7.1 ab	2.0 a
FNWI	4.6 a	2.6 b	17.0 a	8.6 a	5.1 a	6.0 a	3.6 ab	3.7 b	5.0 bc	1.7 b
No N	2.2 b	1.1 c	8.6 b	3.3 b	2.6 b	4.3 b	2.9 b	3.2 b	3.3 c	1.2 c

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α= 0.05

ǂ GWI= granular watered in after application, FWI= foliar watered in after application, FNWI= foliar not watered in after application, No N= no nitrogen

Table 9. Analysis of variance for clipping dry weight, January 1, 2013 to May 29, 2013, Auburn, AL.

Treatment	Date									
	Jan3	Jan18	Feb5	Feb19	Mar5	Mar19	Apr3	Apr19	May7	May21
	P > F									
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 10. Effect of method of fertilizer application on clipping dry weight from a Penn A-4 bentgrass putting green, January 1, 2013 to May 29, 2013, Auburn, AL.

Method	Date				
	January 3	February 19	March 5	April 19	May 7
	Clipping Dry Weight (g m^{-2})				
GWI‡	3.6 a†	1.6 a	0.8 a	3.0 a	6.7 a
FWI	3.4 a	1.5 a	0.7 a	3.0 a	6.4 a
FNWI	3.1 a	1.6 a	0.6 a	2.6 a	5.6 a
No N	2.4 b	0.7 b	0.2 b	0.8 b	3.9 b

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α= 0.05

Ŧ GWI= granular watered in after application, FWI= foliar watered in after application, FNWI= foliar not watered in after application, No N= no nitrogen

Table 11. Analysis of variance for total nitrogen in harvested clippings, 2012, Auburn, AL.

Treatment	Date										
	Dec 9	Jan 12	Jan 26	Feb 9	Feb 23	Mar 12	Mar 26	Apr 2	Apr 16	May 2	May 17
	P > F										
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	NS	NS	0.0122	0.0008	0.0186	0.0001	0.0001	0.0048	0.0001	0.0079	0.0026
NR*M	NS	NS	NS	NS	NS	0.0190	NS	NS	0.0002	NS	NS
	Date										
	June 1	June 21	July 3	July 17	Aug 3	Aug 17	Sept 6	Sept 24	Oct 3	Oct 16	Nov 2
	P > F										
N Rate	0.0001	0.0001	0.0009	0.0091	0.0039	0.0355	NS	0.0001	0.0031	NS	0.0001
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	0.0238	NS	NS	NS
	Date										
	Nov 16										
	P > F										
N Rate	0.0001										
Method	NS										
NR*M	NS										

Table 12. Analysis of variance for total nitrogen in harvested clippings, January 1, 2013 to May 29, 2013, Auburn, AL.

Treatment	Date									
	Jan3	Jan18	Feb5	Feb19	Mar5	Mar19	Apr3	Apr19	May7	May21
	P > F									
N Rate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Method	0.0014	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 13. Effect of method of fertilizer application on total N in bentgrass tissue, 2012, Auburn, AL.

Method	Date									
	Feb 23	Mar 26	April 2	May 17	June 1	July 17	Aug 3	Sept 6	Oct 16	Nov 2
	Total N (g kg^{-1})									
GWI‡	3.1 a†	4.6 a	4.0 a	3.5 a	2.9 a	3.7 a	4.0 a	4.0 a	2.8 a	3.3 a
FWI	2.8 a	4.3 b	3.7 b	3.2 ab	2.9 a	3.4 ab	3.8 ab	4.1 a	2.8 a	3.4 a
FNWI	2.8 a	4.3 b	3.7 b	3.1 b	3.0 a	3.6 a	3.6 ab	4.1 a	2.8 a	3.3 a
No N	2.0 b	4.1 b	2.7 c	2.4 c	2.6 b	3.1 b	3.4 b	3.6 b	2.8 a	2.7 b

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α= 0.05

‡ GWI= granular watered in after application, FWI= foliar watered in after application, FNWI= foliar not watered in after application, No N= no nitrogen

Table 14. Effect of method of fertilizer application on total N in bentgrass tissue, January 1, 2013 to May 29, 2013, Auburn, AL.

Method	Date					
	January 3	February 19	March 5	April 19	May 7	May 21
	Total N (g kg^{-1})					
GWI[Ŧ]	5.4 b[†]	4.3 a	4.4 a	4.8 a	2.6 a	3.5 a
FWI	5.5 ab	4.1 a	4.2 a	4.6 a	2.4 a	3.6 a
FNWI	5.8 a	4.0 a	4.4 a	4.6 a	2.5 a	3.5 a
No N	5.3 b	3.5 b	3.5 b	3.9 b	1.5 b	2.6 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at $\alpha = 0.05$

Ŧ GWI= granular watered in after application, FWI= foliar watered in after application, FNWI= foliar not watered in after application, No N= no nitrogen

Table 15. Analysis of variance for turfgrass shoot density of bentgrass, 2012 and 2013.

Treatment	2012				2013	
	January	April	July	October	January	April
	P > f					
N Rate	0.0217	NS	0.0006	0.0001	0.0001	0.0015
Method	NS	NS	NS	NS	NS	NS
NR*M	0.0330	NS	NS	NS	NS	NS

Table 16. Analysis of variance for turfgrass root length of bentgrass, 2012 and 2013.

Treatment	2012				2013	
	January 26	April 17	July 17	October 9	January 22	April 29
	P > F					
N Rate	0.0409	NS	NS	NS	NS	NS
Method	NS	NS	NS	NS	0.0421	NS
NR*M	NS	NS	NS	NS	NS	0.0040

Table 17. Analysis of variance for turfgrass root dry weight, 2012 and 2013.

Treatment	2012				2013	
	January 26	April 17	July 17	October 9	January 22	April 29
	P > F					
N Rate	0.0212	NS	NS	NS	NS	NS
Method	NS	NS	NS	NS	NS	NS
NR*M	NS	NS	0.0048	NS	NS	NS

Table 18. Analysis of variance for turfgrass percent TNC on an organic matter basis, 2012 and 2013.

Treatment	Date		
	April 12, 2012	October 12, 2012	April 13, 2013
		P > F	
N Rate	NS	0.0006	0.0001
Method	NS	NS	NS
NR*M	NS	NS	NS

Figure 1. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

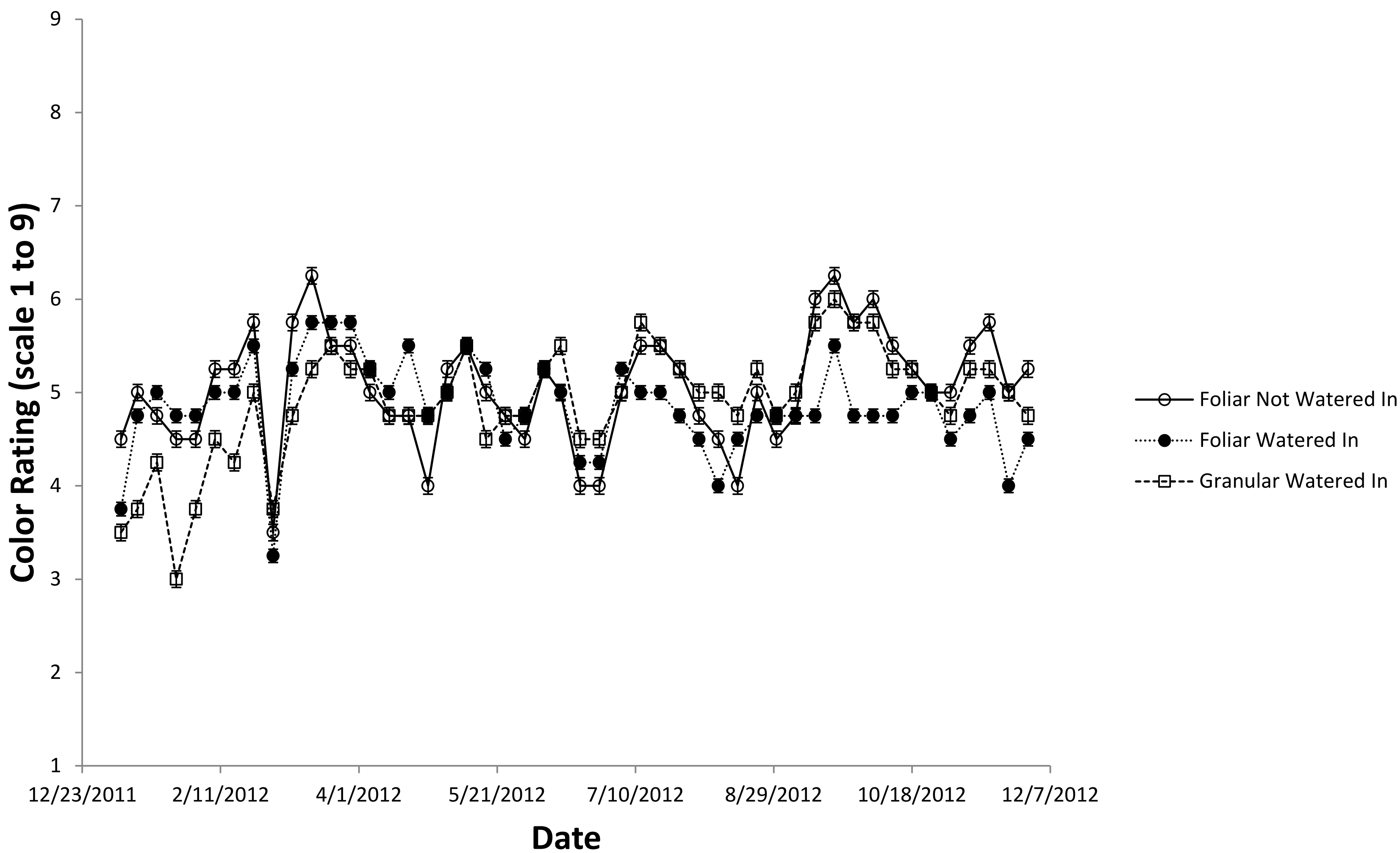


Figure 2. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

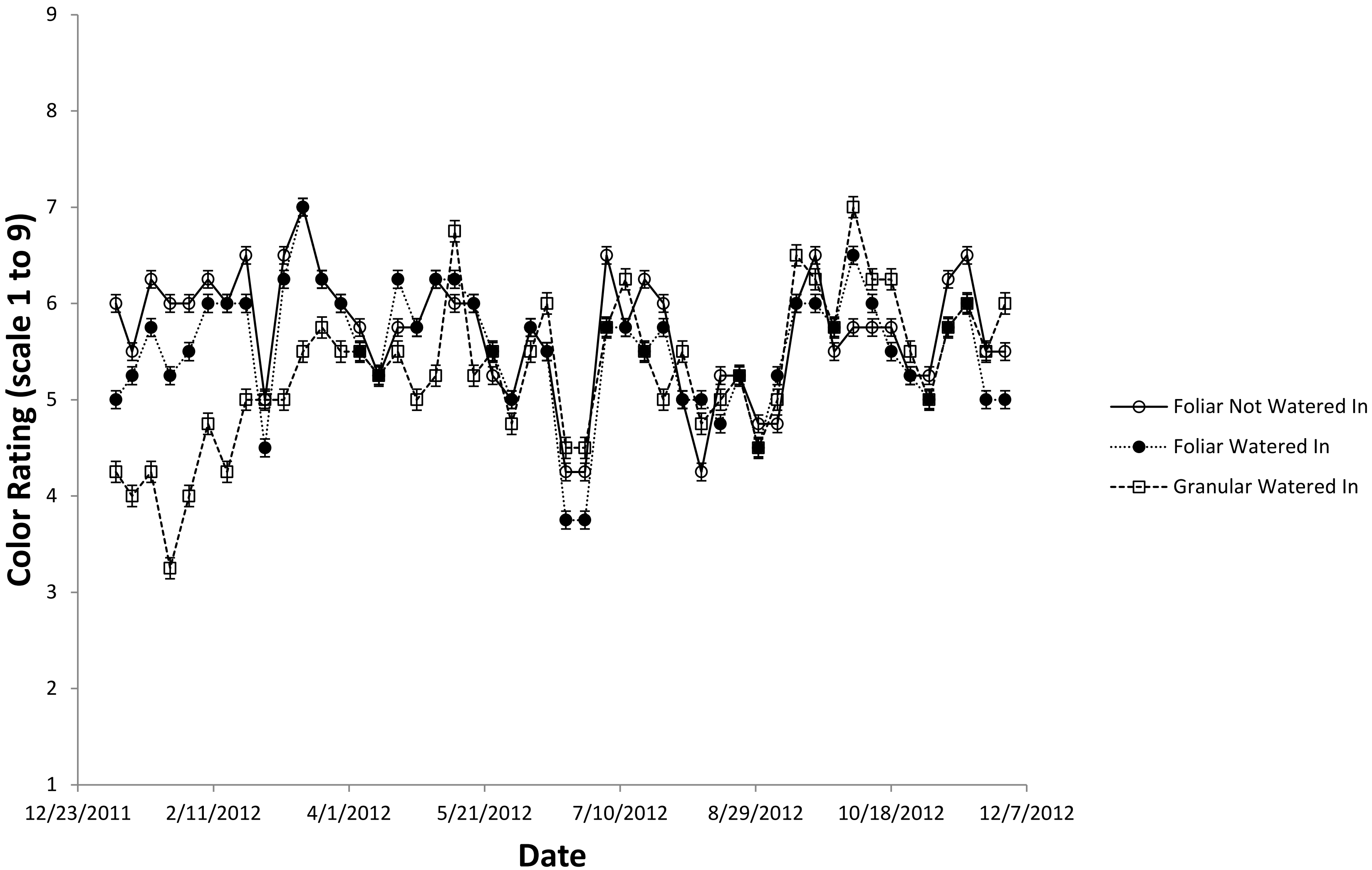


Figure 3. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

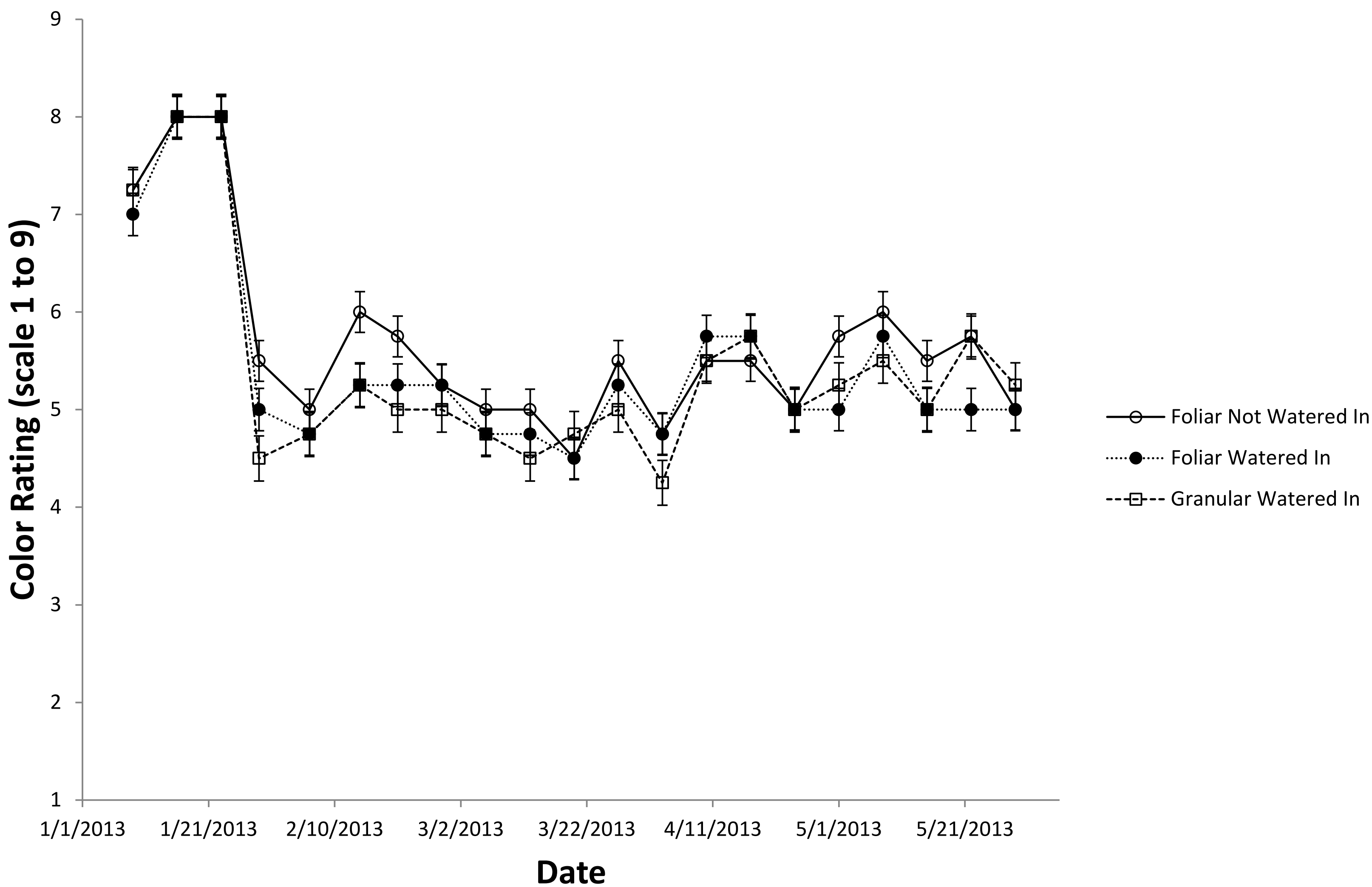


Figure 4. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

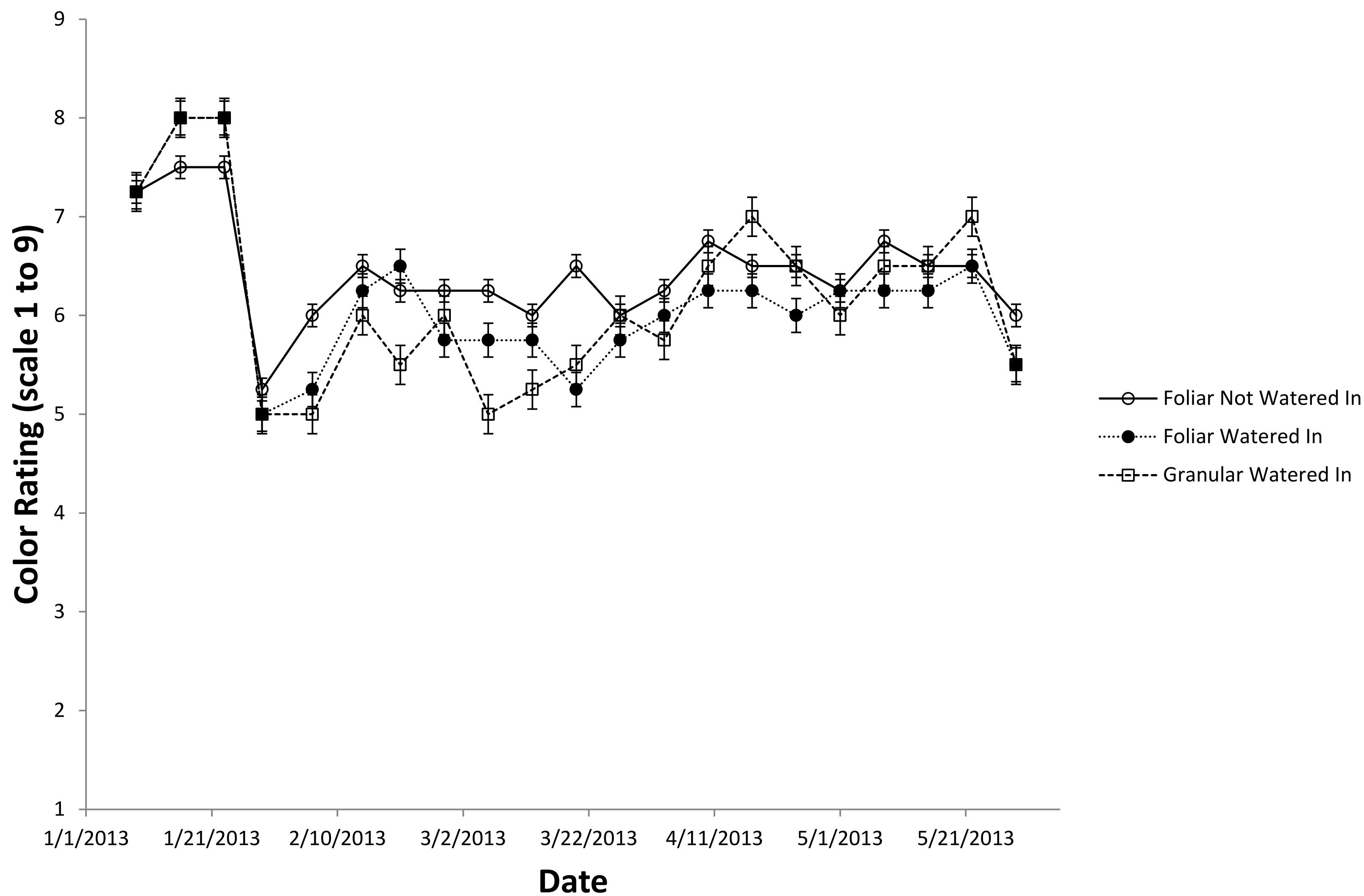


Figure 5. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

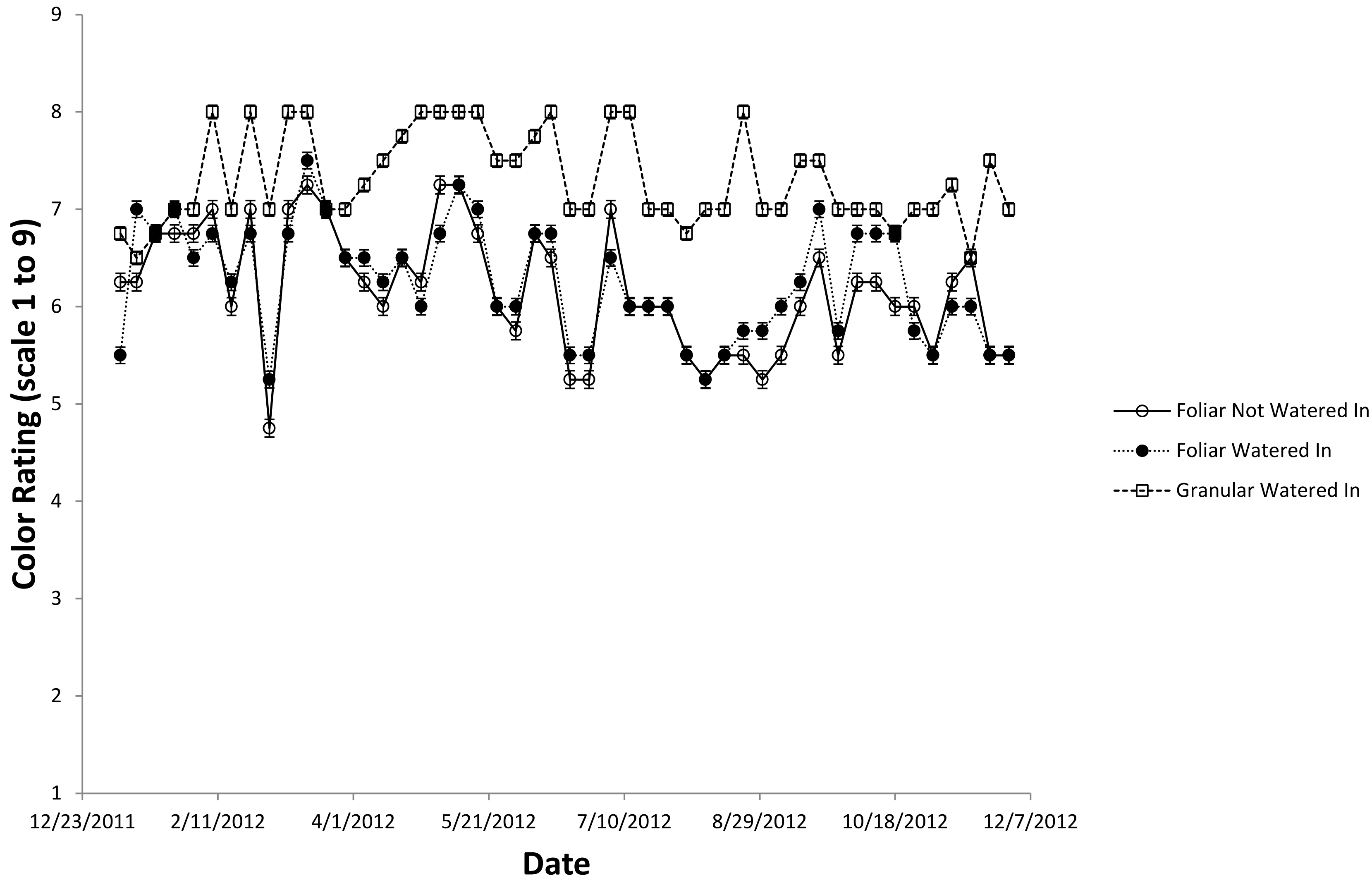


Figure 6. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

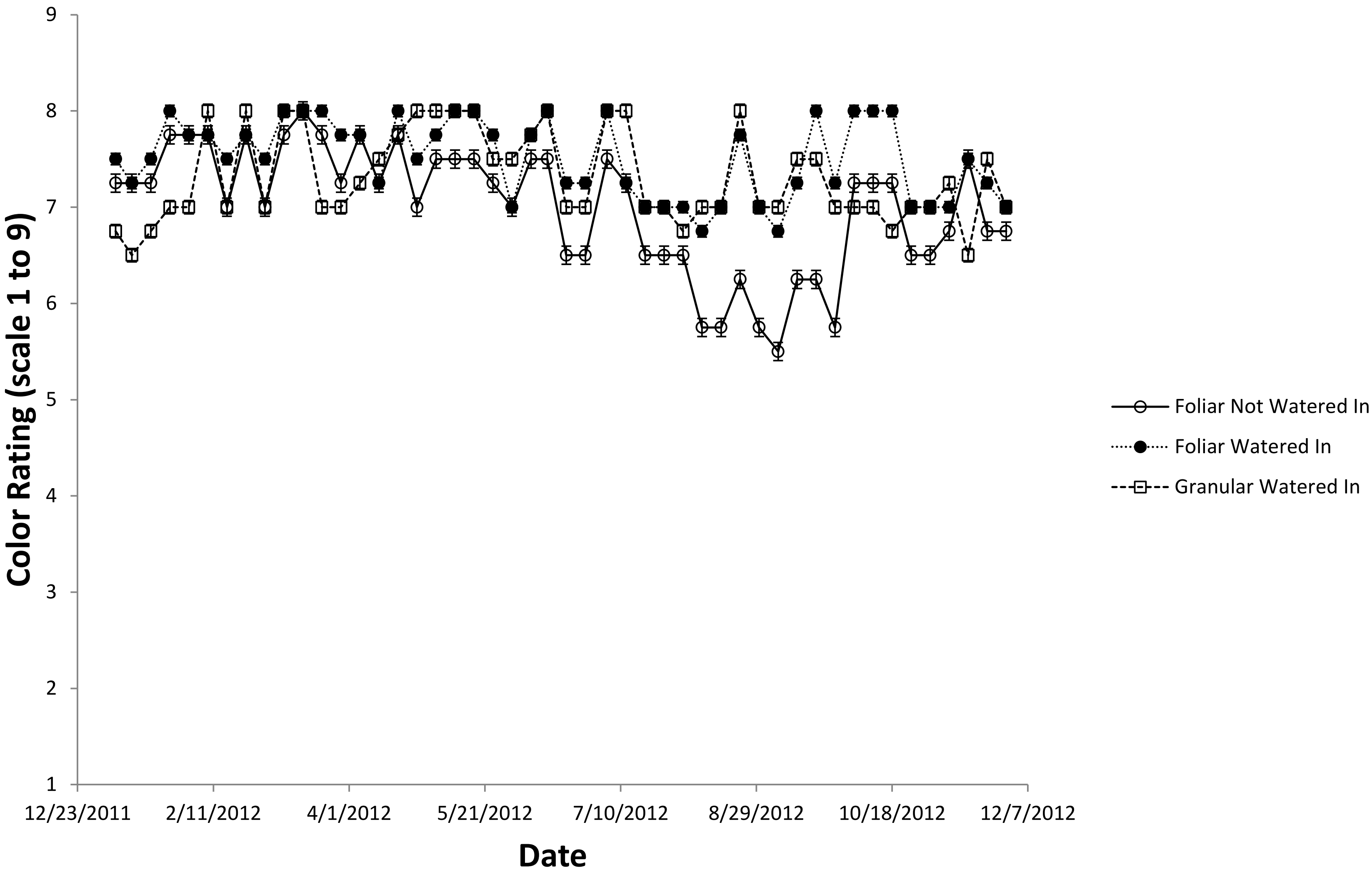


Figure 7. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

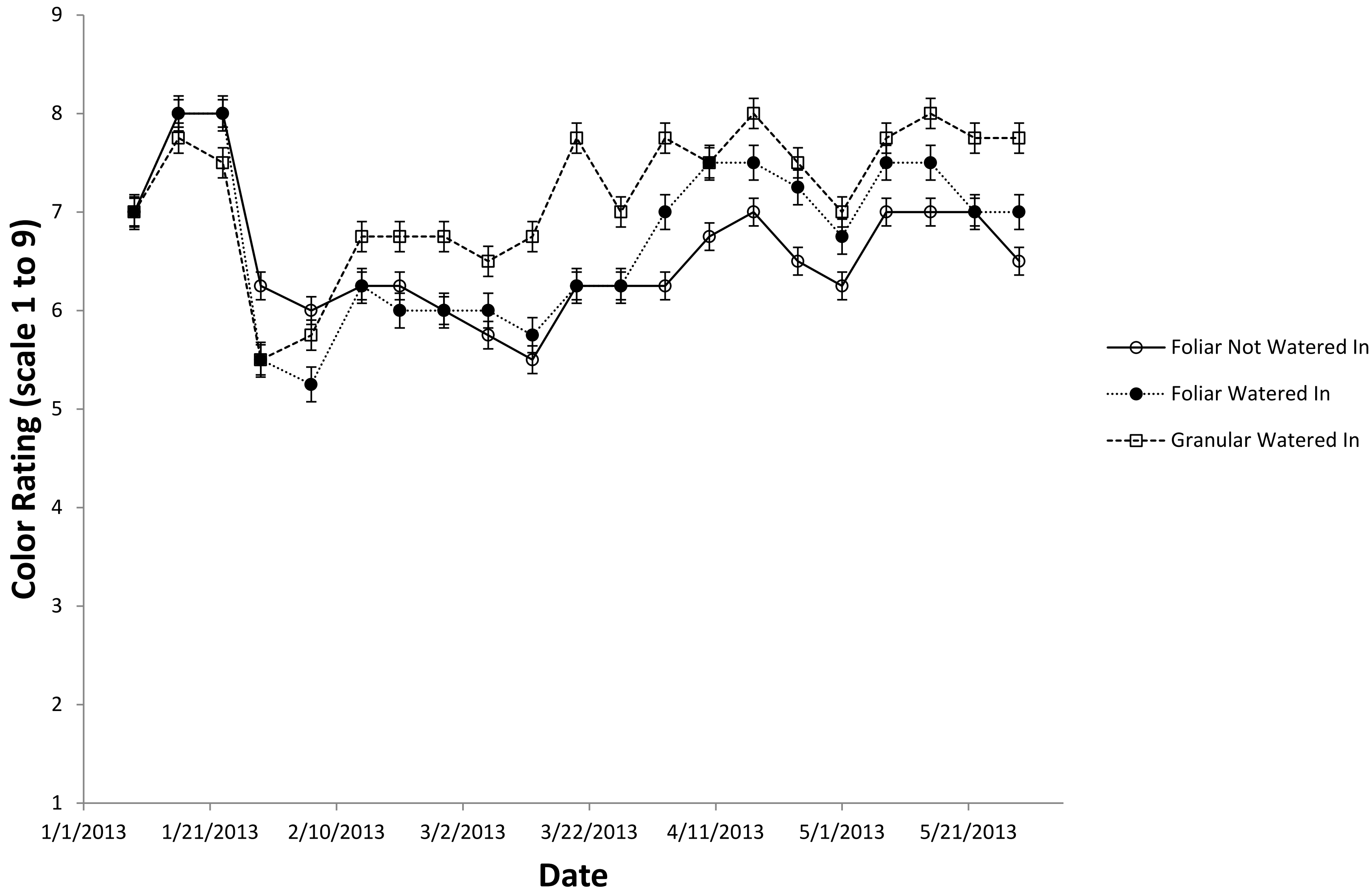
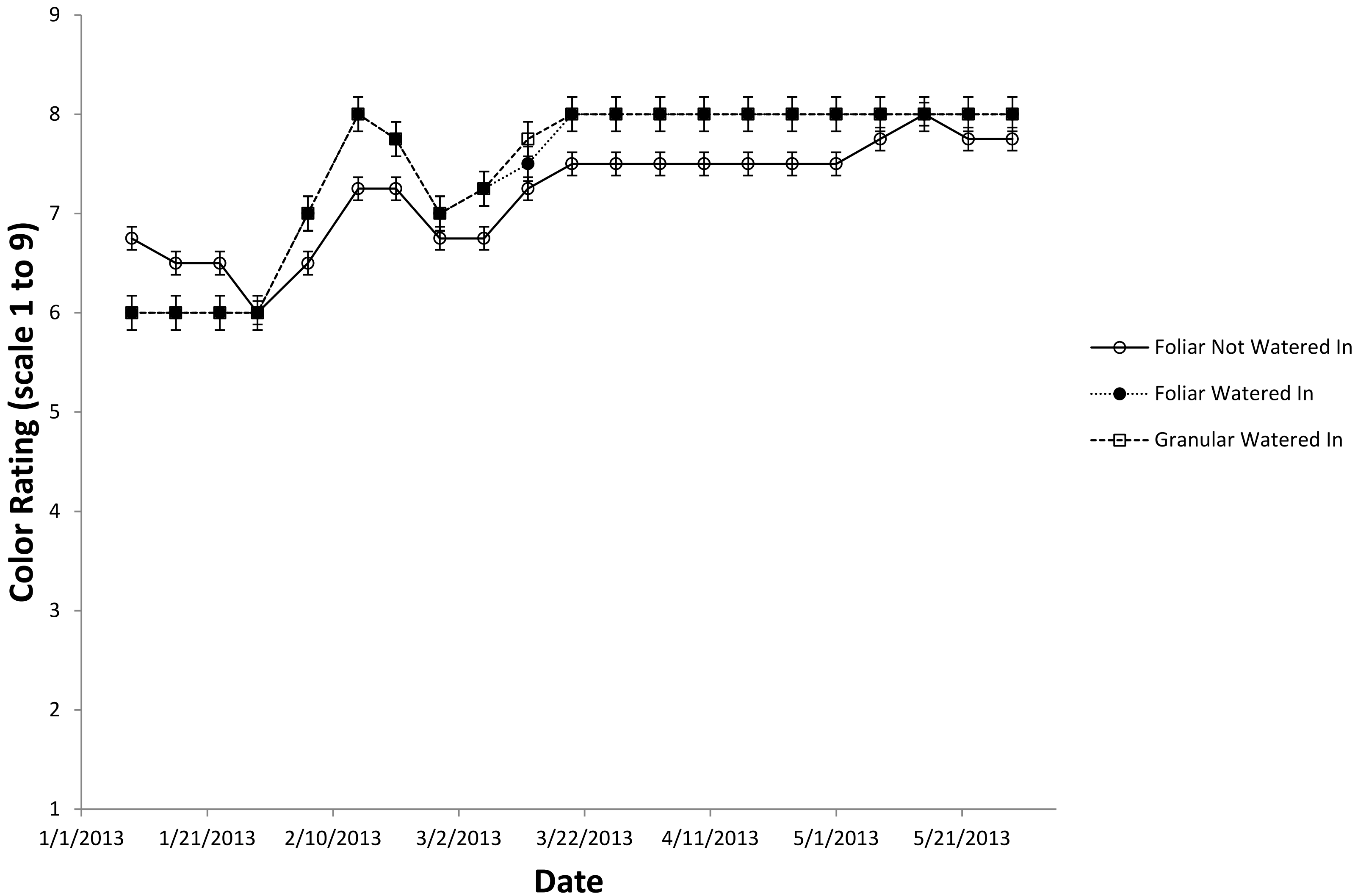


Figure 8. Relative Color of Penn A-4 Creeping Bentgrass (1 = brown, 9 = very green) as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.



† Data for Foliar Watered In and Granular Watered In the same, so data points overlap.

Figure 9. Relative Color of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in November, 2012 (results averaged over 4 November rating dates). Vertical lines on each marker are the standard error about the mean.

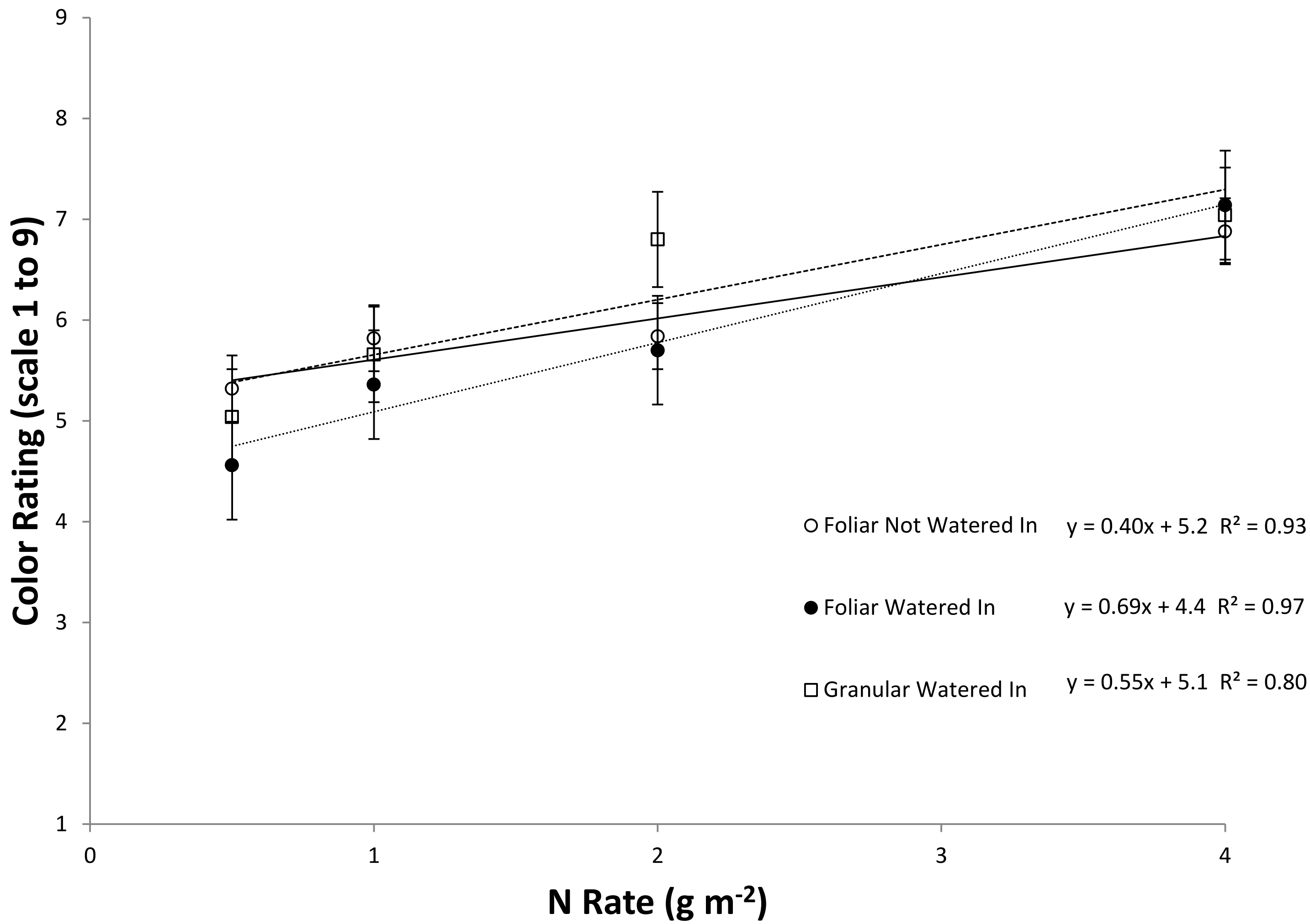


Figure 10. Relative Color of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in May, 2012 (results averaged over 4 May rating dates). Vertical lines on each marker are the standard error about the mean.

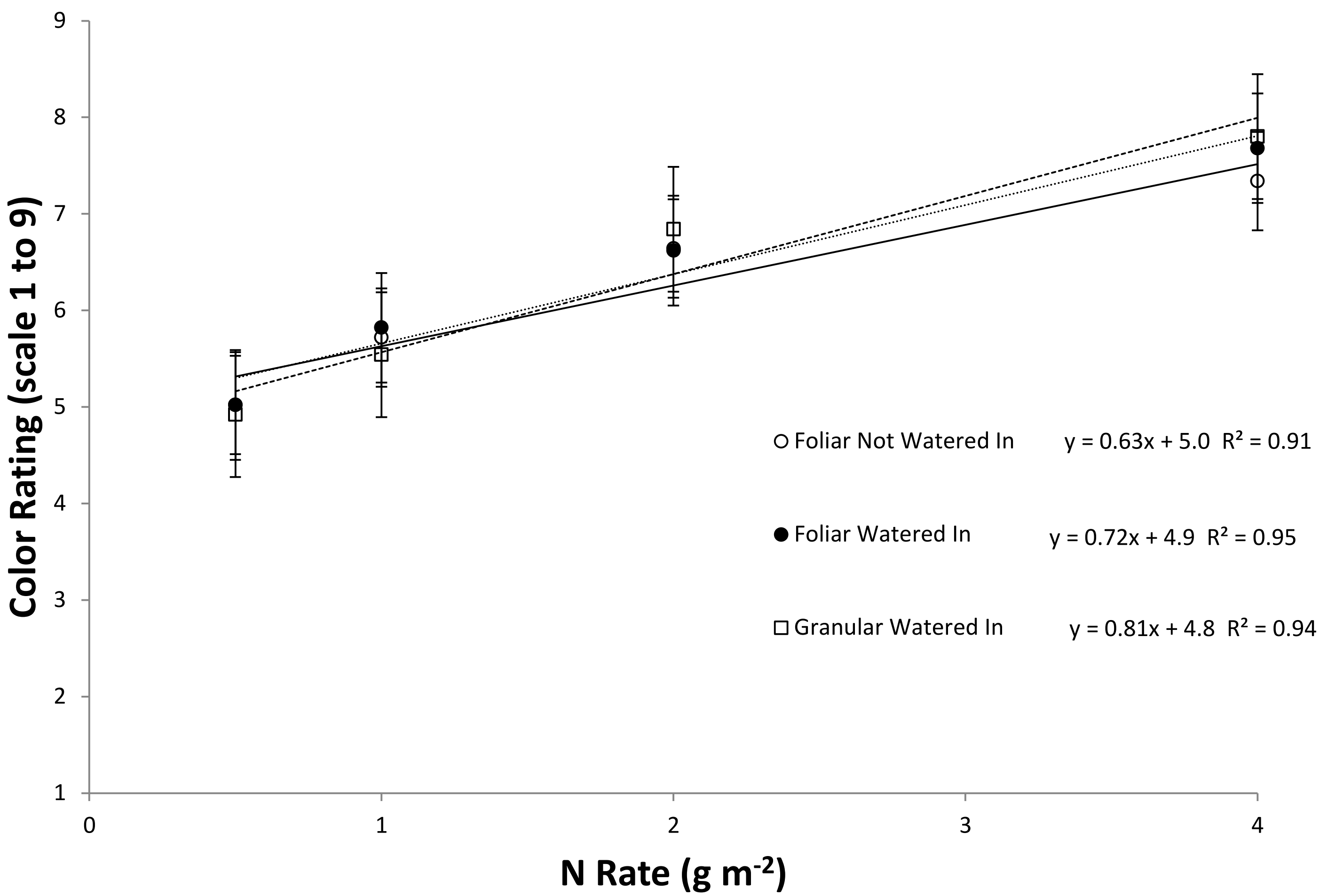


Figure 11. Relative Color of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in August, 2012 (results averaged over 4 August rating dates). Vertical lines on each marker are the standard error about the mean.

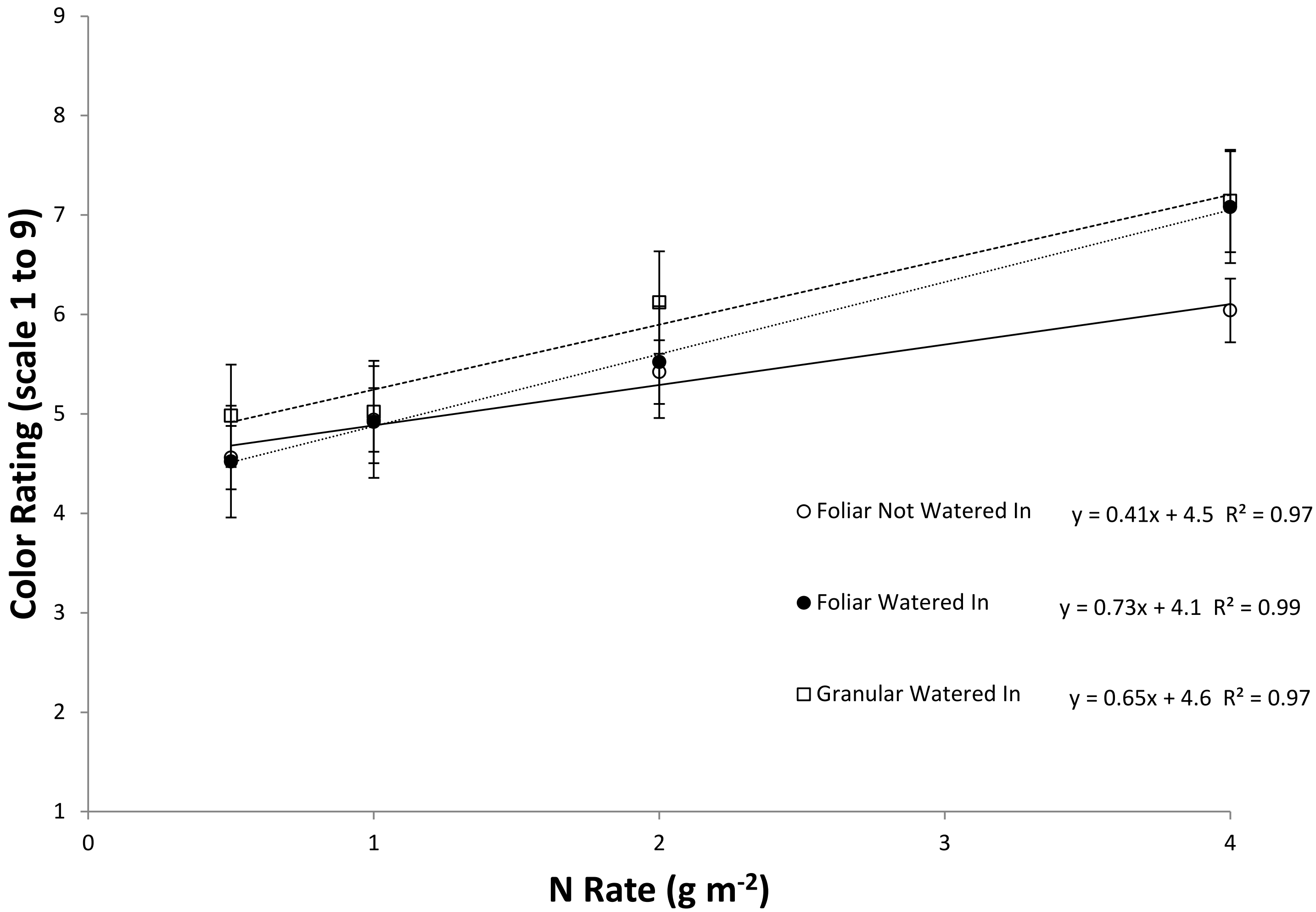


Figure 12. Relative Color of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in May, 2013 (results averaged over 4 May rating dates). Vertical lines on each marker are the standard error about the mean.

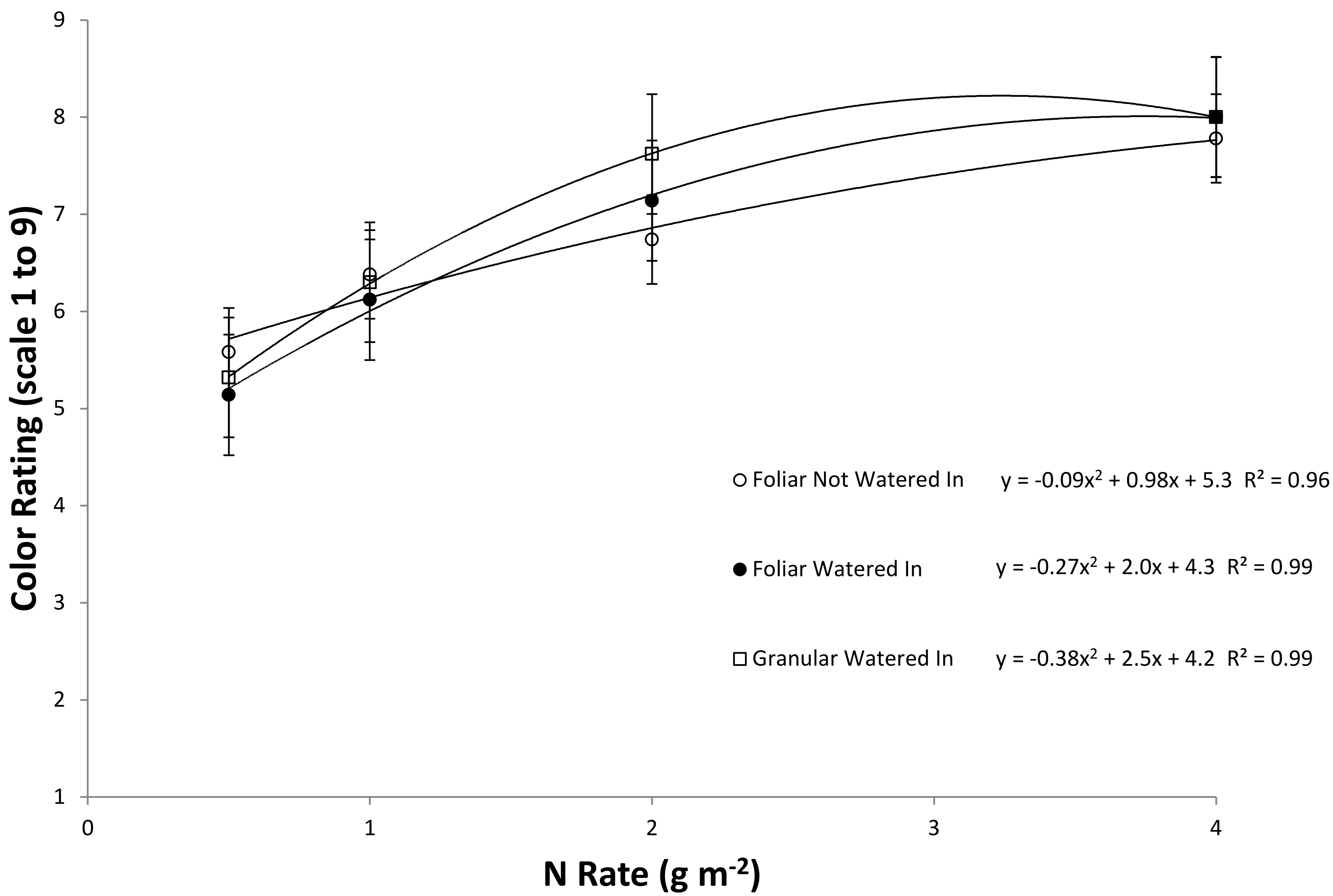


Figure 13. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

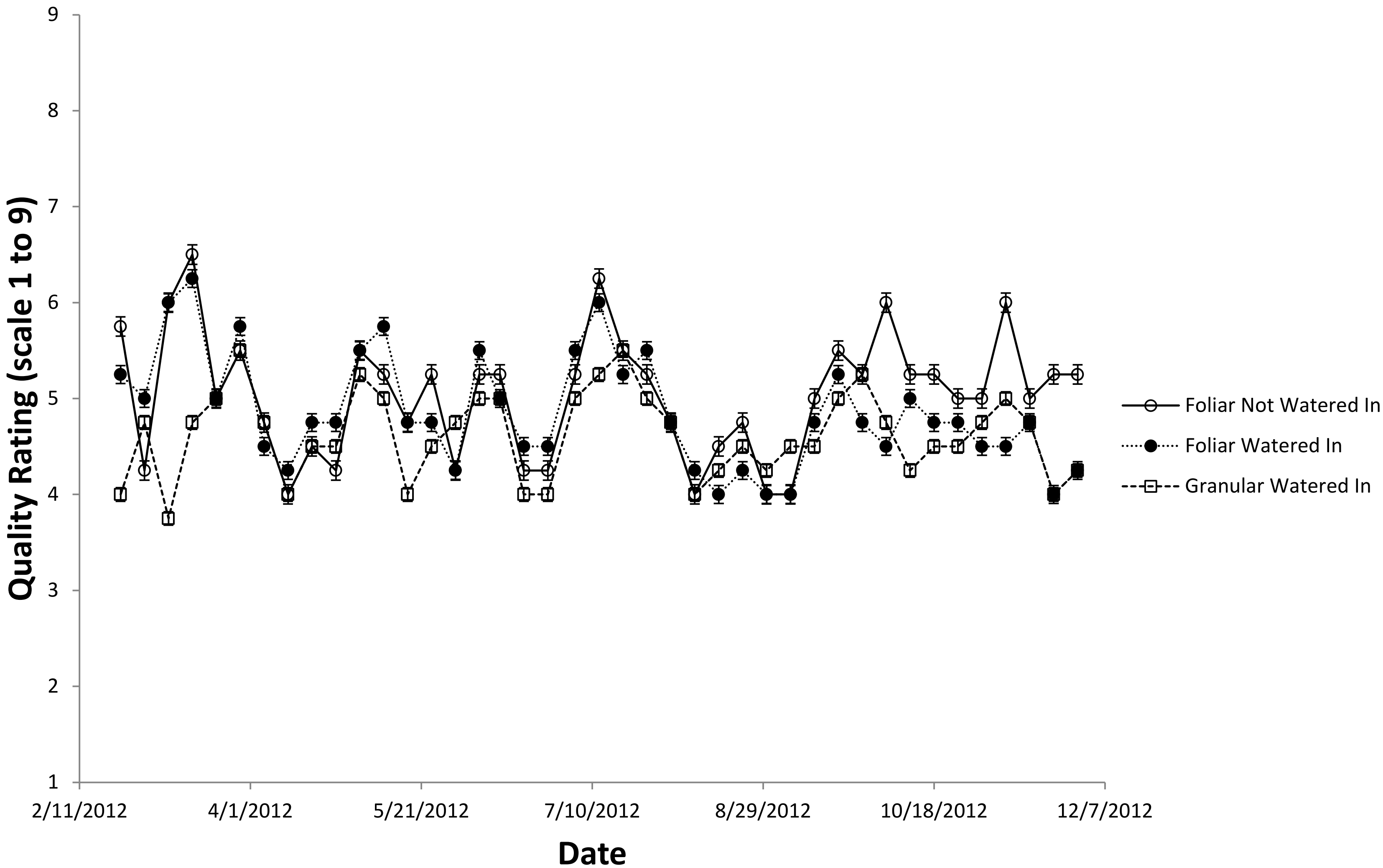


Figure 14. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

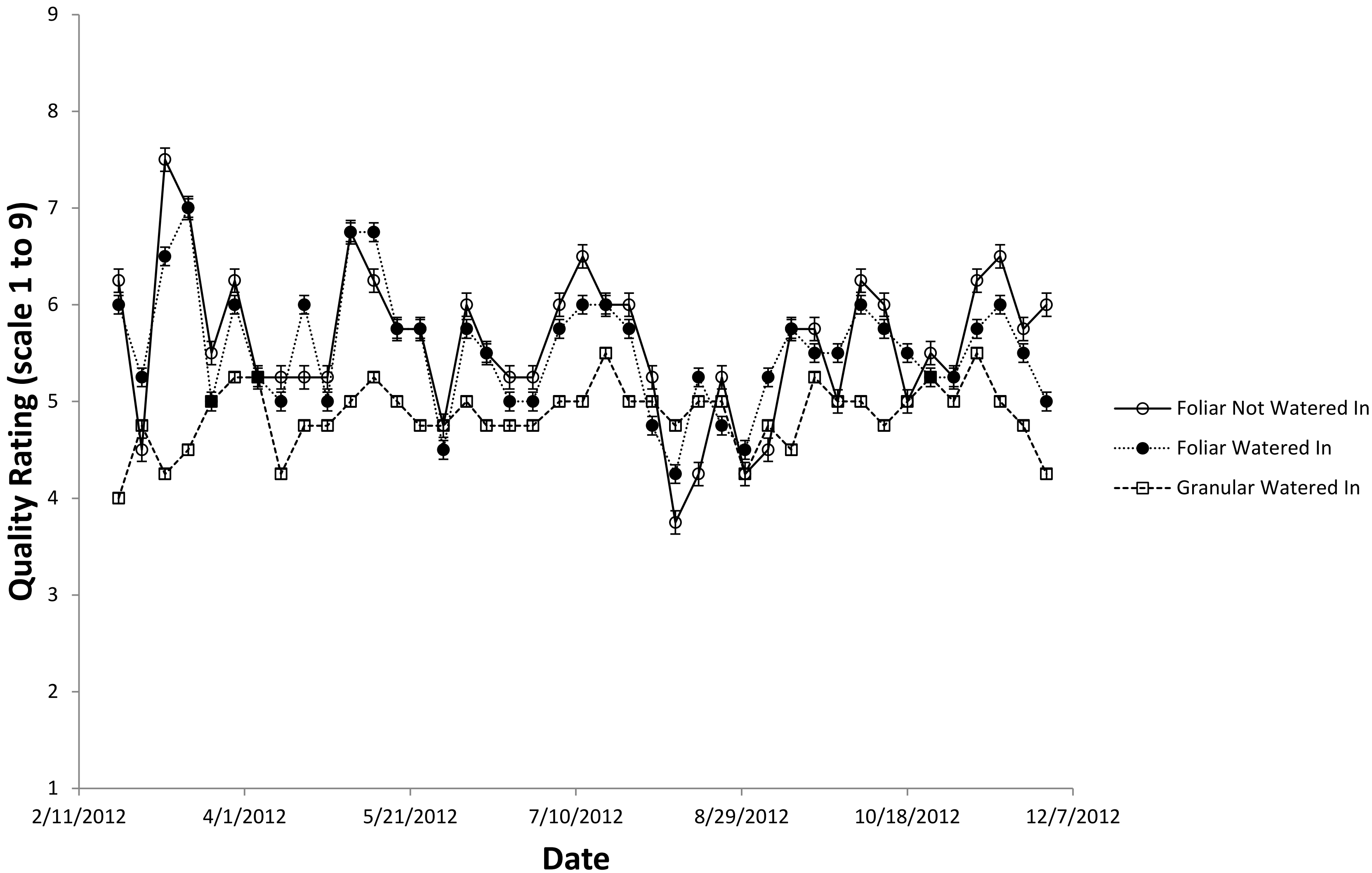
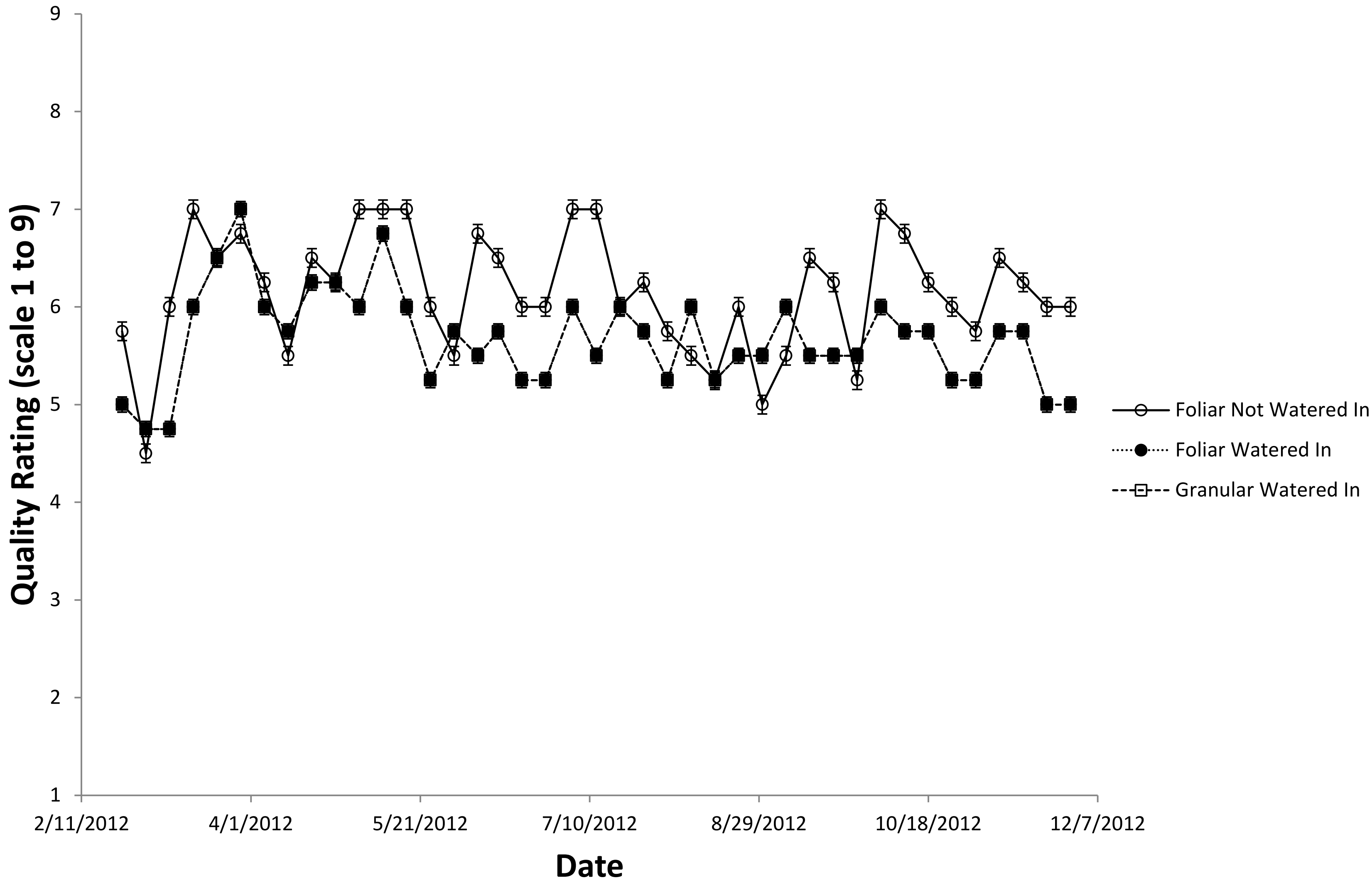


Figure 15. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.



†Data for foliar watered in and granular watered in are exactly the same, so data points overlap.

Figure 16. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

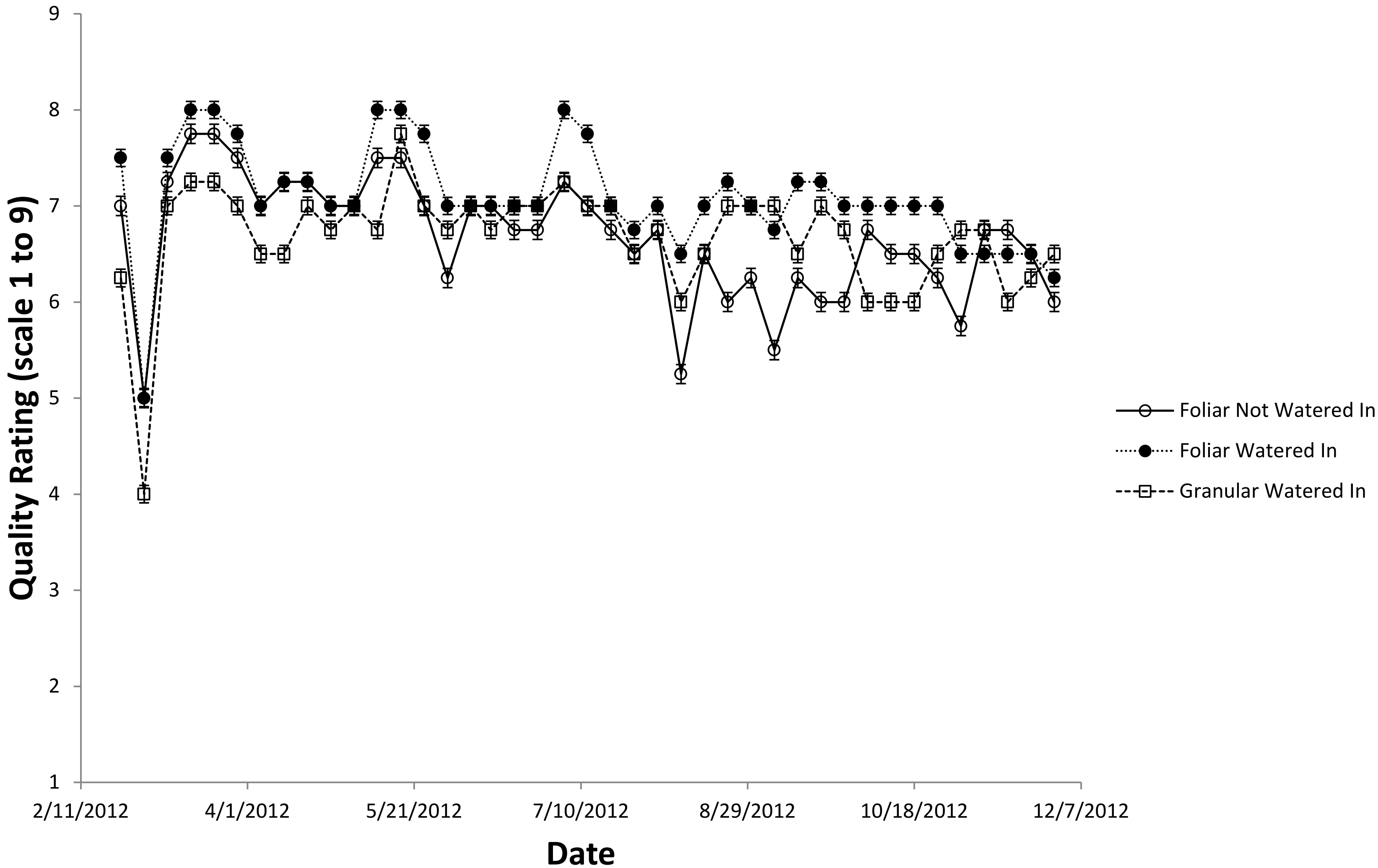


Figure 17. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in February, 2012 (results averaged over 4 February rating dates). Vertical lines on each marker are the standard error about the mean.

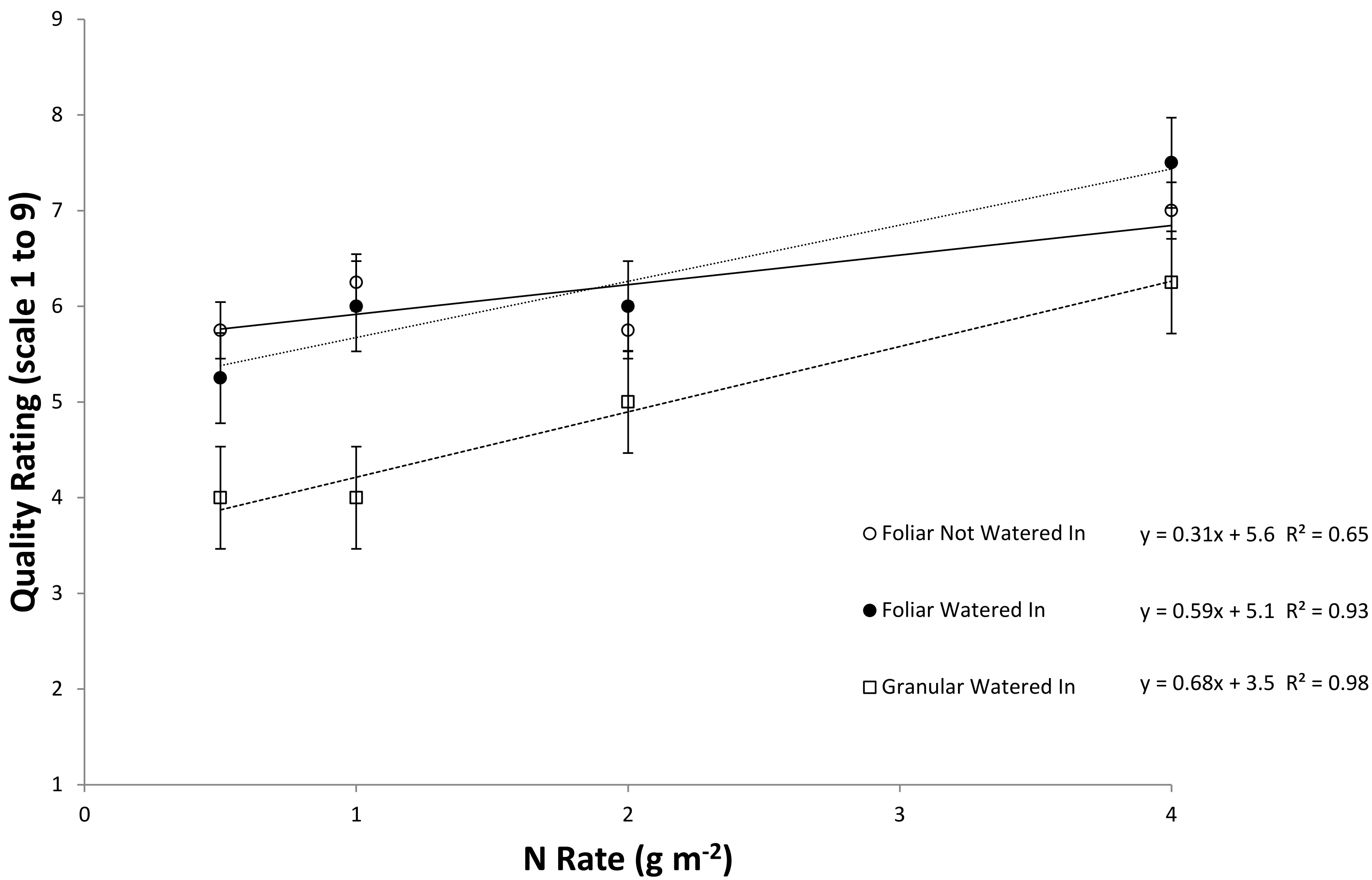
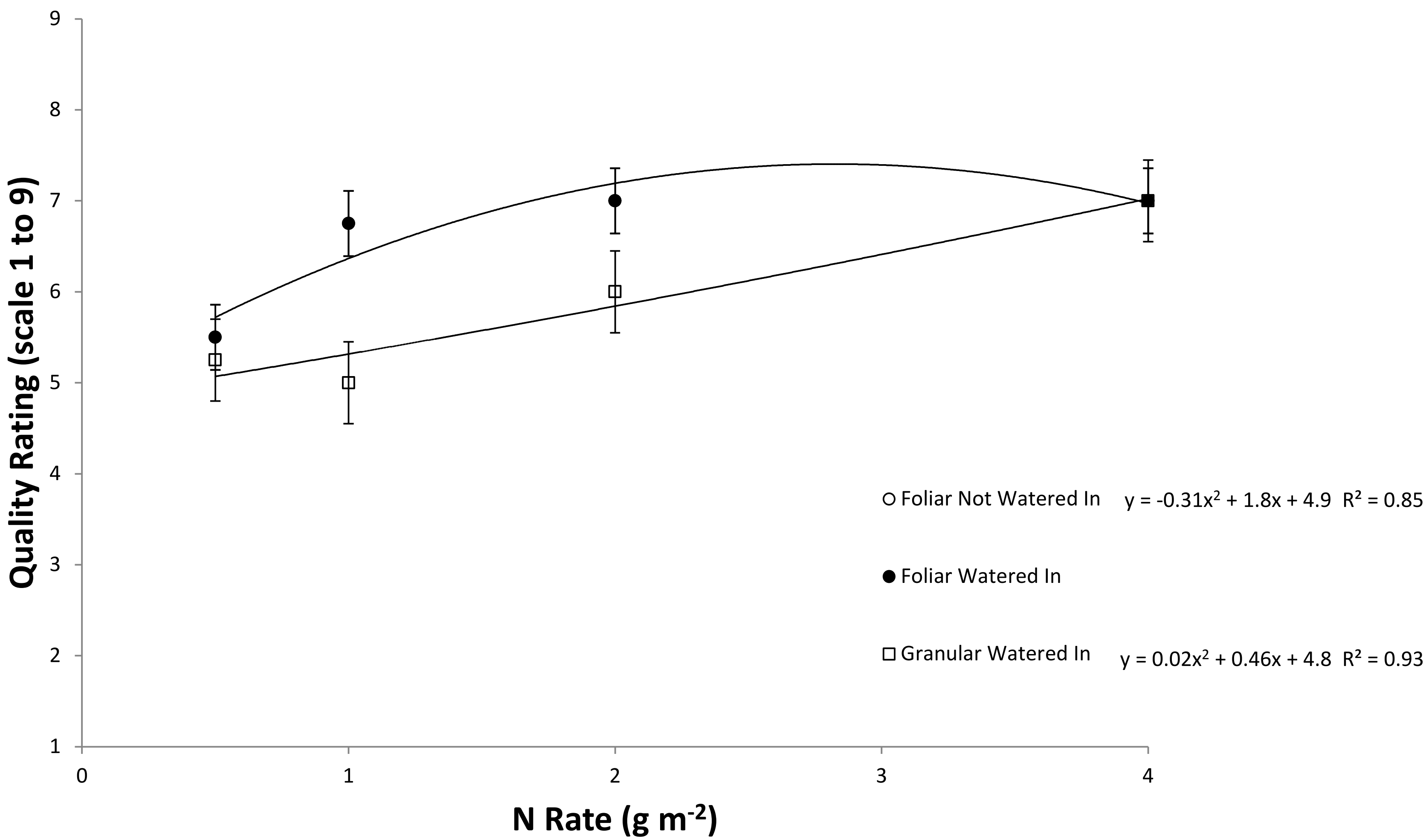


Figure 18. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in May, 2012 (results averaged over 4 May rating dates). Vertical lines on each marker are the standard error about the mean.



†Data for Foliar Not Watered In and Foliar Watered In are exactly the same, so data points overlap. Regression equation is also the same.

Figure 19. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in August, 2012 (results averaged over 4 August rating dates). Vertical lines on each marker are the standard error about the mean.

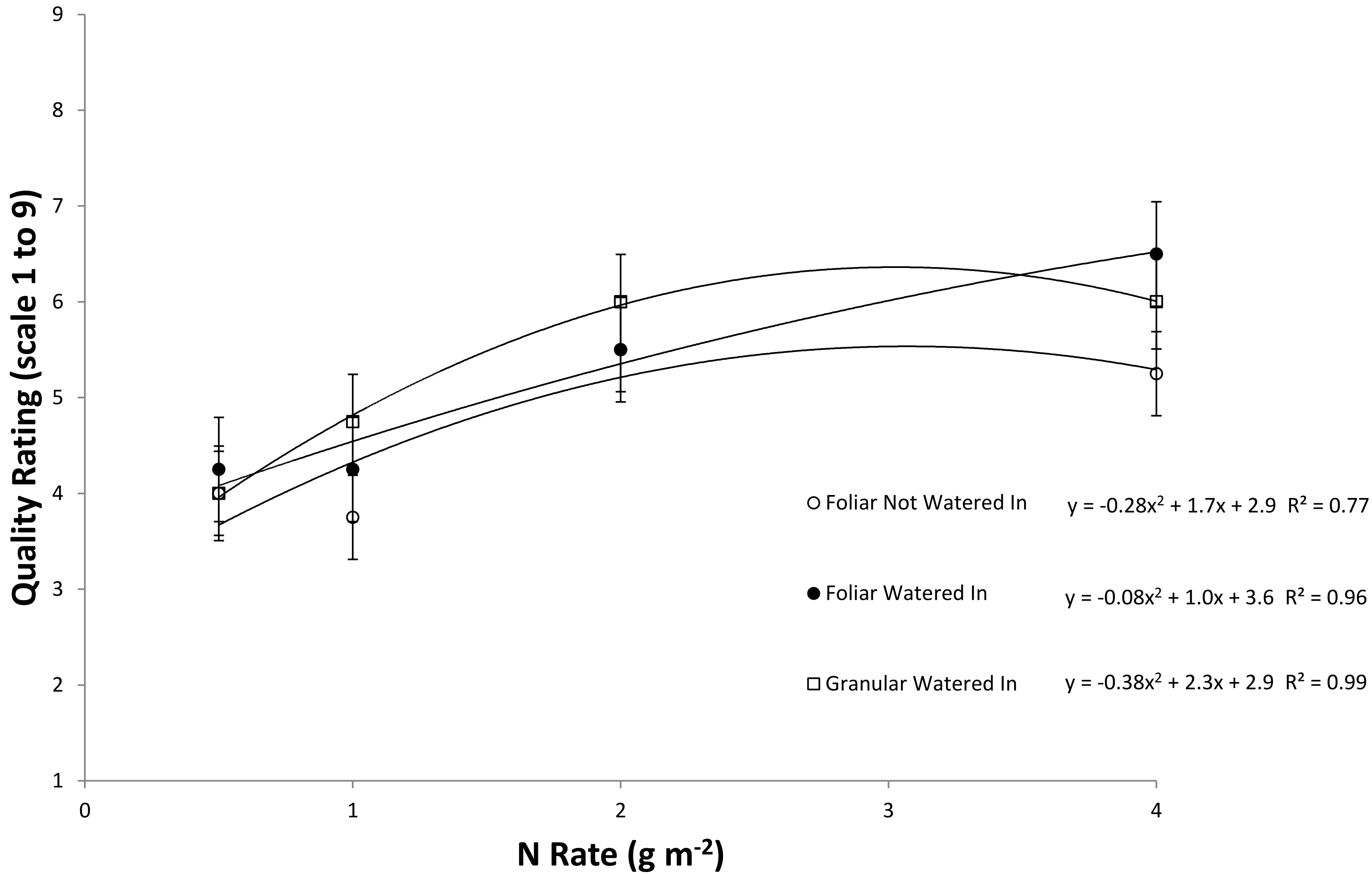


Figure 20. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in November, 2012 (results averaged over 4 November rating dates). Vertical lines on each marker are the standard error about the mean.

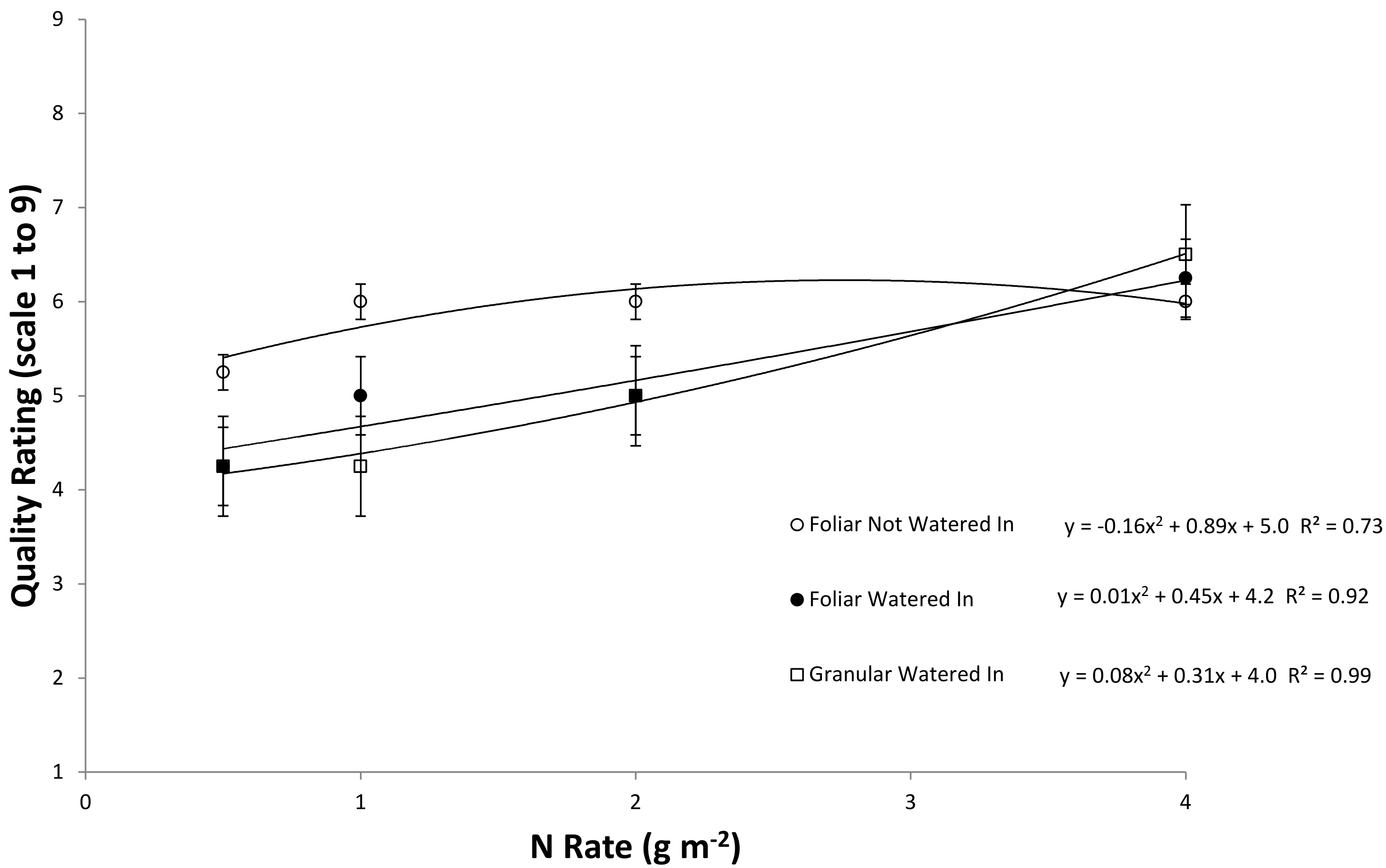


Figure 21. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

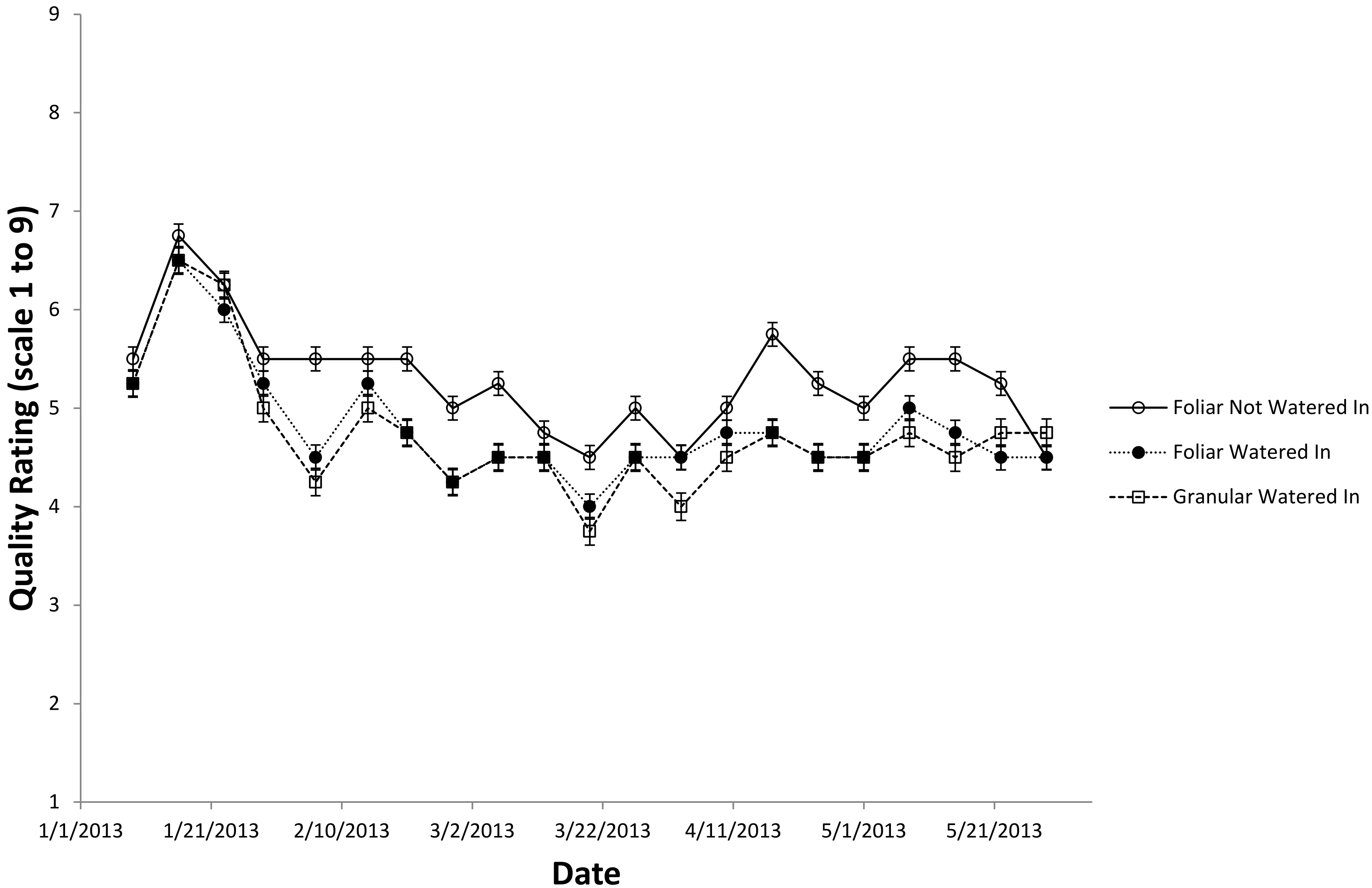


Figure 22. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

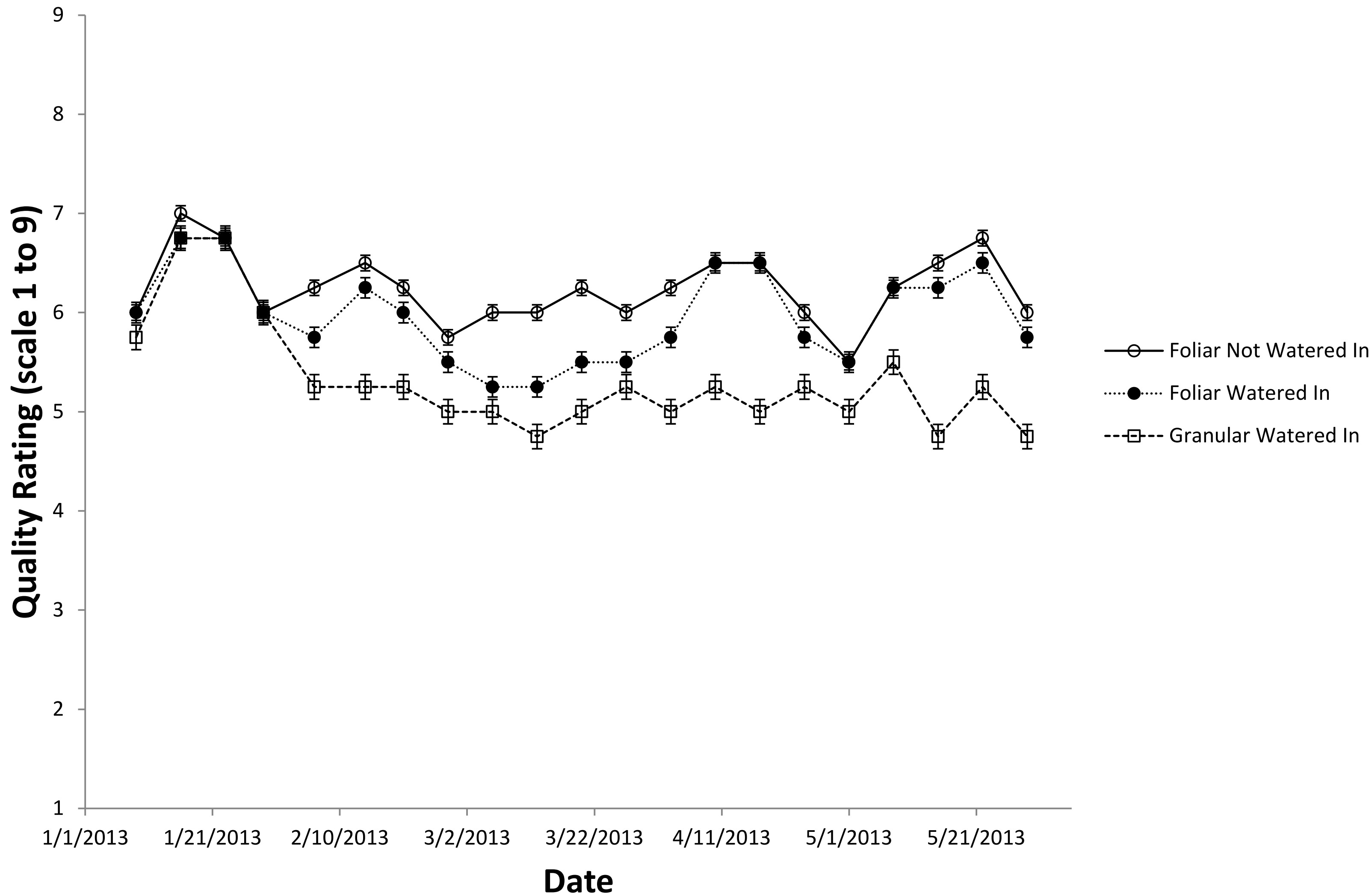


Figure 23. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

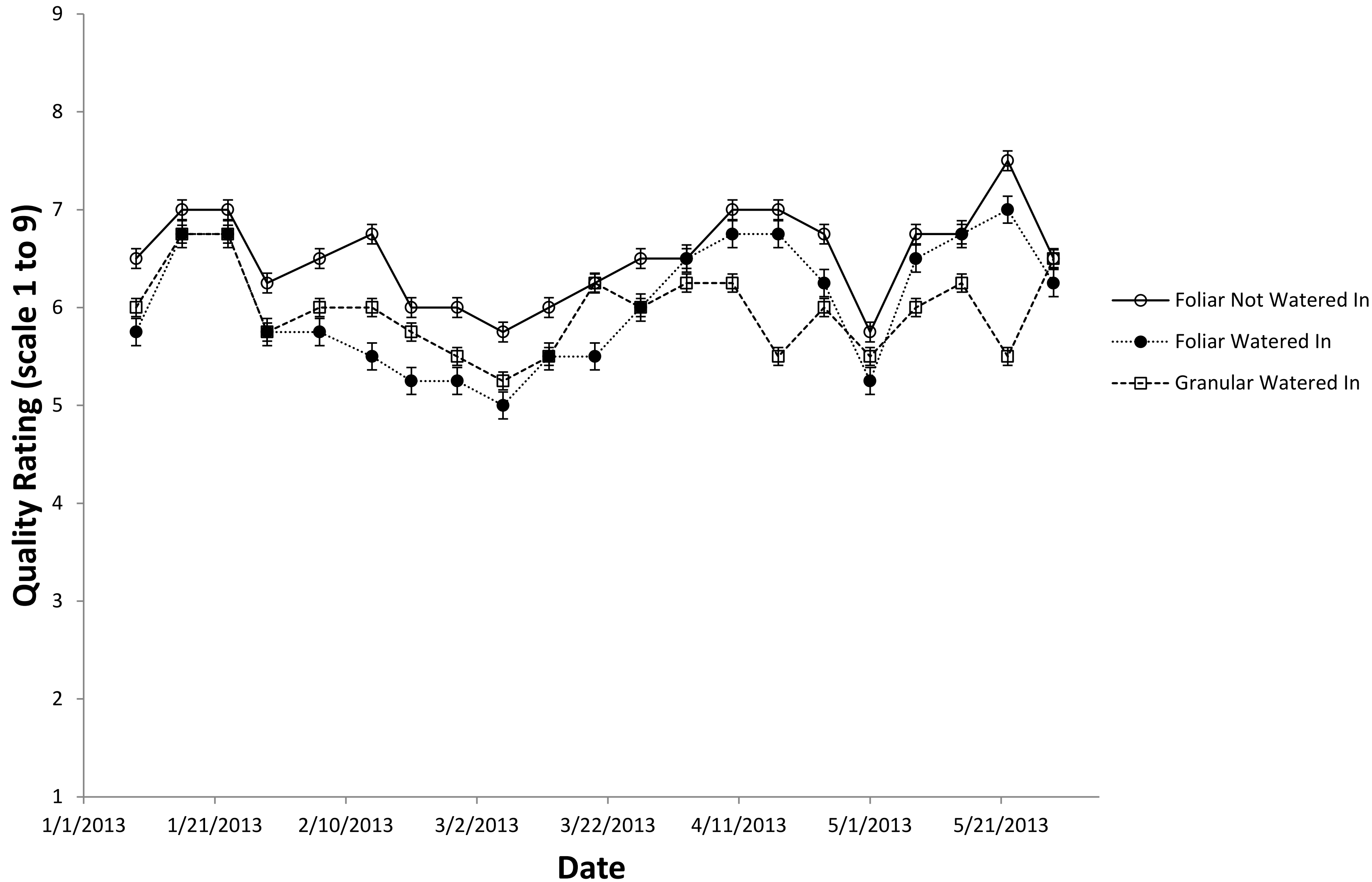


Figure 24. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in February, 2013 (results averaged over 4 February rating dates). Vertical lines on each marker are the standard error about the mean.

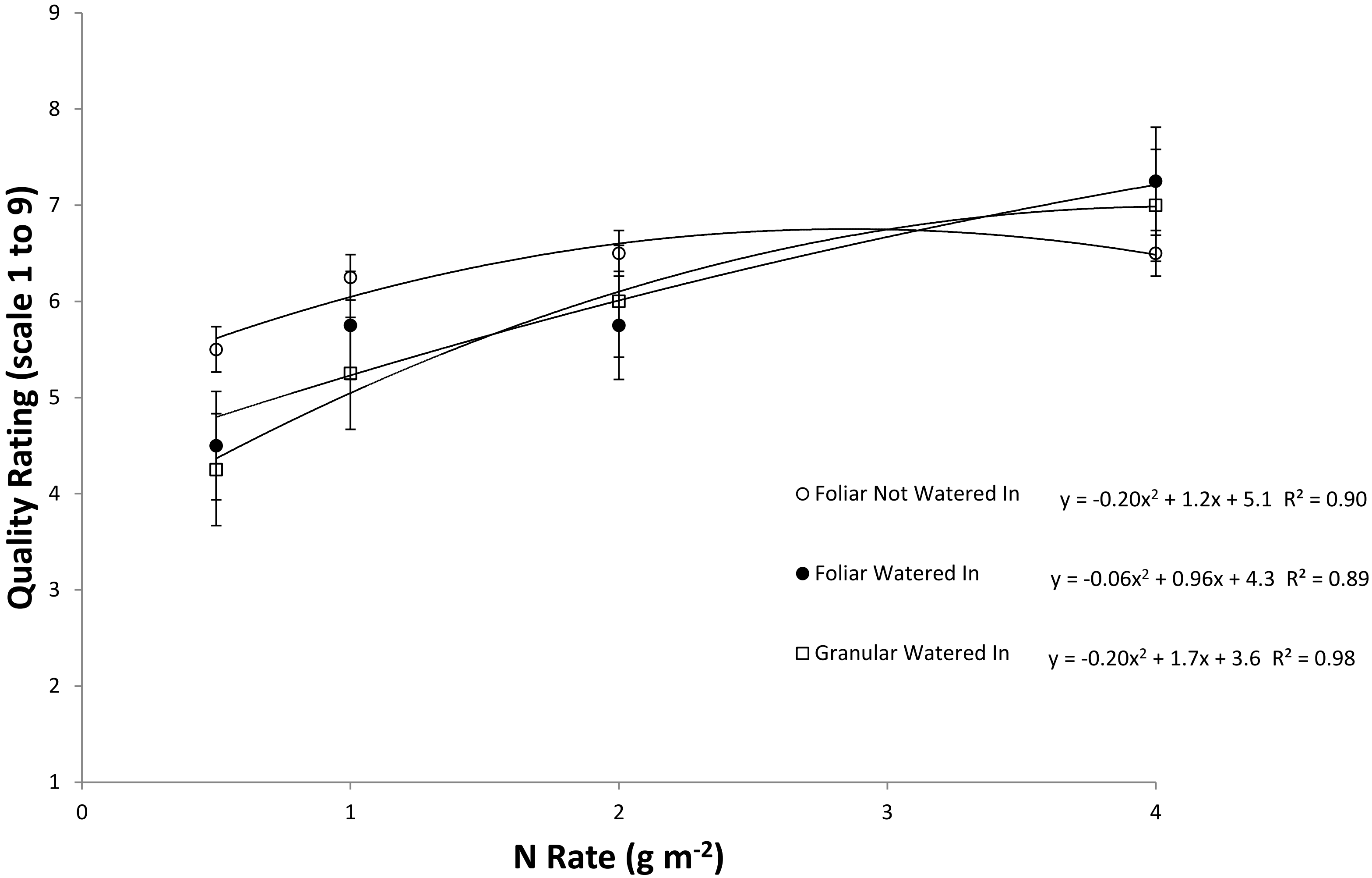


Figure 25. Relative Quality of Penn A-4 Creeping Bentgrass as affected by N rate and method of application in May, 2013 (results averaged over 4 May rating dates). Vertical lines on each marker are the standard error about the mean.

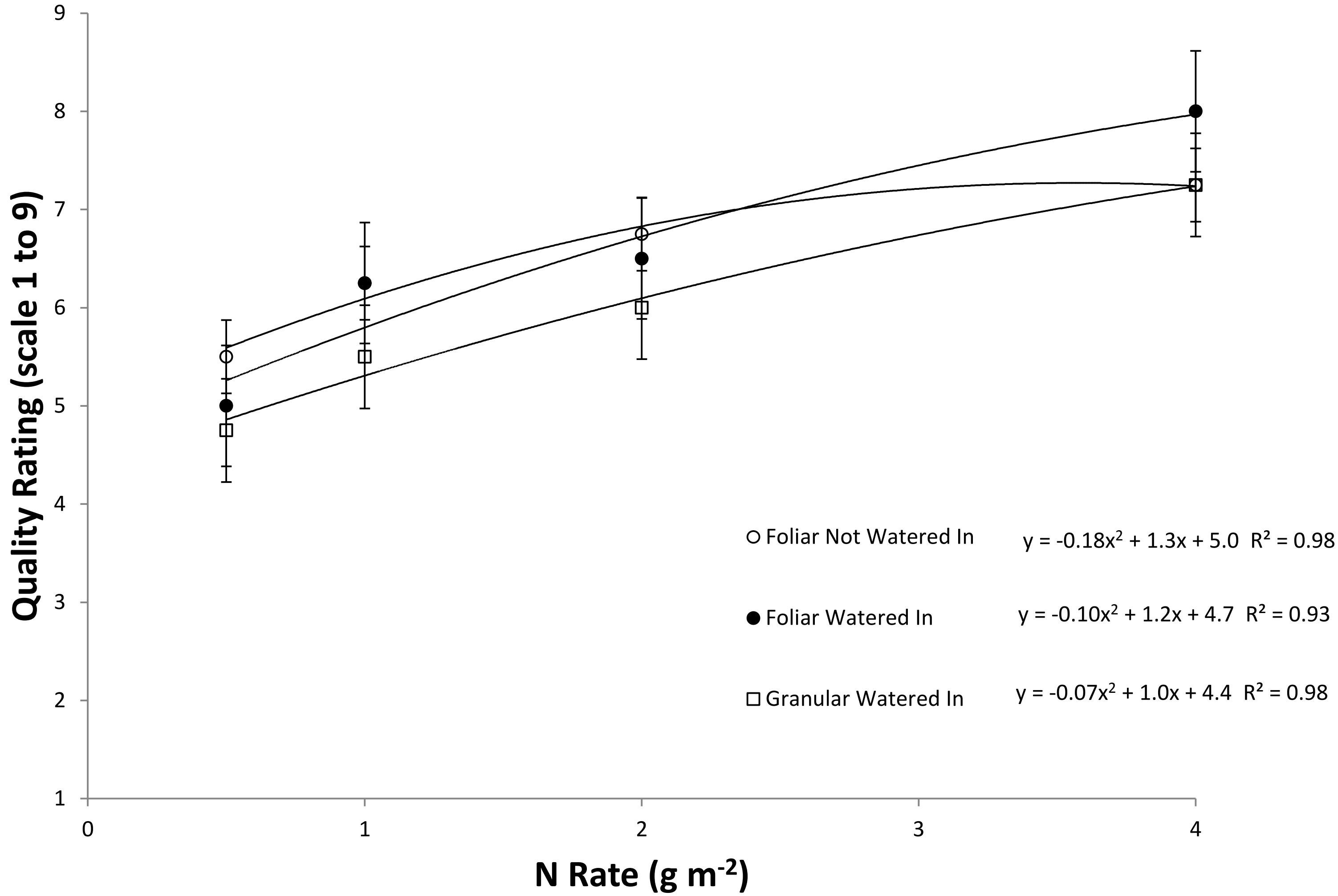


Figure 26. Relative Quality of Penn A-4 Creeping Bentgrass (1 = dead, 9 = lush turf) as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

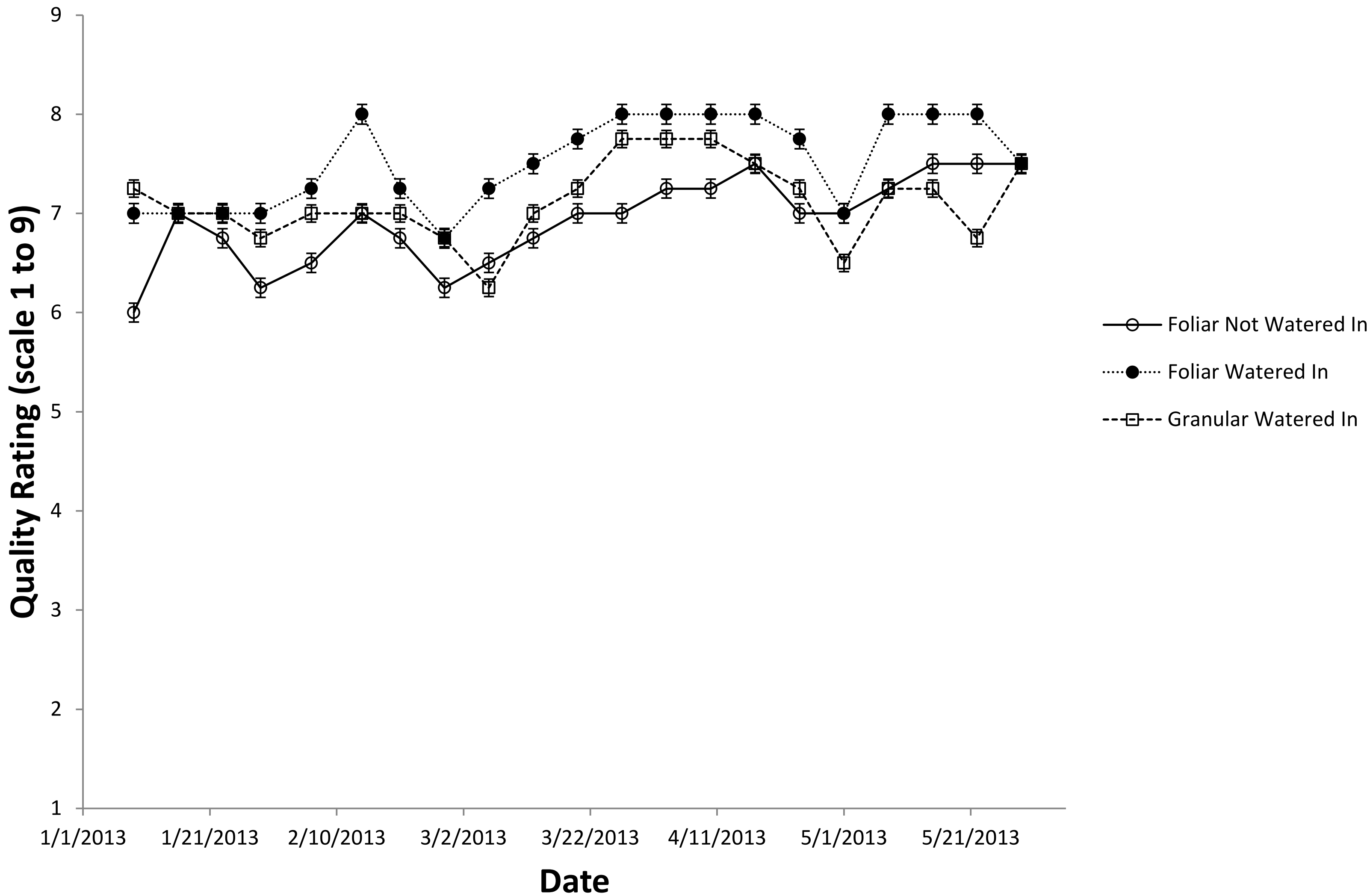


Figure 27. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

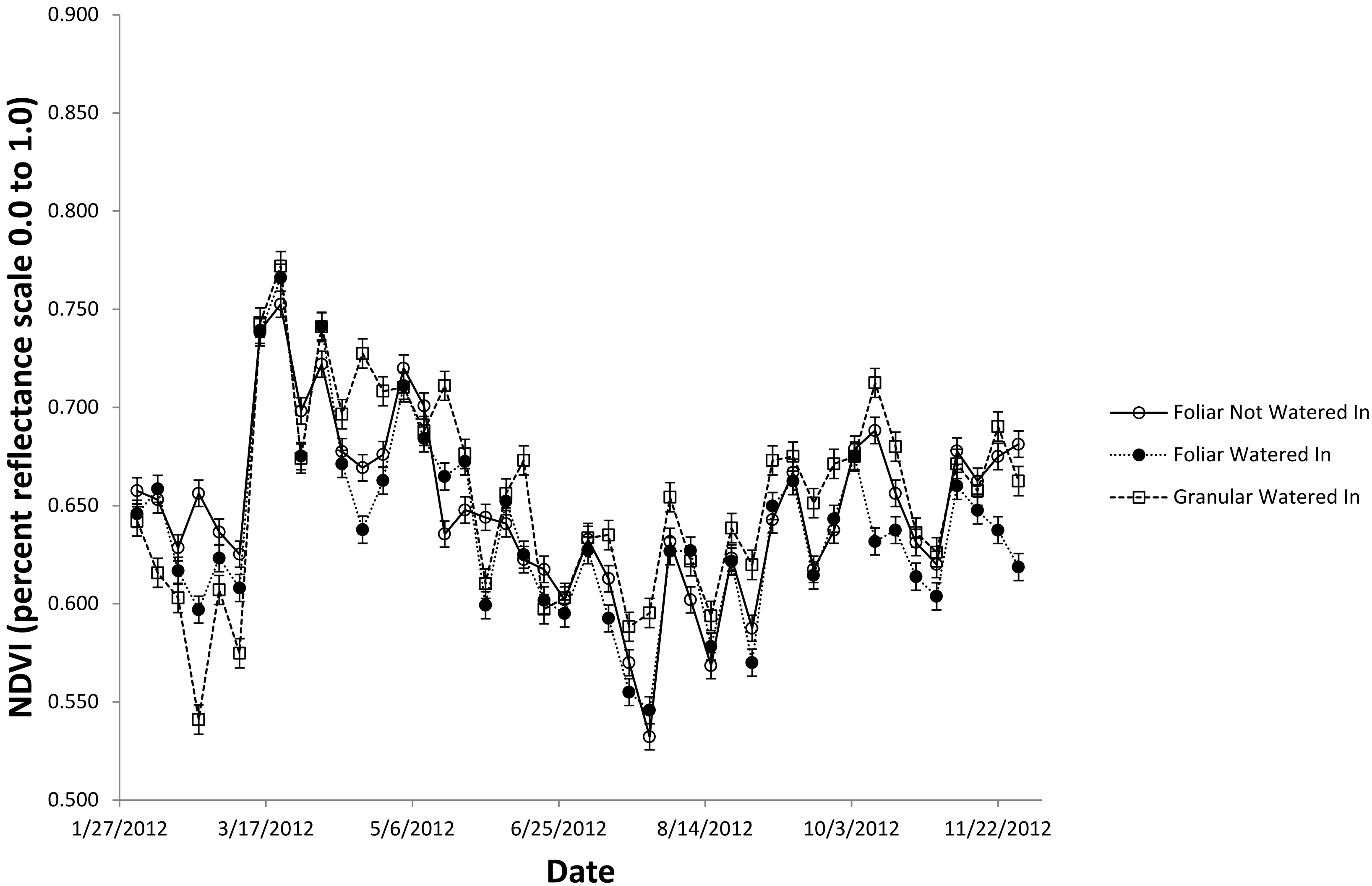


Figure 28. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

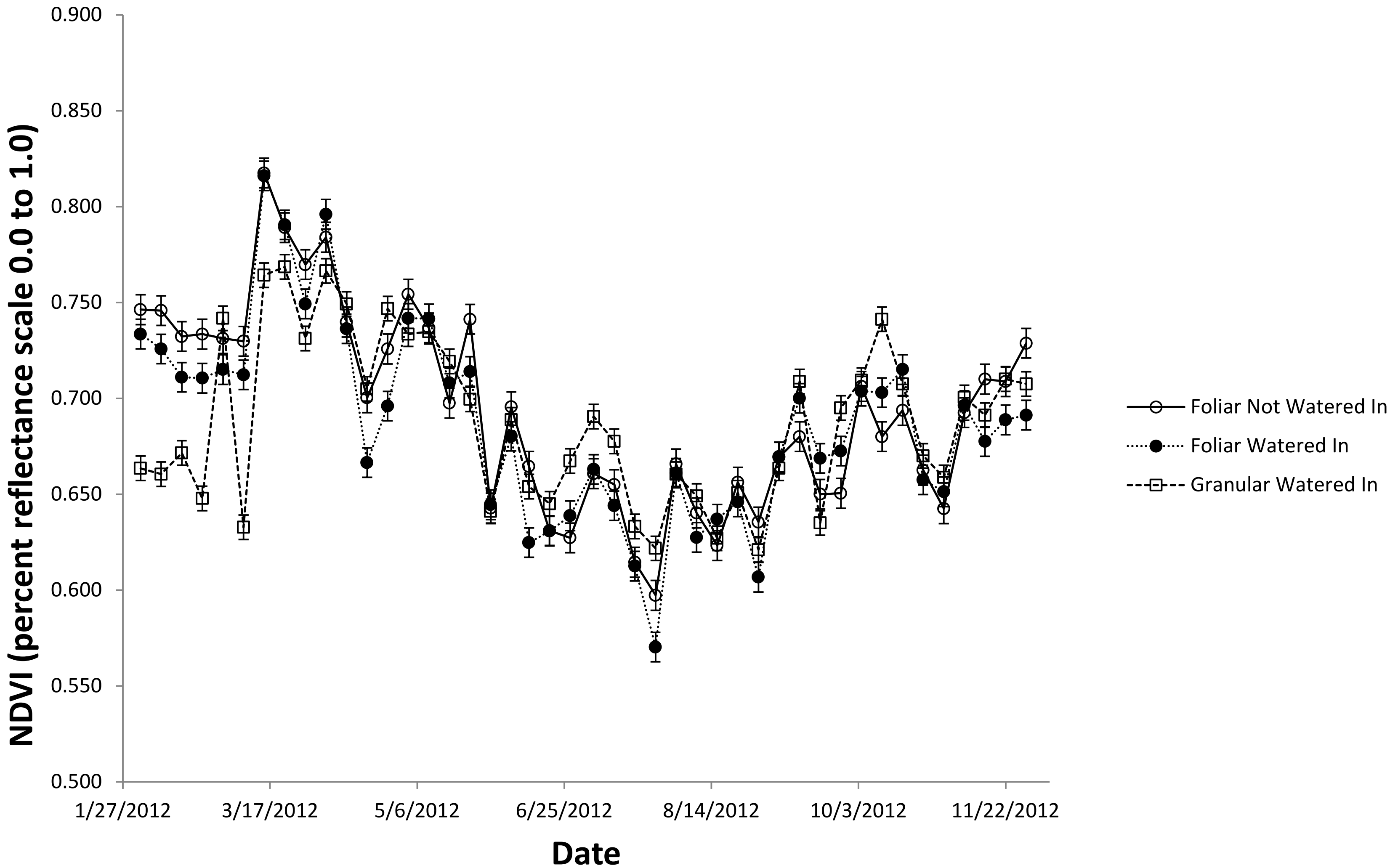


Figure 29. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

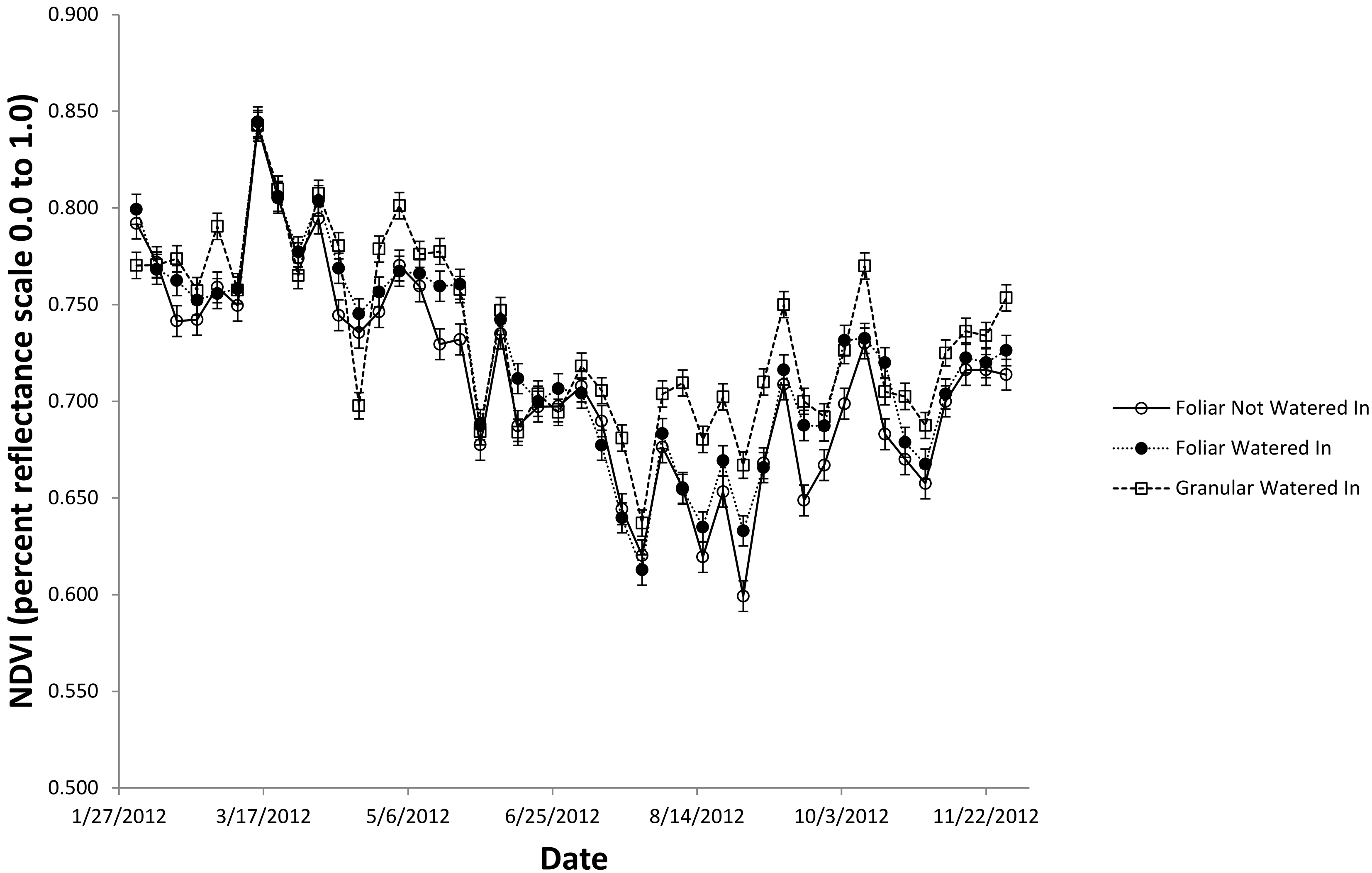


Figure 30. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2012. Vertical lines on each marker are the standard error about the mean.

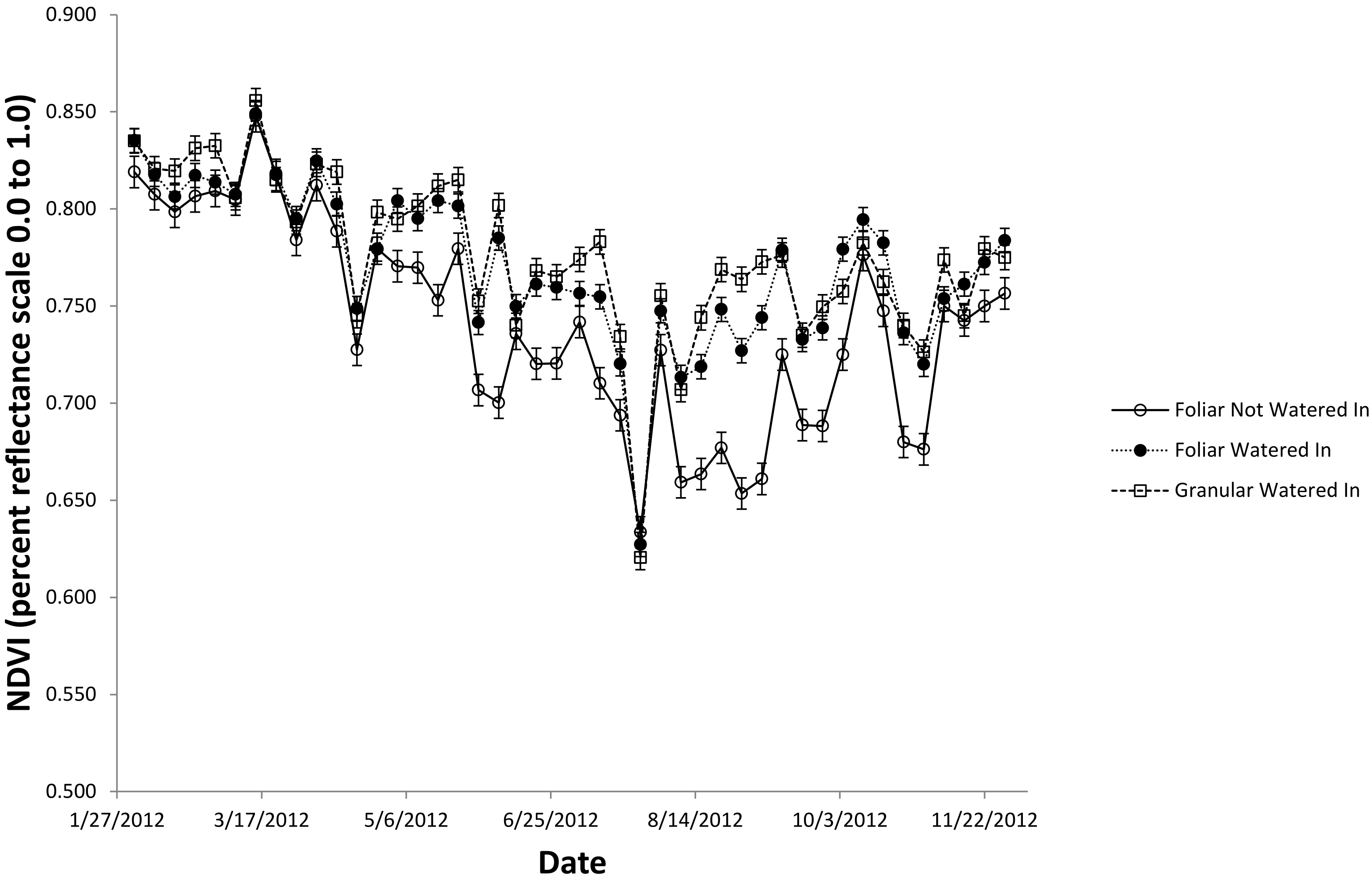


Figure 31. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 0.5 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

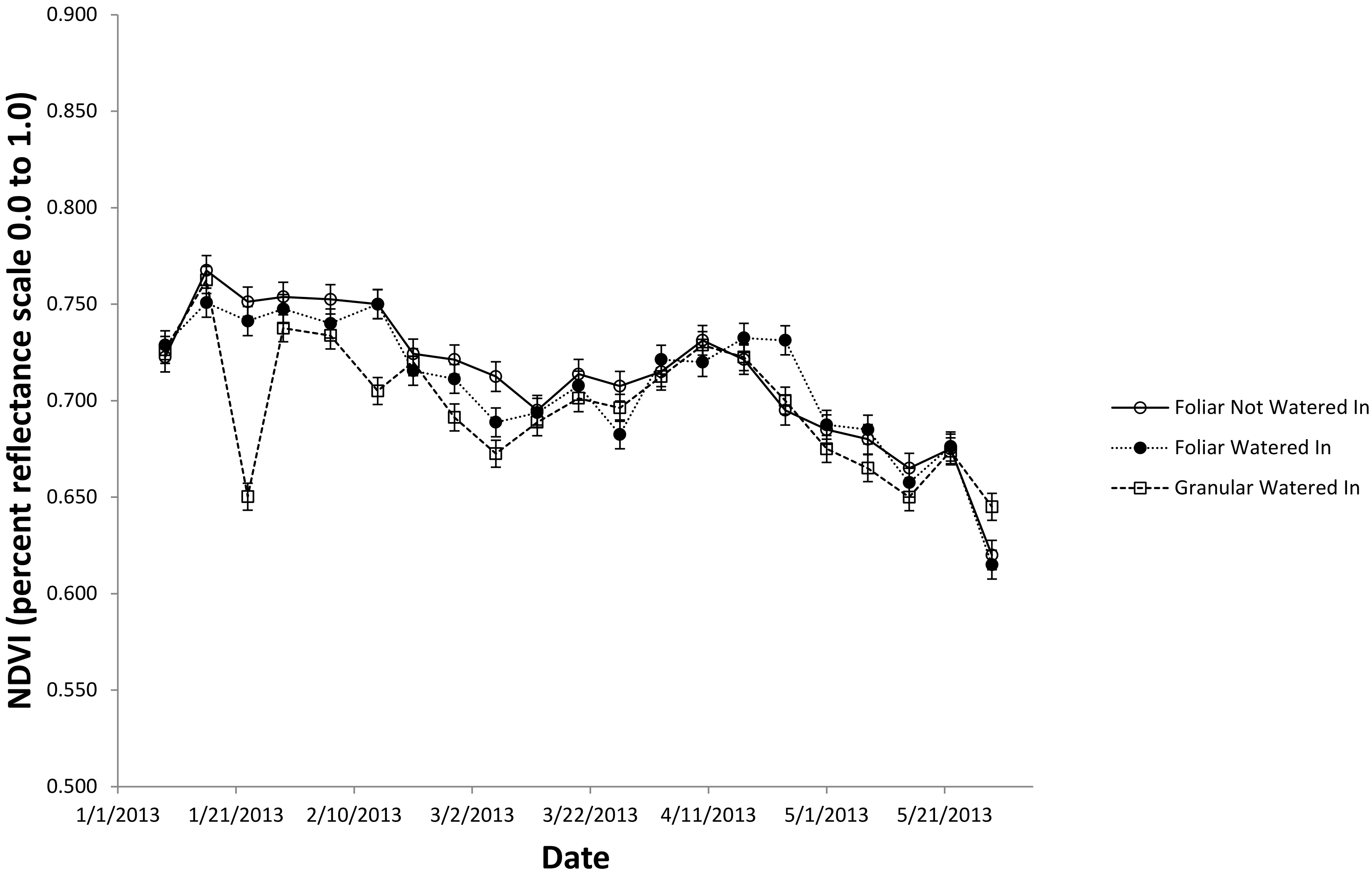


Figure 32. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 1.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

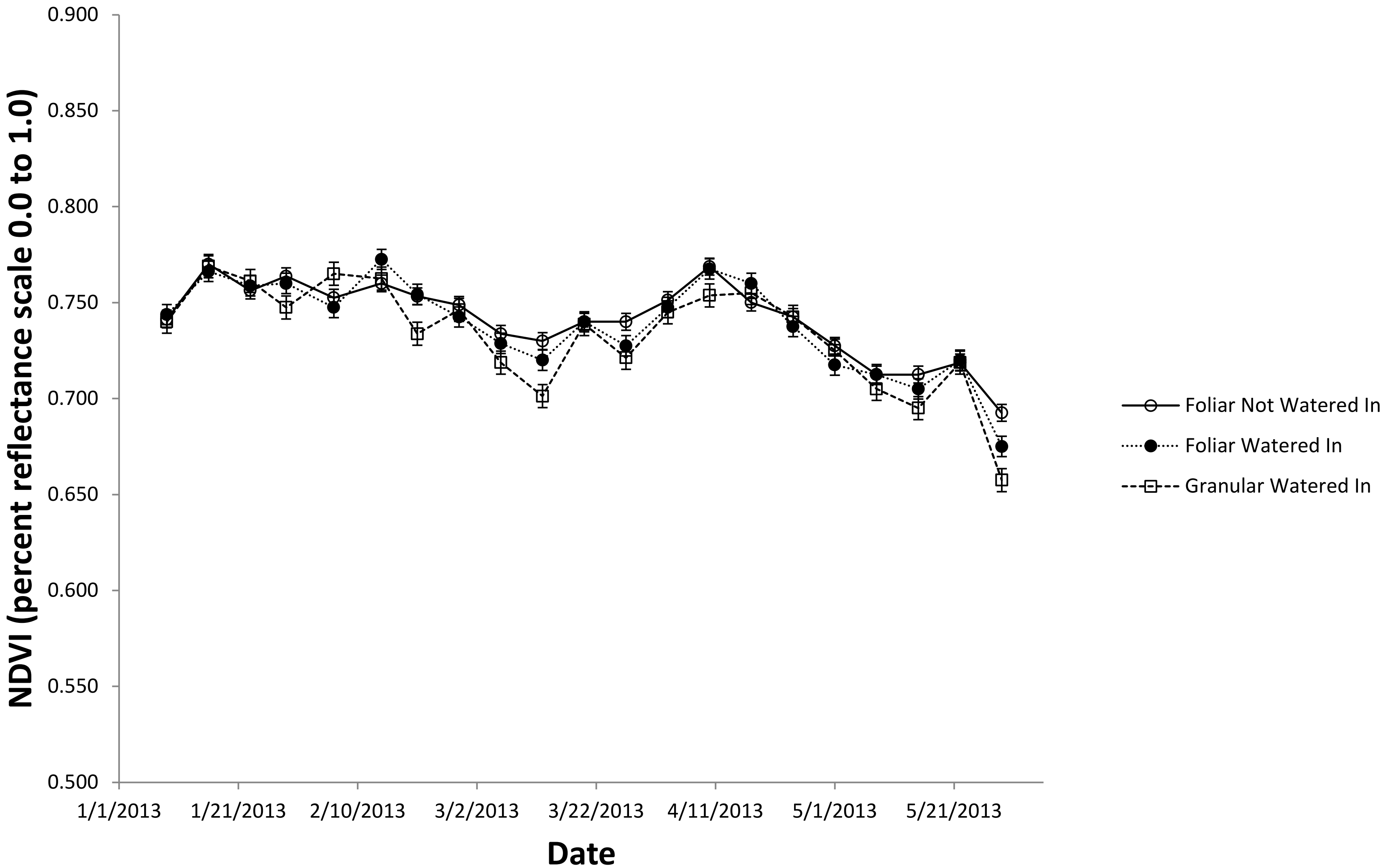


Figure 33. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 2.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

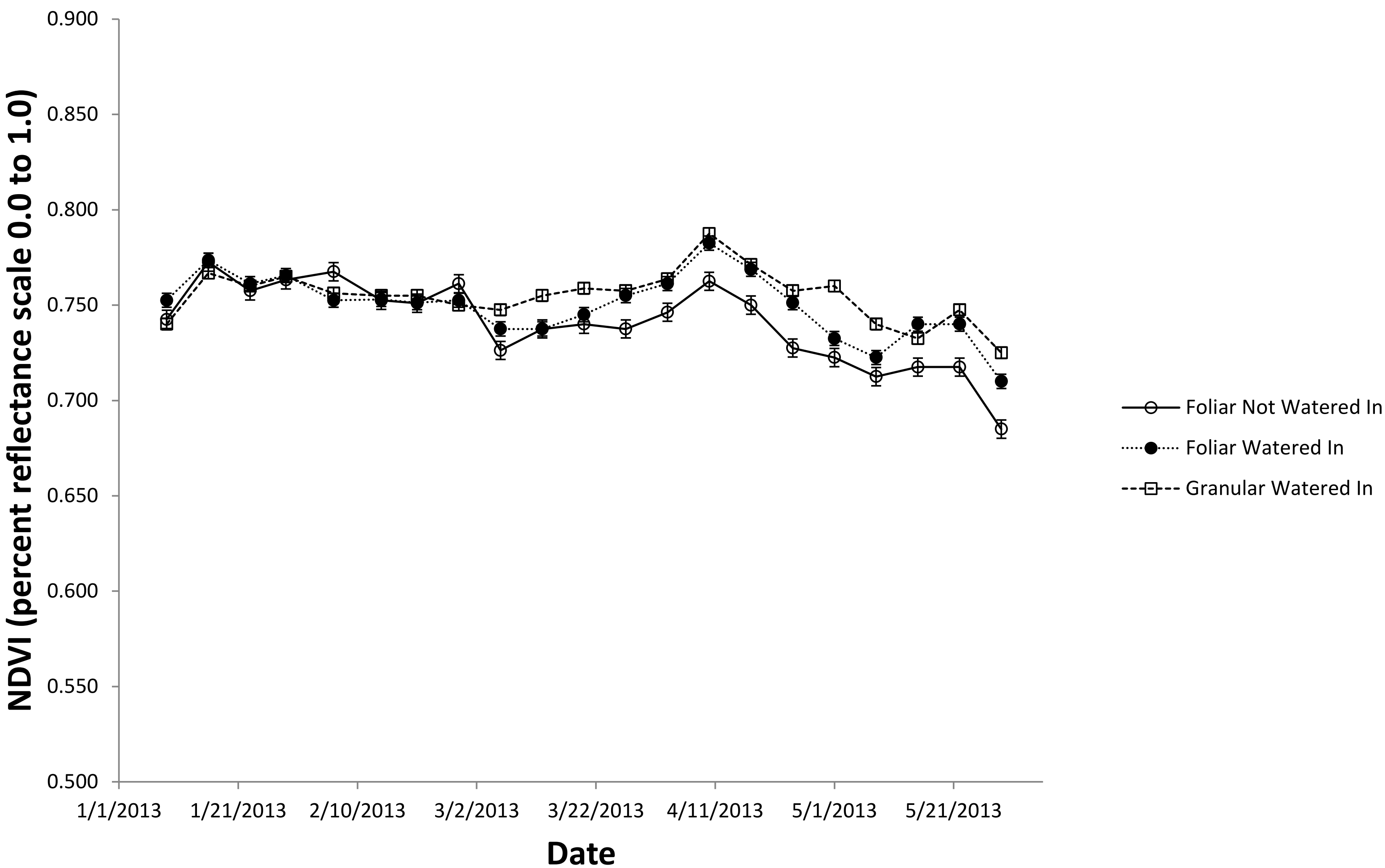


Figure 34. NDVI Readings of Penn A-4 Creeping Bentgrass as affected by method of fertilizer application, N at 4.0 g m^{-2}, 2013. Vertical lines on each marker are the standard error about the mean.

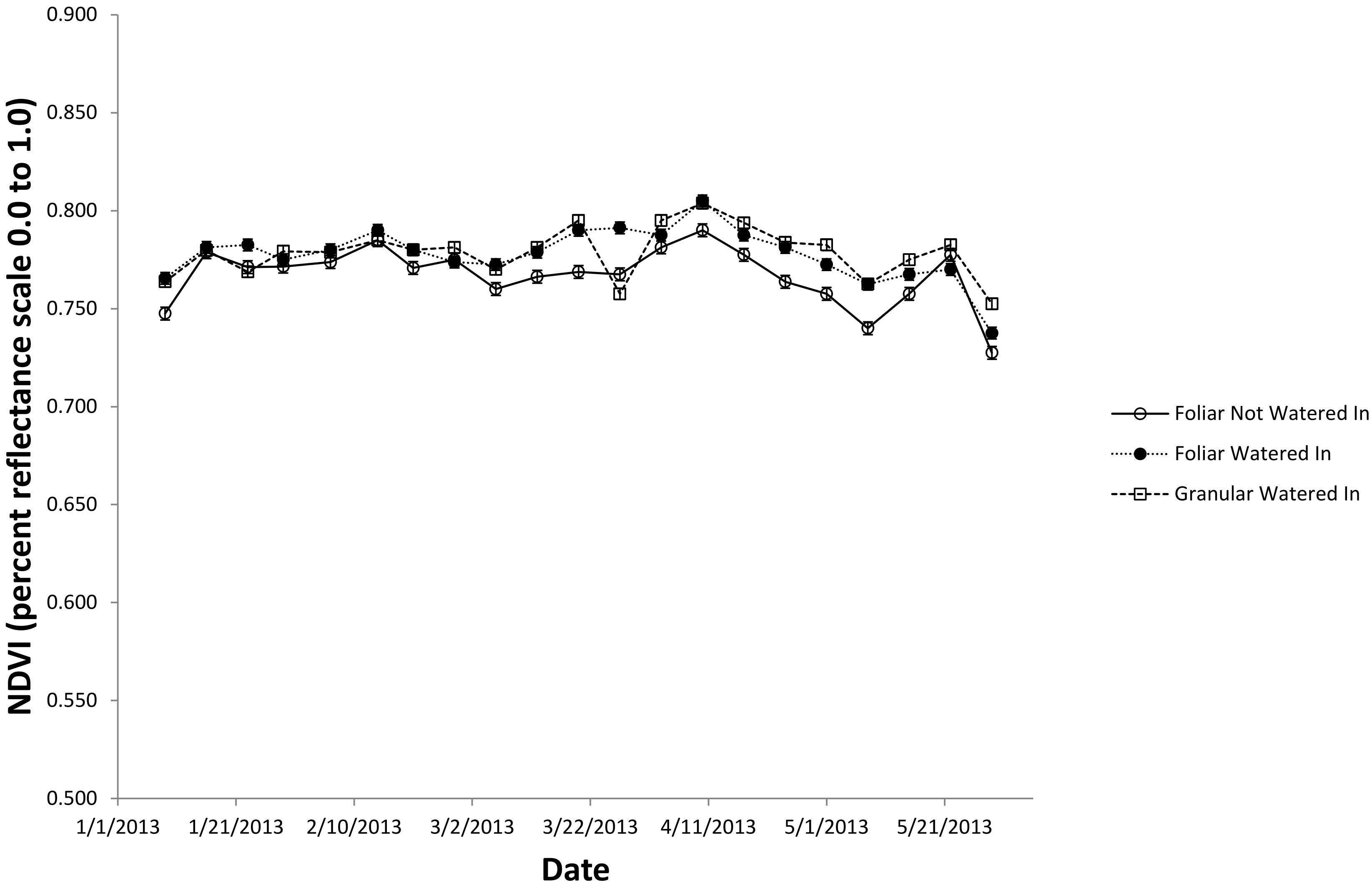


Figure 35. Dry weight of Penn A-4 Creeping Bentgrass clippings as affected by sampling date and N rate, 2012. Vertical lines on each marker are the standard error about the mean.

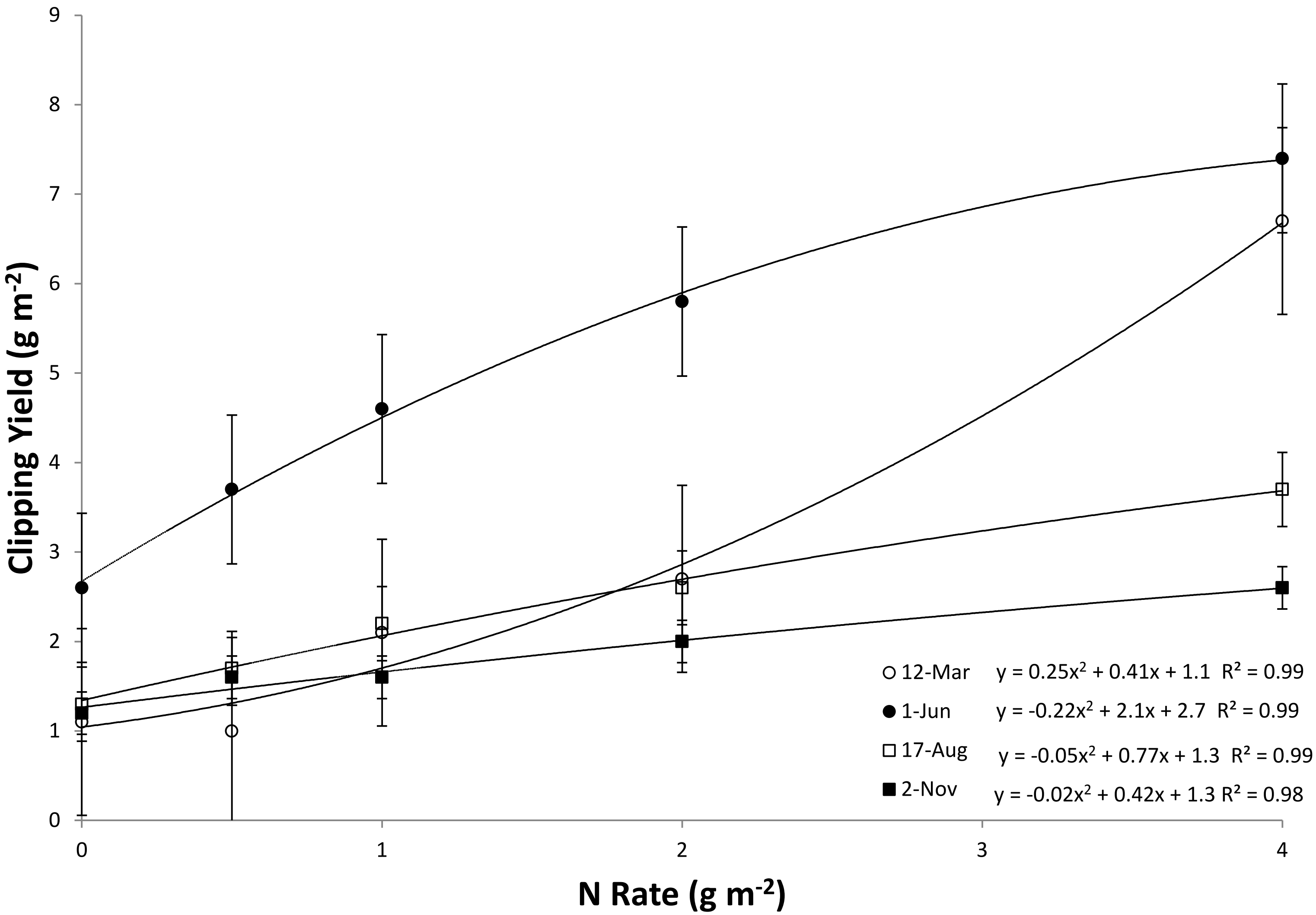


Figure 36. Dry weight of Penn A-4 Creeping Bentgrass clippings as affected by sampling date and N rate, 2013. Vertical lines on each marker are the standard error about the mean.

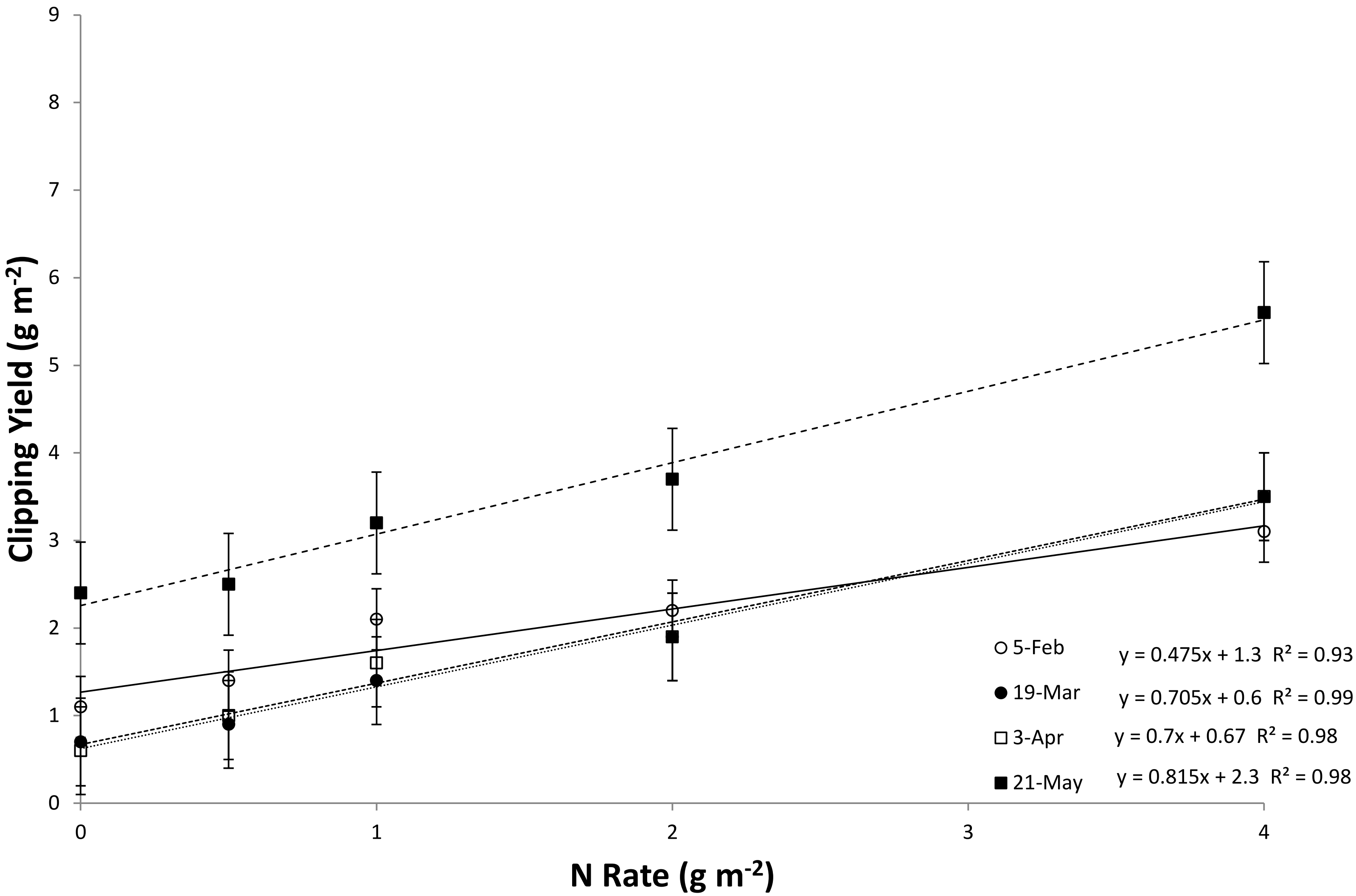


Figure 37. Nitrogen content of harvested Penn A-4 Creeping Bentgrass leaf tissue as affected by sampling date and N rate, 2012. Vertical lines on each marker are the standard error about the mean.

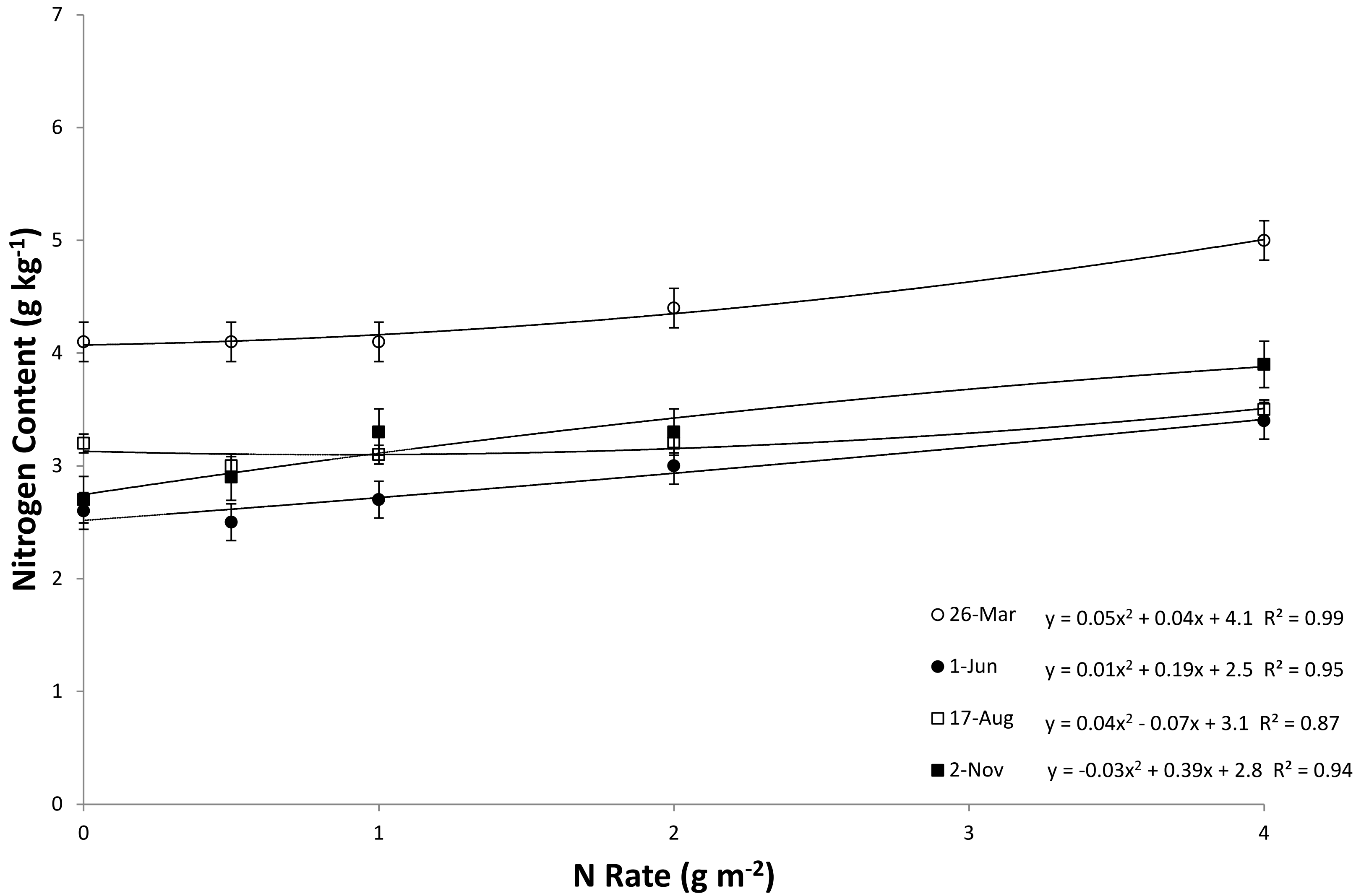


Figure 38. Nitrogen content of harvested Penn A-4 Creeping Bentgrass leaf tissue as affected by sampling date and N rate, 2013. Vertical lines on each marker are the standard error about the mean.

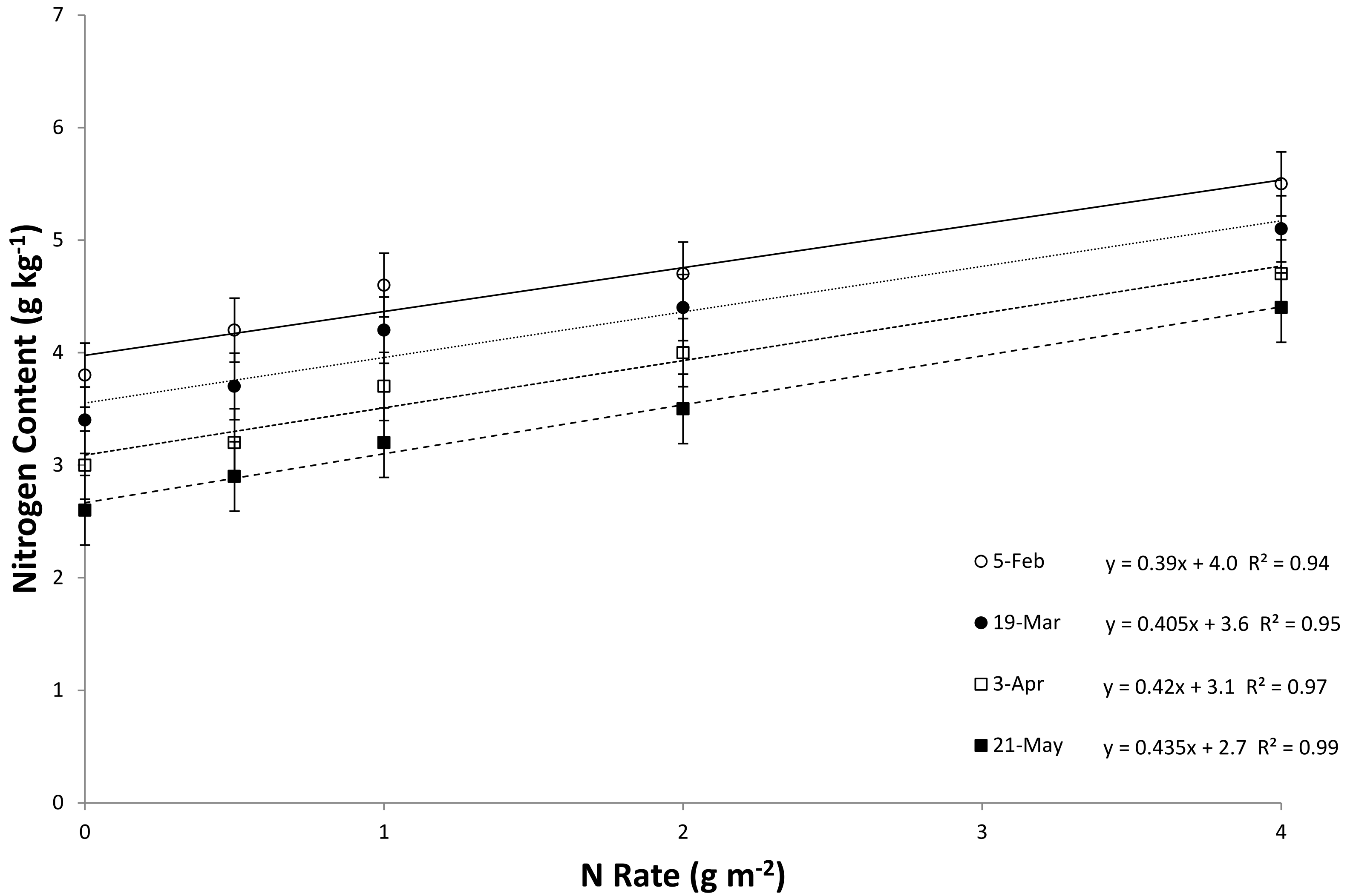


Figure 39. Shoot density of Penn A-4 Creeping Bentgrass as affected by N rate, 2012. Vertical lines on each marker are the standard error about the mean.

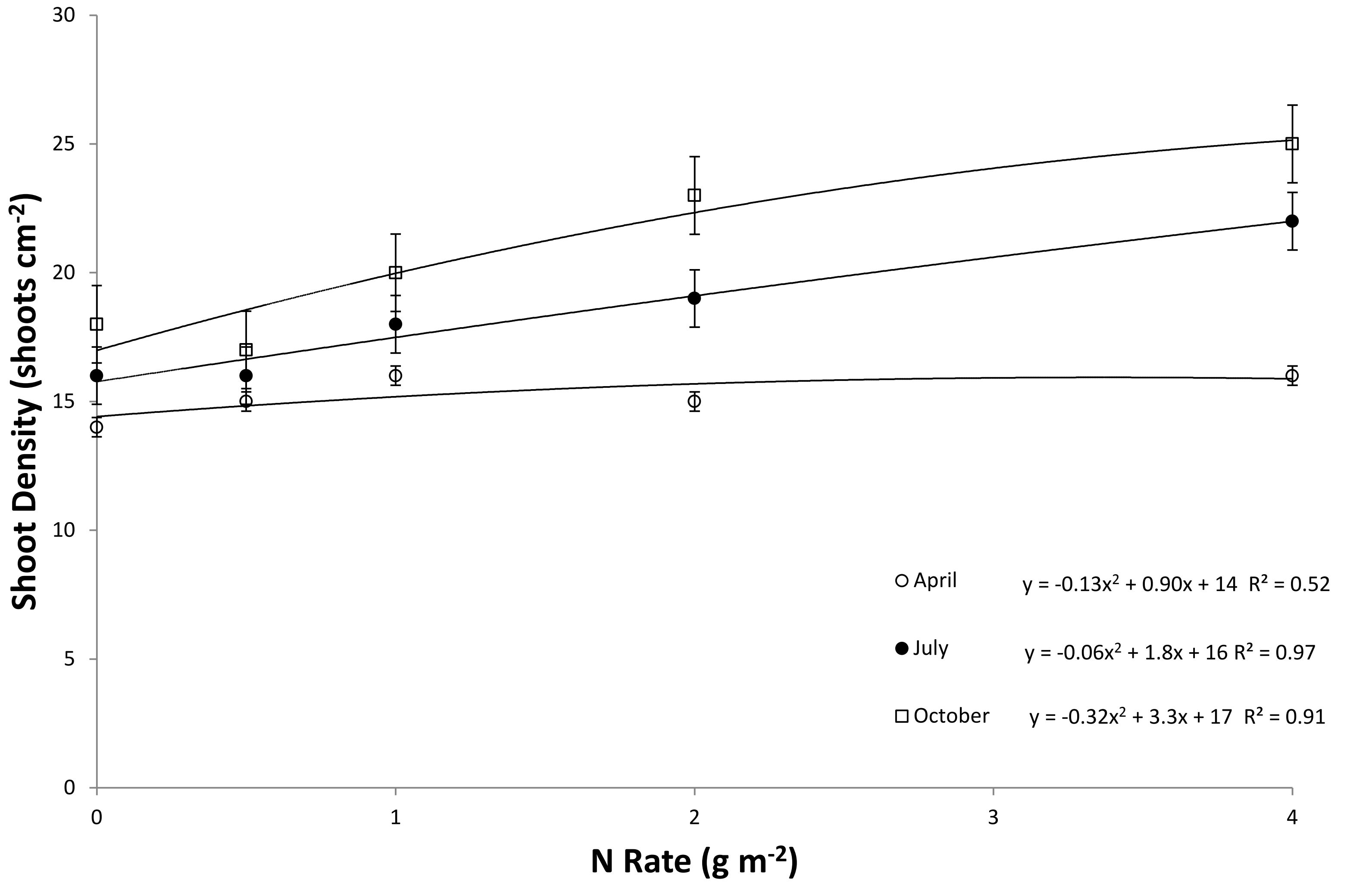


Figure 40. Shoot density of Penn A-4 Creeping Bentgrass as affected by the interaction of N rate and method of fertilizer application, January 2012. Vertical lines on each marker are the standard error about the mean.

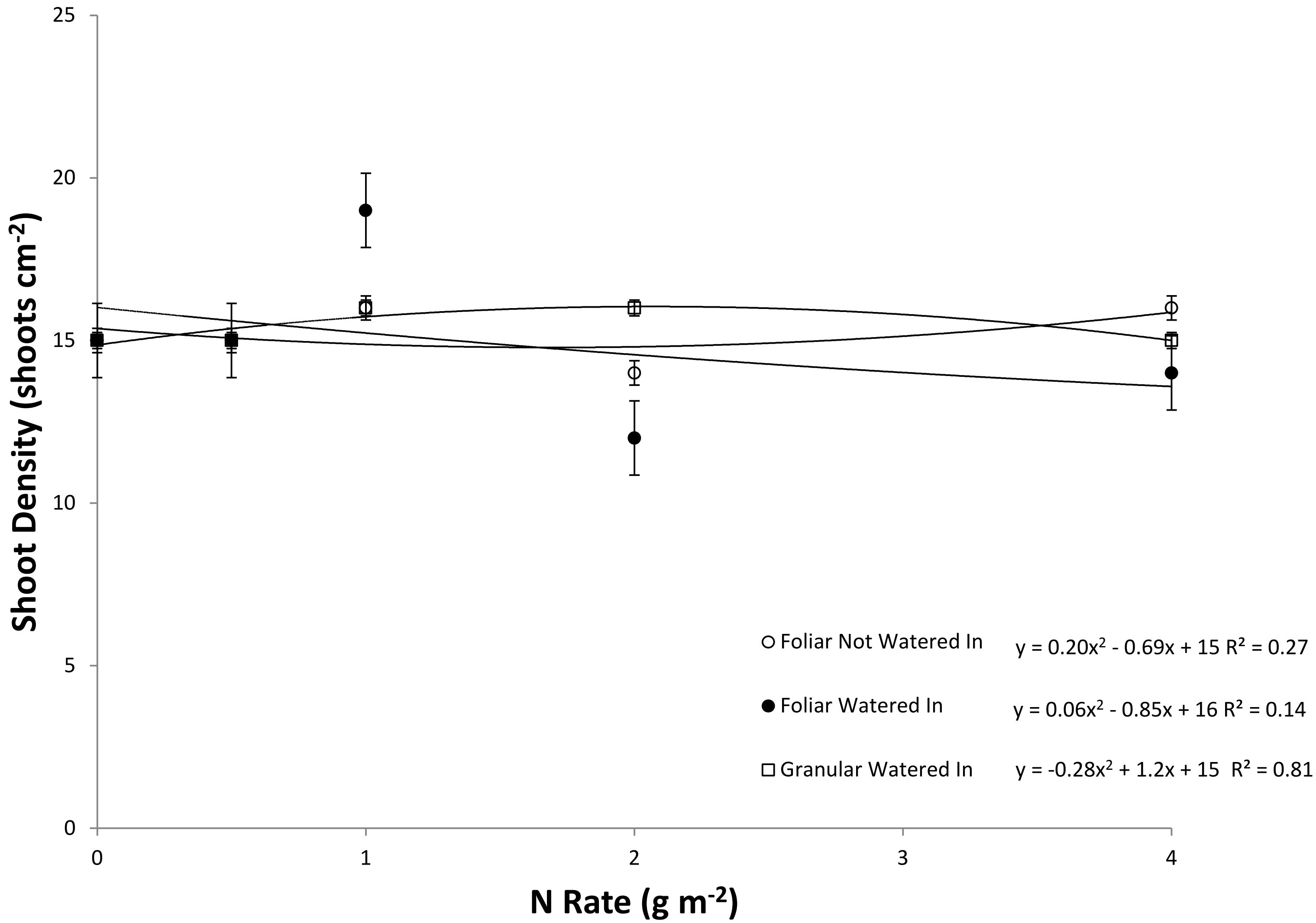


Figure 41. Root length interaction of Penn A-4 Creeping Bentgrass as affected by N rate and method of fertilizer application, April 29, 2013. Vertical lines on each marker are the standard error about the mean.

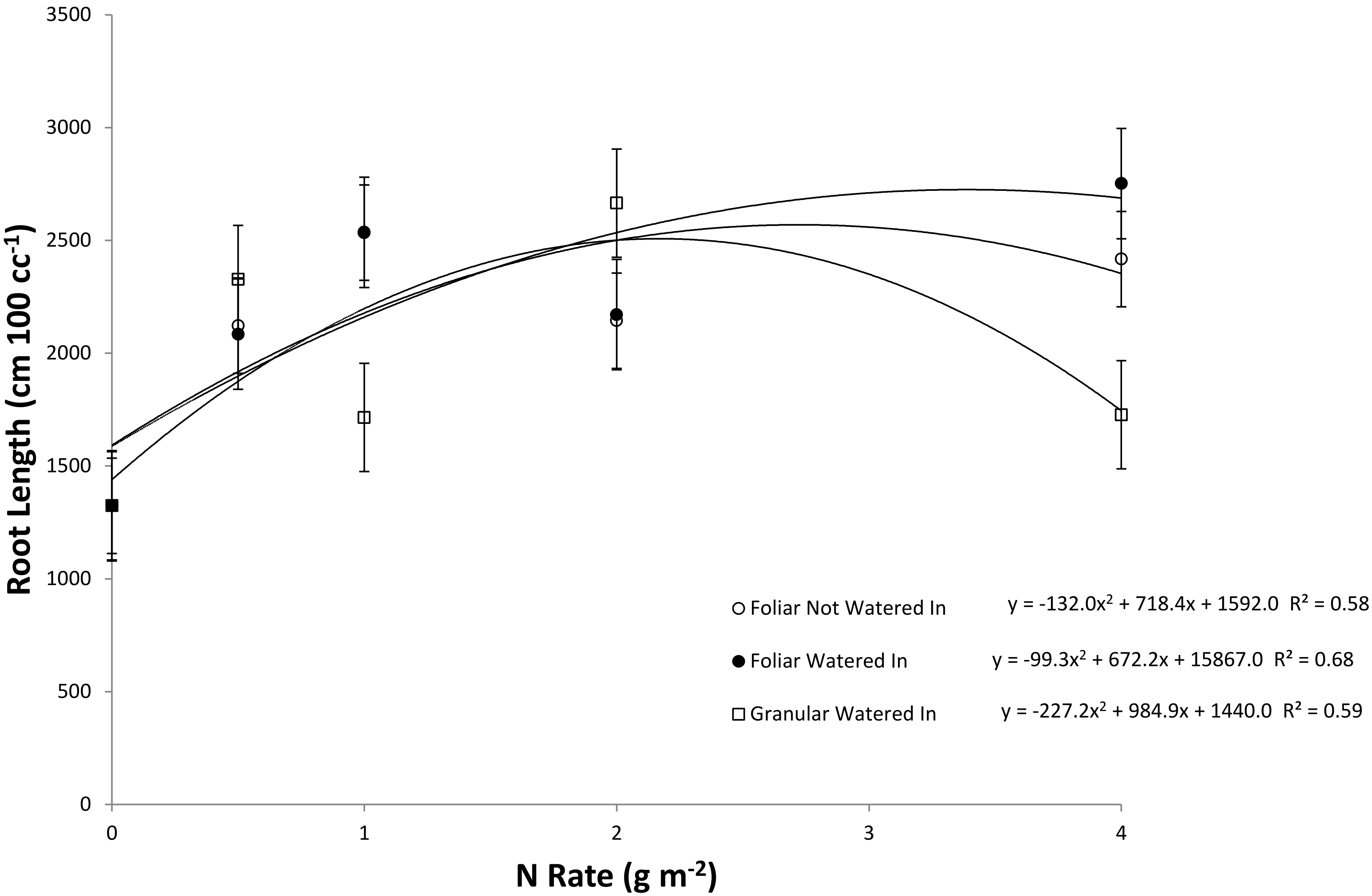


Figure 42. Root length density of Penn A-4 Creeping Bentgrass as affected by N rate and sampling month, 2012. Vertical lines on each marker are the standard error about the mean.

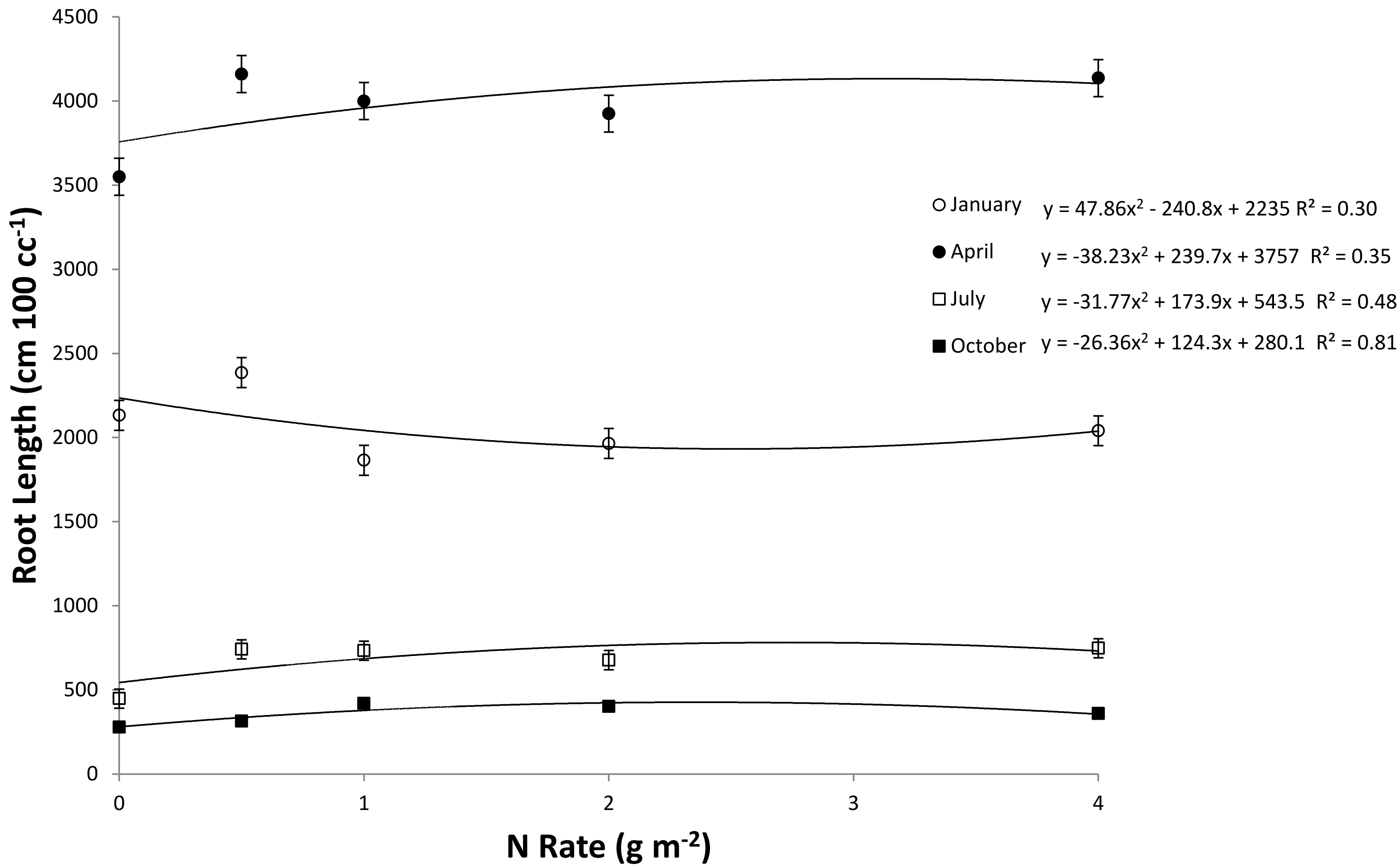


Figure 43. Soluble carbohydrate content (on an organic matter basis) of Penn A-4 Creeping Bentgrass in 2012 and 2013. Vertical lines on each marker are the standard error about the mean.