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Polymer Coated Urea in Kentucky Bluegrass

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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Nitrogen (N) is the most commonly over-applied nutrient in urban environments because of the large visual and growth increases. This over-application has led to an increase in the loss of N gas in the forms of ammonia and nitrous oxide, as well as an increase in nitrate leaching to surface and groundwater. Furthermore, excess N results in increased maintenance costs and landfill volume due to increased shoot growth from mowed clipping removal. Polymer coated urea (PCU) has proven to be an excellent source to these losses of N to the environment, but rate and timing parameters need study. A two-year field study, on sand and sandy loam soils in Provo, UT, was initiated in April 2014. Seven fertilized treatments included: urea split applied monthly; a single application of PCU (Agrium One Ap) applied in spring, a single PCU application in fall; two evenly split applications in spring and late summer; and three evenly split applications in spring, late summer, and late fall. These were compared to an untreated control. In addition the two application of PCU also had reduced rates of half and three-quarters, in addition to the full rate. Height and verdure measurements were taken on a weekly basis, along with periodic visual and biomass readings. All fertilized treatments resulted in a significant response to N as compared to the control. The single annual application treatments had significantly greater shoot growth during the weeks immediately after application and a significant reduction in verdure months later and, therefore, were unacceptable for consumer recommendation. Two applications of PCU, either at the three-quarter or full rates, were nearly identical in all measurements as compared to the spoon feeding of urea applied monthly. The half rate of two applications showed signs of inadequate N. Three applications of PCU was identical to two and, therefore, not recommended. This study shows two applications of PCU at the three-quarter rate is equally effective as spoon feeding the N. Doing so would result in less labor for fertilization. Further work is needed to evaluate other timing approaches for a single annual application, as well as long term effects of a reduced rate of N.

Keywords: polymer coated urea PCU, urea, Kentucky bluegrass, *Poa pratensis*, nitrogen fertilizer, nitrogen timing, nitrogen rate

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Polymer Coated Urea in Kentucky Bluegrass: Application Timing

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ABSTRACT

Nitrogen (N) is the most commonly over-applied nutrient in urban environments because of the obvious difference in "greenness". This over-application has led to nutrient pollution of the atmosphere and hydrosphere. Furthermore, excess N results in increases in maintenance costs and solid waste volume. A two-year study was initiated in April 2014. Four fertilized treatments were applied at two locations in Provo, UT. Treatments included a urea and ammonium sulfate blend split applied monthly compared to a polymer coated urea (PCU) and ammonium sulfate blend applied either once in spring, once in fall, or twice in spring and just ahead of early fall—all applied at the same rate of N at each location. The single annual application treatments resulted in uneven growth and verdure with significant increases shortly after application, but a steady reduction after several weeks. The two-application PCU treatment was virtually identical in verdure and plant growth as compared to the spoon feeding of urea applied monthly. This study shows that one application of PCU is not ideal under the application method tested in this study due to increased need for mowing, but two applications results in steady growth and, as such, is effective. Further work is needed to evaluate other timing approaches for a single annual application.

INTRODUCTION

As urban and suburban developments grow, turfgrass is quickly growing as the principle managed land cover (National Turfgrass Federation, 2003; Walker, 2007). According to the combination of studies done by Milesi et al. (2005) and Runfola et al. (2014) turfgrass coverage in the U.S. is estimated to be 111,683 km^2. Turfgrass occupies 1.9% of the total surface area in the United States and is the leading irrigated crop in the country (Milesi et al., 2005). Turfgrass serves important roles in society. Despite the many benefits, there are also concerns due to consumption of natural resources and pollution issues.

One such concern is related to nitrogen (N) fertilization. Turfgrass managers typically apply between 75 and 500 kg N ha^{-1} each year because it is the nutrient of greatest need and is most likely to show visual symptoms if deficient (Milesi et al., 2005). As such, many home owners and turfgrass managers make the mistake of over applying N. The recommended rate of N to be applied varies between and within species. Warm-season turfgrass requires ~50 kg N ha^{-1} for each month of active growth. Cool-season turfgrass requires ~150-250 kg N ha^{-1}yr^{-1} (Christians, 2007).

Annual worldwide N fertilizer demand for crops is projected to total over 112 thousand metric tons in 2015 but the actual amount applied is projected to be over 156,300,000 tons for the same year (FAO, 2011). Over application of N-based fertilizers leads to an increase in shoot growth at the expense of root growth (Christians, 2007). Poor rooting can result in unhealthy plants, poor surface conditions, and inefficient water and fertilizer recovery rates. In addition, excessive shoot growth results in increased mowing and an increase in clipping wastes and/or damage to the turfgrass if excessive clippings are not removed (Christians, 2007). In addition to problems with plant health, excessive N application increases risk of environmental problems (LeMonte et al., 2016). Nitrogen cycling in the ecosystem is a vital and normal process, but excesses can result in problems with leaching of nitrate (NO_3^-) to groundwater and runoff of NO_3^- and ammonium (NH_4^+) to surface water bodies and atmospheric pollution through nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization.

Ammonia volatilization results in increases in air quality problems, including: photochemical smog, particulate matter, strong odors, and acid rain. In addition, the volatilization of NH_3 is a concern with deposition on land or water bodies in sensitive systems. Excessive N deposition can lead to reduction in plant community loss, as well as a reduction in biodiversity (Sutton et al., 2008). The deposition of NH_3 can also lead to soil acidification (Sutton et al., 2008), as well as surface water eutrophication (Boyd, 2000).

Another gaseous N environmental issue is related to N_2O. Hirsch et al. (2006) estimated anthropogenic emissions of N_2O to have increased by about 40-50% over preindustrial levels. It is estimated that emissions directly related to fertilization account for 78% of the total annual anthropogenic N_2O losses (LeMonte et al., 2016; USEPA, 2007). The processes of nitrification and denitrification lead to the formation of N_2O which is lost to the environment (McTaggart et al., 1994). The concern with N_2O is that it is a long-lived, potent greenhouse gas with a significantly greater potential of global warming by almost 300 times that of carbon dioxide (CO_2) (IPCC, 1995; USEPA, 2007).

Nitrogen excess in the hydrosphere is also a serious concern. Soil NO_3^- is easily leached below the rooting zone due to it being a highly soluble anion that is repelled by negatively charged soil. It has been reported that the annual rate of N leaching from turfgrass ranges between 0 and 160 kg N ha^{-1} $year^{-1}$—representing up to 30% of applied N (Barton, 2006). Contaminated drinking water high in NO_3^- causes methemoglobinemia (baby blue syndrome) in mammalian infants (Olson et al., 2009). It is also speculated to cause other health issues in humans, but this is not proven.

Surface water contamination is also a concern. Both NH_4^+ and NO_3^- can be easily transported via surface water runoff and soil erosion (Easton, 2004). As with groundwater, NO_3^- in surface water is also a potential drinking water problem. Additionally, excess N in surface water can lead to problems from algal blooms—which can result in injury or death of the aquatic life or organisms drinking the water, decreases in biodiversity, unsightly conditions, strong odors, economic losses, and a decrease in recreational use (Fangmeier et al., 1994; Mulvaney et al., 2009).

Along with needing to reduce the environmental impacts of N loss, it is also important to recognize that N fertilizers are manufactured using natural gas and other nonrenewable resources. In order to conserve resources and minimize environmental impacts, N loss needs to be minimized by maximizing plant utilization of the applied N (Hopkins et al., 2008). Many argue that planting turfgrass should be discouraged or even illegal. Although there are negative impacts associated with turfgrass due to the over fertilization of the crop in agriculture and urban settings and other issues (such as pesticide use and water consumption), there are many positive impacts to society and the environment.

In addition to being aesthetically pleasing, providing a safe surface for many recreational activities, and generating oxygen, turfgrass reduces: air temperature, atmospheric pollutants, erosion, water and chemicals in storm drains, chemicals leached to groundwater, flooding, noise pollution, and fire risk. By maintaining a low growing and green plant material next to buildings, fires are less likely to spread. Air quality is improved because turfgrass is a good filter for capturing smoke and dust. Sulfur and carbon dioxides are also absorbed from the atmosphere—

reducing acid rain and greenhouse gas concentration. In addition to the impact on global temperature, the cooling effect of turfgrass makes for a more pleasant urban environment and results in reduced use of natural resources to cool the interiors of neighboring buildings.

Sequestering carbon (C) into the soil results in improved soil health. Carbon sequestration is the removal of C from the atmosphere in the form of carbon dioxide (CO_2), which is then held in the soil (Bremer, 2007). A possible concern with turfgrass is that it has to be mowed and that the mowers are putting C into the atmosphere. It has been found that turfgrass is able to sequester four times more C from the air than is put into the air by the typical lawnmower engine. If the lawn is cared for with proper water, fertilizer, and mowing inputs then the net carbon intake is five to seven times higher, which is up to 800 lbs of C per acre per year (Qian, 2015), than the carbon output of the mowers used in managing the lawn (Bandaranayake, 2003; Milesi; Qian, 2015; Sahu).

However, in order to have these benefits, N is needed. Turfgrass requires a steady supply of N to grow successfully (Christians, 2007; Geary et al., 2015). Nitrogen is the mineral nutrient generally found in the highest concentration in plants and deficiencies can be dramatic from a visual perspective. Nitrogen plays a vital role in many processes in the life cycle of a plant and they would not be able to complete their life cycles without it. One of the most important biochemical processes which N plays a role in is the formation of chlorophyll (Marschner, 2012). With N playing such a vital role in many processes there is a high demand for N to facilitate the essential biochemical processes. Due to this high demand, as well as the high mobile nature of N causing it to be easily lost to the surrounding environment, N is often the primary limiting factor for plant growth (Chatterjee, 2012). Without the adequate concentrations of N, plant vigor, visual quality, verdure, recovery from damage, and overall health are affected due to the production of less chlorophyll and proteins resulting in an increased susceptibility to pests and diseases (Bowman, 2002; Marschner, 2012). The essentialness of N leads to efficient use within the plant following the absorption. Nitrogen is only lost from the plant by rain or mist-induced foliage leaching or defoliation (Barker, 2007). The repeated removal of plant biomass by harvesting or mowing can result in a depletion of N reserves within the plant. Plants are not able to regenerate N to the levels required following the removal of plant biomass—N must be replenished mainly through the addition of fertilizer and soil amendments. A small fraction of N can be replenished through atmospheric deposition, irrigation, and fixation of atmospheric N by legumes. Atmospheric deposition and fixation do not provide adequate amounts of N to meet the demands of plants. In order to meet the demands needed for high crop production and most urban landscapes, N fertilization is required (LeMonte, 2011). Ideally, fertilizer rate and application would be applied to meet the needs of the plant precisely. Unfortunately, this ideal is not possible due to the inherent inefficiencies in the system. Substantial increases in the efficiency of N are possible if best management practices (BMP) are implemented. The key to good stewardship depends on using the right source, at the right rate, at the right time, and with the right placement (Snyder et al., 2007).

The use of inefficient fertilizer types is a contributor to the negative environmental impacts due to a low N-use efficiency (NUE) (Cameron, 2013; Nielson, 2006). It is estimated that NUE for worldwide cereal production is only 33% (Blaylock et al., 2005). Schlesinger (1992) estimated that 10% of all manufactured N fertilizer worldwide is volatilized as NH_3-N gas. In a growth chamber study, volatilization of surface-applied N fertilizers reached an excess of 60% over the first 10 days following fertilization using warm-season bentgrass (*Agrostis palustris* Huds.; Knight et al., 2007). Within North and Central America, about 54% of N_2O-N emitted is attributed to the addition of fertilizer (Blaylock et al., 2005; IPCC, 1996). The NUE for turfgrass would be expected to be similarly low without best management practices.

Measures need to be taken in order to assure that the negative impacts of urban turfgrass does not outweigh the positives. As shown by LeMonte et al. (2016), Minami (1994), and Ransom (2014) the losses of N to the environment can be reduced with the use of control release fertilizers (CRF) and slow release fertilizers (SRF). These fertilizers are used to allow for the delivery of N over extended periods while reducing risk of loss to the environment and, thus, increasing NUE. These CRF and SRF materials are designed to release N over extended time periods, as opposed to traditional “quick release” fertilizers, which release N to the soil all at once. The engineering of the CRF and SRF materials is an attempt to match more closely plant N needs throughout the growing season, while reducing the exposure time and loss of N (Blaylock et al., 2005). The SRFs are different from CRFs in their mode of action. The release of nutrients from SRFs occur through the bursting or degradation of the coating due to chemical or microbial processes or infiltration of water vapor which creates a high internal pressure. Once any point of the coating surrounding the nutrients is broken, the urea becomes exposed and is then left open to be converted into other forms of N. However, this process is more unpredictable opposed to a CRF (Ellison et al., 2013; Ransom, 2014).

Control release fertilizers have been developed using a coating which surrounds individual granules of fertilizer, with urea being the most widely used. The more common polymer coat used has micropores which allow moisture to infiltrate through the coating to dissolve the urea. As temperature increases, the coating warms and expands—allowing for the urea to escape. The thickness of the coating can be changed to slow the diffusion of N into the soil and, thus, increase the amount of time before the N is fully released (Adams et al., 2013;

Carrow, 1997; Ellison et al., 2013). This mode of action is typically more controlled and predictable, so N applications can potentially be reduced. The polymer coated urea (PCU) products have shown a significant decrease in both NO_3-N leaching (Du et al., 2006; Guillard and Kopp, 2004; Nelson et al., 2009; Pack and Hutchinson, 2003); Pack et al., 2006; Wilson et al., 2010), NH_3 volatilization (Knight et al., 2007; Pereira et al., 2009; Rochette et al., 2009) and N_2O-N emission (LeMonte, 2011; LeMonte et al., 2016; Ransom, 2014). Hyatt et al. (2010) showed that the slow release of N from the PCU products can improve economics as well as environmental impacts due to the ability to eliminate additional in-season applications of N. This can be seen in a study done by Miltner and Stahnke (2004) using PCU in cool-season turf. The PCU was applied in November in Washington, USA, and there was significantly greater turf quality in February through May. This showed that applying a SRF can reduce the need for applying multiple applications of N in the early spring. Although PCU fertilizers have been shown to be very effective in many situations, there is minimal information available on the number of applications needed. The fertilizer industry is promoting a single yearly application as being appropriate. Ransom (2014) showed that N release from PCU incorporated into the soil resulted in extended N release approximately in correlation with manufacturer claims. However, he also showed that surface application of PCU resulted in more rapid release with all N escaping the prill within 45 d. These findings make the suggestion of a single PCU application suspect.

The purpose of this study was to evaluate the impacts of PCU on Kentucky bluegrass height, biomass, health (NDVI), and verdure with one to three applications and to examine the timing of a single PCU application.

MATERIALS AND METHODS

Two irrigated field plot areas were installed in 2012 at Provo, UT (40º24’52.09”N, 111º64’17.61”W) near the BYU Life Sciences Greenhouse Complex. The south field was installed with a constructed sandy loam soil (Table 1). The north field was installed to meet the specifications for a High Performance Sand-Based Rootzones for Athletic Fields per the American Society for Testing and Materials (ASTM) method F2396 (4th and 5th columns of Table 1). Kentucky bluegrass (*Poa pratensis* L. var. P105, Bedazzled, Prosperity, and Moonlight SLT) were established as sod at both sites.

Studies were initiated in April 2014. The soils had minimal soil N with no confounding results due to previous applications (Table 1). Four treatments (Table 2) with four blocks were applied with a randomized block control design (RBCD) with plots of 2.6 m by 1 m. A control with no added N was also included but not fully reported herein. The Grower’s Standard of Practice (GSP) served as the “ideal” treatment with a steady supply of N throughout the growing season. All treatments had ammonium sulfate included as part of the total N to serve as a source of sulfur and to insure that each fertilized treatment included at least some rapidly available N. The other treatments were various combinations of a PCU (Agrium One Ap, Agrium Advanced Technologies, Loveland, CO, USA).

The fertilizer for each treatment was spread by hand. Height and Normalized Difference Vegetative Index (NDVI; an assessment of plant health) measurements were taken every seven days (d). Shoot height was averaged over three locations in each plot by measuring from the thatch layer to the tip of the grass blades. The NDVI (FieldScout TCM 500 NDVI Turf Color Meter, Spectrum Technologies, Inc., Aurora, IL, USA) measurements were also averaged over three locations in each plot. Shoot biomass samples were collected at 135 and 275 ordinal d in 2014 and on 238, 288, and 303 ordinal d in 2015 using a reel mower with a catch basin set at a height of 2.5 cm. After each subplot was mowed, the blades and catch basin were wiped clean. Each biomass sample was stored in a paper bag and left to air dry and then weighed. Visual verdure ratings were taken prior to mowing at 126, 239 and 260 ordinal d in 2014 and on 238 and 305 ordinal d in 2015. Visual ratings were done on a scale of 1-5 with one being completely dormant and five being dense, dark green turfgrass. Final shoot density and biomass measurements were taken at the end of the two year study. Shoot density was measured by taking a plug from each plot and counting the crowns of the turfgrass in two random areas (3 cm^2). After shoot density was measured, all of the shoot biomass was harvested above the crowns. After biomass was calculated, the shoots were ground and analyzed for N content using the CN Determinator (TruSpec Micro, LECO, St. Joseph, MI, USA). Root biomass was measured using the same plugs taken from the plots for shoot density and biomass. The roots were also harvested by washing the soil off and collecting the biomass in a 1 mm screen. Data was checked for normality and analyzed by analysis of variance (ANOVA) with R (R project for Statistical Computing), with significance indicated at $P \leq 0.05$. Any significant means were then separated using a Tukey-Kramer test.

RESULTS

The models for all dependent variables were highly significant with the interaction between treatment and sampling date always significant (Table 3). Therefore, all statistical evaluations were performed for each individual sampling date and the interactions shown in Figs. 1-4. The results for the control are not included in the results below in order to simplify the output, but it is important to note that all fertilized treatments gave a typical N response over the control with significant increases in all cases (see Appendix 1 for control data). It is also noteworthy that a three application of PCU treatment was also evaluated and is not reported below (also for reasons of simplifying the data shown). There were no trends or significant differences in root biomass for both the loam and sand trials (see Appendix).

Growth: Loam Soil Trial

There were highly significant differences in shoot height (Tables 4-5, Fig. 1) and biomass (Table 6) across the various treatments in this study. The biomass readings were made less often than the weekly height readings, but generally followed the same trends —with both as measures of shoot growth. Biomass is a combination of height along with shoot thickness and density.

Shoot growth for the loam soil was never significantly different for 2Ap as compared to the GSP (Tables 4-5, Fig. 1). In contrast, shoot growth was significantly greater for 1Ap-S over the GSP on three dates in spring 2014 and one date in both summer 2014 and spring 2015. Height was never significantly lower for 1Ap-S than the GSP, although there was a trend for less growth in fall 2015. Similarly, although at the opposite time of year, shoot growth was significantly greater for 1Ap-F over the GSP on two dates in fall 2014 and three dates in fall 2015.

The results were similar when comparing 2Ap against 1Ap-S and 1Ap-F (Fig. 1). Shoot growth for 1Ap-S was significantly greater than 2Ap on one date in spring 2014. The effect was even greater for 1Ap-F, but only in 2015—with significantly greater shoot growth over 2Ap on five dates in the fall of that year. The lack of significance in 2014 could be due to larger magnitude of differences in the heights of the treatments in fall 2015 as compared to 2014.

As expected, there were significant shoot growth differences due to timing between the 1Ap-F and 1Ap-S. Height was significantly greater for 1Ap-F than 1Ap-S on one date in fall

2014 and six dates in fall 2015. Surprisingly, there were no differences in spring between these treatments.

Growth: Sand Soil Trial

As with the loam study, there were significant differences in shoot growth with the sand study (Tables 7-8, Fig. 2). Results were similar for the sandy soil with the same general trends and interactions in 2014 as with the loam soil (Figs. 1-2). Results are not shown for 2015 in the sand due to the failure of the sand field in the early spring. Although incomplete for the season, data was collected for late season on the sand in 2015 and is found in Appendix 1.

Shoot growth for 2Ap was significantly different from the GSP on one date in the spring of 2014. However, shoot growth was significantly greater for 1Ap-S over the GSP on six dates in spring. Shoot growth was significantly greater for 1Ap-F over the GSP on one date in fall. These results are virtually the same as with the study done with loam soil, but with a much greater magnitude in differences between treatments

The results were similar when comparing 2Ap against 1Ap-S with shoot growth significantly greater than 2Ap on four dates in the spring (Fig. 2). However, the differences were not significant between 2Ap and 1Ap-F. Additionally, height for 1Ap-F was significantly greater than 1Ap-S on three dates in the fall.

Health: Loam Soil Trial

Plant health and verdure, as represented by weekly NDVI measurements, for the loam soil was never significantly different for 2Ap as compared to the GSP (Tables 9-10; Fig. 3). In contrast, NDVI was significantly greater for 1Ap-S over the GSP on three dates in spring 2014 and no differences in 2015. The NDVI readings for 1Ap-S were never significantly lower than the GSP, although there was a trend for lower NDVI readings in 2015. The NDVI for 1Ap-F was never significantly different than the GSP.

The results were similar when comparing 2Ap to 1Ap-S and 1Ap-F (Fig. 3). NDVI for 1Ap-S was significantly greater than 2Ap on two dates in the spring of 2014, but reverse was true on one date in fall of that year. There were no differences between 2Ap and 1Ap-S in 2015. The NDVI of 1Ap-F was significantly greater than 2Ap on two dates in fall of 2015, but no differences in the prior year.

As expected, there were significant differences between 1Ap-S and 1Ap-F due to timing of application (Fig. 3). The NDVI was significantly greater for 1Ap-F on three dates in the fall of both years. Surprisingly, the NDVI of 1Ap-S was not significantly greater than 1Ap-F in the spring of 2015. The visual ratings had the same general trends as the NDVI readings (Table 11).

Health: Sand Soil Trial

Results were similar for the plant health for the sandy soil (Table 12; Fig. 4) with the same general trends in 2014 but with greater magnitude in the differences over what was observed with the loam study in spring (Figs. 3). In 2014, the 2Ap was significantly greater than the GSP on four dates in the spring and never worse (Fig. 4). Similar to the loam, NDVI was significantly greater for 1Ap-S over the GSP, again with greater magnitude of differences, with it being higher on five dates in the spring. Although not significant, there was a trend in both of the sand and loam studies for the 1Ap-S NDVI to trend below GSP in the fall. NDVI was significantly greater for 1Ap-F over the GSP on one date in the fall. Unfortunately, the spring evaluation for this treatment was not possible due to loss of the sand plots in spring 2015.

Results were similar when comparing 2Ap against 1Ap-S and 1Ap-F (Fig. 4). NDVI readings for 1Ap-S were significantly greater than 2Ap on two dates in the spring. The 1Ap-F treatment was never significantly different from 2Ap. NDVI for 1Ap-F was significantly greater than 1Ap-S on one date in the fall. Visual ratings followed the same general trends as the NDVI readings (Table 13).

Shoot N Concentration

Shoot N concentrations generally followed expected patterns related to fertilization (Table 14). The shoot N was in the order 1Ap-S > 2Ap > GSP in the spring and 1Ap-F > 2Ap > GSP > 1Ap-S in the fall for 2014. The same general trend was observed in 2015, but, in the loam soil, the GSP was higher than 2Ap earlier in the fall but these reversed concentration two weeks later.

Shoot Density

There was a significant impact of fertilization on crown density for the loam soil (Table 15; Fig. 5). All treatments that received at least 50% of the annually applied N fertilizer in the fall had a significant increase in shoot density. A similar trend was observed for the sand with the 1Ap-S having the lowest shoot density for the fertilized treatments (data not shown).

DISCUSSION

In these studies, the GSP was used as the “ideal” fertilizer program in that there is continuous good health and verdure without excessive shoot growth and mowing throughout the growing season. However, this practice is not ideal in terms of labor and associate costs needed to apply the fertilizer monthly. Additionally, the low rates applied are often difficult to achieve accurately with many dry fertilizer spreaders. Furthermore, uncoated urea is prone to relatively high losses of N to the environment (Guillard, 2004; LeMonte, 2011; LeMonte et al., 2016; Ransom 2014) through the leaching of N into ground water and gaseous losses to the atmosphere. This would especially be a problem during hot summer months when volatilization occurs at much higher rates. Finally, the use of traditional fertilizers can have a higher risk of salt damage if errantly applied due to the rapid solubilization of the material.

It is desirable to have a convenient, practical fertilizer approach which will also give an even supply of N throughout the growing season and minimizing environmental impacts and resource use. As such, the fertilizer industry has sought to engineer fertilizer materials that release in a controlled or slow timing, such as the controlled release polymer coated urea. There are several such products commercially available which have claim of "one application per year".

The data presented herein supports the claim by other researchers that PCU can effectively eliminate the need to apply fertilizer monthly in order to get an even supply of N to turfgrass (LeMonte et al., 2016; Ransom, 2014). The data from these studies show that three applications of a PCU/ammonium sulfate blend (3Ap) were always statistically identical to the two applications (2Ap) below and, therefore, were not included to simplify the plethora of data (see Appendix 1 for 3Ap data). The data also shows that two applications of a PCU/traditional fertilizer blend results in equivalent or better results than the GSP. Verdure and plant health were excellent for both the GSP and the two applications of the PCU/traditional fertilizer blend in all cases. And, there were no negative impacts on shoot growth with the use of two applications. Furthermore, the high shoot N concentrations with the PCU suggests increased NUE and warrants a rate reduction (see Chapter 2)—thus reducing consumption of natural resources used in the manufacture and transportation of fertilizer and environmental risks (Buss, 2016).

In contrast, our data shows that a single application of a PCU/traditional fertilizer blend is not as good as two applications or the GSP. This approach resulted in significant increases in shoot growth and verdure shortly after the single fertilizer applications (regardless of timing). This is unacceptable, even for a low maintenance situation, because it would result in an increase in the need for mowing frequency and clipping removal costs. If mowing frequency would not be increased then there would be a likelihood of damage from scalping and/or excessive clippings. Several months after application, there were minor trends for less shoot growth in some cases for the single applications compared to the GSP. A reduction in growth would be desirable if not accompanied by loss of verdure. However, the reduced growth weeks after a single PCU application was accompanied by a slight trend towards poor verdure in some instances.

These results show that a single application is not effective when conducted in the manner that we pursued for these trials. The results are similar to those of Ransom (2014) and Unruh et al. (2013). In the studies previously mentioned, the onetime application of PCU at the beginning of spring was not able to sustain turfgrass over the growing season and over time. In Unruh's study (2013) there was a decrease in visual ratings over a four year period with warm-season grasses. It is possible that an adjustment in rate and/or timing could mitigate the negative effects of a single application. The spring application was clearly a problem, but it is possible that use of a 100% PCU application rather than a blend with traditional fertilizer may result in acceptable growth. In Ransom's study (2014) such was not the case, but the PCU that was used in the study was not a blend of different durations of release like the product that was used in our studies. The single fall application was relatively better and it is possible that a delay in the timing and/or composition of the blend may result in less fall growth and better spring/summer carryover. This research is underway.

Although two applications of PCU was better than a single application, further splits were unnecessary as evidenced by no significant differences between two and three applications in this study (data not shown here—see Appendix 1).

Although there is a significant amount of published research on PCU, there is minimal work done with timing in turfgrass. In a study conducted by Nelson on fall planted wheat (*Triticum aestivum* L.) grown in Novelty, Missouri, the results showed that there was a significant gain in yield when PCU was used, but there was no significant difference in yield between the split application of N in a spring and fall application versus a full application in fall (2014). In Nelson's study, the "fall" application was applied in late October, which could have been the reason why there was no significant difference between the yield for the split application versus the one application. Of course, wheat is grown for grain in contrast to how turfgrass is grown. But examining this data leads to a possible hypothesis that pushing the "fall" application into September or later for the turfgrass study may reduce the spike in shoot growth for the 1Ap-F.

The excess amount of N being applied in agricultural and urban landscapes has negative impacts on the environment due to the loss of N through different loss mechanisms. The process of making N fertilizer also has an impact on the environment due to natural resources being used. Based on the work of LeMonte (2011), LeMonte et al. (2016), and Ransom (2014) it is expected that the environmental benefits in terms of reduced N loss due to leaching and volatilization will be available. A reduction of N applied will also decrease economic and environmental costs associated with applying more N.

LITERATURE CITED

Adams, C., Frantz, J., & Bugbee, B. (2013). Macro- and micronutrient-release characteristics of three polymer-coated fertilizers: Theory and measurements. *J. Plant Nutr. Soil Sci. Journal of Plant Nutrition and Soil Science, 176*(1), 76-88.

Bandaranayake, W., Qian, Y., Parton, W., Ojima, D., & Follet, R. (2003). Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model. *Agronomy Journal, 95(3),* 558-558. Doi:10.2134/agronj2003.0558

Barker, A., and Pilbeam, D. (2007). Handbook of Plant Nutrition. CRC Press, Boca Raton, FL.

Blaylock, A., Binford. G., Dowbenko, R., Kaufmann, J., & Islam, R. (2005). ESN, Controlled-Release Nitrogen for Enhanced Nitrogen Efficiency and Improved Environmental Safety. *Science Press and Science Press USA,* 381-390.

Bowman, D., Cherney, C., & Rufty, T. (2002). Fate and Transport of Nitrogen Applied to Six Warm-Season Turfgrasses. *Crop Science, 42(3),* 833-840. Retrieved December 2, 2014, from http://www.carleton.edu/departments/GEOL/Resources/comps/CompsPDFfiles/2009/Linetd WebPg/Papers/Fate and Transport of Nitrogen Applied to Six Warm Season Turfgrasses.pdf

Bremer, D. (2007) Carbon Sequestration in Turfgrass: An Eco-Friendly Benefit of Your Lawn. *Turfnews, a quarterly Kansas Turfgrass Foundation Newsletter*.

Burton, D. L., Li. X., and Grant, C. A. (2003) Reducing nitrous oxide emissions through the use of fertilizer management technologies. Dept. Soil Science, University of Manitoba, Winnipeg, Manitoba, Canada.

Cameron, K., Di, H., & Moir, J. (2013). Nitrogen Losses From the Soil/Plant System: A review.*Annals of Applied Biology, 162*, 145-173.

Carrow, R. N. (1997). Turfgrass Response to Slow-Release Nitrogen Fertilizers. *Agronomy Journal, 89*(3), 491.

Chatterjee, A. (2012). Reducing Denitrification Loss of Nitrogen Fertilizer. *Crop and Soil Magazine*: 45: 14-15.

Christians, N. (2007). Fertilization. In *Fundamentals of turfgrass management* (4th ed., pp. 141-143). Hoboken, N.J.: John Wiley & Sons.

Du, C., Zhou, J., & Shaviv, A. (2006). Release Characteristics of Nutrients from Polymer-Coated Compound Controlled Release Fertilizers. *Journal of Polymers and the Environment J Polym Environ, 14,* 223-230.

Easton, Z. M., & Petrovic, A. M. (2004). Fertilizer Source Effect on Ground and Surface Water Quality in Drainage from Turfgrass. *Journal of Environment Quality, 33*(2), 645.

Ellison, E., Blaylock, A., Sanchez, C., & Smith, R. (2013, November 17). Exploring Controlled Release Nitrogen Fertilizers for Vegetable and Melon Crop Production in California and Arizona. Lecture presented at Western Nutrient Management Conference, Reno.

Food and Agriculture Organization of the United Nations. Current world fertilizer trends and outlook to 2014/15. Rep. Rome: FAO, 2011.

Guillard, K., & Kopp, K. (2004). Nitrogen Fertilizer Form and Associated Nitrate Leaching from Cool-Season Lawn Turf. *Journal of Environment Quality,* 1822-1827.

Hirsch, A., Michalak, A., Bruhwiler, L., Peters, W., Dlugokencky, E., & Tans, P. (2006). Inverse modeling estimates of the global nitrous oxide surface flux from 1998-2001.*Global Biogeochem. Cycles Global Biogeochemical Cycles*.

Hopkins, B., Rosen, C., Shiffler, A., & Taysom, T. (2008). Enhanced Efficiency Fertilizers for Improved Nutrient Management: Potato. *Crop Management.* Doi:10_1094/CM-20080317-01-RV.

Hyatt, C., Venterea, R., Rosen, C., Mcnearney, M., Wilson, M., & Dolan, M. (2010). Polymer-Coated Urea Maintains Potato Yields and Reduces Nitrous Oxide Emissions in a Minnesota Loamy Sand. *Soil Science Society of America Journal,* 74, 419-428.

IPCC. (1996) Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: ScientificTechnical Analyses. Intergovernmental Panel on Climate Change, Cambridge University Press, Melbourne, Australia.

Knight, E., Guertal, E., & Wood, C. (2007). Mowing and Nitrogen Source Effects on Ammonia Volatilization from Turfgrass. *Crop Science,* 47, 1628-1634.

LeMonte, J. 2011 Environmental Implications of Polymer Coated Urea. Thesis. Brigham Young University. Department of Plant and Wildlife Sciences. *Scholars Archive*. Brigham Young University.

Lemonte, J. J., Jolley, V. D., Summerhays, J. S., Terry, R. E., & Hopkins, B. G. (2016). Polymer Coated Urea in Turfgrass Maintains Vigor and Mitigates Nitrogen's Environmental Impacts. *PLOS ONE PLoS ONE, 11*(1).

Marschner, P. (2012). Mineral Nutrition of Higher Plants (3rd ed.). San Diego, CA: Elsevier.

McTaggart, I., Clayton, H., and Smith, K. (1994) Nitrous oxide flux from fertilized grassland: strategies for reducing emissions. In: Non-CO2 Greenhouse Gases [van Ham, L. et al., Eds.]. Kluwer Academic Publishers, Dordrecht, Netherlands, 421-426.

Milesi, C., Running, S., Elyidge, C., Dietz, J., Tuttle, B., & Nemani, R. (2005). Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States. *Environmental Management, 36*(3), 426-438.

Milesi, C., Elyidge, C., Dietz, J., Tuttle, B., Nemani, R., & Running, S. (n.d.). A Strategy for Mapping and Modeling the Ecological Effects of US Lawns. Retrieved January 8, 2016, from http://www.isprs.org/proceedings/XXXVI/8-W27/milesi.pdf.

Miltner, E., Stahnke, G., Johnston, W., & Golob, C. (2004). Late Fall and Winter Nitrogen Fertilization of Turfgrass in Two Pacific Northwest Climates. *Hortscience,* (39), 1745-1749.

Minami, K. (1994) Effect of Nitrification Inhibitors and Slow-Release Fertilizer on Emission of Nitrous Oxide from Fertilized Soils. In CH4 and N2O: global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources. [Minami, K., Mosier, A.R., and Sass, R. Eds.] NIAES Series 2, Yokendo Publishers, Tokyo, Japan.

National Turfgrass Federation. (2003). The Turfgrass Industry- Present and Future. Retrieved November 28, 2014, from http://www.turfresearch.org/pdf/Industry Turf Initiative.pdf

Nelson, K., Motayalli, P., & Nathan, M. (2014). Nitrogen Fertilizer Sources and Application Timing Affects Wheat and Inter-Seeded Red Clover Yields on Claypan Soils. *Agronomy,* 497-513. doi: 10.3390/agronomy4040497.

Nelson, K., Paniagua, S., & Motavalli, P. (2009). Effect of Polymer Coated Urea, Irrigation, and Drainage on Nitrogen Utilization and Yield of Corn in a Claypan Soil. *Agronomy Journal, 101,* 681-687.

Nielson, R. (2006). N Loss Mechanisms and Nitrogen Use Efficiency. *Purdue Nitrogen Management Workshops,* 1-5. Retrieved December 1, 2014, from http://www.agry.purdue.edu/ext/pubs/2006NLossMechanisms.pdf

Norton, R., Mikkelsen, R., & Jensen, T. (2013). Sulfur for Plant Nutrition. *Better Crops* 97.2 10-12.

Pack, J., & Hutchinson, C. (2003). Potato (Solanum tuberosum L.) Tuber Yields, Specific Gravities, and Nitrate Leaching Under Polymer Coated Urea and Ammonium Nitrate Fertilizer Program. *Hortscience.* (38), 719-720.

Pack, J., Hutchinson, C., & Simonne, E. (2006). Evaluation of Controlled-Release Fertilizers for Northeast Florida Chip Potato Production. *Journal of Plant Nutrition, 29,* 1301-1313.

Qian, Y., & Follett, R. (2015). Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. *Agronomy Journal,* 930-930. doi:10.2134/agronj2002.0930

Ransom, C. (2014) Nitrogen Use Efficiency of Polymer-Coated Urea. Thesis. Brigham Young University. Department of Plant and Wildlife Sciences. *Scholars Archive*. Brigham Young University.

Runfola, D. S., Hamill, T., Pontius, R. G., Jr., Rogan, J., Giner, N., & Decatur, A. (2014). Using Fine Resolution Orthoimagery and Spatial Interpolation to Rapidly Map Turf Grass in Suburban Massachusetts. *International Journal of Geospatial and Environmental Research, 1*(1). Retrieved February 10, 2016, from http://dc.uwm.edu/cgi/viewcontent.cgi?article=1004&context=ijger.

Sahu, R. (n.d.). Technical Assessment of the Carbon Sequestration Potential of Managed Turfgrass in the United States. Retrieved January 8, 2016, from http://opei.org/content/uploads/2014/02/TurfGrassSahu.pdf.

Snyder, C., Bruulsema, T., and Jensen, T. (2007). Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management—a literature review. International Plant Nutrition Institute, Norcross, Georgia, U.S.A.

Sutton, M., Erisman, J., Dentener, F., & Moller, D. (2008). Ammonia in the Environment: From Ancient Times to the Present. *Environmental Pollution*. (156), 583-604.

Unruh, J.B., Telenko, D. E. P, &Trenholm, L.E. (2013). Influence of Nitrogen Source on Nitratenitrogen Leaching When Applied to Centipedegrass and St. Augustinegrass. In Abstracts, ASA•CSSA•SSSA International Annual Meetings, Tampa, FL. 3-6 Nov. 2013. ASACSSA-SSSA, Madison, WI.

USEPA (2007). Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990–2005. EPA 430-R- 07-002. USEPA, Washington, DC.

Walker, K., Bigelow, C., Smith, D., Scoyoc, G., & Reicher, Z. (2007). Aboveground Responses of Cool-Season Lawn Species to Nitrogen Rates and Application Timings. *Crop Science, 47*(3), 1225-1225. doi:10.2135/cropsci2003.09.0595.

Wilson, M., Rosen, C., & Moncrief, J. (2010). Effects of Polymer-Coated Urea on Nitrate Leaching and Nitrogen Uptake by Potato. *Journal of Environment Quality, 39,* 492-499.

FIGURES

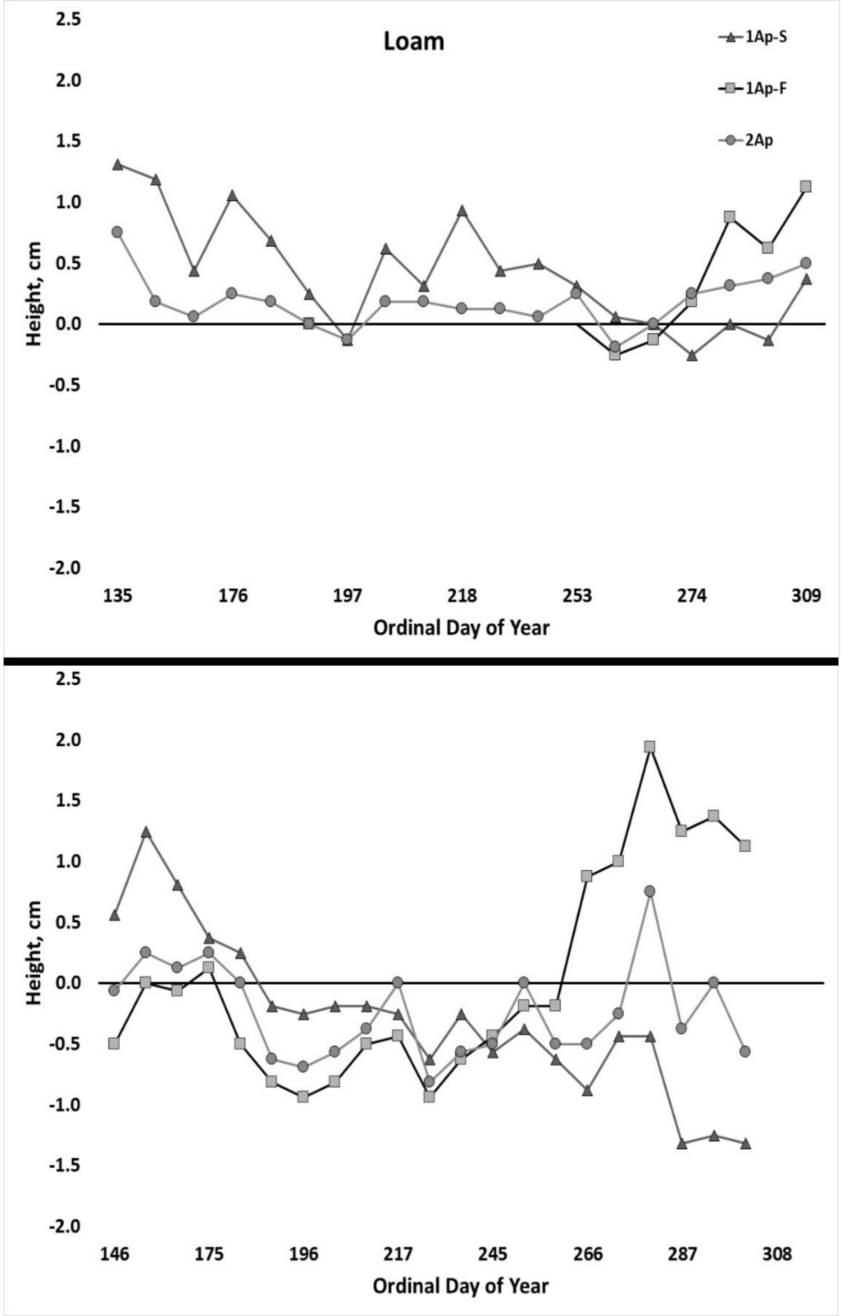

Figure 1 Kentucky bluegrass heights over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split two application once in spring and again in fall (2Ap) all at the 100% rate. Statistics are shown in Tables 4 and 5.

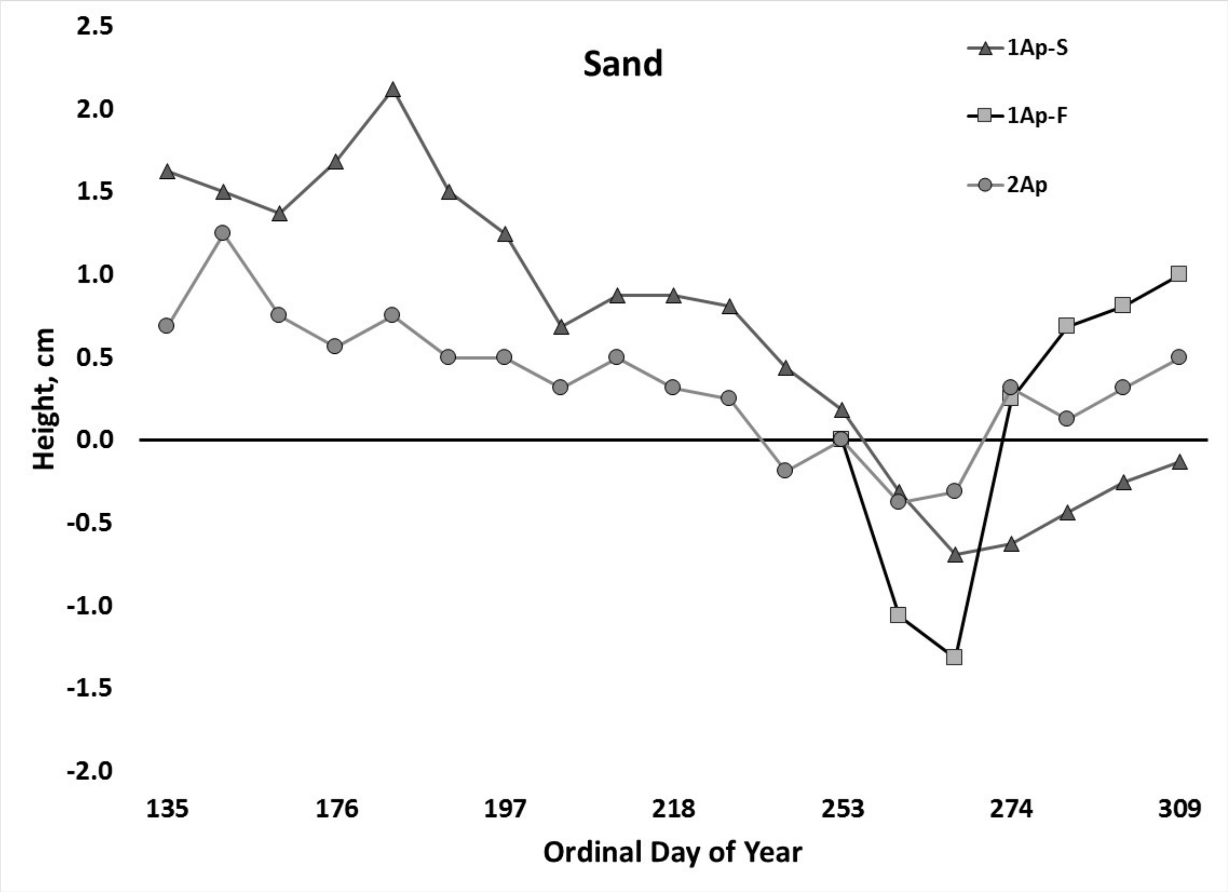

Figure 2 Kentucky bluegrass heights for 2014 for a trial on sand soil. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split two application once in spring and again in fall (2Ap) all at the 100% rate. Statistics are shown in Table 7.

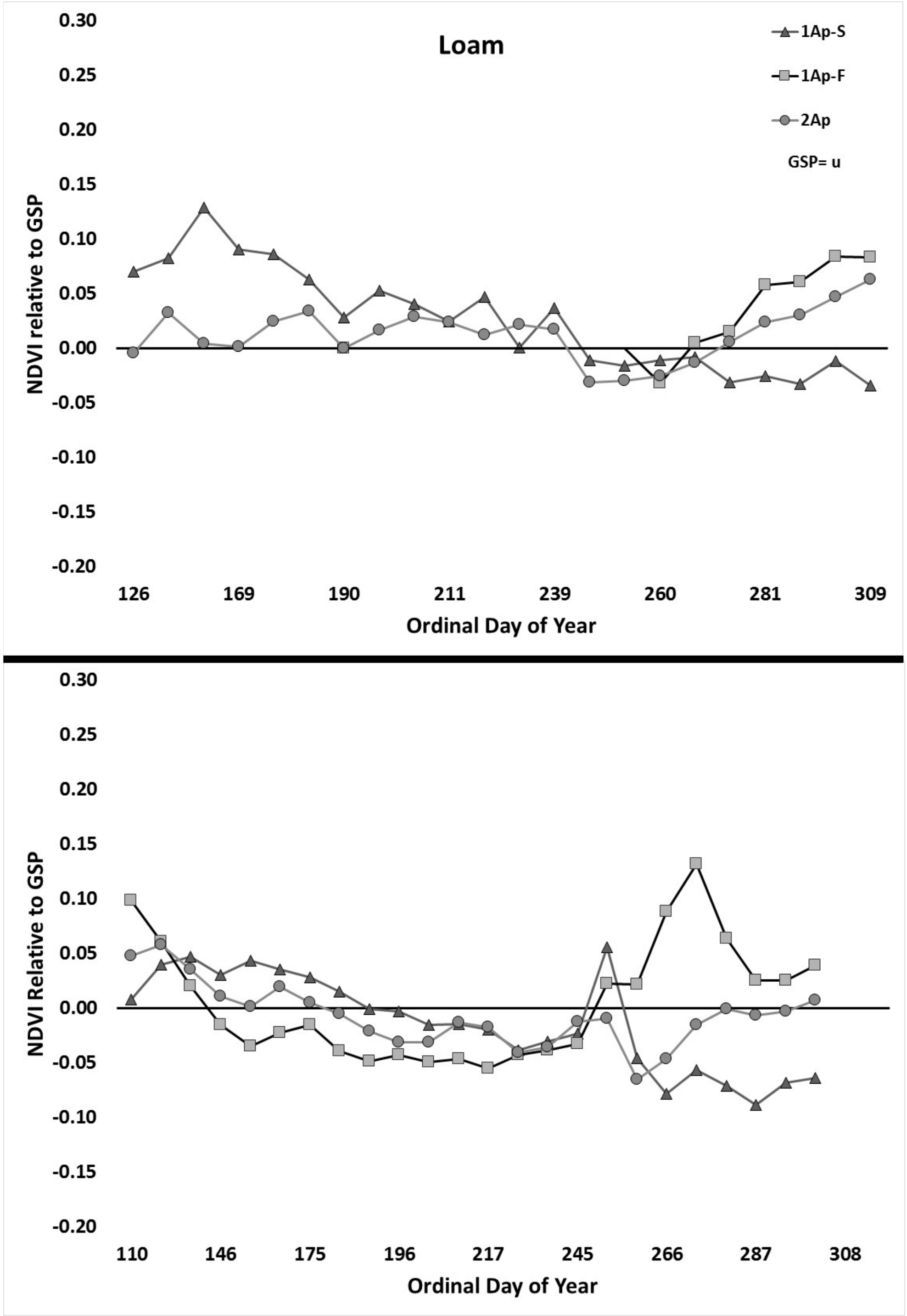

Figure 3 Kentucky bluegrass NDVI readings over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split two application once in spring and again in fall (2Ap) all at the100% rate. Statistics are shown in Tables 9 and 10.

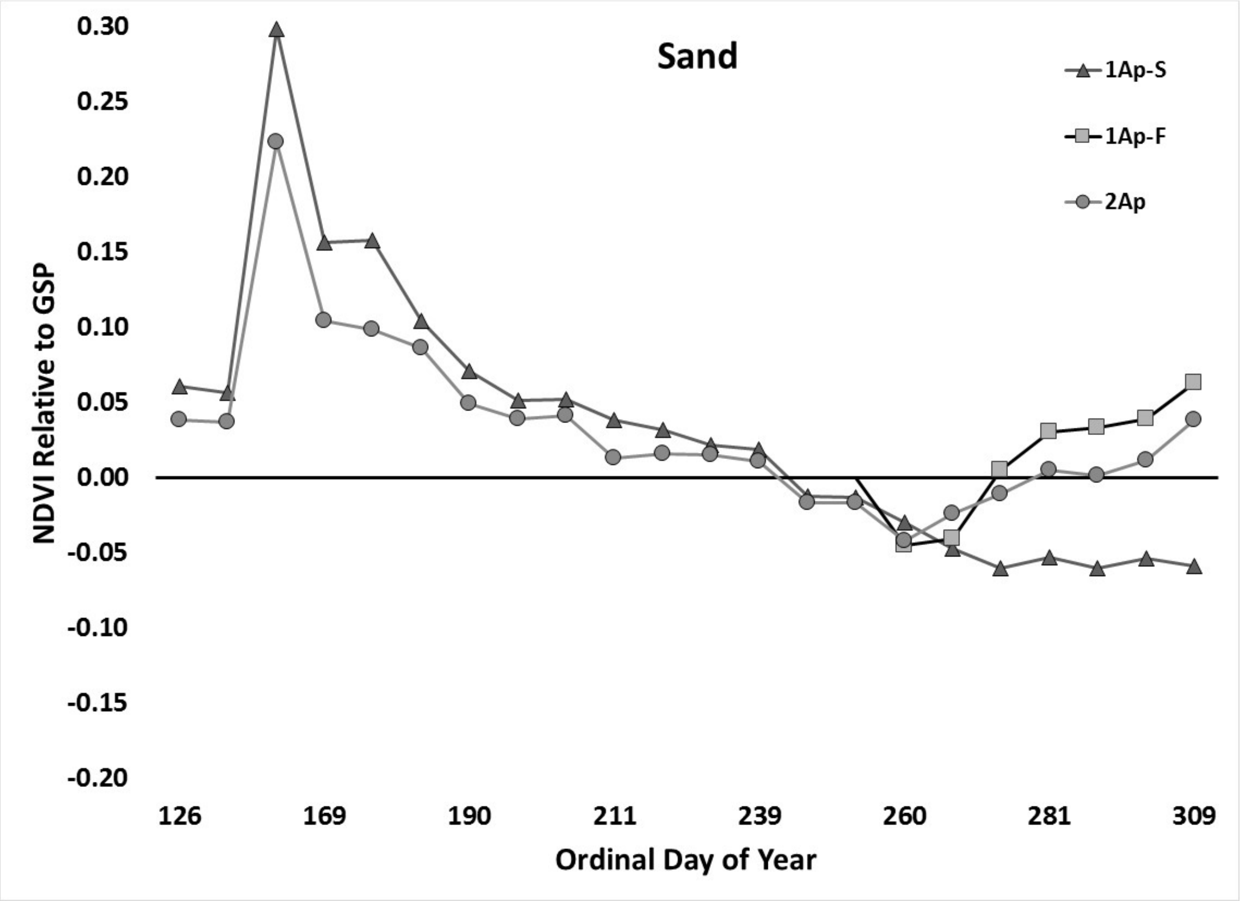

Figure 4 Kentucky bluegrass NDVI readings for 2014 for a trial on sand soil. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split two application once in spring and again in fall (2Ap) all at the 100% rate. Statistics are shown in Table 12.

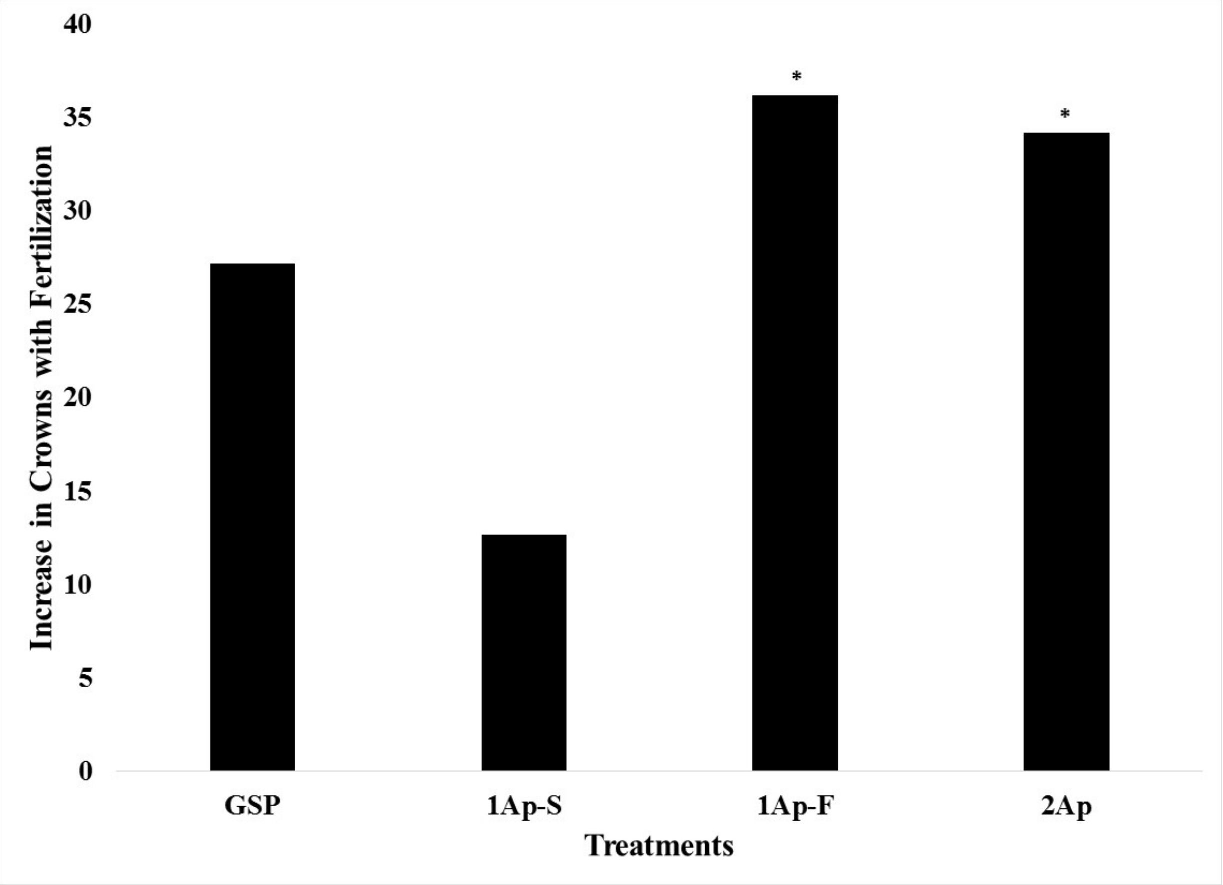

Figure 5 Kentucky bluegrass shoot density for 2015 for a trial on loam soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split two application once in spring and again in fall (2Ap) all at the 100% rate are shown. Astericks correspond with significance. Data shown in Table 15.

TABLES

Table 1 Soil test values for two Kentucky bluegrass trials (Loam and Sand)

Texture		Sandy Loam	Sand
pH (2:1)		8	7.4
ECe (2:1)	mmhos/cm^{-1}	0.5	0.2
excess lime	%	5	0
OM		2.4	1.6
NO_3-N	mg kg^{-1}	4	2
NH_4-N		2	2
P (bicarb)		19	5
K		275	75
S		15	5
Ca		2203	200
Mg		377	24
Na		92	23
Zn DTPA		1.6	0.5
Fe		9	5
Mn		8	2
Cu		0.6	0.3
B H_2O		1.1	0.5

Table 2 Percentages of the full rate of nitrogen fertilizer for Kentucky bluegrass trials treatments. The N rate for each treatment was 19.5 and 29.3 g m-2 for loam and sand trials, respectively. Treatments included a grower's standard practice (GSP) compared to polymer coated urea (PCU)/ammonium sulfate (AS) blends applied once in spring (1Ap-S), once in fall (1Ap-F), or with two annual applications—in spring and fall (2Ap).

		GSP	1Ap-S	1Ap-F	2Ap
		%			
April	urea	8.3			
	AS	4.2	33.3		16.5
	PCU		66.7		33.5
May	urea	8.3			
	AS	4.2			
	PCU				
June	urea	8.3			
	AS	4.2			
	PCU				
July	urea	8.3			
	AS	4.2			
	PCU				
August	urea	8.3			
	AS	4.2		33.3	16.5
	PCU			66.7	33.5
September	urea	8.3			
	AS	4.2			
	PCU				
October	urea	8.3			
	AS	4.2			
	PCU				
November	urea	8.3			
	AS	4.2			
	PCU				

Table 3 *P*-values for each measurement taken in the corresponding year and soil study. Statistically significant values are in bold-faced type.

		Sand 2014	Loam 2014	Loam 2015
NDVI	ordinal day	**<.0001**	**<.0001**	**<.0001**
	treatment	**<.0001**	**<.0001**	**0.0030**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**
verdure	ordinal day	**0.0005**	**0.0025**	**0.0081**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**0.0004**	**0.0012**	**<.0001**
shoot biomass	ordinal day	0.4343	**0.0101**	0.5687
	treatment	**<.0001**	**0.0003**	**<.0001**
	ordinal day*treatment	**0.0016**	**0.0004**	**<.0001**
height	ordinal day	**<.0001**	**<.0001**	**<.0001**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**
shoot N	ordinal day	**0.0007**	**0.0003**	**<.0001**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**

Table 4 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

	Date									
	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year									
	135	162	170	176	183	190	197	204	211	218
	mm									
GSP	50 b	34 b	34	32 b	31	30	30	26	28	29 b
2Ap	58 ab	36 b	35	34 ab	33	30	29	28	30	30 ab
1Ap-S	63 a	46 a	39	43 a	38	33	29	33	31	38 a

	Date								
	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
	Ordinal Day of Year								
	239	246	253	260	267	274	281	295	309
	mm								
GSP	32	30	32	32	36	36	31 b	36	29 b
2Ap	33	31	34	30	36	38	34 ab	39	34 ab
1Ap-S	36	35	35	33	36	33	31 b	34	33 ab
1Ap-F				29	34	38	39 a	42	41 a

Table 5 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

	Date										
	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12
	Ordinal Day of Year										
	146	157	164	175	182	189	196	203	210	217	224
	mm										
GSP	38	43	37	30	35	39	39	39	36	35	41
2Ap	37	45	38	33	35	33	32	33	33	35	33
1Ap-S	43	55	45	34	38	37	36	37	34	33	35
1Ap-F	33	43	36	31	30	31	29	31	31	31	32

	Date									
	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
	Ordinal Day of Year									
	238	245	252	261	266	273	280	287	294	301
	mm									
GSP	36	38	34	39	41 ab	36 ab	39 b	45 b	39 b	40 ab
2Ap	31	33	34	34	36 b	34 b	47 ab	41 bc	39 b	34 bc
1Ap-S	34	32	30	33	33 b	32 b	35 b	32 c	26 c	27c
1Ap-F	30	33	32	37	50 a	46 a	59 a	58 a	53 a	51 a

Table 6 Biomass values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

	2014		2015		
Date	5/15	10/2	8/26	10/15	10/30
Ordinal Day of Year	135	275	238	288	303
GSP	30.45 a	23.84 a	21.43 a	14.19 ab	14.64 a
2Ap	42.29 a	38.57 ab	13.83 a	14.10 ab	12.69 a
1Ap-S	61.28 a	29.41 b	17.74 a	5.82 b	4.66 a
1Ap-F		27.82 a	8.48 a	19.41a	28.19 b

Table 7 Height values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

	Date									
	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year									
	135	162	170	176	183	190	197	204	211	218
	mm									
GSP	53 b	45 b	36	36 b	35 b	34 b	34 b	28	31	29
2Ap	60 ab	58 a	44	41 b	43 b	39 b	39 ab	31	36	32
1Ap-S	69 a	60 a	50	53 a	56 a	49 a	46 a	35	40	38

	Date								
	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
	Ordinal Day of Year								
	239	246	253	260	267	274	281	295	309
	mm								
GSP	31	33	37	37 a	41 a	43	35 ab	33 ab	31 b
2Ap	33	31	37	33 ab	38 a	46	36 ab	36 ab	36 ab
1Ap-S	39	37	39	34 ab	34 ab	36	31 b	30 b	29 b
1Ap-F				26 b	28 b	45	42 a	41 a	41 a

Table 8 Biomass values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

	Date	
	5/15	10/2
	Ordinal Day of Year	
	135	275
GSP	28.78 ab	45.11 a
2Ap	45.13 a	59.08 a
1Ap-S	62.30 ab	33.61 a
1Ap-F		25.59 a

Table 9 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

Date	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
Ordinal Day of Year	126	134	160	169	176	183	190	197	204	211	218
GSP	65	63	55 b	62 b	62 b	64	69	68	63	62	64
2Ap	65	66	55 b	62 b	64 ab	68	69	69	66	65	65
1Ap-S	72	71	67 a	71 a	70 a	71	72	73	67	65	68

Date	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
Ordinal Day of Year	233	239	246	253	260	267	274	281	288	295	309
GSP	67	66	70	70	68	71	69	71	71 ab	69 ab	66 ab
2Ap	69	68	66	67	65	69	70	74	74 ab	74 ab	72 a
1Ap-S	67	70	68	69	67	70	66	69	68 b	68 b	63 b
1Ap-F				66	65	71	71	77	77 a	78 a	74 a

Table 10 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

	Date											
	4/20	4/24	5/1	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29
	Ordinal Day of Year											
	110	114	121	146	154	161	175	182	189	196	203	210
GSP	47	56	65	75	71	73	69	72	74	71	73	70
2Ap	52	62	69	76	71	74	69	72	72	68	70	69
1Ap-S	48	60	70	78	76	76	72	74	74	71	72	69
1Ap-F	57	62	67	73	68	70	67	68	69	67	68	65
	Date											
	8/5	8/12	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
	Ordinal Day of Year											
	217	224	238	245	252	261	266	273	280	287	294	301
GSP	73	72	64	68	53	62	61 ab	50 ab	66 ab	71	74	74
2Ap	72	68	60	67	52	55	57 b	49 b	66 ab	71	74	74
1Ap-S	71	68	61	66	59	57	53 b	45 b	59 b	63	67	67
1Ap-F	68	68	60	65	56	64	70 a	64 a	73 a	74	76	77

Table 11 Visual values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower’s standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. The statistics within the table display those treatments with the same letters as not being significantly different. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05.

No data is shown for 1Ap-F prior to its first date of fertilization.

		2014		2015	
			Date		
	5/6	8/27	9/17	8/26	11/1
			Ordinal Day of Year		
	126	239	260	238	305
GSP	2.00 ab	2.75 ab	3.00 a	3.44 a	3.69 ab
2Ap	2.50 a	2.88 ab	2.75 a	2.88 a	3.63 ab
1Ap-S	4.00 b	3.63 ab	3.13 a	2.69 a	2.88 a
1Ap-F		1.88 a	2.25 a	2.63 b	4.13 b

Table 12 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

	Date										
	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year										
	126	134	160	169	176	183	190	197	204	211	218
GSP	63	64	31 b	53 b	57 b	64 b	68	68	68	66	65
2Ap	67	68	53 a	63 a	66 a	72 a	73	72	72	67	67
1Ap-S	69	70	61 a	69 a	72 a	74 a	75	73	73	70	68

	Date										
	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
	Ordinal Day of Year										
	233	239	246	253	260	267	274	281	288	295	309
GSP	71	69	70	69	71	74	74	75	75 a	74 ab	70 ab
2Ap	72	70	68	68	66	71	73	75	75 a	76 a	74 a
1Ap-S	73	71	69	68	68	69	68	70	69 b	69 b	64 b
1Ap-F				67	66	70	75	78	78 a	78 a	76 a

Table 13 Visual values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

No data is shown for 1Ap-F prior to its first date of fertilization.

		Date	
	5/6	8/27	9/17
		Ordinal Day of Year	
	126	239	260
GSP	2.25 a	3.25 ab	3.50 ab
2Ap	2.75 a	3.88 ab	3.38 ab
1Ap-S	3.00 a	4.13 a	3.75 a
1Ap-F		1.75 b	2.13 b

Table 14 Total N values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 on the top and the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to polymer coated urea/ammonium sulfate blend urea fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05.

No data is shown for 1Ap-F prior to its first date of fertilization.

	2014		2015	
	Loam			
	Date			
	5/15	10/2	10/15	10/30
	Ordinal Day of Year			
	135	275	288	303
GSP	2.24 b	3.09 c	4.44 ab	3.36 b
2Ap	2.69 b	3.81 b	4.26 a	3.53 b
1Ap-S	3.44 a	2.97 c	2.99 b	2.46 b
1Ap-F		4.62 a	4.94 a	4.23 a
	Sand			
	Date			
	5/15	10/2		
	Ordinal Day of Year			
	135	275		
GSP	2.39 c	3.91 c		
2Ap	3.19 b	4.55 b		
1Ap-S	4.24 a	3.28 d		
1Ap-F		5.40 a		

Table 15 Shoot density with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

	Date
	10/30
	Ordinal Day of Year
	303
GSP	61.5
2Ap	68.5
1Ap-S	47.0
1Ap-F	70.5

Polymer Coated Urea in Kentucky Bluegrass: Rate of Application

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ABSTRACT

Nitrogen (N) is the most commonly over-applied nutrient in urban environments because of the obvious difference in “greenness”. This over-application has led to nutrient pollution of the atmosphere and hydrosphere. Furthermore, excess N results in increases in maintenance costs and solid waste volume. A two-year study was initiated in April 2014. Four fertilized treatments were applied at two locations in Provo, UT. Treatments included full recommended rate of a urea and ammonium sulfate blend split applied monthly compared to a polymer coated urea (PCU) and ammonium sulfate blend applied at 50, 75, or 100% of the full rate applied in two equal applications early and late in the growing season. The PCU blend applied at the full rate performed virtually the same as the blend with uncoated urea. Reducing the rate to 75% gave very similar results for verdure and shoot growth at both locations. However, further reduction to the half rate consistently had significantly lower plant verdure as compared to the other treatments. This study shows that a reduction in rate by 25% results in similar plant verdure and shoot growth as the full rate, but reducing the rate by 50% results in lower shoot growth as well as lower plant verdure. Further work is needed to evaluate the long-term effects of a reduced rate of N.

INTRODUCTION

As urban and suburban developments grow, turfgrass is quickly growing as the principle managed land cover (National Turfgrass Federation, 2003; Walker, 2007). According to the combination of studies done by Milesi et al. (2005) and Runfola et al. (2014) turfgrass coverage in the U.S. is estimated to be 111,683 km^2. Turfgrass occupies 1.9% of the total surface area in the United States and is the leading irrigated crop in the country (Milesi et al., 2005). Turfgrass serves important roles in society. Despite the many benefits, there are also concerns due to consumption of natural resources and pollution issues.

One such concern is related to nitrogen (N) fertilization. Turfgrass managers typically apply between 75 and 500 kg N ha^{-1} each year because it is the nutrient of greatest need and is most likely to show visual symptoms if deficient (Milesi et al., 2005). As such, many homeowners and turfgrass managers make the mistake of over applying N. The recommended rate of N to be applied varies between and within species. Warm-season turfgrass requires ~50 kg N ha^{-1} for each month of active growth. Cool-season turfgrass requires ~150-250 kg N $ha^{-1}yr^{-1}$ (Christians, 2007).

Annual worldwide N fertilizer demand is projected to total over 112 thousand metric tons in 2015 but the actual total applied is projected to be over 156,300,000 tons for the same year (FAO, 2011). Over application of N-based fertilizers leads to an increase in shoot growth at the expense of root growth. Poor rooting can result in unhealthy plants, poor surface conditions, and inefficient water and fertilizer recovery rates. In addition, excessive shoot growth results in increased mowing and an increase in clipping wastes and/or damage to the turfgrass if excessive clippings are not removed. In addition to problems with plant health, excessive N application increases risk of environmental problems. Nitrogen cycling in the ecosystem is a vital and normal process, but excesses can result in problems with leaching of nitrate (NO_3^-) to groundwater and runoff of NO_3^- and ammonium (NH_4^+) to surface water bodies and atmospheric pollution through nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization.

Ammonia volatilization results in increases in air quality problems, including: photochemical smog, particulate matter, strong odors, and acid rain. In addition, the volatilization of NH_3 is a concern with deposition on land or water bodies in sensitive systems. Excessive N deposition can lead to reduction in plant community loss, as well as a reduction in biodiversity (Sutton et al., 2008). The deposition of NH_3 can also lead to soil acidification (Sutton et al., 2008), as well as surface water eutrophication (Boyd, 2000).

Another gaseous N environmental issue is related to N_2O. Hirsch et al. (2006) estimated anthropogenic emissions of N_2O to have increased by about 40-50% over preindustrial levels. It is estimated that emissions directly related to fertilization account for 78% of the total annual anthropogenic N_2O losses (LeMonte et al., 2016; USEPA, 2007). The processes of nitrification and denitrification lead to the formation of N_2O which is lost to the environment (McTaggart et al., 1994). The concern with N_2O is that it is a long-lived, potent greenhouse gas with a significantly greater potential of global warming by almost 300 times that of carbon dioxide (CO_2) (IPCC, 1995; USEPA, 2007).

Nitrogen excess in the hydrosphere is also a serious concern. Soil NO_3^- is easily leached below the rooting zone due to it being a highly soluble anion that is repelled by negatively charged soil. It has been reported that the annual rate of N leaching from turfgrass ranges between 0 and 160 kg N ha^{-1} $year^{-1}$—representing up to 30% of applied N (Barton, 2006). Contaminated drinking water high in NO_3^- causes methemoglobinemia (baby blue syndrome) in mammalian infants (Olson et al., 2009). It is also speculated to cause other health issues in humans, but this is not proven.

Surface water contamination is also a concern. Both NH_4^+ and NO_3^- can be easily transported via surface water runoff and soil erosion (Easton, 2004). As with groundwater, NO_3^- in surface water is also a potential drinking water problem. Additionally, excess N in surface water can lead to problems from algal blooms—which can result in injury or death of the aquatic life or organisms drinking the water, decreases in biodiversity, unsightly conditions, strong odors, economic losses, and a decrease in recreational use (Fangmeier et al., 1994; Mulvaney et al., 2009).

Along with needing to reduce the environmental impacts of N loss, it is also important to recognize that N fertilizers are manufactured using natural gas and other nonrenewable resources. In order to conserve resources and minimize environmental impacts, N loss needs to be minimized by maximizing plant utilization of the applied N (Hopkins et al., 2008). Many argue that planting turfgrass should be discouraged or even illegal. Although there are negative impacts associated with turfgrass due to the over fertilization of the crop in agriculture and urban settings and other issues (such as pesticide use and water consumption), there are many positive impacts to society and the environment.

In addition to being aesthetically pleasing, providing a safe surface for many recreational activities, and generating oxygen, turfgrass reduces: air temperature, atmospheric pollutants, erosion, water and chemicals in storm drains, chemicals leached to groundwater, flooding, noise pollution, and fire risk. By maintaining a low growing and green plant material next to buildings, fires are less likely to spread. Air quality is improved because turfgrass is a good filter for capturing smoke and dust. Sulfur and carbon dioxides are also absorbed from the atmosphere—reducing acid rain and greenhouse gas concentration. In addition to the impact on global temperature, the cooling effect of turfgrass makes for a more pleasant urban environment and results in reduced use of natural resources to cool the interiors of neighboring buildings.

Sequestering carbon (C) into the soil results in improved soil health. Carbon sequestration is the removal of C from the atmosphere in the form of carbon dioxide (CO_2), which is then held in the soil (Bremer, 2007). A possible concern with turfgrass is that it has to be mowed and that the mowers are putting C into the atmosphere. It has been found that turfgrass is able to sequester four times more C from the air than is put into the air by the typical lawnmower engine. If the lawn is cared for with proper water, fertilizer, and mowing inputs then the net carbon intake is five to seven times higher, which is up to 800 lbs of C per acre per year (Qian, 2015), than the carbon output of the mowers used in managing the lawn (Bandaranayake, 2003; Milesi; Qian, 2015; Sahu).

However, in order to have these benefits, N is needed. Turfgrass requires a steady supply of N to grow successfully (Christians, 2007). Nitrogen is the mineral nutrient generally found in the highest concentration in plants and deficiencies can be dramatic from a visual perspective. Nitrogen plays a vital role in many processes in the life cycle of a plant and they would not be able to complete their life cycles without it. One of the most important biochemical processes which N plays a role in is the formation of chlorophyll (Marshchner, 2012). With N playing such a vital role in many processes there is a high demand for N to facilitate the essential biochemical processes. Due to this high demand, as well as the high mobile nature of N causing it to be easily lost to the surrounding environment, N is often the primary limiting factor for plant growth (Chatterjee, 2012). Without the adequate concentrations of N, plant vigor, visual quality, verdure, recovery from damage, and overall health are affected due to the production of less chlorophyll and proteins resulting in a chlorosis and an increased susceptibility to pests and diseases (Bowman, 2002; Geary, 2015; Marshchner, 2012). The essentialness of N leads to efficient use within the plant following absorption. Nitrogen is only lost from the plant by rain or mist-induced foliage leaching or defoliation (Barker, 2007). The repeated removal of plant biomass by harvesting or mowing can result in a depletion of N reserves within the plant. Plants are not able to regenerate N to the levels required following the removal of plant biomass—N must be replenished mainly through the addition of fertilizer and soil amendments. A small fraction of N can be replenished through atmospheric deposition, irrigation, and fixation of atmospheric N by legumes. Atmospheric deposition and fixation do not provide adequate amounts of N to meet the demands of plants. In order to meet the demands needed for high crop production and most urban landscapes, N fertilization is required (LeMonte, 2011). Ideally, fertilizer rate and application would be applied to meet the needs of the plant precisely. Unfortunately, this ideal is not possible due to the inherent inefficiencies in the system. Substantial increases in the efficiency of N are possible if best management practices (BMP) are implemented. The key to good stewardship depends on using the right source, at the right rate, at the right time, and with the right placement (Snyder et al., 2007).

The use of inefficient fertilizer types is a contributor to the negative environmental impacts due to a low N-use efficiency (NUE) (Cameron, 2013; Nielson, 2006). It is estimated that NUE for worldwide cereal production is only 33% (Blaylock et al., 2005). Schlesinger (1992) estimated that 10% of all manufactured N fertilizer worldwide is volatilized as NH_3-N gas. In a growth chamber study, volatilization of surface-applied N fertilizers reached an excess of 60% over the first 10 days following fertilization using warm-season bentgrass (*Agrostis palustris* Huds.; Knight et al., 2007). Within North and Central America, about 54% of N_2O-N emitted is attributed to the addition of fertilizer (Blaylock et al., 2005; IPCC, 1996). The NUE for turfgrass would be expected to be similarly low without best management practices.

Measures need to be taken in order to assure that the negative impacts of urban turfgrass does not outweigh the positives. In trends over the last few decades, it has been shown that there has been an increase in the rate of N fertilizer applied to crops especially corn. This has led to less fertilizer nutrient recovery from the crops at harvest. It has been estimated that N recovery was about 50% in the late 1980's (Newbound, 1989). This indicates that there is a great deal of N being lost to the environment (Bock, 1991; Shaviv, 1993). As shown by Ransom (2014), LeMonte et al. (2016), and Minami (1994) the losses of N to the environment can be reduced with the use of control release fertilizers (CRF) and slow release fertilizers (SRF). These fertilizers are used to allow for the delivery of N over extended periods while reducing risk of loss to the environment and, thus, increasing NUE. These CRF and SRF materials are designed to release N over extended time periods, as opposed to traditional "quick release" fertilizers, which release N to the soil all at once. The engineering of the CRF and SRF materials is an attempt to match more closely plant N needs throughout the growing season, while reducing the exposure time and loss of N (Blaylock et al., 2005). Research shows that SRF and CRFs have made significant impacts on crop yields and impacts on N loss to the environment (Hyatt, 2010; Taysom, 2015; Blaylock, 2005; Nelson, 2014; Ellison, 2013; Hopkins, 2008; Guertal, 1999). These fertilizers have also been evaluated in turfgrass with similar significant impacts on turf quality and health as well as a decrease in loss of N to the environment (Guillard, 2004; Knight, 2007; Zhang, 1998; Guertal, 2012; Huckaby, 2012; Easton, 2004; Ransom, 2014; LeMonte, 2016; Hollingsworth, 2005).

There is a plethora of N fertilizer rate studies, including studies on PCU rates for agricultural crops (Ellison, 2013; Nelson, 2014; Taysom, 2015; Guertal, 1999; Hopkins, 2008) and turfgrass (Ransom, 2014). Studies conducted on the rate of N showed that a lower rate of a CRF, such as polymer coated urea (PCU), could reduce how much N needs to be applied while still maintaining crop yield as well as the health of the crops (Hopkins, 2008; Taysom, 2015). Similar results were found for turfgrass (Ransom, 2014). In Ransom's study, there was a urea split monthly, and then all other treatments were applied all at once in the spring with PCU being applied at differing rates of 100%, 75% rate, and 50% rate. Compared to urea, the PCU 100% and 75% had no significant differences in NDVI or shoot growth in comparison to the urea treatment throughout the growing season. However, the 50% PCU treatment had lower NDVI than the urea. The urea gave significant shoot growth initially, but then eventually wore off. This study shows that the PCU helps to maintain N availability to the plants over the growing season unlike the urea (Ransom, 2014).

The SRFs are different from CRFs in their mode of action. The release of nutrients from SRFs occur through the bursting or degradation of the coating due to chemical or microbial processes or infiltration of water vapor which creates a high internal pressure. Once any point of the coating surrounding the nutrients is broken, the urea becomes exposed and is then left open to be converted into other forms of N. However, this process is more unpredictable opposed to a CRF (Ellison et al., 2013; Ransom, 2014).

Control release fertilizers have been developed using a coating which surrounds individual granules of fertilizer, with urea being the most widely used. The more common polymer coat used has micropores that allow moisture to infiltrate through the coating to dissolve the urea. As temperature increases, the coating warms and expands—allowing for the urea to escape. The thickness of the coating can be changed to slow the diffusion of N into the soil and, thus, increase the amount of time before the N is fully released (Adams et al., 2013; Carrow, 1997; Ellison et al., 2013). This mode of action is typically more controlled and predictable, so N applications can potentially be reduced. The polymer coated urea (PCU) products have shown a significant decrease in both NO_3-N leaching (Bowman, 1989; Du et al., 2006; Guillard and Kopp, 2004; Nelson et al., 2009; Pack et al., 2006; Pack and Hutchinson, 2003; Wilson et al., 2010), NH_3 volatilization (Bowman, 1989; Knight et al., 2007; Pereira et al., 2009; Rochette et al., 2009) and N_2O-N emission (Ransom, 2014; LeMonte, 2011; LeMonte et al., 2016) in comparison to urea.

Rate of N fertilizer applied is very important to maintain adequate plant growth while protecting the environment (Christians, 2007). Geary et al. (2015) show a very clear effect of the rate effect of N on plant growth and have done similar work for turfgrass (Black et al., 2015). As PCU's have been shown to have improved NUE (Carrow, 1997) the rate likely needs to be reduced. Although PCU fertilizers have been shown to be effective in many situations, there is minimal information available on the rate that is needed to maintain plant verdure while reducing the amount of N lost to the environment. Studies have been conducted on many agricultural crops, including potato, Swiss chard, and maize (Yan, 2013; Michalczyk, 2014; and Miceli, 2013; Taysom, 2015) and showed that a reduction in N applied does not negatively affect crop yield. In fact, the use of the full rate or a higher rate of PCU on warm-season grasses, St. Augustinegrass (*Stenotaphrum secundatum*) and Centipedegrass (*Eremochloa ophiuroides*), led to lower visual and quality ratings for turf over four years of application (Unruh, 2013).The purpose of this study was to evaluate the impacts of PCU on Kentucky bluegrass height, biomass, health (NDVI), and verdure as a function of 50, 75, and 100% of the recommended N rates.

MATERIALS AND METHODS

Two irrigated field plot areas were installed in 2012 at Provo, UT (40º24’52.09”N, 111º64’17.61”W) near the BYU Life Sciences Greenhouse Complex. The south field was installed with a constructed sandy loam soil (Table 1). The north field was installed to meet the specifications for a High Performance Sand-Based Rootzones for Athletic Fields per the American Society for Testing and Materials (ASTM) method F2396 (4th and 5th columns of Table 1). Kentucky bluegrass (*Poa pratensis* L. var. P105, Bedazzled, Prosperity, and Moonlight SLT) were established as sod at both sites.

Studies were initiated in April 2014. The soils had minimal soil N with no confounding results due to previous applications. Four treatments (Table 2) with four blocks were applied with a randomized block control design (RBCD) with plots of 2.6 m by 1 m. A control with no added N was also included but not fully reported herein. The Grower’s Standard of Practice (GSP) served as the “ideal” treatment with a steady supply of N throughout the growing season. All treatments had ammonium sulfate included as part of the total N to serve as a source of sulfur and to insure that each fertilized treatment included at least some rapidly available N. The other treatments were various combinations of a PCU (Agrium One Ap, Agrium Advanced Technologies, Loveland, CO, USA).

The fertilizer for each treatment was spread by hand. Height and Normalized Difference Vegetative Index (NDVI; an assessment of plant health) measurements were taken every seven days (d). Shoot height was averaged over three locations in each plot by measuring from the thatch layer to the tip of the grass blades. The NDVI (FieldScout TCM 500 NDVI Turf Color

Meter, Spectrum Technologies, Inc., Aurora, IL, USA) measurements were also averaged over three locations in each plot. Shoot biomass samples were collected at 135 and 275 ordinal d in 2014 and on 238, 288, and 303 ordinal d in 2015 using a reel mower with a catch basin set at a height of 2.5 cm. After each subplot was mowed, the blades and catch basin were wiped clean. Each biomass sample was stored in a paper bag and left to air dry and then weighed. Visual verdure ratings were taken prior to mowing at 126, 239 and 260 ordinal d in 2014 and on 238 and 305 ordinal d in 2015. Visual ratings were done on a scale of 1-5 with one being completely dormant and five being dense, dark green turfgrass. Final shoot density and biomass measurements were taken at the end of the two-year study. Shoot density was measured by taking a plug from each plot and counting the crowns of the turfgrass in two random areas (3 cm^2). After shoot density was measured, all of the shoot biomass was harvested above the crowns. After biomass was calculated, the shoots were ground and analyzed for N content using the CN Determinator (TruSpec Micro, LECO, St. Joseph, MI, USA). Root biomass was measured using the same plugs taken from the plots for shoot density and biomass. The roots were also harvested by washing the soil off and collecting the biomass in a 1 mm screen. Data was checked for normality and analyzed by analysis of variance (ANOVA) with R (R project for Statistical Computing), with significance indicated at $P \leq 0.05$. Any significant means were then separated using a Tukey-Kramer test.

RESULTS

The models for all dependent variables were highly significant with the interaction between treatment and sampling date always significant (Table 3). Therefore, all statistical evaluations were performed for each individual sampling date and the interactions shown in Figs. 1-4. In general, the PCU blend applied at the full rate (P100) and the GSP were numerically similar and statistically identical—as discussed in Chapter 1 of this thesis. There were no trends or significant differences in root biomass (see Appendix). The focus of the remaining discussion will be upon the effect of reducing the rate for the PCU/ammonium sulfate blend applied twice annually.

Growth: Loam Soil Trial

Shoot growth, as determined by height and biomass measurements, was never significantly different for P75 as compared to the GSP and P100 applied to loam soil (Tables 4-6, Fig. 1). The P75 mimicked the P100 and GSP quite closely for a majority of both years of this study.

In contrast, the reduced rate (P50) was consistently below the GSP and P100 (Tables 4-6; Fig. 1). This rate resulted in significantly lower shoot heights than the GSP on one date in the spring and one date in the fall of 2015. The P50 was also significantly below P100 on one date in the spring and one date in the fall of 2014, as well as two dates in the spring of 2015. In the second year of the study, the differences in shoot height had greater magnitude with P50 trending much lower than the other treatments as compared to 2014. The shoot biomass results generally followed these same trends—especially in the second year with very low growth for P50 (Table 6). Unfortunately, some of the biomass data was lost due to technician error and direct comparisons across years for spring/summer dates were not possible.

Growth: Sand Soil Trial

In comparison to the loam study, there were more significant differences and a greater magnitude in the differences in shoot growth with the sand soil study (Tables 7-8, Fig. 2).

Although the differences were larger, the results were similar for the trials conducted on both soil types. Unfortunately, the sand field failed during the spring of 2015 and had to be replanted. Treatments were applied and data was collected for late summer and fall, but is not presented here due to this problem (see Appendix 2 for the sand 2015 data).

As with the loam study, there were no significant differences for shoot growth among the reduced rate of P75 as compared to the full rates applied with the GSP and P100 (Table 7). In contrast, shoot growth for P50 was significantly lower than the GSP on two dates in the fall and significantly lower than P100 on two dates in each spring, summer, and fall.

Although shoot biomass followed similar trends as heights, it is interesting to observe that both of the reduced rates showed significantly less overall growth than the P100 at the spring sampling date (Table 8). The P50 treatment had significantly lower growth than the GSP on that date as well. There were no differences in biomass by the end of the fall.

Health: Loam Soil Trial

Plant health and verdure, as represented by weekly NDVI measurements, for the loam soil was never significantly different for any of the treatments which included as PCU as compared to the GSP in both years of the study (Tables 9-10, Fig. 3). The NDVI readings for P100 was significantly greater than P50 on one date in the spring of 2015, otherwise there are no other significant differences in NDVI readings between the treatments. Although not significant, there is a trend for P50 to be below all of the other treatments throughout the two year study (Fig. 3).

Although NDVI did not show a difference on ordinal day 126 when the first visual ratings of plant verdure were made in 2014, the P100 treatment had significantly higher visual ratings than P50 (Table 11). On the following visual rating dates, there were no significant differences, which corresponds with the NDVI readings on the same dates. Similarly, the GSP had significantly greater visual ratings than P50 on the first date in 2015 although the NDVI readings for the same date were not statistically different. The second date in 2015 did not show any significance in the visual ratings or the NDVI readings for the same date.

Health: Sand Soil Trial

Results were different for plant health in sandy soil (Tables 12-13, Fig. 4) in 2014 compared to what was observed with the loam study in spring (Tables 9 and 11, Fig. 3). As with the loam, the P100 never had worse NDVI values than the GSP. However, the P100 treatment had significantly greater NDVI values than the GSP on four dates in the spring. Even one of the reduced rate PCU treatments (P75) was significantly greater than GSP on one date in the spring. However, similar to the loam study the P50 was significantly lower than the GSP on one date in the summer. Although not significant, there was a trend in both of the sand and loam studies for the P50 NDVI to trend below the GSP throughout the entire growing season, especially in the second year.

When comparing P100 against P75 and P50 there were significant differences in NDVI (Table 12, Fig. 4). The P100 was significantly greater than P75 on one date in the spring, and significantly greater than P50 on four dates in the spring and three dates in the summer. And, the P75 was significantly greater than P50 on three dates in the spring and one date in the summer.

Visual ratings on the first date evaluated showed a significant difference between P100 and P50, which did not correspond with the NDVI readings for that same date but did follow the overall trend (Tables 12-13, Fig. 4). On both the second and third dates, the visual ratings showed no significant differences between the treatments which did correspond with the NDVI readings for those dates.

Shoot N Concentration

The P100 tended to have the highest concentration of shoot N in both soils in both years (Table 14). The N in P100 treated plants was numerically higher than the GSP in five of six instances, with significant differences half of the time. The P100 resulted in significantly greater N as compared to P75 in the sand, but not in the loam. The 75% rate (P75) resulted in approximately the same N concentration as the GSP, with no instances of these being significantly different than one another. Not surprisingly, the 50% rate (P50) had significantly lower N concentration than the other treatments, being significantly lower than the P100 four instances and lower than the P75 twice. The P50 treatment had the same shoot N concentration as the GSP for the loam, but was lower in the sand trial.

Shoot Density

There was a significant impact of fertilization on crown density for the loam soil (Table 15; Fig. 5). All treatments receiving two applications of PCU had a significant increase in shoot density, but the GSP did not. A similar trend was observed for the sand with the exception that the GSP also had increased shoot density for the fertilized treatments (data not shown).

DISCUSSION

The GSP was used as the “ideal” fertilizer program in that there was continuous good health and verdure without excessive shoot growth and mowing throughout the growing season. However, this practice is not ideal in terms of labor and associated costs needed to apply the fertilizer monthly. Additionally, the low rates applied are often difficult to achieve accurately with the use of many dry fertilizer spreaders. Furthermore, uncoated urea is prone to relatively high losses of N to the environment (Guillard, 2004; LeMonte, 2011; LeMonte et al., 2016; Ransom, 2014) through the leaching of N into ground water and gaseous losses to the atmosphere. This would especially be a problem during hot summer months when volatilization occurs at much higher rates. Finally, the use of traditional fertilizers can have a higher risk of salt damage if errantly applied due to the rapid solubilization of the material.

It is desirable to have a convenient, practical fertilizer program which will also give an even supply of N throughout the growing season while minimizing the environmental impacts and the amount of resources used. As such, the fertilizer industry has developed products which release in a controlled or slow timing, such as the controlled release polymer coated urea. In a study done by Buss (2016) it was found that the use of a polymer coated urea/ammonium sulfate blend resulted in the ability to reduce the number of applications of N to two in a growing season without excessive shoot growth or any negative effects on turf health. The next step is to determine if a reduction in the rate would result in similar plant health and greenness as the full rate, thus reducing the amount of fertilizer being applied and in turn reducing the negative environmental impacts. The excess amount of N being applied in agricultural and urban landscapes has negative impacts on the environment due to the loss of N through different loss mechanisms. The process of making N fertilizer also has an impact on the environment due to natural resources being used. Based on the work of LeMonte (2011), LeMonte et al. (2016), and Ransom (2014) it is expected that the environmental benefits in terms of reduced N loss due to leaching and volatilization will be available. A reduction of N applied will also decrease economic and environmental costs associated with applying more N.

The data presented herein shows that a reduction in the rate will give similar results as the full rate without having significant negative impacts. The data from these studies show that two applications of a PCU/traditional fertilizer blend results in equivalent or better results than the GSP. The two application of PCU at the full rate was almost never different from the GSP in both the loam and sand trials in shoot growth. Similarly the plant health for the two application at the full rate was never significantly different than the GSP in the loam trial, and had significantly greater plant health in the sand trial on multiple dates in the spring. The reduced rate of 75% was rarely statistically different from the GSP or the two application full rate for shoot growth and verdure in both the loam and sand trials. This data shows that a reduction in the rate to 75% does not have any negative effects on plant verdure throughout the growing season. These results are similar to those found by Carrow (1997), JaiLin et al. (2009), Karcher and Robinson (2007), and Ransom (2014) in turfgrass as well as the results found in agricultural crops (maize and Swiss chard) in the studies conducted by Yan (2013), Miceli (2013), and Michalczyk (2014). JaiLin et al. (2009) found that when PCU was applied in early spring to tall fescue, there was similar turf quality to urea with less clipping collection needed as well as greater uniformity of turf growth. In Ransom's study (2014) it was found that a reduction of 50% gave lower NDVIs for the turf but there was no significant difference between the 75% rate and the 100% rate of PCU. As well as there was no significant difference between the 75% rate and 100% rate of PCU when compared to the urea split monthly, which is the same result which was found in this study. In his study there was only one application of PCU that was meant for 120d release, whereas in the studies conducted herein there were two applications of PCU, but the results are similar. In these studies, they found that a reduction in applied N maintained plant health while reducing the amount of N applied as well as the N lost to the environment. The studies conducted on agricultural crops used urea and ammonium nitrate, but it can be assumed that using a PCU product would have similar to better results due to the slow release of N. In Yan's study (2013), it was found that the rate of N could be reduced by 33% while maintaining the crop yields similar to the crops which received the full rate. In Miceli's (2013) study they found with the higher N rates the Swiss chard had more growth in the leaves resulting in larger leaves. However, the reduced rates of N Swiss chard had no significant difference in the size of the leaf or in the yield. The difference was that there was more leaf growth than petiole growth (which is not harvested) for the reduced rate of N. This is similar to our findings in that there was not a significant difference in shoot growth which then means that mowing requirements were not minimized, but plant verdure was maintained while applying less N. In most high maintenance turfgrass environments mowing is already being done frequently, and a greener, more healthy turf is desirable. The 75% rate would be more ideal for this type of environment due to the higher plant verdure while helping to conserve on fertilizer costs as well as reduce the amount of N being lost to the environment.

However, the further reduction of N to 50% led to less shoot growth, but at the expense of lower plant verdure. Although the reduced rate of 50% rarely had significant differences in shoot growth and plant verdure from all of the other treatments, it consistently trended much lower. This practice of using half the rate could be tolerable if used in a low maintenance environment where mowing requirements need to be minimal while maintaining a plant verdure that is bearable and still functional.

The lower trend of the 50% rate began to be more drastic in the second year in the loam trial, indicating that there could be negative effects of the reduced rate. Due to seeing this trend in the second year, ongoing studies are being conducted to see if there are long term negative effects on having a reduced rate of N. These studies were only conducted over a two year period on Kentucky bluegrass in calcareous soils in Utah, USA. Further studies should be conducted in different climates, with multiple different turf species for a longer period of time to determine if there are more long term effects of the reduced rates of N. Further studies should also be conducted on fine tuning how much the rate can be reduced before there are negative effects on turf. The excess amount of N being applied has negative effects on the environment due to the loss of N into the environment. It is expected that if the rate of application is reduced then the associated environmental benefits of less N in the system will be available. Other benefits such as less labor costs due to mowing less, less clippings being put into a landfill, and lower financial costs associated with the purchase of fertilizer will also be available (Cisar, 2004; Walker, 2007).

LITERATURE CITED

Adams, C., Frantz, J., & Bugbee, B. (2013). Macro- and micronutrient-release characteristics of three polymer-coated fertilizers: Theory and measurements. *J. Plant Nutr. Soil Sci. Journal of Plant Nutrition and Soil Science, 176*(1), 76-88.

Bandaranayake, W., Qian, Y., Parton, W., Ojima, D., & Follet, R. (2003). Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model. *Agronomy Journal, 95(3),* 558-558. Doi:10.2134/agronj2003.0558

Barker, A., & Pilbeam, D. (2007). Handbook of Plant Nutrition. CRC Press, Boca Raton, FL.

Black, B., Neville, B., Ewell, C., Geary, B. D., & Hopkins, B. G. (2015). Nitrogen Nutrition Impact on Incidence of Rhizoctonia Infection of Agrostis Stolonifera. In *Western Nutrient Management Conference* (Vol. 11, pp. 112-116). Reno, NV. Retrieved from http://www.ipni.net/ipniweb/conference/wnmc.nsf/e0f085ed5f091b1b852579000057902e/4be3031d1d87927a85257e37004fa7a8/$FILE/WNMC2015 Neville pg112.pdf

Blaylock, A., Binford. G., Dowbenko, R., Kaufmann, J., & Islam, R. (2005). ESN, Controlled-Release Nitrogen for Enhanced Nitrogen Efficiency and Improved Environmental Safety. *Science Press and Science Press USA,* 381-390.

Bock, B. & Hergert, G. (1991). Fertilizer Nitrogens Management. In: *Follet RF et al. (eds) Managing Nitrogen for Ground Water Quality and Farm Profitability,* 139-164. SSSA Madison, WI.

Bowman, D., Cherney, C., & Rufty, T. (2002). Fate and Transport of Nitrogen Applied to Six Warm-Season Turfgrasses. *Crop Science, 42(3),* 833-840. Retrieved December 2, 2014, from http://www.carleton.edu/departments/GEOL/Resources/comps/CompsPDFfiles/2009/Linetd WebPg/Papers/Fate and Transport of Nitrogen Applied to Six Warm Season Turfgrasses.pdf

Bremer, D. (2007) Carbon Sequestration in Turfgrass: An Eco-Friendly Benefit of Your Lawn. *Turfnews, a quarterly Kansas Turfgrass Foundation Newsletter.*

Burton, D. L., Li. X., and Grant, C. A. (2003) Reducing nitrous oxide emissions through the use of fertilizer management technologies. Dept. Soil Science, University of Manitoba, Winnipeg, Manitoba, Canada.

Cameron, K., Di, H., & Moir, J. (2013). Nitrogen Losses From the Soil/Plant System: A review.*Annals of Applied Biology, 162*, 145-173.

Carrow, R. N. (1997). Turfgrass Response to Slow-Release Nitrogen Fertilizers. *Agronomy Journal, 89*(3), 491. Chatterjee, A. (2012). Reducing Denitrification Loss of Nitrogen Fertilizer. *Crop and Soil Magazine*: 45: 14-15.

Christians, N. (2007). Fertilization. In *Fundamentals of turfgrass management* (4th ed., pp. 141-143). Hoboken, N.J.: John Wiley & Sons.

Cisar, J.L. (2004). Managing Turf Sustainably. In 4th International Crop Science Congress Proc., 26 Sep. – 1 Oct 2004, Brisbane, Austalia. CSSA, Madison, WI.

Du, C., Zhou, J., & Shaviv, A. (2006). Release Characteristics of Nutrients from Polymer-Coated Compound Controlled Release Fertilizers. *Journal of Polymers and the Environment J Polym Environ, 14,* 223-230.

Easton, Z. M., & Petrovic, A. M. (2004). Fertilizer Source Effect on Ground and Surface Water Quality in Drainage from Turfgrass. *Journal of Environment Quality, 33*(2), 645.

Ellison, E., Blaylock, A., Sanchez, C., & Smith, R. (2013, November 17). Exploring Controlled Release Nitrogen Fertilizers for Vegetable and Melon Crop Production in California and Arizona. Lecture presented at Western Nutrient Management Conference, Reno.

Food and Agriculture Organization of the United Nations. Current world fertilizer trends and outlook to 2014/15. Rep. Rome: FAO, 2011.

Geary, B., Clark, J., Hopkins, B., & Jolley, V. (2015). Deficient, Adequate and Excess Nitrogen Levels Established in Hydroponics for Biotic and Abiotic Stress-Interaction Studies in Potato. *Journal of Plant Nutrition*. 38: 41-50.

Guillard, K., & Kopp, K. (2004). Nitrogen Fertilizer Form and Associated Nitrate Leaching from Cool-Season Lawn Turf. *Journal of Environment Quality,* 1822-1827.

Hirsch, A., Michalak, A., Bruhwiler, L., Peters, W., Dlugokencky, E., & Tans, P. (2006). Inverse modeling estimates of the global nitrous oxide surface flux from 1998-2001.*Global Biogeochem. Cycles Global Biogeochemical Cycles*.

Hopkins, B., Rosen, C., Shiffler, A., & Taysom, T. (2008). Enhanced Efficiency Fertilizers for Improved Nutrient Management: Potato. *Crop Management.* Doi:10_1094/CM-20080317-01-RV.

Hyatt, C., Venterea, R., Rosen, C., Mcnearney, M., Wilson, M., & Dolan, M. (2010). Polymer-Coated Urea Maintains Potato Yields and Reduces Nitrous Oxide Emissions in a Minnesota Loamy Sand. *Soil Science Society of America Journal,* 74, 419-428.

IPCC. (1996) Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: ScientificTechnical Analyses. Intergovernmental Panel on Climate Change, Cambridge University Press, Melbourne, Australia.

Karcher, D. E., & Richardson, M. D. (2003). Quantifying Turfgrass Color Using Digital Image Analysis. *Crop Science, 43*(3), 943.

Knight, E., Guertal, E., & Wood, C. (2007). Mowing and Nitrogen Source Effects on Ammonia Volatilization from Turfgrass. *Crop Science,* 47, 1628-1634.

LeMonte, J. 2011 Environmental Implications of Polymer Coated Urea. Thesis. Brigham Young University. Department of Plant and Wildlife Sciences. *Scholars Archive*. Brigham Young University.

Lemonte, J. J., Jolley, V. D., Summerhays, J. S., Terry, R. E., & Hopkins, B. G. (2016). Polymer Coated Urea in Turfgrass Maintains Vigor and Mitigates Nitrogen's Environmental Impacts. *PLOS ONE PLoS ONE, 11*(1).

Marshchner, P. (2012). Mineral Nutrition of Higher Plants (3rd ed.). San Diego, CA: Elsevier.

McTaggart, I., Clayton, H., and Smith, K. (1994) Nitrous oxide flux from fertilized grassland: strategies for reducing emissions. In: Non-CO2 Greenhouse Gases [van Ham, L. et al., Eds.]. Kluwer Academic Publishers, Dordrecht, Netherlands, 421-426.

Miceli, A., & Miceli, C. (2014). Effect of Nitrogen Fertilization on the Quality of Swiss Chard at Harvest and During Storage as Minimally Processed Produce. *Journal of Food Quality J Food Qual,* 125-134.

Michalczyk, A., Kersebaum, K., Roelcke, M., Hartmann, T., Yue, S., Chen, X., & Zhang, F. (2014) Model-Based Optimisation of Nitrogen and Water Management for Wheat-Maize Systems in the North China Plain. *Nutrient Cycling in Agroecosystems Nutr Cycl Agroecosyst, 98,* 203-222.

Milesi, C., Running, S., Elyidge, C., Dietz, J., Tuttle, B., & Nemani, R. (2005). Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States. *Environmental Management, 36*(3), 426-438.

Milesi, C., Elyidge, C., Dietz, J., Tuttle, B., Nemani, R., & Running, S. (n.d.). A Strategy for Mapping and Modeling the Ecological Effects of US Lawns. Retrieved January 8, 2016, from http://www.isprs.org/proceedings/XXXVI/8-W27/milesi.pdf.

Miltner, E., Stahnke, G., Johnston, W., & Golob, C. (2004). Late Fall and Winter Nitrogen Fertilization of Turfgrass in Two Pacific Northwest Climates. *Hortscience,* (39), 1745-1749.

Minami, K. (1994) Effect of Nitrification Inhibitors and Slow-Release Fertilizer on Emission of Nitrous Oxide from Fertilized Soils. In CH4 and N2O: global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources. [Minami, K., Mosier, A.R., and Sass, R. Eds.] NIAES Series 2, Yokendo Publishers, Tokyo, Japan.

National Turfgrass Federation. (2003). The Turfgrass Industry- Present and Future. Retrieved November 28, 2014, from http://www.turfresearch.org/pdf/Industry Turf Initiative.pdf

Nelson, K., Motayalli, P., & Nathan, M. (2014). Nitrogen Fertilizer Sources and Application Timing Affects Wheat and Inter-Seeded Red Clover Yields on Claypan Soils. *Agronomy,* 497-513. doi: 10.3390/agronomy4040497.

Nelson, K., Paniagua, S., & Motavalli, P. (2009). Effect of Polymer Coated Urea, Irrigation, and Drainage on Nitrogen Utilization and Yield of Corn in a Claypan Soil. *Agronomy Journal, 101,* 681-687.

Newbound, P. (1989). The Use of Fertiliser in Agriculture. Where Do We Go Practically and Ecologically? *Plant Soil* 115:297-311.

Nielson, R. (2006). N Loss Mechanisms and Nitrogen Use Efficiency. *Purdue Nitrogen Management Workshops,* 1-5. Retrieved December 1, 2014, from http://www.agry.purdue.edu/ext/pubs/2006NLossMechanisms.pdf

Norton, R., Mikkelsen, R., & Jensen, T. (2013). Sulfur for Plant Nutrition. *Better Crops* 97.2 10-12.

Pack, J., & Hutchinson, C. (2003). Potato (Solanum tuberosum L.) Tuber Yields, Specific Gravities, and Nitrate Leaching Under Polymer Coated Urea and Ammonium Nitrate Fertilizer Program. *Hortscience.* (38), 719-720.

Pack, J., Hutchinson, C., & Simonne, E. (2006). Evaluation of Controlled-Release Fertilizers for Northeast Florida Chip Potato Production. *Journal of Plant Nutrition, 29,* 1301-1313.

Qian, Y., & Follett, R. (2015). Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. *Agronomy Journal,* 930-930. doi:10.2134/agronj2002.0930

Ransom, C. (2014) Nitrogen Use Efficiency of Polymer-Coated Urea. Thesis. Brigham Young University. Department of Plant and Wildlife Sciences. *Scholars Archive*. Brigham Young University.

Runfola, D. S., Hamill, T., Pontius, R. G., Jr., Rogan, J., Giner, N., & Decatur, A. (2014). Using Fine Resolution Orthoimagery and Spatial Interpolation to Rapidly Map Turf Grass in Suburban Massachusetts. *International Journal of Geospatial and Environmental Research, 1*(1). Retrieved February 10, 2016, from http://dc.uwm.edu/cgi/viewcontent.cgi?article=1004&context=ijger.

Sahu, R. (n.d.). Technical Assessment of the Carbon Sequestration Potential of Managed Turfgrass in the United States. Retrieved January 8, 2016, from http://opei.org/content/uploads/2014/02/TurfGrassSahu.pdf.

Shaviv, A. and Mikkelsen, R.L (1993) Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation - a review. Fertilizer Res. 35 1-12.

Snyder, C., Bruulsema, T., and Jensen, T. (2007). Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management—a literature review. International Plant Nutrition Institute, Norcross, Georgia, U.S.A.

Sutton, M., Erisman, J., Dentener, F., & Moller, D. (2008). Ammonia in the Environment: From Ancient Times to the Present. *Environmental Pollution*. (156), 583-604.

Taysom, T. W. (2015). *Polymer Coated Urea in Russet Burbank Potato Production*

(Unpublished master's thesis). University of Idaho.

USEPA (2007). Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990–2005. EPA 430-R- 07-002. USEPA, Washington, DC.

Walker, K., Bigelow, C., Smith, D., Scoyoc, G., & Reicher, Z. (2007). Aboveground Responses of Cool-Season Lawn Species to Nitrogen Rates and Application Timings. *Crop Science, 47*(3), 1225-1225. doi:10.2135/cropsci2003.09.0595.

Wilson, M., Rosen, C., & Moncrief, J. (2010). Effects of Polymer-Coated Urea on Nitrate Leaching and Nitrogen Uptake by Potato. *Journal of Environment Quality, 39,* 492-499.

Yan, G., Zheng, X., Cui, F., Yao, Z., Zhou, Z., Deng, J., & Xu, Y. (2013) Two-year Simultaneous Records of N2O and NO Fluxes from a Farmed Cropland in the Northern China Plain with a Reduced Nitrogen Addition Rate by One-Third. *Agriculture, Ecosystems & Environment, 178,* 39-50.

FIGURES

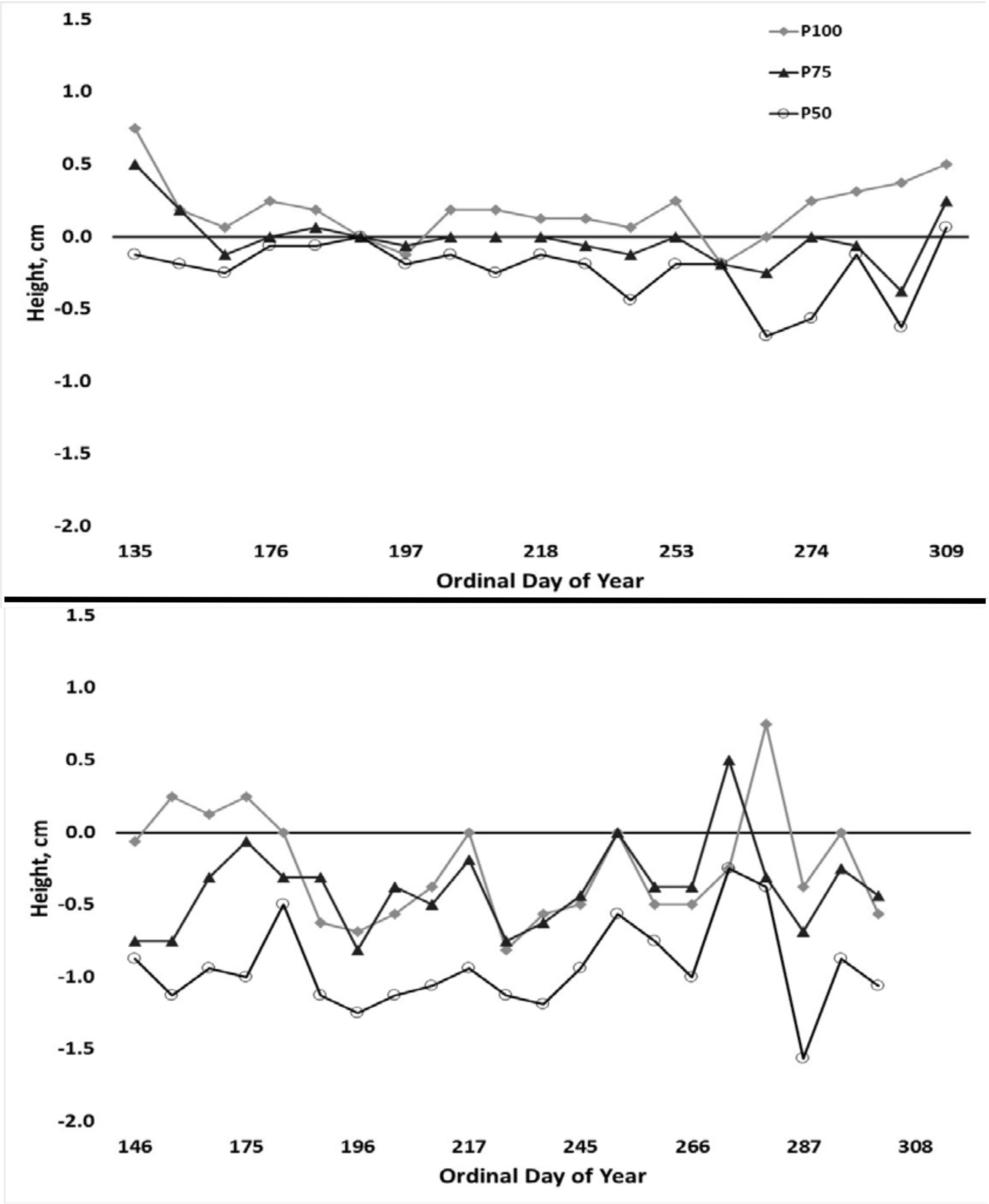


Figure 1 Kentucky bluegrass heights over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics shown in Tables 4 and 5.

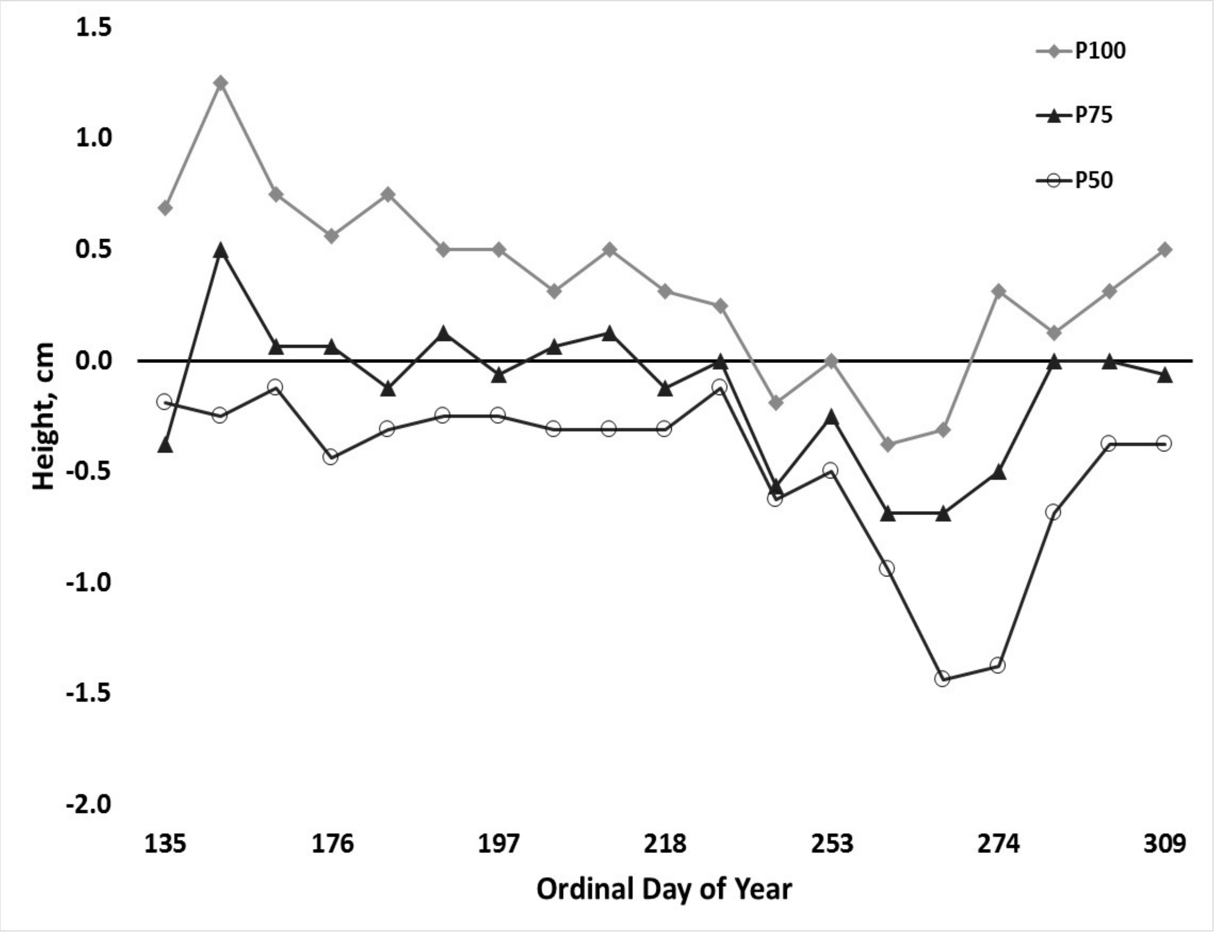


Figure 2 Kentucky bluegrass heights for 2014 for a trial on sand soil. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics shown in Table 7.

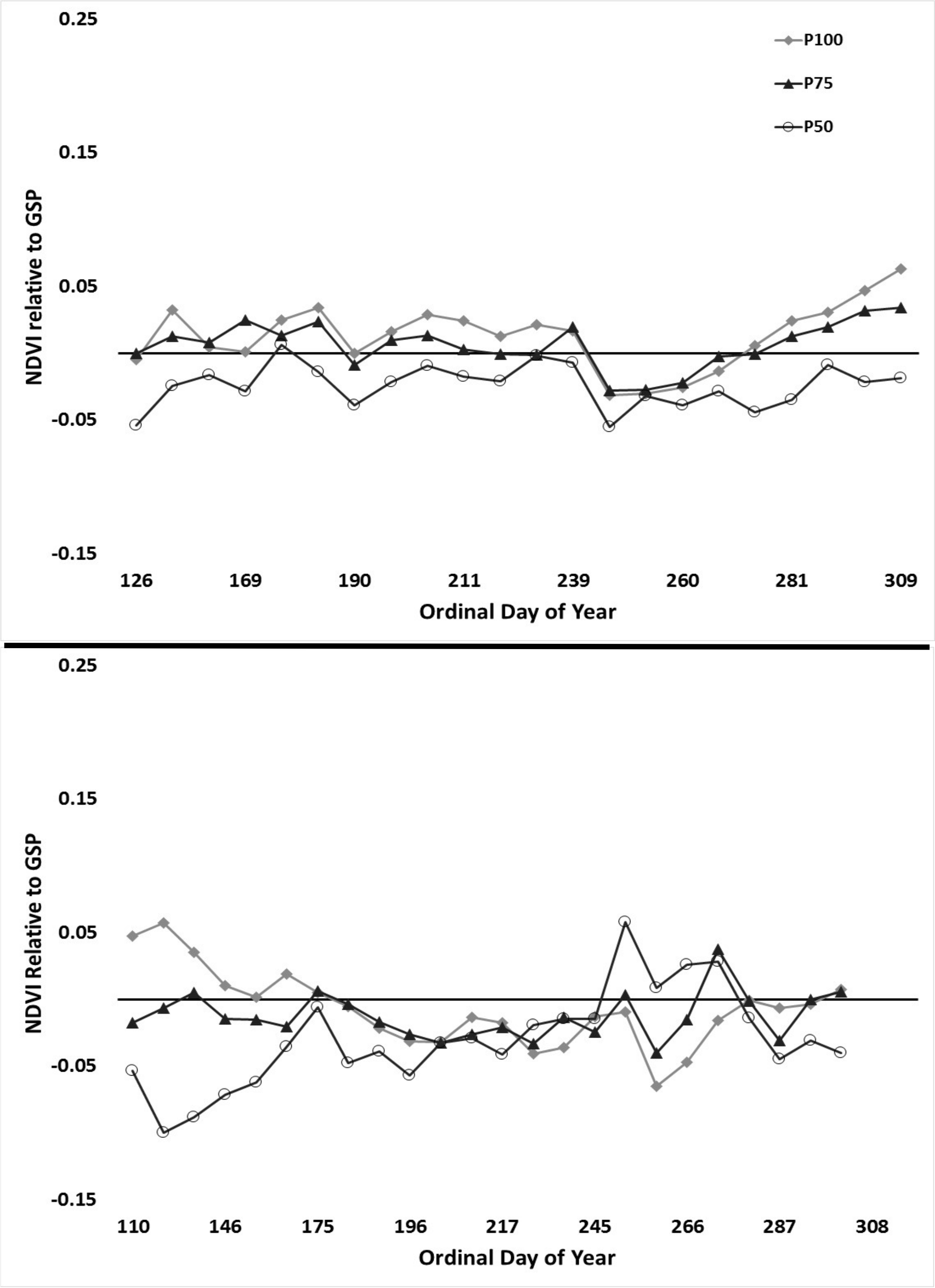


Figure 3 Kentucky bluegrass verdure as measured by NDVI readings over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics shown in Tables 9 and 10.

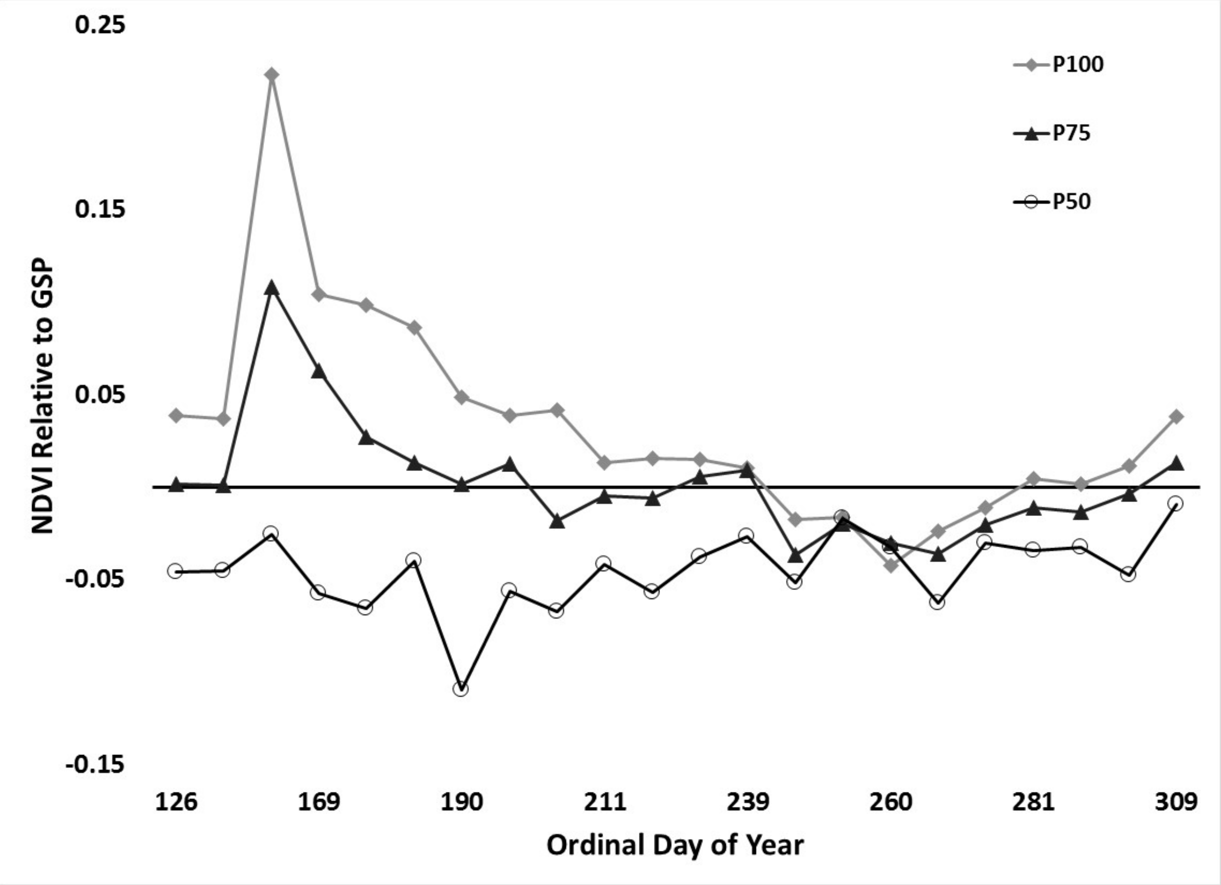


Figure 4 Kentucky bluegrass verdure as measured by NDVI readings for 2014 for a trial on sand soil. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics shown in Table 12.

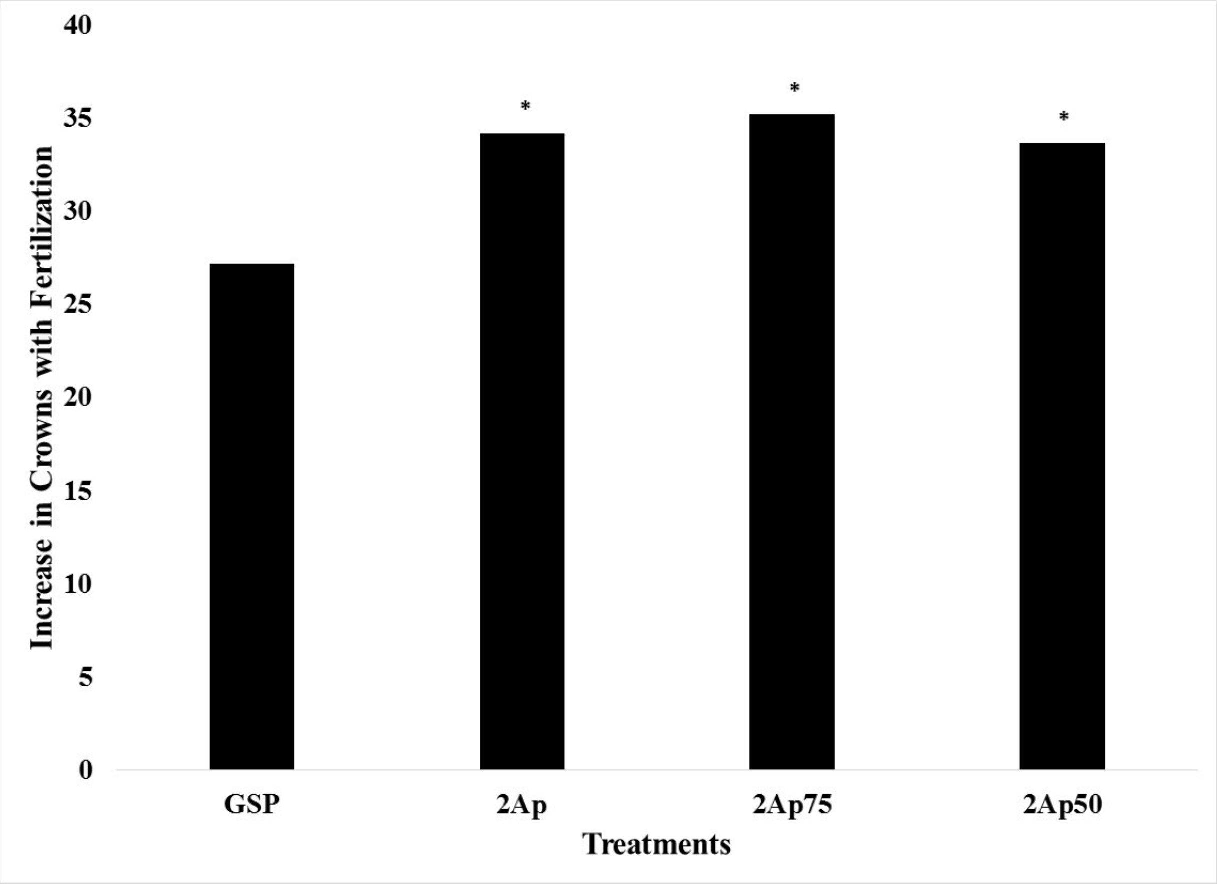


Figure 5 Kentucky bluegrass Shoot density for 2015 for a trial on loam soil. The data has been transformed with the control in comparison to the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium polymer coated urea applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Data shown in Table 15.

TABLES

Table 1 Soil test values for two Kentucky bluegrass trials (Loam and Sand)

Texture		Sandy Loam	Sand
pH (2:1)		8	7.4
ECe (2:1)	mmhos cm^{-1}	0.5	0.2
excess lime	%	5	0
OM		2.4	1.6
NO_3-N	mg kg^{-1}	4	2
NH_4-N		2	2
P (bicarb)		19	5
K		275	75
S		15	5
Ca		2203	200
Mg		377	24
Na		92	23
Zn DTPA		1.6	0.5
Fe		9	5
Mn		8	2
Cu		0.6	0.3
B H_2O		1.1	0.5

Table 2 Percentages of the full rate of nitrogen fertilizer for Kentucky bluegrass trials treatments. The full rate for the grower's standard practice (GSP) and the polymer coated urea (PCU)/ammonium sulfate (AS) blend was 19.5 and 29.3 g m-2 for loam and sand trials, respectively. The reduced rate treatments had 50% and 75% of these amounts for P50 and P75, respectively.

		GSP	P100	P75	P50
		---------------------------- % ----------------------------			
April	urea	8.3			
	AS	4.2	16.5	12.5	8.5
	PCU		33.5	25.0	16.5
May	urea	8.3			
	AS	4.2			
	PCU				
June	urea	8.3			
	AS	4.2			
	PCU				
July	urea	8.3			
	AS	4.2			
	PCU				
August	urea	8.3			
	AS	4.2	16.5	12.5	8.5
	PCU		33.5	25.0	16.5
September	urea	8.3			
	AS	4.2			
	PCU				
October	urea	8.3			
	AS	4.2			
	PCU				
November	urea	8.3			
	AS	4.2			
	PCU				

Table 3 *P* values for each measurement taken in the corresponding year and soil study. Statistically significant values are in bold-faced type.

		Sand 2014	Loam 2014	Loam 2015
NDVI	ordinal day	**<.0001**	**<.0001**	**<.0001**
	treatment	**<.0001**	**<.0001**	**0.0030**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**
verdure	ordinal day	**0.0005**	**0.0025**	**0.0081**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**0.0004**	**0.0012**	**<.0001**
shoot biomass	ordinal day	0.4343	**0.0101**	0.5687
	treatment	**<.0001**	**0.0003**	**<.0001**
	ordinal day*treatment	**0.0016**	**0.0004**	**<.0001**
height	ordinal day	**<.0001**	**<.0001**	**<.0001**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**
shoot N	ordinal day	**0.0007**	**0.0003**	**<.0001**
	treatment	**<.0001**	**<.0001**	**<.0001**
	ordinal day*treatment	**<.0001**	**<.0001**	**<.0001**

Table 4 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower’s standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

	Date									
	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year									
	135	162	170	176	183	190	197	204	211	218
	mm									
GSP	50 ab	34	34	32	31	30	30	26	28	29
P100	58 a	36	35	34	33	30	29	28	30	30
P75	55 ab	36	33	32	31	30	29	26	28	29
P50	49 b	33	32	31	30	30	28	25	26	28

	Date								
	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
	Ordinal Day of Year								
	239	246	253	260	267	274	281	295	309
	mm								
GSP	32	30	32	32	36	36	31	36 ab	29
P100	33	31	34	30	36	38	34	39 a	34
P75	31	29	32	30	33	36	30	32 ab	32
P50	30	26	30	30	29	30	29	29 b	30

Table 5 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

Date	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12
Ordinal Day of Year	146	157	164	175	182	189	196	203	210	217	224
	mm										
GSP	38	43 ab	37	30 ab	35	39	39 a	39	36	35	41
P100	37	45 a	38	33 a	35	33	32 ab	33	33	35	33
P75	30	35 ab	34	29 ab	32	36	31 ab	35	31	33	34
P50	29	31 b	28	20b	30	28	26 b	28	26	26	30

Date	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
Ordinal Day of Year	238	245	252	261	266	273	280	287	294	301
	mm									
GSP	36	38	34	39	41	36	39	45 a	39	40
P100	31	33	34	34	36	34	47	41 ab	39	34
P75	30	33	34	35	38	41	36	38 ab	36	36
P50	24	28	28	31	31	34	36	29 b	30	29

Table 6 Biomass values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. $P = 0.05$

	----------- 2014 -----------		------------- 2015 -------------		
Date	5/15	10/2	8/26	10/15	10/30
Ordinal Day of Year	135	275	238	288	303
GSP	30.5 ab	23.8 a	21.4 a	14.2 a	14.6 a
P100	42.3 a	38.6 a	13.8 ab	14.1 a	12.7 a
P75	33.1 ab	21.2 a	10.8 ab	8.6 a	11.1 a
P50	28.2 b	8.1 a	2.9 b	2.1 a	2.1 a

Table 7 Height values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

	Date									
	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year									
	135	162	170	176	183	190	197	204	211	218
GSP	5.3 ab	4.5 b	3.6	3.6 ab	3.5 ab	3.4	3.4	2.8	3.1	2.9
P100	6.0 a	5.8 a	4.4	4.1 a	4.3 a	3.9	3.9	3.1	3.6	3.2
P75	4.9 b	5.0 ab	3.7	3.6 ab	3.4 ab	3.5	3.3	2.9	3.3	2.8
P50	5.1 ab	4.3 b	3.50	3.1 b	3.2 b	3.1	3.1	2.5	2.8	2.6

	Date								
	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
	Ordinal Day of Year								
	239	246	253	260	267	274	281	295	309
GSP	3.1	3.3	3.7	3.7	4.1 a	4.3 a	3.5	3.3	3.1
P100	3.3	3.1	3.7	3.3	3.8 a	4.6 a	3.6	3.6	3.6
P75	3.1	2.7	3.4	3.0	3.4 ab	3.8 ab	3.5	3.3	3.0
P50	2.9	2.6	3.2	2.8	2.6 b	2.9 b	2.8	2.9	2.7

Table 8 Biomass values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

	Date	
	5/15	10/2
	Ordinal Day of Year	
	135	275
GSP	28.78 ab	45.11 a
P100	45.13 a	59.08 a
P75	28.61 bc	25.46 a
P50	24.85 c	9.73 a

Table 9 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). There were no significant differences between treatments within any date. *P* = 0.05

	Date										
	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year										
	126	134	160	169	176	183	190	197	204	211	218
GSP	65	63	55	62	62	64	69	68	63	62	64
P100	65	66	55	62	64	68	69	69	66	65	65
P75	65	64	55	64	63	67	68	69	65	62	64
P50	60	61	53	59	62	63	65	66	62	60	62

	Date										
	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
	Ordinal Day of Year										
	233	239	246	253	260	267	274	281	288	295	309
GSP	67	66	70	70	68	71	69	71	71	69	66
P100	69	68	66	67	65	69	70	74	74	74	72
P75	67	68	67	67	66	71	69	73	73	72	69
P50	67	65	64	67	64	68	65	68	70	67	64

Table 10 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

	Date											
	4/20	4/24	5/1	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29
	Ordinal Day of Year											
	110	114	121	146	154	161	175	182	189	196	203	210
GSP	47	56 ab	65	75	71	73	69	72	74	71	73	70
P100	52	62 a	69	76	71	74	69	72	72	68	70	69
P75	46	56 ab	66	73	70	71	70	72	72	69	70	67
P50	42	46 b	56	68	65	69	68	68	70	66	70	67
	Date											
	8/5	8/12	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
	Ordinal Day of Year											
	217	224	238	245	252	261	266	273	280	287	294	301
GSP	73	72	64	68	53	62	61	50	66	71	74	74
P100	72	68	60	67	52	55	57	49	66	71	74	74
P75	71	69	62	66	54	58	60	54	66	68	74	74
P50	69	70	62	67	59	63	64	53	65	67	71	70

Table 11 Visual values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). The statistics within the table display those treatments with the same letters as not being significantly different. Values sharing the same letter within a date are not significantly different from one another. $P = 0.05$

	2014			2015	
	Date				
	5/6	8/27	9/17	8/26	11/1
	Ordinal Day of Year				
	126	239	260	238	305
GSP	2.00 ab	2.75 a	3.00 a	3.44 a	3.69 a
P100	2.50 a	2.88 a	2.75 a	2.88 ab	3.63 a
P75	2.13 ab	2.63 a	2.38 a	2.69 ab	3.38 a
P50	1.38 b	2.13 a	2.38 a	2.56 b	2.94 a

Table 12 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

	Date										
	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year										
	126	134	160	169	176	183	190	197	204	211	218
GSP	63	64	31 c	53 bc	57 bc	64 b	68 a	68 ab	68 ab	66	65
P100	67	68	53 a	63 a	66 a	72 a	73 a	72 a	72 a	67	67
P75	63	64	42 b	59 ab	59 ab	65 ab	68 a	69 ab	66 ab	65	65
P50	59	60	28 c	47 c	50 c	60 b	57 b	62 b	61 b	62	60

	Date										
	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
	Ordinal Day of Year										
	233	239	246	253	260	267	274	281	288	295	309
GSP	71	69	70	69	71	74	74	75	75	74	70
P100	72	70	68	68	66	71	73	75	75	76	74
P75	71	70	66	67	68	70	72	74	73	74	71
P50	67	66	65	68	67	67	71	72	71	70	69

Table 13 Visual values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

		Date	
	5/6	8/27	9/17
		Ordinal Day of Year	
	126	239	260
GSP	2.25 ab	3.25 a	3.50 a
P100	2.75 a	3.88 a	3.38 a
P75	2.25 ab	3.00 a	3.00 a
P50	1.38 b	2.88 a	2.88 a

Table 14 Total N values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 on the top and the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to polymer coated urea/ammonium sulfate bled fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. $P = 0.05$.

Loam

	2014		2015	
Date	5/15	10/2	10/15	10/30
Ordinal Day of Year	135	275	288	303
GSP	2.24 ab	3.09 a	4.44 a	3.36 a
P100	2.69 b	3.81 b	4.26 a	3.53 a
P75	2.31 b	3.21 ab	3.73 a	3.13 a
P50	1.87 a	2.67 a	3.00 a	2.53 a

Sand

Date	5/15	10/2
Ordinal Day of Year	135	275
GSP	2.39 a	3.91 b
P100	3.19 b	4.55 c
P75	2.58 a	3.77 b
P50	2.07 a	3.03 a

Table 15 Shoot density with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

	Date
	10/30
	Ordinal Day of Year
	303
GSP	61.5
P100	68.5
P75	69.5
P50	90.7

Appendix A

The following is supplementary data collected for the Timing Study (Chapter 1), but not included in the main paper.

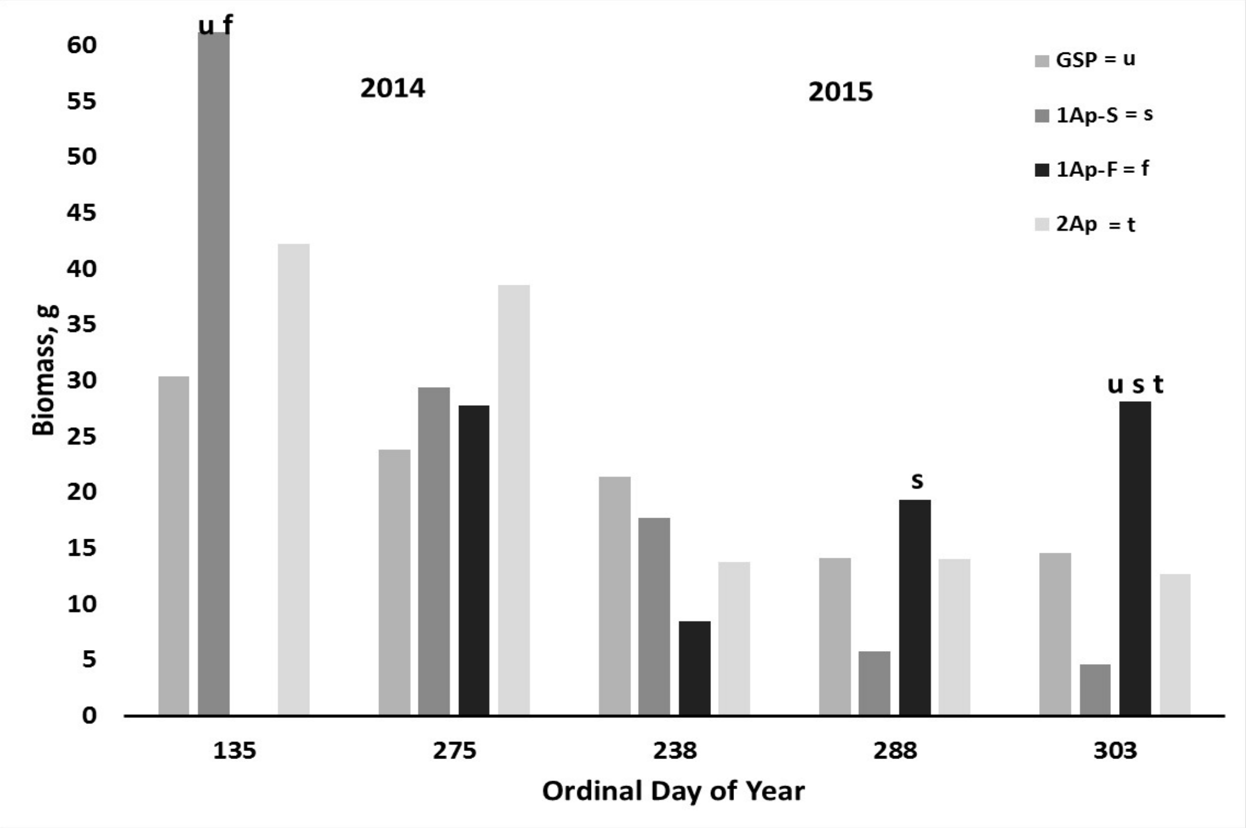
Root Density: Loam Soil Trial

Appendix Table 1 Root density (g) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

Date	
	10/30
Ordinal Day of Year	
	303
GSP	3.91 a
2Ap	3.19 a
1Ap-S	3.01 a
1Ap-F	5.10 a

Loam Biomass

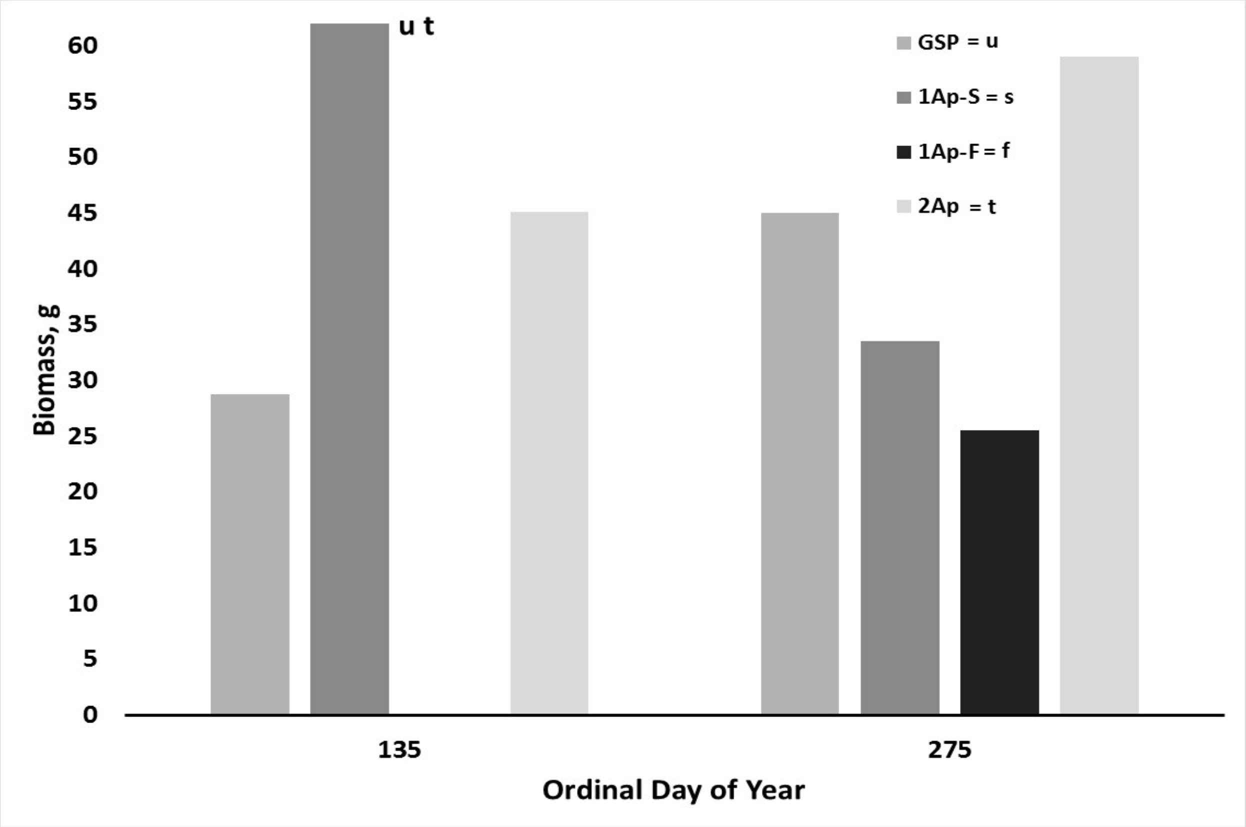
Shoot biomass at the first sampling date in 2014 showed a significant difference between 1Ap-S and the GSP with 1Ap-S having a larger biomass which corresponds directly with the significant height difference for 1Ap-S over the GSP on the same date (Fig. 1). There were no significant biomass differences on the second date in 2014 which also corresponds with the height measurements on the same date. There were no differences for the first date in 2015 for biomass or height. The second date in 2015 had significant differences in the biomass of 1Ap-F having significantly greater biomass than 1Ap-S. The height for the same date is different from the biomass with the 1Ap-F being significantly greater than the GSP, 1Ap-S, and 2Ap. There was a significant difference in biomass on the third date of 2015 with 1Ap-F having significantly greater biomass than the GSP, 1Ap-S, and 2Ap. The height results slightly differ from the biomass for the same date in that the height of 1Ap-F was not significantly greater than the GSP.



Appendix Figure 1 Kentucky bluegrass biomass for 2014 and 2015 for a trial on loam soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split application once in spring and again in fall (2Ap) all at the 100% rate are shown. Letters above bars correspond with the treatments in which it is statistically significant. Bars without letters did not have significance in relation to the other treatments. The biomass is not shown for 1Ap-F until after the application in fall 2014. Data shown in Table 6.

Sand Biomass

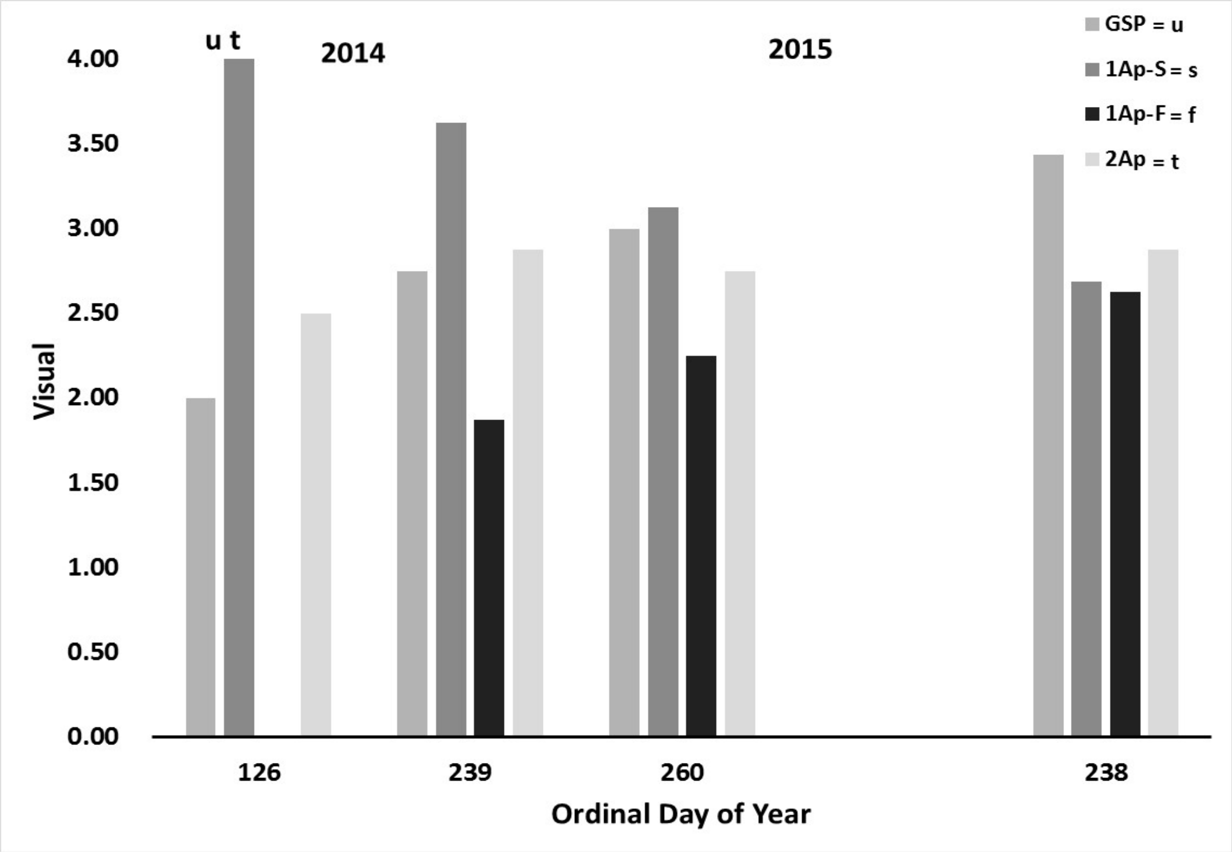
Shoot biomass at the first sampling date in 2014 showed a significant difference between 1Ap-S and the GSP and 2Ap with 1Ap-S having a larger biomass (Table 8). These differences correspond with the significant height difference for 1Ap-S over the GSP and 2Ap on the same date. There were no significant differences on the second date in 2014 which is also consistent with the heights on the same date.



Appendix Figure 2 Kentucky bluegrass biomass for 2014 for a trial on sand soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split application once in spring and again in fall (2Ap) all at the 100% rate are shown. Letters above bars correspond with the treatments in which it is statistically significant. Bars without letters did not have significance in relation to the other treatments. The biomass is not shown for 1Ap-F until after the application in fall 2014. Data shown in Table 8.

Loam Visual

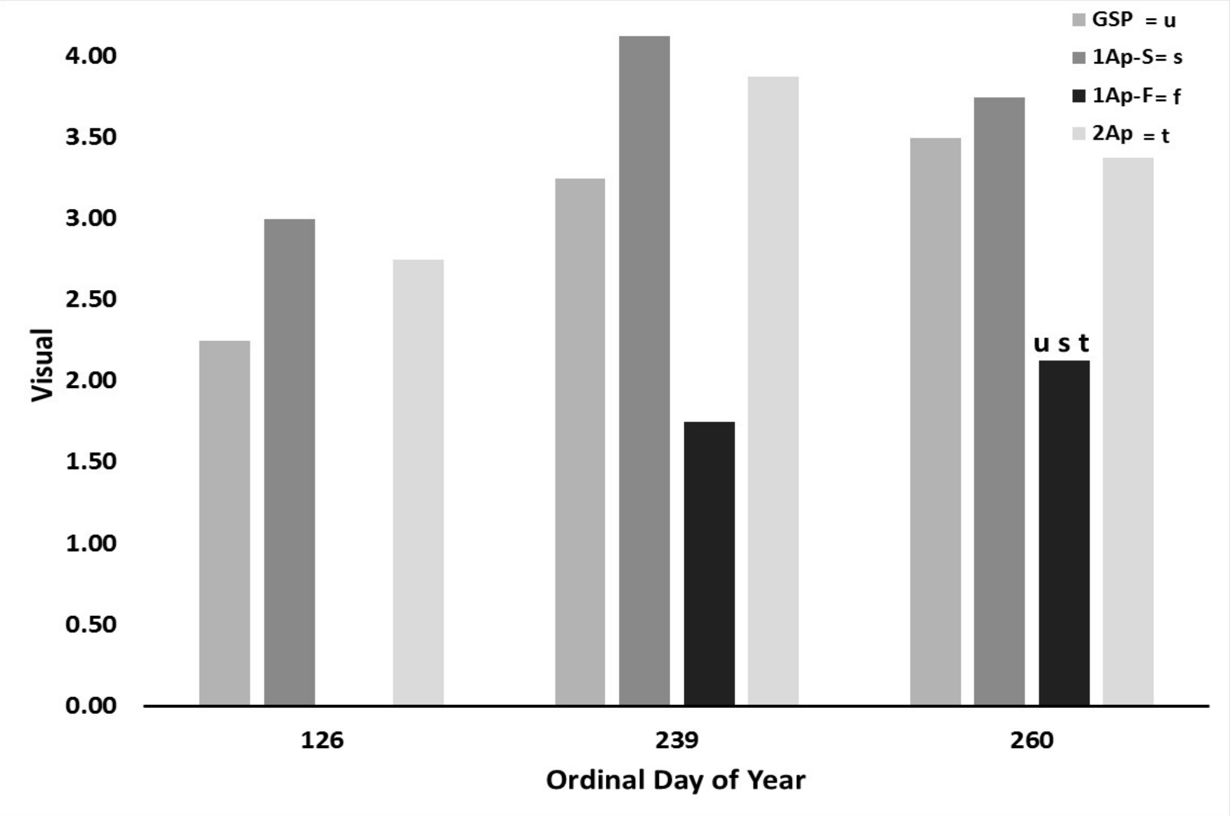
Although NDVI did not show a difference on ordinal day 126, when the first visual ratings of plant health and verdure were made in 2014, 1Ap-S had significantly higher ratings than GSP and 2Ap (Table 11; Fig. 4). On the subsequent visual rating dates, there were no significant differences for visual ratings, which corresponds with the NDVI readings on the same dates. In 2015, there were no significant differences for visual ratings on either of the dates. This correspond with the NDVI readings for the same two dates. For both years, the visual ratings followed the same trend for the different treatments as the NDVI readings for the same dates.



Appendix Figure 3 Kentucky bluegrass visual ratings for 2014 and 2015 for a trial on loam soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split application once in spring and again in fall (2Ap) all at the 100% rate are shown. Letters above bars correspond with the treatments in which it is statistically significant. Bars without letters did not have significance in relation to the other treatments. The visual ratings are not shown for 1Ap-F until after the application in fall 2014. Data shown in Table 11.

Sand Visual

Visual ratings on the first and second dates in 2014 (Table 13) showed no significant differences, which corresponds with the NDVI readings for the same dates (Fig. 5 and 8). On the third date the visual ratings showed a significant difference with the GSP, 1Ap-S, and 2Ap having greater visual ratings than 1Ap-F (Fig. 6). This does not correspond with the NDVI readings for the same date, but there were the same general trends between the visual ratings and the NDVI readings.



Appendix Figure 4 Kentucky bluegrass visual ratings for 2014 for a trial on sand soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly, and polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) and fall (1Ap-F) and a split application once in spring and again in fall (2Ap) all at the 100% rate are shown. Letters above bars correspond with the treatments in which it is statistically significant. Bars without letters did not have significance in relation to the other treatments. The visual ratings are not shown for 1Ap-F until after the application in fall 2014. Data shown in Table 13.

Three Applications

When three applications was rarely statistically different in shoot height as well as plant verdure in both the loam and sand trials when compared to the GSP (Appendix Figs. 5-12). Similarly, the three applications was never statistically different than two applications of PCU. This shows that a reduction of applications to two can be done without any negative effects on the turf.

Appendix Table 2 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

Date	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
Ordinal Day of Year	135	162	170	176	183	190	197	204	211	218
	mm									
GSP	50 b	34	34	32	31	30	30	26	28	29
2Ap	58 ab	36	35	34	33	30	29	28	30	30
3Ap	62 a	39	35	33	34	31	29	27	30	30

Date	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
Ordinal Day of Year	239	246	253	260	267	274	281	295	309
	mm								
GSP	32	30	32	32	36	36	31	36	29
2Ap	33	31	34	30	36	38	34	39	34
3Ap	33	30	34	31	31	36	34	36	36

Appendix Table 3 Height values with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

	Date									
	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12
	Ordinal Day of Year										
	146	157	164	175	182	189	196	203	210	217	224
	mm										
GSP	38	43	37	30	35	39	39	39	36	35	41
2Ap	37	45	38	33	35	33	32	33	33	35	33
3Ap	41	53	44	33	38	36	36	36	37	33	35

	Date									
	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
	Ordinal Day of Year									
	238	245	252	261	266	273	280	287	294	301
	mm									
GSP	36	38	34	39	41	36	39	45	39	40
2Ap	31	33	34	34	36	34	47	41	39	34
3Ap	31	36	34	34	36	36	40	45	41	39

Appendix Table 4 Height values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

	Date									
	5/15	6/11	6/19	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year									
	135	162	170	176	183	190	197	204	211	218
	mm									
GSP	53 b	45 b	36	36	35	34	34	28	31	29
2Ap	60 ab	58 a	44	41	43	39	39	31	36	32
3Ap	65 a	55 a	40	41	41	38	36	30	34	31

	Date								
	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/22	11/5
	Ordinal Day of Year								
	239	246	253	260	267	274	281	295	309
	mm								
GSP	31	33	37	37	41	43	35	33	31
2Ap	33	31	37	33	38	46	36	36	36
3Ap	31	30	36	33	37	43	38	35	34

Appendix Table 5 Biomass values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

	2014		2015		
Date	5/15	10/2	8/26	10/15	10/30
Ordinal Day of Year	135	275	238	288	303
GSP	30.45 a	23.84 a	21.43 a	14.19 a	14.64 a
2Ap	42.29 a	38.57 a	13.83 a	14.10 a	12.69 a
3Ap	38.64 a	33.49 a	20.90 a	15.73 a	15.63 a

Appendix Table 6 Biomass values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

Date	5/15	10/2
Ordinal Day of Year	135	275
GSP	28.78 a	45.11 a
2Ap	45.13 a	59.08 a
3Ap	60.70 a	46.94 a

Appendix Table 7 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) and three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

	Date										
	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
	Ordinal Day of Year										
	126	134	160	169	176	183	190	197	204	211	218
GSP	65	63	55	62	62	64	69	68	63	62	64
2Ap	65	66	55	62	64	68	69	69	66	65	65
3Ap	65	67	60	66	65	66	70	70	66	65	65
	Date										
	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
	Ordinal Day of Year										
	233	239	246	253	260	267	274	281	288	295	309
GSP	67	66	70	70	68	71	69	71	71	69	66
2Ap	69	68	66	67	65	69	70	74	74	74	72
3Ap	68	68	68	66	66	70	71	73	73	73	71

Appendix Table 8 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. $P = 0.05$

	Date											
	4/20	4/24	5/1	5/26	6/3	6/10	6/24	7/1	7/8	7/15	7/22	7/29
	Ordinal Day of Year											
	110	114	121	146	154	161	175	182	189	196	203	210
GSP	47	56	65	75	71	73	69	72	74	71	73	70
2Ap	52	62	69	76	71	74	69	72	72	68	70	69
3Ap	57	66	70	77	74	75	70	73	74	70	70	69
	Date											
	8/5	8/12	8/26	9/2	9/9	9/18	9/23	9/30	10/7	10/14	10/21	10/28
	Ordinal Day of Year											
	217	224	238	245	252	261	266	273	280	287	294	301
GSP	73	72	64	68	53	62	61	50	66	71	74	74
2Ap	72	68	60	67	52	55	57	49	66	71	74	74
3Ap	72	69	63	66	48	58	60	49	67	71	74	75

Appendix Table 9 NDVI values (multiplied by 100) with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in one application in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. Dates without letters have no significant differences between any treatments on that date. *P* = 0.05

Date	5/6	5/14	6/9	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6
Ordinal Day of Year	126	134	160	169	176	183	190	197	204	211	218
GSP	63	64	31 b	53 b	57 b	64 b	68	68	68	66	65
2Ap	67	68	53 a	63 a	66 a	72 a	73	72	72	67	67
3Ap	66	68	53 a	63 a	67 a	72 ab	73	71	70	68	67

Date	8/21	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	11/5
Ordinal Day of Year	233	239	246	253	260	267	274	281	288	295	309
GSP	71	69	70	69	71	74	74	75	75	74	70
2Ap	72	70	68	68	66	71	73	75	75	76	74
3Ap	73	70	68	67	68	71	72	74	74	75	72

Appendix Table 10 Visual values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. The statistics within the table display those treatments with the same letters as not being significantly different. Values sharing the same letter within a date are not significantly different from one another. $P = 0.05$

	2014			2015	
	Date				
	5/6	8/27	9/17	8/26	11/1
	Ordinal Day of Year				
	126	239	260	238	305
GSP	2.00 a	2.75 a	3.00 a	3.44 a	3.69 a
2Ap	2.50 a	2.88 a	2.75 a	2.88 a	3.63 a
3Ap	2.63 a	3.13 a	2.88 a	3.00 a	3.81 a

Appendix Table 11 Visual values with statistical analysis for a Kentucky bluegrass trial at the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. $P = 0.05$

	Date		
	5/6	8/27	9/17
	Ordinal Day of Year		
	126	239	260
GSP	2.25 a	3.25 a	3.50 a
2Ap	2.75 a	3.88 a	3.38 a
3Ap	2.75 a	3.88 a	3.38 a

Appendix Table 12 Total N values with statistical analysis for Kentucky bluegrass trials at the loam site in 2014 and 2015 on the top and the sand site in 2014 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to polymer coated urea/ammonium sulfate blend urea fertilizer applied in two applications (2Ap) or three applications (3Ap). Fertilizer was applied at a full rate 100%. Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

	2014		2015	
	Loam			
	Date			
	5/15	10/2	10/15	10/30
	Ordinal Day of Year			
	135	275	288	303
GSP	2.24 a	3.09 a	4.44 a	3.36 a
2Ap	2.69 a	3.81 b	4.26 a	3.53 a
3Ap	2.69 a	3.60 b	4.19 a	3.45 a
	Sand			
	Date			
	5/15	10/2		
	Ordinal Day of Year			
	135	275		
GSP	2.39 a	3.91 b		
2Ap	3.19 b	4.55 a		
3Ap	3.12 b	4.21 ab		

P-values

The following tables give the p-values for each treatment on the corresponding ordinal days.

Appendix Table 13 P-values for root biomass in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	1Ap-S	0.9998
303	GSP	1Ap-F	0.9998
303	GSP	2Ap	1.0000
303	GSP	3Ap	0.9969
303	GSP	ctrl	0.9979
303	1Ap-S	1Ap-F	0.9681
303	1Ap-S	2Ap	1.0000
303	1Ap-S	3Ap	0.9482
303	1Ap-S	ctrl	1.0000
303	1Ap-F	2Ap	0.9804
303	1Ap-F	3Ap	1.0000
303	1Ap-F	ctrl	0.9343
303	2Ap	3Ap	0.9660
303	2Ap	ctrl	1.0000
303	3Ap	ctrl	0.9063

Appendix Table 14 P-values for root biomass in the sand trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	1Ap-S	1.0000
303	GSP	1Ap-F	1.0000
303	GSP	2Ap	0.8347
303	GSP	3Ap	0.9997
303	GSP	ctrl	0.6806
303	1Ap-S	1Ap-F	0.9999
303	1Ap-S	2Ap	0.9181
303	1Ap-S	3Ap	1.0000
303	1Ap-S	ctrl	0.7991
303	1Ap-F	2Ap	0.7374
303	1Ap-F	3Ap	0.9976
303	1Ap-F	ctrl	0.5668
303	2Ap	3Ap	0.9740
303	2Ap	ctrl	1.0000
303	3Ap	ctrl	0.9057

Appendix Table 15 P-values height in the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
135	GSP	1Ap-S	<.0001
135	GSP	3Ap	<.0001
135	GSP	ctrl	<.0001
135	1Ap-S	1Ap-F	<.0001
135	1Ap-S	ctrl	<.0001
135	1Ap-F	2Ap	<.0001
135	1Ap-F	3Ap	<.0001
135	2Ap	ctrl	<.0001
135	3Ap	ctrl	<.0001
162	GSP	1Ap-S	<.0001
162	1Ap-S	1Ap-F	<.0001
162	1Ap-S	2Ap	0.0005
162	1Ap-S	ctrl	<.0001
176	GSP	1Ap-S	<.0001
176	1Ap-S	1Ap-F	<.0001
176	1Ap-S	3Ap	0.0005
176	1Ap-S	ctrl	<.0001
218	GSP	1Ap-S	0.0027
218	1Ap-S	1Ap-F	<.0001
218	1Ap-S	ctrl	<.0001
246	1Ap-S	1Ap-F	0.0005
281	GSP	1Ap-F	0.0128
281	1Ap-S	1Ap-F	0.0128
309	GSP	1Ap-F	<.0001
309	1Ap-F	ctrl	0.0059

Appendix Table 16 P-values height in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
146	GSP	ctrl	0.0004
146	1Ap-S	ctrl	<.0001
146	2Ap	ctrl	0.0014
146	3Ap	ctrl	<.0001
154	GSP	1Ap-S	0.0199
154	GSP	ctrl	<.0001
154	1Ap-S	1Ap-F	0.0199
154	1Ap-S	ctrl	<.0001
154	1Ap-F	ctrl	<.0001
154	2Ap	ctrl	<.0001
154	3Ap	ctrl	<.0001
161	GSP	ctrl	0.0179
161	1Ap-S	ctrl	<.0001
161	1Ap-F	ctrl	0.0440
161	2Ap	ctrl	0.0024
161	3Ap	ctrl	<.0001
182	GSP	ctrl	0.0217
182	1Ap-S	ctrl	0.0003
182	2Ap	ctrl	0.0217
182	3Ap	ctrl	0.0003
196	GSP	ctrl	0.0057
203	GSP	ctrl	0.0050
210	GSP	ctrl	0.0049
210	3Ap	ctrl	0.0017
224	GSP	ctrl	<.0001
238	GSP	ctrl	0.0022
245	GSP	ctrl	0.0018
245	3Ap	ctrl	0.0353
261	GSP	ctrl	0.0003
261	1Ap-F	ctrl	0.0080
266	GSP	ctrl	<.0001
266	1Ap-S	1Ap-F	<.0001
266	1Ap-S	ctrl	0.0281
266	1Ap-F	2Ap	0.0022
266	1Ap-F	3Ap	0.0022
266	1Ap-F	ctrl	<.0001
266	2Ap	ctrl	<.0001
266	3Ap	ctrl	<.0001
273	GSP	ctrl	0.0020
273	1Ap-S	1Ap-F	0.0007
273	1Ap-F	2Ap	0.0199
273	1Ap-F	ctrl	<.0001
273	3Ap	ctrl	0.0057
280	GSP	1Ap-F	<.0001
280	1Ap-S	1Ap-F	<.0001
280	1Ap-F	3Ap	<.0001
280	1Ap-F	ctrl	<.0001
280	2Ap	ctrl	<.0001
280	3Ap	ctrl	0.0316
287	GSP	1Ap-S	0.0069
287	GSP	1Ap-F	0.0199
287	GSP	ctrl	<.0001
287	1Ap-S	1Ap-F	<.0001
287	1Ap-S	3Ap	0.0069
287	1Ap-F	2Ap	<.0001
287	1Ap-F	3Ap	0.0199
287	1Ap-F	ctrl	<.0001
287	2Ap	ctrl	0.0012
287	3Ap	ctrl	<.0001
294	GSP	1Ap-S	0.0199
294	GSP	1Ap-F	0.0022
294	1Ap-S	1Ap-F	<.0001
294	1Ap-S	2Ap	0.0199
294	1Ap-S	3Ap	0.0002
294	1Ap-F	2Ap	0.0022
294	1Ap-F	ctrl	<.0001
294	3Ap	ctrl	0.0035
301	GSP	1Ap-S	0.0069
301	GSP	ctrl	<.0001
301	1Ap-S	1Ap-F	<.0001
301	1Ap-F	2Ap	<.0001
301	1Ap-F	3Ap	0.0069
301	1Ap-F	ctrl	<.0001
301	2Ap	ctrl	0.0203
301	3Ap	ctrl	<.0001

Appendix Table 17a P-values height in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value	Ordinal Day	Treatments		p-value	Ordinal Day	Treatments		p-value
135	GSP	1Ap-S	<.0001	176	2Ap	ctrl	0.0005	246	1Ap-S	ctrl	<.0001
135	GSP	3Ap	0.0005	176	3Ap	ctrl	0.0005	253	GSP	1Ap-F	0.0269
135	GSP	ctrl	<.0001	183	GSP	1Ap-S	<.0001	253	GSP	ctrl	0.0020
135	1Ap-S	1Ap-F	<.0001	183	1Ap-S	1Ap-F	<.0001	253	1Ap-S	1Ap-F	0.0005
135	1Ap-S	ctrl	<.0001	183	1Ap-S	2Ap	<.0001	253	1Ap-S	ctrl	<.0001
135	1Ap-F	2Ap	<.0001	183	1Ap-S	3Ap	<.0001	253	1Ap-F	2Ap	0.0269
135	1Ap-F	3Ap	<.0001	183	1Ap-S	ctrl	<.0001	253	2Ap	ctrl	0.0020
135	1Ap-F	ctrl	0.0075	183	1Ap-F	2Ap	0.0001	253	3Ap	ctrl	0.0269
135	2Ap	ctrl	<.0001	183	1Ap-F	3Ap	0.0020	260	GSP	1Ap-F	0.0079
135	3Ap	ctrl	<.0001	183	2Ap	ctrl	0.0001	267	GSP	1Ap-F	<.0001
162	GSP	1Ap-S	<.0001	183	3Ap	ctrl	0.0020	267	GSP	ctrl	<.0001
162	GSP	2Ap	0.0001	190	GSP	1Ap-S	<.0001	267	1Ap-F	2Ap	0.0269
162	GSP	3Ap	0.0269	190	1Ap-S	1Ap-F	<.0001	267	2Ap	ctrl	0.0001
162	1Ap-S	1Ap-F	<.0001	190	1Ap-S	2Ap	0.0269	267	3Ap	ctrl	0.0005
162	1Ap-S	ctrl	<.0001	190	1Ap-S	3Ap	0.0020	274	GSP	ctrl	<.0001
162	1Ap-F	2Ap	<.0001	190	1Ap-S	ctrl	<.0001	274	1Ap-S	ctrl	0.0079
162	1Ap-F	3Ap	<.0001	197	GSP	1Ap-S	0.0001	274	1Ap-F	ctrl	<.0001
162	2Ap	ctrl	<.0001	197	1Ap-S	1Ap-F	<.0001	274	2Ap	ctrl	<.0001
162	3Ap	ctrl	<.0001	197	1Ap-S	3Ap	0.0269	274	3Ap	ctrl	<.0001
170	GSP	1Ap-S	<.0001	197	1Ap-S	ctrl	<.0001	281	1Ap-S	1Ap-F	0.0020

Appendix Table 17b P-values height in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

170	1Ap-S	1Ap-F	<.0001	204	1Ap-S	1Ap-F	0.0269	281	1Ap-F	ctrl	<.0001
170	1Ap-S	3Ap	0.0079	204	1Ap-S	ctrl	0.0269	281	3Ap	ctrl	0.0020
170	1Ap-S	ctrl	<.0001	211	1Ap-S	1Ap-F	<.0001	295	1Ap-S	1Ap-F	0.0079
170	1Ap-F	2Ap	0.0020	211	1Ap-S	ctrl	<.0001	295	1Ap-F	ctrl	<.0001
170	2Ap	ctrl	0.0269	211	1Ap-F	2Ap	0.0079	295	2Ap	ctrl	0.0079
176	GSP	1Ap-S	<.0001	211	2Ap	ctrl	0.0079	295	3Ap	ctrl	0.0269
176	1Ap-S	1Ap-F	<.0001	218	1Ap-S	1Ap-F	0.0001	309	GSP	1Ap-F	0.0269
176	1Ap-S	2Ap	0.0020	218	1Ap-S	ctrl	0.0269	309	1Ap-S	1Ap-F	0.0020
176	1Ap-S	3Ap	0.0020	239	1Ap-S	1Ap-F	<.0001	309	1Ap-F	ctrl	<.0001
176	1Ap-S	ctrl	<.0001	239	1Ap-S	ctrl	<.0001	309	2Ap	ctrl	<.0001
176	1Ap-F	2Ap	0.0020	246	GSP	1Ap-F	0.0269	309	3Ap	ctrl	<.0001
176	1Ap-F	3Ap	0.0020	246	1Ap-S	1Ap-F	<.0001				

Appendix Table 18 P-values for biomass in the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
275	GSP	1Ap-S	0.0045
275	1Ap-S	1Ap-F	0.0001
275	1Ap-S	ctrl	0.0007

Appendix Table 19 P-values for biomass in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
238	GSP	ctrl	0.0003
238	1Ap-S	ctrl	0.0054
238	1Ap-F	ctrl	0.0105
238	2Ap	ctrl	0.0156
288	1Ap-F	ctrl	0.0015
288	3Ap	ctrl	0.0255
303	GSP	1Ap-F	0.0408
303	1Ap-S	1Ap-F	<.0001
303	1Ap-F	2Ap	0.0087
303	1Ap-F	ctrl	<.0001
303	3Ap	ctrl	0.0317

Appendix Table 20 P-values for biomass in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
135	1Ap-S	2Ap	0.0234
135	1Ap-F	2Ap	0.0032
275	GSP	1Ap-S	0.0075
275	1Ap-S	1Ap-F	0.0014
275	1Ap-S	ctrl	0.0001
275	1Ap-F	2Ap	0.0404
275	1Ap-F	3Ap	0.0103
275	2Ap	ctrl	0.0044
275	3Ap	ctrl	0.0015

Appendix Table 21 P-values for NDVI readings for the loam trial in 2014 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value		Ordinal Day	Treatments		p-value
126	1Ap-S	1Ap-F	<.0001		197	1Ap-S	1Ap-F	0.0003
134	1Ap-S	1Ap-F	<.0001		197	1Ap-S	ctrl	0.0001
134	1Ap-S	ctrl	0.0005		204	1Ap-S	1Ap-F	<.0001
134	1Ap-F	2Ap	0.0181		204	1Ap-S	ctrl	0.0005
134	1Ap-F	3Ap	0.0027		204	1Ap-F	2Ap	0.0181
160	GSP	1Ap-S	<.0001		204	1Ap-F	3Ap	0.0027
160	1Ap-S	1Ap-F	<.0001		218	1Ap-S	ctrl	0.0370
160	1Ap-S	2Ap	<.0001		281	1Ap-F	ctrl	0.0148
160	1Ap-S	ctrl	0.0177		288	1Ap-S	1Ap-F	0.0060
169	GSP	1Ap-S	0.0121		288	1Ap-F	ctrl	0.0098
169	1Ap-S	1Ap-F	0.0008		295	1Ap-S	1Ap-F	0.0035
169	1Ap-S	2Ap	0.0171		295	1Ap-F	ctrl	0.0003
169	1Ap-S	ctrl	0.0218		309	1Ap-S	1Ap-F	<.0001
176	GSP	1Ap-S	0.0311		309	1Ap-S	2Ap	0.0020
176	1Ap-S	1Ap-F	<.0001		309	1Ap-S	3Ap	0.0300
176	1Ap-S	ctrl	0.0012		309	1Ap-F	ctrl	0.0002
183	1Ap-S	1Ap-F	0.0153		309	2Ap	ctrl	0.0199
190	1Ap-S	1Ap-F	0.0279					

Appendix Table 22 P-values for NDVI readings for the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
114	GSP	ctrl	<.0001
114	1Ap-S	ctrl	<.0001
114	1Ap-F	ctrl	<.0001
114	2Ap	ctrl	<.0001
114	3Ap	ctrl	<.0001
154	GSP	ctrl	0.0079
154	1Ap-S	ctrl	<.0001
154	2Ap	ctrl	0.0060
154	3Ap	ctrl	<.0001
266	1Ap-S	1Ap-F	0.0002
266	1Ap-F	2Ap	0.0295
273	1Ap-S	1Ap-F	<.0001
273	1Ap-F	2Ap	0.0002
273	1Ap-F	3Ap	0.0001
280	1Ap-S	1Ap-F	0.0306

Appendix Table 23a P-values for NDVI readings for the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. $P = 0.05$

Ordinal Day	Treatments		p-value	Ordinal Day	Treatments		p-value	Ordinal Day	Treatments		p-value
126	1Ap-S	1Ap-F	<.0001	176	1Ap-F	2Ap	<.0001	211	GSP	ctrl	0.0027
126	1Ap-F	2Ap	<.0001	176	1Ap-F	3Ap	<.0001	211	1Ap-S	1Ap-F	<.0001
126	2Ap	3Ap	0.0002	176	2Ap	ctrl	<.0001	211	1Ap-S	ctrl	<.0001
134	GSP	1Ap-F	0.0001	176	3Ap	ctrl	<.0001	211	1Ap-F	2Ap	0.0003
134	GSP	ctrl	0.0024	183	GSP	1Ap-S	0.0007	211	1Ap-F	3Ap	<.0001
134	1Ap-S	1Ap-F	<.0001	183	GSP	1Ap-F	<.0001	211	2Ap	ctrl	<.0001
134	1Ap-S	ctrl	<.0001	183	GSP	2Ap	0.0469	211	3Ap	ctrl	<.0001
134	1Ap-F	2Ap	<.0001	183	GSP	ctrl	0.0029	218	GSP	1Ap-F	<.0001
134	1Ap-F	3Ap	<.0001	183	1Ap-S	1Ap-F	<.0001	218	1Ap-S	1Ap-F	<.0001
134	2Ap	ctrl	<.0001	183	1Ap-S	ctrl	<.0001	218	1Ap-S	ctrl	0.0004
134	3Ap	ctrl	<.0001	183	1Ap-F	2Ap	<.0001	218	1Ap-F	2Ap	<.0001
160	GSP	1Ap-S	<.0001	183	1Ap-F	3Ap	<.0001	218	1Ap-F	3Ap	<.0001
160	GSP	1Ap-F	0.0098	183	2Ap	ctrl	<.0001	218	2Ap	ctrl	0.022
160	GSP	2Ap	<.0001	183	3Ap	ctrl	<.0001	218	3Ap	ctrl	0.0241
160	GSP	3Ap	<.0001	190	GSP	1Ap-F	<.0001	233	1Ap-F	3Ap	0.0356
160	1Ap-S	1Ap-F	<.0001	190	GSP	ctrl	<.0001	239	1Ap-S	1Ap-F	0.0173
160	1Ap-S	ctrl	<.0001	190	1Ap-S	1Ap-F	<.0001	274	GSP	ctrl	0.0126
160	1Ap-F	2Ap	<.0001	190	1Ap-S	ctrl	<.0001	274	1Ap-F	ctrl	0.0035
160	1Ap-F	3Ap	<.0001	190	1Ap-F	2Ap	<.0001	281	GSP	ctrl	0.0445
160	2Ap	ctrl	<.0001	190	1Ap-F	3Ap	<.0001	281	1Ap-F	ctrl	<.0001
160	3Ap	ctrl	<.0001	190	2Ap	ctrl	<.0001	281	2Ap	ctrl	0.0149

Appendix Table 23b P-values for NDVI readings for the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. $P = 0.05$

169	GSP	1Ap-S	<.0001	190	3Ap	ctrl	<.0001	288	GSP	ctrl	0.0052
169	GSP	1Ap-F	<.0001	197	GSP	1Ap-F	<.0001	288	1Ap-S	1Ap-F	0.0104
169	GSP	2Ap	0.0007	197	GSP	ctrl	<.0001	288	1Ap-F	ctrl	<.0001
169	GSP	3Ap	0.001	197	1Ap-S	1Ap-F	<.0001	288	2Ap	ctrl	0.0033
169	GSP	ctrl	<.0001	197	1Ap-S	ctrl	<.0001	288	3Ap	ctrl	0.0476
169	1Ap-S	1Ap-F	<.0001	197	1Ap-F	2Ap	<.0001	295	GSP	ctrl	<.0001
169	1Ap-S	ctrl	<.0001	197	1Ap-F	3Ap	<.0001	295	1Ap-S	1Ap-F	0.0112
169	1Ap-F	2Ap	<.0001	197	2Ap	ctrl	<.0001	295	1Ap-F	ctrl	<.0001
169	1Ap-F	3Ap	<.0001	197	3Ap	ctrl	<.0001	295	2Ap	ctrl	<.0001
169	2Ap	ctrl	<.0001	204	GSP	1Ap-F	<.0001	295	3Ap	ctrl	<.0001
169	3Ap	ctrl	<.0001	204	GSP	ctrl	0.0022	309	GSP	ctrl	0.0012
176	GSP	1Ap-S	<.0001	204	1Ap-S	1Ap-F	<.0001	309	1Ap-S	1Ap-F	<.0001
176	GSP	1Ap-F	<.0001	204	1Ap-S	ctrl	<.0001	309	1Ap-S	2Ap	0.004
176	GSP	2Ap	0.0028	204	1Ap-F	2Ap	<.0001	309	1Ap-F	ctrl	<.0001
176	GSP	3Ap	0.0013	204	1Ap-F	3Ap	<.0001	309	2Ap	ctrl	<.0001
176	GSP	ctrl	0.0006	204	2Ap	ctrl	<.0001	309	3Ap	ctrl	<.0001
176	1Ap-S	1Ap-F	<.0001	204	3Ap	ctrl	<.0001				
176	1Ap-S	ctrl	<.0001	211	GSP	1Ap-F	0.0094				

Appendix Table 24 P-values for visual ratings for the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
126	GSP	1Ap-S	<.0001
126	1Ap-S	1Ap-F	<.0001
126	1Ap-S	2Ap	0.0008
126	1Ap-S	3Ap	0.0030
126	1Ap-S	ctrl	<.0001
126	1Ap-F	2Ap	0.0110
126	1Ap-F	3Ap	0.0030
239	1Ap-S	1Ap-F	<.0001
239	1Ap-F	3Ap	0.0110

Appendix Table 25 P-values for visual ratings for the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
238	GSP	1Ap-F	0.0393
303	GSP	1Ap-S	0.0393
303	GSP	ctrl	<.0001
303	1Ap-S	1Ap-F	0.0004
303	1Ap-S	3Ap	0.0109
303	1Ap-S	ctrl	0.0090
303	1Ap-F	ctrl	<.0001
303	2Ap	ctrl	<.0001
303	3Ap	ctrl	<.0001

Appendix Table 26 P-values for visual ratings for the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. $P = 0.05$

Ordinal Day	Treatments		p-value
126	GSP	1Ap-F	0.012
126	GSP	ctrl	0.012
126	1Ap-S	1Ap-F	<.0001
126	1Ap-S	ctrl	<.0001
126	1Ap-F	2Ap	<.0001
126	1Ap-F	3Ap	<.0001
126	2Ap	ctrl	<.0001
126	3Ap	ctrl	<.0001
239	GSP	1Ap-F	0.0008
239	GSP	ctrl	<.0001
239	1Ap-S	1Ap-F	<.0001
239	1Ap-S	ctrl	<.0001
239	1Ap-F	2Ap	<.0001
239	1Ap-F	3Ap	<.0001
239	2Ap	ctrl	<.0001
239	3Ap	ctrl	<.0001
260	GSP	1Ap-F	0.0033
260	1Ap-S	1Ap-F	0.0002
260	1Ap-F	2Ap	0.012
260	1Ap-F	3Ap	0.012

Appendix Table 27 P-values for nitrogen concentration for the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
135	GSP	1Ap-S	0.0001
135	1Ap-S	1Ap-F	<.0001
135	1Ap-S	2Ap	0.0207
135	1Ap-S	3Ap	0.0216
135	1Ap-S	ctrl	<.0001
135	1Ap-F	2Ap	0.0023
135	1Ap-F	3Ap	0.0022
135	2Ap	ctrl	0.0039
135	3Ap	ctrl	0.0037
275	GSP	1Ap-F	<.0001
275	GSP	2Ap	0.0309
275	1Ap-S	1Ap-F	<.0001
275	1Ap-S	2Ap	0.0073
275	1Ap-F	2Ap	0.0108
275	1Ap-F	3Ap	0.0009

Appendix Table 28 P-values for nitrogen concentration for the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
238	GSP	ctrl	0.0003
238	1Ap-S	ctrl	0.0054
238	3Ap	ctrl	0.0004
288	1Ap-S	1Ap-F	0.0397
288	1Ap-F	ctrl	0.0015
288	3Ap	ctrl	0.0255
303	GSP	1Ap-F	0.0408
303	1Ap-S	1Ap-F	<.0001
303	1Ap-F	2Ap	0.0087
303	1Ap-F	ctrl	<.0001
303	3Ap	ctrl	0.0317

Appendix Table 29 P-values for nitrogen concentration for the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Only statistically significant p-values are shown. *P* = 0.05

Ordinal Day	Treatments		p-value
135	GSP	1Ap-S	<.0001
135	GSP	1Ap-F	0.0079
135	GSP	2Ap	0.0019
135	GSP	3Ap	0.0052
135	GSP	ctrl	0.0052
135	1Ap-S	1Ap-F	<.0001
135	1Ap-S	2Ap	<.0001
135	1Ap-S	3Ap	<.0001
135	1Ap-S	ctrl	<.0001
135	1Ap-F	2Ap	<.0001
135	1Ap-F	3Ap	<.0001
135	2Ap	ctrl	<.0001
135	3Ap	ctrl	<.0001
275	GSP	1Ap-S	0.0191
275	GSP	1Ap-F	<.0001
275	GSP	2Ap	0.0191
275	1Ap-S	1Ap-F	<.0001
275	1Ap-S	2Ap	<.0001
275	1Ap-S	3Ap	0.0003
275	1Ap-F	2Ap	0.001
275	1Ap-F	3Ap	<.0001

Appendix Table 30 P-values for shoot density in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	1Ap-S	0.5986
303	GSP	1Ap-F	0.9380
303	GSP	2Ap	0.9835
303	GSP	3Ap	0.9914
303	GSP	ctrl	0.0681
303	1Ap-S	1Ap-F	0.1053
303	1Ap-S	2Ap	0.1678
303	1Ap-S	3Ap	0.1980
303	1Ap-S	ctrl	0.7937
303	1Ap-F	2Ap	1.0000
303	1Ap-F	3Ap	1.0000
303	1Ap-F	ctrl	0.0072
303	2Ap	3Ap	1.0000
303	2Ap	ctrl	0.0121
303	3Ap	ctrl	0.0146

Appendix Table 31 P-values for shoot density in the sand trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and a single application of PCU applied in spring (1Ap-S) or fall (1Ap-F) or in two applications (2Ap) or three applications (3Ap) all at the full rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	1Ap-S	0.3305
303	GSP	1Ap-F	0.9991
303	GSP	2Ap	0.9989
303	GSP	3Ap	1.0000
303	GSP	ctrl	0.0281
303	1Ap-S	1Ap-F	0.6510
303	1Ap-S	2Ap	0.1264
303	1Ap-S	3Ap	0.2641
303	1Ap-S	ctrl	0.8850
303	1Ap-F	2Ap	0.9438
303	1Ap-F	3Ap	0.9960
303	1Ap-F	ctrl	0.0886
303	2Ap	3Ap	0.9998
303	2Ap	ctrl	0.0080
303	3Ap	ctrl	0.0205

Appendix B

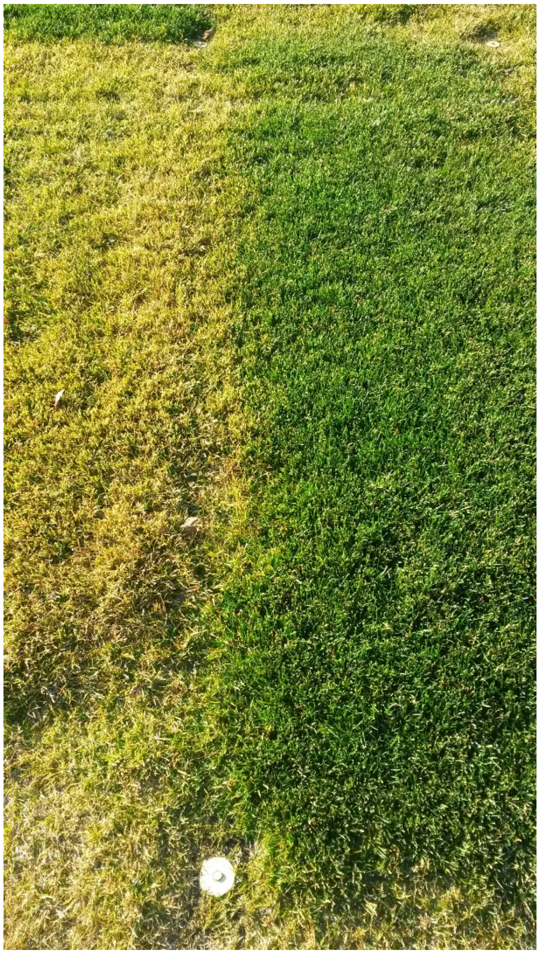
Appendix Figure 5 Treatments in the loam trial in November 2014. Lighter colored plots had less nitrogen applied in the fall or no nitrogen applied.

Appendix Figure 6 Treatments in the sand trial in November 2014. Lighter colored plots had less nitrogen applied in the fall or no nitrogen applied.

Appendix Figure 7 Treatments in the loam trial in April 2015. Lighter colored plots came out of dormancy later than the plots which had nitrogen applied in the fall.

Appendix Figure 8 Treatments in the sand trial in September 2015. Darker plots received more nitrogen in the fall than the lighter plots.

Appendix Figure 9 Treatments in the loam trial in November 2014. The plot on the left had nitrogen applied once in spring (1Ap-S) and the plot on the right had nitrogen applied once in fall (1Ap-F).



Appendix Figure 10 Treatments in the sand trial in December 2014. The plot on the left had nitrogen applied once in spring (1Ap-S) and the plot on the right had nitrogen applied once in fall (1Ap-F).

Appendix A

The following is supplementary data collected for the Rate Study (Chapter 2), but not included in the main paper.

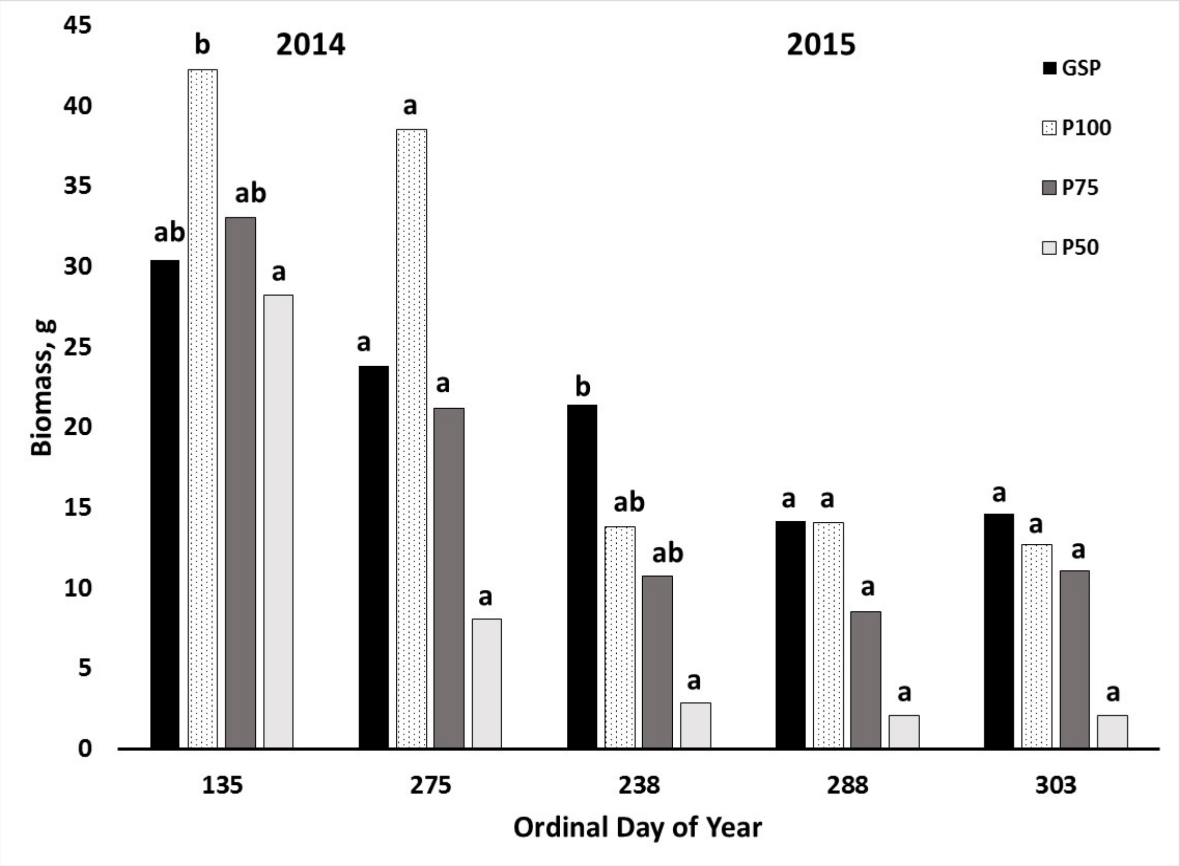
Root Density: Loam Soil Trial

Appendix Table 1 Root density (g) with statistical analysis for a Kentucky bluegrass trial at the loam site in 2015 with a grower's standard of practice (GSP) applied monthly as a urea/ammonium sulfate blend compared to a polymer coated urea/ammonium sulfate blend fertilizer applied in two applications at differing rates with a full rate (P100), three-quarter the rate (P75), and half the rate (P50). Values sharing the same letter within a date are not significantly different from one another. *P* = 0.05

Date	10/30
Ordinal Day of Year	303
GSP	3.91 a
P100	3.19 a
P75	3.74 a
P50	1.36 a

Loam Growth

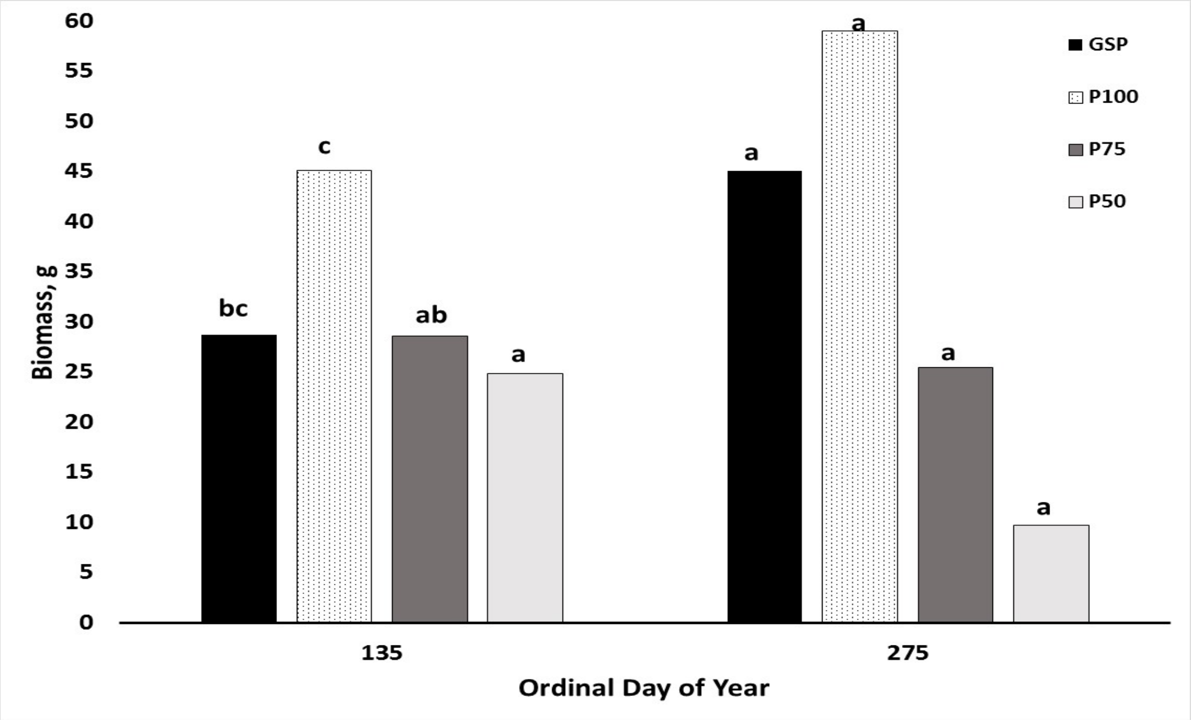
Shoot biomass was significant on the second sampling date in 2014 with the P100 being significantly greater than P50 (Appendix Fig. 1; Table 6). All other sampling dates for the biomass were not significant. On the same date, the height difference was not significant although there was still a greater amount of shoot growth for the P100 over P50 (Figs. 1 and 2; Tables 4 and 5).



Appendix Figure 1 Kentucky bluegrass biomass for 2014 and 2015 for a trial on loam soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly at the 100% rate, and polymer coated urea/ammonium sulfate split applied once in spring and again in fall at the 100% (P100), 75% (P75), and 50% (P50) rate are shown. Statistical significance is shown within the figure. Data shown in Table 6.

Sand Growth

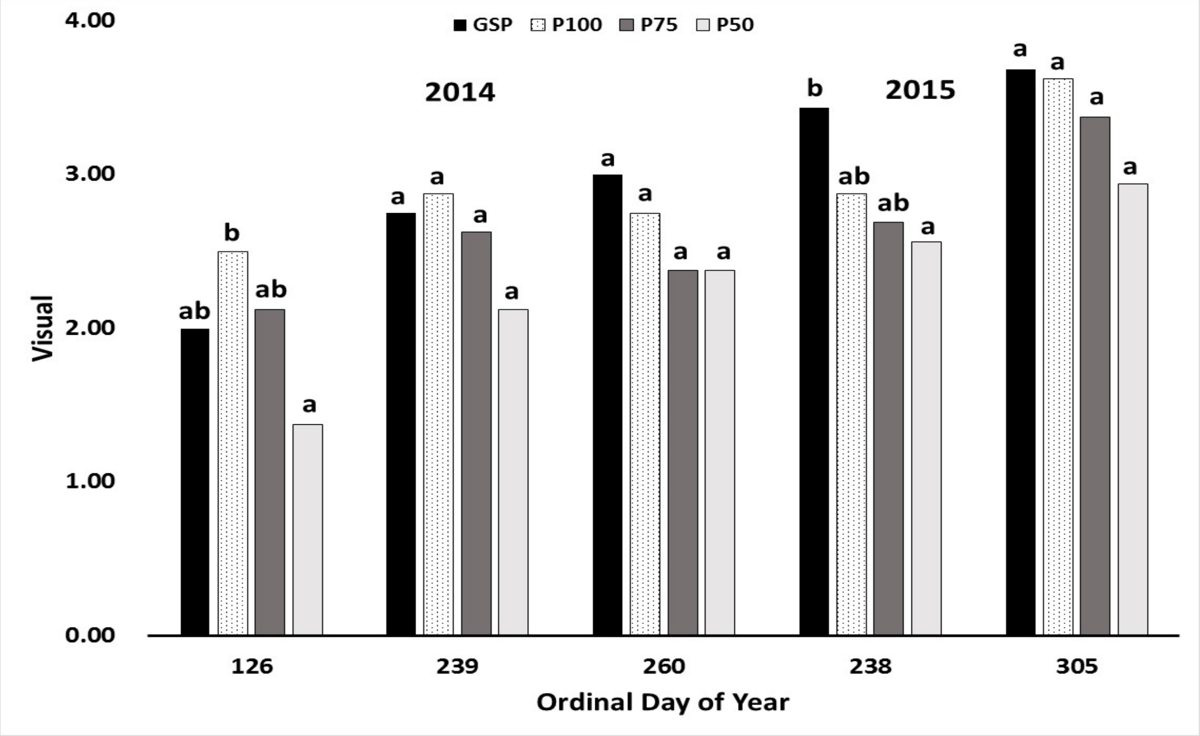
Shoot biomass at the first sampling date in 2014 showed no significant difference, but the heights for the same date had a significant difference between P100 and P50 (Appendix Fig. 2; Fig. 2; Tables 7 and 8). On the second sampling date for biomass, there was a significant difference with P100 having significantly greater biomass than P75 and P50. On the same date, P50 had significantly less biomass than the GSP. There was the same trend in the heights for the same date, but the only ones with significance were the GSP and P100 having greater heights than P50.



Appendix Figure 2 Kentucky bluegrass biomass for 2014 for a trial on sand soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly at the 100% rate, and polymer coated urea/ ammonium sulfate split applied once in spring and again in fall at the 100% (P100), 75% (P75), and 50% (P50) rates are shown. Statistical significance is shown within the figure. Data shown in Table 8.

Loam Health

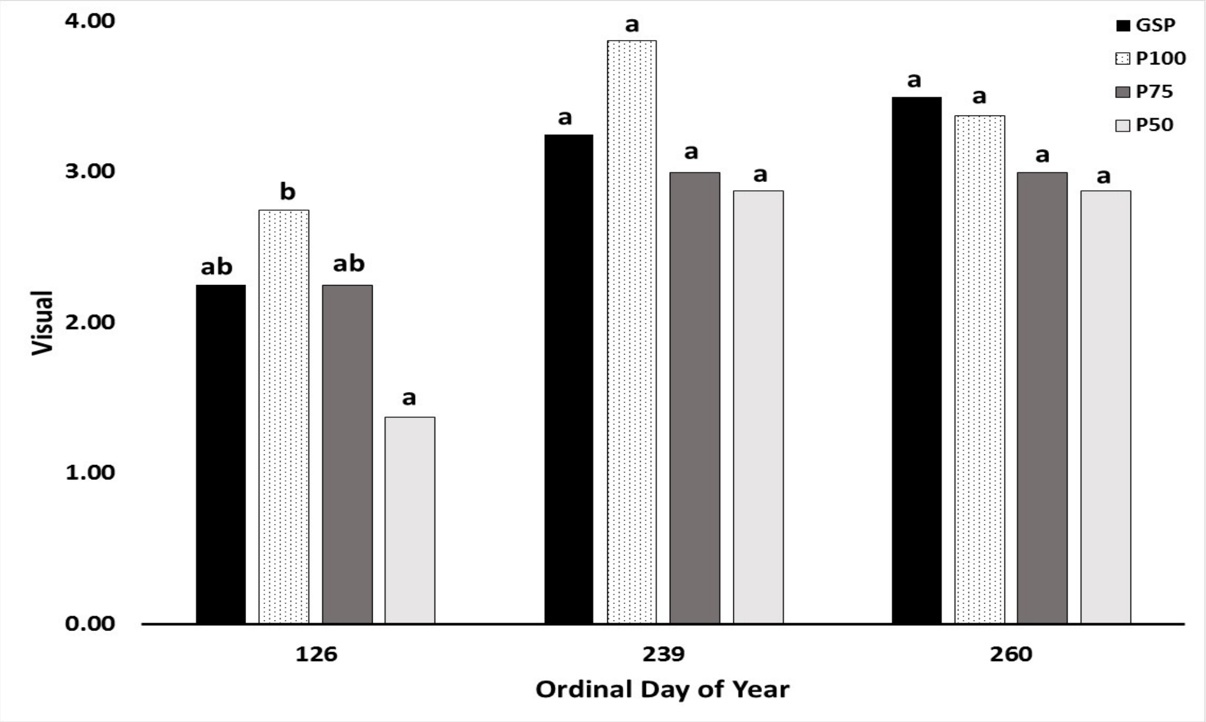
Although NDVI did not show a difference on ordinal day 126, when the first visual ratings of plant health and verdure were made in 2014, P100 had significantly higher ratings than P50 (Fig. 3; Appendix Fig. 3; Tables 9-11). On the following visual rating dates, there were no significant differences which corresponds with the NDVI readings on the same dates. In 2015, the GSP had significantly greater visual ratings than P50 on the first date, but this was not present in the NDVI readings for the same date. The second date in 2015 did not show any significance in the visual ratings or the NDVI readings for the same date.



Appendix Figure 3 Kentucky bluegrass visual ratings for 2014 and 2015 for a trial on loam soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly at the 100% rate, and polymer coated urea/ammonium sulfate split applied once in spring and again in fall at the 100% (P100), 75% (P75), and 50% (P50) rate are shown. Statistical significance is shown within the figure. Data shown in Table 11.

Sand Health

Visual ratings on the first dates showed a significant difference between P100 and P50 which did not correspond with the NDVI readings for the same date (Fig. 4; Appendix Fig. 4; Tables 12 and 13). On both the second and third dates, the visual ratings showed no significant differences between the treatments which corresponds with the NDVI readings for the same dates.



Appendix Figure 4 Kentucky bluegrass visual ratings for 2014 for a trial on sand soil. The grower's standard practice (GSP) of urea/ammonium sulfate applied monthly at the 100% rate, and polymer coated urea/ammonium sulfate split applied once in spring and again in fall at the 100% (P100), 75% (P75), and 50% (P50) rate are shown. Statistical significance is shown within the figure. Data shown in Table 13.

P-values

The following tables give the p-values for each treatment on the corresponding ordinal days.

Appendix Table 2 P-values for root biomass in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	P100	1.0000
303	GSP	P75	1.0000
303	GSP	P50	0.9138
303	GSP	ctrl	0.9979
303	P100	P75	1.0000
303	P100	P50	0.9844
303	P100	ctrl	1.0000
303	P75	P50	0.9373
303	P75	ctrl	0.9990
303	P50	ctrl	0.9996

Appendix Table 3 P-values for root biomass in the sand trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Significance is at *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	P100	0.8347
303	GSP	P75	1.0000
303	GSP	P50	0.9998
303	GSP	ctrl	0.6806
303	P100	P75	0.7938
303	P100	P50	0.9709
303	P100	ctrl	1.0000
303	P75	P50	0.9994
303	P75	ctrl	0.6304
303	P50	ctrl	0.8985

Appendix Table 4 P-values for height in the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
135	GSP	ctrl	<.0001
135	P100	P50	0.0128
135	P100	ctrl	<.0001
135	P75	ctrl	<.0001
135	P50	ctrl	<.0001
295	P100	P50	0.0005

Appendix Table 5 P-values for height in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
146	GSP	ctrl	0.0004
146	P100	ctrl	0.0014
154	GSP	ctrl	<.0001
154	P100	P50	0.0022
154	P100	ctrl	<.0001
154	P75	ctrl	0.0073
161	GSP	ctrl	0.0179
161	P100	ctrl	0.0024
175	P100	P50	0.0199
182	GSP	ctrl	0.0217
182	P100	ctrl	0.0217
196	GSP	P50	0.0199
196	GSP	ctrl	0.0057
203	GSP	ctrl	0.0050
210	GSP	ctrl	0.0049
224	GSP	ctrl	<.0001
238	GSP	ctrl	0.0022
245	GSP	ctrl	0.0018
261	GSP	ctrl	0.0003
266	GSP	ctrl	<.0001
266	P100	ctrl	<.0001
266	P75	ctrl	<.0001
273	GSP	ctrl	0.0020
273	P75	ctrl	<.0001
280	P100	ctrl	<.0001
287	GSP	P50	<.0001
287	GSP	ctrl	<.0001
287	P100	ctrl	0.0012
301	GSP	ctrl	<.0001
301	P100	ctrl	0.0203
301	P75	ctrl	0.0028
238	GSP	ctrl	0.0022

Appendix Table 6 P-values for height in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value		Ordinal Day	Treatments		p-value
135	P100	P75	0.0079		253	GSP	ctrl	0.002
135	P100	ctrl	<.0001		253	P100	ctrl	0.002
135	P75	ctrl	<.0001		267	GSP	P50	<.0001
135	P50	ctrl	<.0001		267	GSP	ctrl	<.0001
162	GSP	P100	0.0001		267	P100	P50	0.002
162	P100	P50	<.0001		267	P100	ctrl	0.0001
162	P100	ctrl	<.0001		274	GSP	P50	<.0001
162	P75	ctrl	0.0269		274	GSP	ctrl	<.0001
170	P100	ctrl	0.0269		274	P100	P50	<.0001
176	P100	P50	0.0269		274	P100	ctrl	<.0001
176	P100	ctrl	0.0005		274	P75	ctrl	0.0005
183	P100	P50	0.0079		295	P100	ctrl	0.0079
183	P100	ctrl	0.0001		309	P100	ctrl	<.0001
211	P100	ctrl	0.0079					

Appendix Table 7 P-values for biomass in the loam trial in 2014-2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

2014					2015			
Ordinal Day	Treatments		p-value		Ordinal Day	Treatments		p-value
135	P100	P50	0.0050		238	GSP	P50	0.0006
					238	GSP	ctrl	0.0003

Appendix Table 8 P-values for biomass in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
135	GSP	P50	0.0021
135	P100	P75	0.0032
135	P100	P50	0.0001
275	P100	ctrl	0.0044

Appendix Table 9 P-values for NDVI readings in the loam trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
309	P100	ctrl	0.0199

Appendix Table 10 P-values for NDVI readings in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
114	GSP	ctrl	<.0001
114	P100	P50	0.0008
114	P100	ctrl	<.0001
114	P75	ctrl	0.0002
154	GSP	ctrl	0.0079
154	P100	ctrl	0.0060

Appendix Table 11 P-values for NDVI readings in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value		Ordinal Day	Treatments		p-value
134	GSP	ctrl	0.0024		190	GSP	ctrl	<.0001
134	P100	ctrl	<.0001		190	P100	P50	<.0001
134	P75	ctrl	0.0017		190	P100	ctrl	<.0001
160	GSP	P100	<.0001		190	P75	P50	<.0001
160	GSP	P75	0.0002		190	P75	ctrl	<.0001
160	P100	P75	<.0001		197	GSP	ctrl	<.0001
160	P100	P50	<.0001		197	P100	P50	0.0066
160	P100	ctrl	<.0001		197	P100	ctrl	<.0001
160	P75	P50	<.0001		197	P75	ctrl	<.0001
160	P75	ctrl	<.0001		204	GSP	ctrl	0.0022
169	GSP	P100	0.0007		204	P100	P50	0.0002
169	GSP	ctrl	<.0001		204	P100	ctrl	<.0001
169	P100	P50	<.0001		211	GSP	ctrl	0.0027
169	P100	ctrl	<.0001		211	P100	ctrl	<.0001
169	P75	P50	<.0001		211	P75	ctrl	0.0079
169	P75	ctrl	<.0001		218	P100	ctrl	0.022
176	GSP	P100	0.0028		274	GSP	ctrl	0.0126
176	GSP	ctrl	0.0006		281	GSP	ctrl	0.0445
176	P100	P50	<.0001		281	P100	ctrl	0.0149
176	P100	ctrl	<.0001		288	GSP	ctrl	0.0052
176	P75	P50	0.0128		295	GSP	ctrl	<.0001
176	P75	ctrl	<.0001		295	P100	ctrl	<.0001
183	GSP	P100	0.0469		295	P75	ctrl	0.0002
183	GSP	ctrl	0.0029		309	GSP	ctrl	0.0012
183	P100	P50	<.0001		309	P100	ctrl	<.0001
183	P100	ctrl	<.0001		309	P75	ctrl	<.0001
183	P75	ctrl	<.0001		309	P50	ctrl	0.0121
190	GSP	P50	0.0002					

Appendix Table 12 P-values for visual ratings in the loam trial in 2014 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
126	P100	P50	0.0369

Appendix Table 13 P-values for visual ratings in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
238	GSP	P50	0.0208
303	P100	ctrl	<.0001
303	P75	ctrl	<.0001
303	P50	ctrl	0.0049

Appendix Table 14 P-values for visual ratings in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
126	GSP	ctrl	0.012
126	P100	P50	0.0033
126	P100	ctrl	<.0001
126	P75	ctrl	0.012
239	GSP	ctrl	<.0001
239	P100	ctrl	<.0001
239	P75	ctrl	0.0008
239	P50	ctrl	0.0033

Appendix Table 15 P-values for nitrogen concentration in the loam trial in 2014-2015 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

2014					2015			
Ordinal Day	Treatments		p-value		Ordinal Day	Treatments		p-value
135	P100	P50	0.0087		238	GSP	P50	0.0006
135	P100	ctrl	0.0039		238	GSP	ctrl	0.0003
275	GSP	P100	0.0309					
275	P100	P50	0.0002					

Appendix Table 16 P-values for nitrogen concentration in the sand trial in 2014 for treatments in relation to each other. The treatments include the grower’s standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
135	GSP	P100	0.0019
135	GSP	ctrl	0.0052
135	P100	P75	0.0247
135	P100	P50	<.0001
135	P100	ctrl	<.0001
135	P75	ctrl	0.0004
275	GSP	P100	0.0191
275	GSP	P50	0.0007
275	P100	P75	0.0028
275	P100	P50	<.0001
275	P75	P50	0.0045

Appendix Table 17 P-values for crown density in the loam trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	P100	0.9835
303	GSP	P75	0.9659
303	GSP	P50	0.9892
303	GSP	ctrl	0.0681
303	P100	P75	1.0000
303	P100	P50	1.0000
303	P100	ctrl	0.0121
303	P75	P50	1.0000
303	P75	ctrl	0.0093
303	P50	ctrl	0.0137

Appendix Table 18 P-values for crown density in the sand trial in 2015 for treatments in relation to each other. The treatments include the grower's standard of practice (GSP) and two applications of PCU at the full (P100), 75% (P75), or 50% (P50) rate as well as the control (ctrl). Only statistically significant p-values are shown. *P*= 0.05

Ordinal Day	Treatments		p-value
303	GSP	P100	0.9989
303	GSP	P75	0.9781
303	GSP	P50	0.9470
303	GSP	ctrl	0.0281
303	P100	P75	0.7946
303	P100	P50	0.6986
303	P100	ctrl	0.0080
303	P75	P50	1.0000
303	P75	ctrl	0.1811
303	P50	ctrl	0.2424

Appendix B

Appendix Figure 5 Treatments in the loam trial in November 2014. Lighter colored plots had less nitrogen applied in the fall or no nitrogen applied.

Appendix Figure 6 Treatments in the sand trial in November 2014. Lighter colored plots had less nitrogen applied in the fall or no nitrogen applied.

Appendix Figure 7 Treatments in the loam trial in April 2015. Lighter colored plots came out of dormancy later than the plots which had nitrogen applied in the fall.

Appendix Figure 8 Treatments in the sand trial in September 2015. Darker plots received more nitrogen in the fall than the lighter plots.