Nitrogen Release Characteristics of Commercial Organic Fertilizers in Turfgrass

by

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Abstract

Although organic fertilizer sources are widely marketed for application to turfgrasses, there is limited research that examines their nitrogen (N) release characteristics. For this research project, 'organic' refers to commercial fertilizers which are manufactured from wastes such as sewage sludge (bio-solid), poultry by-products (manure, litter, feather-meal), or other by-products (whey, meals, oils). The process of mineralization, which is the microbially-mediated conversion of organic N to plant available ammonium-N (NH4) and nitrate-N (NO_3) forms, is the controlling factor of N release from organic fertilizers. Thus, organic fertilizers behave as a slow release N fertilizer, with a delayed greening response, low burn potential, and varying N release rates in different environments. Of the environmental variables, temperature has perhaps the greatest effect on microbial activity, which in turn controls inorganic N release from the organic sources. Although N mineralization from raw wastes such as manure or bio-solids has been widely studied, N release from processed, commercially-blended organic fertilizers has been less studied, especially in turfgrass systems.

Two separate three-month studies evaluated the effects of organic fertilizers on hybrid bermudagrass growth and performance. In general, application of sources with large portions (or 100%) of soluble N (urea and Scotts Turf Builder) produced turf with a darker green color, higher shoot density and greater clipping yield than plots fertilized with large portions of organic N. Although organic fertilizers are often touted as maintaining color for longer periods of time, it was not the case in this study, as urea provided consistent high quality color for the same 8-10

week period as the organic sources. There were few differences in soil N, C, or microbial biomass due to N source.

Six individual ten-week incubation studies (two repetitions per temperature) were performed at 15, 25, and 35°C. Mineralization of organic N was measured and it was significantly affected by treatment and a treatment x temperature interaction. Optimum inorganic N release was observed at 25°C, with the least amount of N mineralization occurring at 15°C. Ammonium-N was largely produced during the first two weeks after application, and then converting to mostly NO_3-N.

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Introduction

The early 19th century sparked a new revolution in fertilization technology, when the first chemically produced fertilizer, superphosphate, was made from bones treated with sulfuric acid. The first synthetic nitrogen (N) fertilizer was produced in 1903 by the electric arc process, which converted nitric acid into calcium nitrate. Ten years later synthetic ammonia (NH_3) became widely available (Russel and Williams, 1977). Chemical fertilizers have made a major impact on agriculture, allowing for greater yields of crops and more aesthetically pleasing ornamentals and turfgrass (Sheridan, 1979).

Chemically produced fertilizers have proven to be beneficial, but are by no means the only option. The expense of these products, coupled with a global economy in which fertilizer prices are increasing, has directed attention to alternative fertilizer sources. Renewed interest in recycling and natural product usage has increased interest in the reuse of industrial waste products, including municipal solid wastes, processing wastes, bio-solids, manures, and other materials that would otherwise find their way into landfills.

Organic waste products have been studied in row crop production, but research on their utility for turfgrass fertilization is limited. With increasing marketing of new organic products in the turfgrass industry, research is needed to support the benefits of many of these products. In order to evaluate a waste product for its potential as a fertilizer, it is critical to know its nutrient release characteristics.

Several methods have been used to evaluate nutrient release characteristics in organic wastes (Balkcom et al., 2001; Mamo et al., 1999; Carrow, 1997). Organic products are often slow to break down and release nutrients. He et al. (2000) observed a 23.5 and 48.4% recovery of added N at the end of a one year experiment using yard waste and bio-solid composts. Nadelhoffer (1990) studied organic products using a microlysimeter system, and was able to obtain reproducible N release measurements with experiments lasting 45 weeks. These types of studies, coupled with field studies that examine variables such as turf color, density, and growth, provide a thorough investigation of the effect of organic fertilization on turf.

Wastes in Agriculture

The term waste generally carries a negative connotation; however, research studies have shown that the reuse of some waste products can have a positive impact on our environment. An EPA survey reported that a total of 226 million Mg of municipal solid waste (yard trimmings, food, and packaging wastes) was generated in 2008, of which only 33.1 million Mg were recycled (EPA, 2008). Typically 67% of the municipal solid waste in the United States is placed in a landfill, 23% is recycled, and 10% is incinerated (Entry et al., 1997).

The increasing cost of safe disposal of municipal solid waste in landfills is one reason for renewed interest in application of organic by-products to agricultural lands. Municipal solid wastes have variable carbon (C) to N ratios, which strongly controls the rate of nutrient release (Mamo et al., 1999; Sims, 1990). Studies have shown that municipal solid wastes can supply a sufficient amount of N for plant growth as well as small amounts of phosphorus (P), potassium

(K), calcium (Ca), magnesium (Mg), sulfur (S), and iron (Fe) (Warman et al., 2009; Mamo et al., 1999). Trace elements including copper (Cu), manganese (Mn), zinc (Zn), boron (Bo), cadmium (Cd), chromium (Cr), nickel (NI), and lead (Pb) were also present (Warman et al., 2009; Meima and Comans, 1999).

Waste products encompass much more than household garbage. Metals and fuel drive western economies today, and with as much of these resources being used, there are by-products requiring disposal. Precious metals and coal are probably the two most important resources used today which require mining. Mining operations are intensive and have large impacts on the local areas surrounding these mines, as the United States has 1,458 coal mines that produced about 1.1 million Mg of coal in 2008 (U. S. Department of Energy, 2008).

Coal powered plants create a residue known as fly ash. Belyaeva and Hayes (2009) observed that a 25% fly ash addition to green manure increased water retention by 75%. Hermann et al. (2009) examined fly ash in landfill cover liners. Fly ash was mixed with sewage sludge and placed under 2.4 J cm^{-3} of pressure. Hydraulic conductivity was between 1.7 X 10^{-11} and 8.9 X 10^{-10} m s^{-1}, which met the hazardous waste landfill cover requirement of less than 10^{-9} m s^{-1}.

When metal is extracted from ore, the by-product that is produced is known as slag. For every 0.9 Mg of steel produced, roughly 150 kg of slag is generated. Slag has been shown to have high concentrations of Ca (29%) and Mg (5%), which indicates its use as a potential liming agent. Rodriguez et al. (1994) observed that the highest application of slag (7,500 kg ha^{-1}) raised the pH of the soil from 5.3 to 6.5. Pierre (1927) quantified the amount of slag needed to correct acidity developed from applying nitrogenous fertilizers and found that 1 kg of slag was required to correct the acidity formed from 0.45 kg of ammonium sulfate ($(NH_4)_2SO_4$), and 1.5-2.2 kg of slag offered the same effect as 0.45 kg of calcium carbonate ($CaCO_3$). Slag is also known to have high concentrations of phosphate, and will increase plant concentrations of Ca, Mg, and P, while lowering K and Mn (Rodriguez et al., 1994). Other benefits of slag usage include aiding in P removal from wastewater and reducing methane emission from rice fields (Pratt et al., 2008; Ali et al., 2008).

However, many waste products, such as fly ash, municipal solid waste, and animal manures have high concentrations of heavy metals, specifically Cu, Cr, Pb, Zn, and Ag, which have the potential to contaminate ground and surface waters (Chandler et al., 1997; Hargreaves et al., 2007; Del Castilho et al., 1993). In Alabama, a 1999 survey reported that 1.5 million Mg of broiler litter was produced and mainly applied as an organic fertilizer; however, elevated levels of As, Cd, Co, and Cr in the litter may cause additional agronomic management issues (Kpomblekou et al., 2002)..

Prior to the 1840's, farmers used manures, wood ashes, and bones as sources of crop nutrients. In 1843, the first widely used commercial fertilizer in the United States was derived from Peruvian guano, containing large amounts of N and P (Sheridan, 1979). In the United States, an increased demand for animal products has resulted in greater animal and animal processing wastes, including manure, litter, tankage, and feather, bone, and blood meal. Concentrated animal feeding operations (CAFO) maintain large numbers of livestock in small areas of land. The amount of waste that accumulates in these CAFO's is large, and disposing of these products safely has become burdensome and expensive. Using these waste products as fertilizers has become a renewed practice, and is growing in popularity.

Cattle and poultry manures are two of the most frequently used materials for organic fertilizers. A study comparing the effects of dairy manure and inorganic fertilizers to turfgrass showed a significant increase in soil organic matter with dairy manure compost. Soils with applied manure compost showed increases in electrical conductivity, pH, and overall soil nutrient levels (Butler et al., 2008). A study of dairy and poultry manure compost applications to Kentucky bluegrass (*Poa pratensis*) and perennial ryegrass (*Lolium perenne*) resulted in higher turf quality as compared to the non-treated and inorganic fertilizer treatments. The researchers concluded that manures may have a beneficial long-term effect (Petrovic et al., 2008). The nutrient content and release characteristics of manures are highly variable and require research to assess their agronomic benefits and/or limitations.

Nutrients in Animal Wastes

'Organic' in the simplest form means that a compound contains C; however, fertilizer products that are made from animal by-products are generally referred to as 'organic' fertilizers. From here on, the term organic will be used to signify a fertilizer that contains C and are derived from recycled animal wastes. Many organic fertilizers are derived from animal excrement, such as poultry litter and cow manure, but also contain by-products such as bone, feather, and blood meals. Poultry litter may provide plant macro and micronutrients, but additives such as feather, bone, and blood meal are used to augment the overall fertilizer nutrition (King and Torbert, 2007).

Organic N can only be absorbed by the root after conversion to inorganic N by the process of mineralization. Ammonification, the first step in mineralization, is an enzymatic process in which soil microbes actively breakdown organic N compounds into ammonia (NH_3)

and ammonium (NH_4). This is performed by both aerobic and anaerobic microorganisms that cause an enzymatic oxidation (Eldridge et al., 2008). Following ammonification, NH_3 can be further oxidized in the second process of nitrification. In nitrification, *Nitrosomonas* and *Nitrobacter* are the two most crucial N oxidizing bacteria. *Nitrosomonas* oxidizes NH_3 to nitrite (NO_2), while *Nitrobacter* converts NO_2 to NO_3. These bacterial colonies can be found in higher concentrations than other soil nitrifiers (Belser and Schmidt, 1978).

Bio-solids typically have 3.5–6% total N, and 80-90% is in the organic form (Eldridge et al., 2008). The N in these products is largely organic N, and must be mineralized to be plant available. Compost and bio-solids have been shown to increase the concentration of microbial biomass in the root zone, as well as soil contents of organic N and C (Tian et al., 2008; Hartl and Erhart, 2005). Addition of organic fertilizers increased total bacterial counts within 4 days of application, and nitrifier populations were three times more prevalent in fertilized soils (Li, 2005; Hermansson and Lindgren, 2001).

Golf course superintendents typically apply large amounts of N fertilizer in order to maintain high quality playing surfaces (Brown et al., 1982). Application of inorganic fertilizers, such as ammonium nitrate (NH_4NO_3), can result in NO_3 leaching into groundwater due to the abundant amount of highly soluble N that exceeds plant uptake ability. Given their slow-release nature, organic waste fertilizers may be one solution to these problems. When nutrients such as N and P are bound by organic matter, they are less susceptible to losses through surface runoff and leaching (Balkcom et al., 2001). They are slowly mineralized and become available to the plant. Turkey litter, for example, showed less than 1% N loss due to leaching from a top-dress application (Johnson et al., 2006). Cumulative NO_3 loss from plots of bermudagrass [*Cynodon* *dactylon* (L) Pers.], showed significantly less NO_3 loss from plots receiving poultry and dairy manures than NH_4NO_3 (King and Torbert, 2007).

Soils amended with organic N have improved physical, chemical, and microbiological soil properties (Entry et al., 1997). Organic fertilizers increased soil organic matter, which increased water holding capacity, soil aggregation, soil aeration and permeability, while decreasing bulk density (Johnson et al., 2006). Although there are beneficial qualities of organic fertilizers in plant production, there are also negative issues. Carrow (1997) concluded that no single organic fertilizer contained the most desired mix of immediate and long-term N release characteristics. Organic fertilizers generally have a low nutrient analysis and thus need larger application rates to reach desired fertility recommendations. Organics are accompanied by a noticeable odor and have pesticide sorption tendencies that could pose a problem, especially for applications on golf courses (Li, 2005).

Poultry litter has an average N to P ratio of 3:1, and when applied on a N basis, it delivers more P than most agronomic crops can utilize (Moore et al., 1995; Pote et al., 1996). Long-term applications of poultry litter can result in P runoff. Surface-applied fertilizers typically have the greatest P runoff, which occurs within the first 24 hours after application (Baker et al., 2007; Shuman, 2002). Phosphorus runoff may lead to eutrophication of lakes and streams, eventually igniting algal blooms that lead to subsequent fish kills (Sharpley et al, 2003). Pote et al. (1996) looked at P runoff from swine, broiler, caged litter, and manure sources at P application rates ranging from 0 to 304 kg P ha^{-1}. Concentrations of P in runoff samples taken 30 minutes after application were 0.31 to 1.81 mg L^{-1} of dissolved reactive P and 0.37 to 2.18 mg L^{-1} of bio-available P.

Importance of Nitrogen

Nitrogen is crucial for plant chlorophyll, proteins, and amino acids. The N requirement for individual plant species varies greatly depending on the plant itself (Petrovic, 1990). Plant uptake of N is mainly through the root system and is also a function of N availability and concentration (Petrovic, 1990). Turfgrass quality is largely controlled by N. It has been shown that sufficient N must be applied to turf annually to maintain shoot growth, recuperative potential, color, and quality (Kerek et al., 2003).

High N uptake has been correlated with periods of high color intensity and clipping yield (Landschoot and Waddington, 1987). Once N has been absorbed through the roots and utilized in the plant, overall plant available N in the soil becomes deficient and the turfgrass requires additional N to sustain normal growth. When N is lacking, stunted growth and overall yellowing of the shoots occurs. Bowman (2003) discussed the importance of controlled daily N additions in order to achieve stable growth and tissue-N pools. Weekly and monthly N applications to perennial ryegrass caused erratic fluctuations in growth and tissue-N pools. Earlier studies on birch (*Betula lenta)* and *Salix* showed that unexpected changes in daily N additions created unstable tissue-N levels and leaf chlorosis (Ingstead, 1980 and 1981; Ericsson, 1981; Ingstead and McDonald, 1989). Marshall et al. (2001) observed 43% N uptake in tall fescue fertilized with broiler litter applied at rates from 103 to 252 kg N ha^{-1}.

Plants take up considerable N to maintain overall plant health and quality. Mowing practices on golf courses, which generally involve reel mowers, are an important source of N loss via clipping removal. A study that evaluated clipping return showed that return of clippings increased dry matter yield from 30 to 72%, total N uptake from 48 to 60%, and N use efficiency from 52 to 71%. Some plots also showed an increase in overall turf quality due to clipping return (Kopp and Guillard, 2002). Fagerness et al. (2004) applied NH_4NO_3 to bermudagrass at 50 kg N ha^{-1} three times over 14 weeks, and recovered 65% of the total N in plant tissue (clipping, root, and rhizome). Shi et al. (2006b) measured N mineralization rates from bermudagrass clippings in a 28-day incubation study. They found that 20 to 30% of N in the clippings had mineralized by the end of the incubation study. Yao et al. (2009) measured total C and N mineralization increases of 58 and 33%, respectively, during a similar clipping return study on bermudagrass and perennial ryegrass.

Fate of Nitrogen

Nitrogen has multiple sources of entries and outlets from which it can enter the plant/soil or be lost to the environment. These include mineralization (ammonification and nitrification), immobilization (NO_3 to organic N), volatilization (NH_3), denitrification (NO_2, NO, and N_2), plant uptake, and clay fixation. Nitrogen can accumulate in the soil from N fixation via lightning, plant decomposition, organic wastes, or via the application of fertilizers. Losses of N from the soil include plant uptake, gaseous atmospheric loss, soil storage, leaching, runoff, and clipping removal (Petrovic, 1990). Once fertilizer N is in the soil, it becomes part of the soil organic matter, plant, or soluble N pool (NO_3 and NH_4) (Kerek et al., 2003). Bowman and Paul (1992) observed a 35% foliar absorption of N within 48 hours of a 5 g N m^{2-} application of urea to perennial ryegrass. The partitioning of N was 32, 52, and 16% amongst new leaves, old leaves and shoot tissue, and roots, respectively.

Plants take up N in two forms: NH_4 and NO_3. When organic-N is applied to the soil, it must first be mineralized to NH_3, then protonated chemically to form NH_4. Ammonium is fairly stable in the soil and its loss is often negligible as the cation is not prone to leaching (Mazur and White, 1983). Ammonium can then be converted into NO_3 via NO_2 in the nitrification process. Nitrate, an anion, is highly leachable (Di and Cameron, 2002). Mineralization of organic N is influenced by several factors, including but not limited to: N content of compost, C:N ratio, soil texture, and climate (Hartl and Erhart, 2005). Mineralization rates of N are comparable among alkaline and acidic soils (Yao et al., 2009). High correlations between C released as CO_2 and available N have been shown (Castellanos and Pratt, 1981).

Soil moisture content is a significant factor in determining mineralization rates, with measured mineralization greatest at field capacity (Watts et al., 2007). Soil temperature also affects mineralization. Amongst three soil temperatures, maximum N mineralization occurred at 25°C, which was 3.7 times faster than mineralization at 15°C, while mineralization at 15°C was 13 times faster than at 5°C (Watts et al., 2007). There is limited research that examines mineralization at temperatures greater than 25°C, but some research suggests that maximum microbial activity occurs between 30 and 35°C (Jones and Hood, 1980; Fdz-Polanco et al., 1994; Lee et al., 2001).

Once ammonification has taken place, NH_3 is vulnerable to atmospheric loss through volatilization. Ammonia volatilization is more prevalent in soils with higher pH values in warmer windier climates (Clay et al., 1990; Ferguson and Kissel, 1986). Mulvaney et al. (2008a) found drastic seasonal differences in NH_3 volatilization. Nitrogen sources included beef feces, dairy feces, and dairy urine. Ammonia losses ranged from 1.8% during the winter to 20.9% during summer. Ammonia loss through volatilization has been shown to be highly variable and drastically reduced by watering immediately after application of urea fertilizer (Petrovic, 1990; Bowman et al., 1987). Another study suggests that less than 1% of added N treatments were lost as gaseous forms (Burger and Venterea, 2008). Marshall et al. (2001) observed a 6% loss of applied N from volatilization and denitrification combined from a boiler litter application to tall fescue (*Festuca arundinacea)* pastures. When chicken litter was applied at 70 kg N ha^{-1} to tall fescue plots, volatilization was not a major pathway for N loss (Marshall et al, 1998). Studies with slow-release fertilizers showed less than 2% N loss through volatilization (Knight et al., 2007; Torello et al., 1983; Nelson et al., 1980). Fertilizer applications to bentgrass (*Agrostis stolonifera*) had volatile N loss in the descending order: urea, sulfur-coated urea, methylene urea, composted sewage sludge, NH_4NO_3, and polymer coated urea (Knight et al., 2007).

Nitrate, an anion, is highly mobile in the soil and may be lost via leaching, denitrification, and plant uptake (Johnson et al., 2006; Civeira and Lavado, 2007). Factors affecting the concentration and rate of leaching include soil type, irrigation rate, N-application rate, frequency and timing of fertilizer applications, stand density, rooting characteristics, and plant N demands (Petrovic, 1990). Nitrate leaching may also differ from season to season, with fall applications having a lower rate of loss (Burger and Venterea, 2008). Up to one half to two thirds of applied N may leach in the first 14 days after fertilizer application (Pare et al., 2008). Nitrates leached from fertilizer applications have the potential to negatively affect water quality and subsequently cause human health concerns, especially with pregnant women and nursing infants (Pare et al., 2008).

Nitrate loss may be controlled through management practices. Snyder et al. (1984) looked at the potential of tension-meter controlled irrigation systems to reduce N leaching. Ammonium nitrate and sulfur-coated urea were applied at a 5 g N m^{-2} $month^{-1}$. Nitrogen loss ranged from 22 to 56% from the daily irrigated NH_4NO_3 plots (no sensors) and from <1 to 6%

from all sensor irrigated plots. The study concluded that sensor irrigation significantly reduced N leaching from all N sources.

Some studies have shown that NO_3 leaching may also be reduced through plant cultivar selection. One study looked at a St. Augustine (*Stenotaphrum secumdatum*) lawn versus a mixed medium landscape (12 ornamental species) and found total N leaching losses of 4.1 and 48.3 kg N ha^{-1} in one year, respectively (Erickson et al., 2001). Bowman et al. (2002) found similar results amongst 6 different turf species, with St. Augustine being the most effective and Meyer zoysiagrass (*Zoysia japonica*) the least effective. Studies have also concluded that NO_3 leaching is more prevalent on sandy soils (Brown et al., 1982; Bigelow et al., 2001; Bowman et al., 1998; Rieke and Ellis, 1972; Starr and DeRoo, 1981). Nitrate leaching may also be reduced in dense or deep rooted turf species (Pare et al., 2006; Bowman et al., 1998).

Due to the expense that homeowners and turfgrass managers incur with inorganic fertilizers, alternative fertilizer sources have been studied. Guillard and Kopp (2004) looked at the potential of organic N sources on cool season grasses. Two treatments, polymer-coated sulfur-coated urea (synthetic organic) and Sustane® (organic slow release), showed significantly less NO_3 loss through leaching, compared to NH_4NO_3. Spanning the entire three-year study, a total of 441 kg N ha^{-1} was applied for each treatment, and total NO_3-leaching loss was 16.8, 1.7, and 0.6% of total applied N for NH_4NO_3, polymer-coated sulfur-coated urea, and Sustane®, respectively.

King and Torbert (2007) observed NO_3 losses from NH_4NO_3, sulfur-coated urea, composted dairy manure, and poultry litter applied on bermudagrass. They found that over a 10 week period NH_4NO_3, sulfur-coated urea, composted dairy manure, and poultry litter treated plots lost 37, 25, 10, and 7% of total N applied, respectively. Brown et al. (1982) found similar results among NH_4NO_3, 12-12-12 (12% ammoniacal N), Milorganite, isobutylene diurea, and urea formaldehyde fertilized plots, with the largest N loss from turf fertilized with NH_4NO_3, and decreasing in order as listed. The largest NO_3 loss was 23%, and there was a 25 to 30 day delay before NO_3 appeared in leachate from the Milorganite source. They concluded that applications of slow-release N sources would provide minimum NO_3 loss, while offering a continuous N supply.

Nitrate can also be denitrified, a microbial process converting NO_3 or nitrous dioxide to N gas or nitrous oxide, with subsequent loss to the atmosphere (Parsons et al., 1991; Mahimairaja et al., 1995). Factors promoting the rate of denitrification include: 1) high irrigation frequency (Christensen, 1983), 2) high rate of N fertilization (Mahimairaja, 1995; Williams et al, 1992; Webster and Dowdell, 1982), 3) addition of organic matter (Christensen, 1983; Mancino and Torello, 1986), 4) saturated or high soil water content (Mancino et al., 1988; Petrovic, 1990), and, 5) warm soil temperatures (Mancino et al., 1988; Bijoor et al., 2008). Highest NO_X (mono-N oxides) emissions occur directly after N addition (Thornton et al., 1998). These gaseous forms of N are lost more rapidly in finer-textured soils (Gentile et al., 2008; Mancino et al., 1988). Mancino et al. (1988) found denitrification-N loss rates from potassium nitrate to be 2.2 and 5.4% of applied N. Soil temperatures of 30°C and saturated soils significantly increased N loss to between 44.6 and 92.6% of applied N (Mancino et al., 1988). When soils were not saturated, NO and NO_2 emissions were below 1% (Mancino et al., 1998).

Nitrate may also be immobilized and rendered unavailable to plants in the soil by reverting to organic N through microbial processes, and it will no longer be plant available. Factors that affect immobilization include: 1) organic matter content, 2) C:N ratio, and, 3) soil microbial biomass (Hadas et al., 1992). A microbial efficiency factor of 0.4 and a C:N ratio of 19:1 or higher are required for immobilization to occur (Hadas et al., 1992; Calderon et al., 2004). A study looking at hog manure and liquid dairy manure found N immobilization to be 14 and 40% of initial NH_4 applied, respectively (Burger and Venterea, 2008).

Turfgrass and Nitrogen

There is an abundance of research on waste products and their beneficial properties on conventional row crops; however, research in organic fertilization in turfgrass systems is lacking. Turfgrasses are the most crucial component of athletic fields, golf courses, and homeowner lawns (Beard, 1973). In the southeast U.S., the warm humid environment requires the use of mostly warm season turfgrasses, such as bermudagrass, zoysiagrass , centipedegrass (*Eremochloa ophiuroides*), and St. Augustinegrass. Warm season turfgrasses assimilate CO_2 via the C_4 (four C atom in C fixation process during photosynthesis) pathway, with optimized growth between 27 and 35°C and dormancy in temperatures lower than 10°C (McCarty, 2001).

Bermudagrass is a suitable selection for establishment in the Southeast because of its vigorous growth, and for golf course and athletic fields this is an important property (Guertal and Hicks, 2009). Nitrogen is an essential element for turf establishment, and finding an appropriate rate can be challenging. Nitrogen plays an important role in turf color, growth, shoot rhizome and stolon densities, wear tolerance, and recovery (Carrow et al., 1987). Turfgrass managers will often apply excessive amounts of N in order to overcome stress and injury wear, but this practice can not only cause negative effects to the turf, but also negative environmental effects (Guertal and Evans, 2006). Over-fertilizing turf with N can cause problems such as increased mowing frequency, decreased recovery, decreased rhizomes and stolons, and decreased disease tolerance (Ramos and Curbelo, 1978; Goatley et al., 1994; Mitchell and Dickens, 1979; Golembiewski and Danneberger, 1998).

'Tifsport' bermudagrass was released from the University of Georgia Coastal Plain Experimental Station in 1997 and is rapidly becoming the most popular turf species for southern golf courses and athletic fields (Hanna et al., 1997). 'Tifsport' is a good fit for Alabama turf systems because of its cold tolerance, reduced genetic variability, and ability to recover from stress and injury (Hanna et al., 1997; Trenholm and Unruh, 2005; Karcher et al., 2005). Bermudagrass is also beneficial because of its rapid establishment via lateral stems (rhizomes/stolons) makes it competitive against weeds and disease (Guertal and Evans, 2006; Patton et al., 2004.)

Typical fertilizer programs for bermudagrass fairways require about 20 to 40 kg N ha^{-1} growing $month^{-1}$ (Wu et al., 2007). This is done to prevent loss of N through NO_3 leaching, NH_3 volatilization, and other gaseous losses. Fertilizer N loss can be high and is a function of management, such as irrigation, N source, rate, and timing (Pare et al., 2008). Organic products may have a role here, because of their slow-release properties.

Cool season grasses such as bentgrass, fine fescue, tall fescue, and bluegrass (*Poa spp.*) have optimal growth between 16 and 24°C (Jiang and Huang, 2000). Cool season grasses have only limited adaptation in the South and perform the best in the spring and fall. Bentgrass is used only for putting greens, even though the heat of the summer months will decrease root and shoot growth (Guertal et al., 2005). In order to maintain a green color on golf course greens and a smooth putting surface during the winter months, bentgrass is a common selection, but management practices must be adapted to increase its survivability during the summer (Guertal et al. 2005). The main reason for decreased root density is due to canopy heat, which can be reduced by syringing and/or the use of fans to circulate the air over the green (Guertal et al., 2005).

Koeritz and Stier (2009) showed that an application of 146 kg N ha^{-1} yr^{-1} produced best turf quality, spring green-up, and highest shoot density for cool season putting greens. Creeping bentgrass requires intensive maintenance due to its disease susceptibility to dollar spot (*Sclertonia homeocarpa F.T Bennett*), brown patch (*Rhizoctonia solani Kuhn*), pink snow mold [*Microdochium nivale* (Fries) Samuels and Hallett], and gray snow mold (*Typhula spp*.) (Warnke, 2003).

Common Nitrogen Fertilizer Sources

There are many available N sources that will sufficiently supply nutrients to turfgrass. These are often classified as inorganic soluble, synthetic organic soluble, synthetic organic slow release, and natural organic slow release. The most commonly used are inorganic soluble fertilizers. These generally release nutrients for immediate plant utilization, but nutrients are vulnerable to environmental loss. These products have proven effective, but Landschoot and Waddington (1987) showed that more frequent applications are needed to obtain the uniformity of turfgrass quality that organics offer. Examples of inorganic soluble fertilizers are NH_4NO_3 and $(NH_4)_2SO_4$. These fertilizers are often used when large amounts of N need to be added to the soil, and they are plant available immediately after application. Ammonium sulfate can be used to lower soil pH.

The only soluble synthetic organic fertilizer, urea, is often used in turfgrass fertilization. Urea is organic because it contains C, but it is not commonly applied as a “true organic” fertilizer because it is manufactured synthetically. Urea offers a high nutrient analysis (46-0-0) and a rapid turf response that produces similar yields and color response to that of NH_4NO_3 (Landschoot and Waddington, 1987; Carrow, 1997).

Synthetic organic slow-release products are classified as a physical or chemical slow release. Physical slow-release fertilizers contain resin coats or sulfur coats that degrade, releasing nutrients as a function of coat integrity (Peacock and DiPaola, 1992). The release rate varies with the thickness and degradation properties of the resin coat (Hummel, 1989). Nutrients are released when water moves by osmosis through the resin coat, and urea solution diffuses back out (Hummel, 1989). Besemer (1963) reported that bentgrass fertilized every 13 to 17 weeks with sulfur-coated urea offered similar turf quality to that of a monthly application of soluble fertilizers. Hummel and Waddington (1984) found sulfur-coated urea pellets 3 years after application, which contained up to 26% of applied N. Coated slow-release products have shown reduced NO_3 leaching losses when compared to soluble fertilizers (Guillard and Kopp, 2004). Hummel (1989) found the highest N recoveries with sulfur-coated urea and resin-coated urea when compared to standard soluble urea and concluded that resin-coated ureas were an excellent choice for N supply.

Synthetic chemical slow-release products, such as IBDU (isobutylenediurea) and methylene urea, release N by hydrolysis and microbial activity. Short-chain methylene ureas can provide a rapid initial color response, but this varies with source (Carrow, 1997). Slow-release products offer a low risk for crop burn, fewer applications at higher rates with longer duration, and less risk of N loss to volatilization and leaching (Hummel and Waddington, 1981). Slow-release N sources also come in several particle sizes and wide variations of long-term N release, offering more choices to match the proper application (Carrow, 1997).

Natural organics, otherwise known as slow-release N fertilizers (SRN), contain C, but are derived from waste products (Christians, 2004). Natural slow-release organics are finding new popularity with fertilizer companies because they have been shown to provide substantial plant-available N, as well as a source of micronutrients (Eldridge et al., 2008). Besides offering a slow-release quality, there are numerous sources of waste by-products to be reused. Natural organic slow-release N products release nutrients more quickly as particle size decreases (Hummel and Waddington, 1981). Slow-release N products also have lower tissue burn potentials, so fewer applications at higher rates can be made, while providing a longer duration of N release (Hummel and Waddington, 1981). The inconsistency of N release from slow-release N products presents the need to study individual products to determine accurate fertilizer recommendations (Hummel and Waddington, 1981).

Organic Nitrogen in Turf

Organic wastes have demonstrated their ability to provide nutrients to plants at rates sufficient for quality growth (Mamo et al., 1999). Research is limited on the efficacy of organic sources in turfgrass systems, but some research shows that organics have potential in turfgrass fertilizer programs. The release pattern of organic products is inconsistent and each individual product must be evaluated so that accurate recommendations for fertilizer programs may be made (Carrow, 1997).

The slow-release property that organic products offer may help reduce fertilizer N loss and may help reduce the factors (e.g., irrigation schedule, N source, rate and timing of application) that effect N loss (Kerek et al., 2003). Nitrates are often leaches from the soil, especially in sandy golf course greens (Mazur and White, 1983). One study has shown that plots fertilized with organics only contained 0.6 and 1.7% NO_3–N of N applied, while applications of NH_4NO_3 had 16.8% NO_3 in the leachate (Guillard and Kopp, 2004).

A University of Florida study on St. Augustine grass showed equal or greater response from Milorganite and Scotts Turf Builder treatments (The Scotts Company, LLC., Marysville, OH) when compared to other commercially available inorganic products (Cisar, 2004). Many organic products have proven to be a legitimate selection for turf fertilization, but there is some research that shows organics have limited turf response, and results show high variability within sources (Carrow, 1997; Peacock and Daniel, 1992). Landschoot and Waddington (1987) examined organic fertilizer application on bluegrass and found that turf response varied widely with source.

Some organic N fertilizers have been shown to have disease suppressing traits allowing turf to outgrow disease problems (King and Torbert, 2007). Organics have been shown to reduce dollar spot severity as compared to the control (Davis and Dernoeden, 2002), and they also reduced necrotic ring spot (Guillard and Kopp, 2004; Melvin and Vargas, 1994). Organic products contain C compounds, which increased soil bacterial populations within four days after treatment (Li, 2005). A study of bentgrass showed increased populations and increased microbial activity in plots treated with compost and sludge (Tian et al., 2008).

Study Objectives

The objectives of this research were to: 1) evaluate turfgrass response to organic fertilizers in the field by measuring turf color, quality, clipping yield, N uptake, and soil NO_3-N and NH_4-N, and 2) measure N mineralization from organic fertilizers as affected by soil temperature in the laboratory.

Materials and Methods

Field Study

In 2009 and 2010, field studies were conducted at the Auburn University Turfgrass Research Unit (TGRU) located on the Auburn University campus. Studies were initiated on 27 Apr. 2009 and 4 May 2010. The experiments were conducted on Tifsport and Tifway hybrid bermudagrass (*Cynodon dactylon* L. × *Cynodon transvaalensis* Burtt-Davy) fairways, respectively. Both studies were conducted on a Marvyn loamy sand (Fine-loamy, siliceous, thermic Typic Paleudult) soil type. Initial soil tests for each experiment are listed in Table 1. There were no N fertilizers applied to the field studies for one year prior to the application of treatments used for this study. Fungicide and pesticide treatments were used as needed and followed recommended guidelines. Table 2 includes dates, rates, and products used for each individual study.

The fertilizer treatments listed in Tables 3 and 4 were used in each study, plus one unfertilized control. The ten treatments were replicated four times in a randomized complete block design. Each study was mown prior to fertilizer application. Treatments were hand applied to 1.2 x 2.4 m plots at 4.9 g N m^{-2} and irrigated directly after application.

The two studies were mown once per week at a height of 1.9 cm with a Tru-Cut H-2C reel mower (Advanced Mower, Bessemer, AL.) and clippings were removed for analysis. Each plot was irrigated with 2.54 cm water $week^{-1}$ in the absence of rainfall. Data collected from both experiments included clipping yield, fertilizer pickup, shoot density, rhizome/stolon density, root density, visual color ratings, colorimeter measurements, soil total and extractable N, and an end of studyl soil microbial biomass extraction. Turfgrass color response was measured weekly via qualitative visual color ratings. The scale was from one to nine, with one being brown turf and nine being an optimal dark green color.

Weekly colorimeter measurements were also taken with a Fieldscout CM 1000 chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL.). The colorimeter is a remote sensing device that directs a band of light onto the turf surface, and a meter collects reflectance data. The reflectance data is thought to correlate to turf chlorophyll content and hence greenness. Widely marketed in the turf industry, the device lacks calibration data, and this was one reason for inclusion in our study. In every case, five colorimeter measurements were taken from each plot, and results were averaged. Measurements were recorded with the colorimeter hand-held at a 1-m height between 1000 and 1400 hours on cloudless days.

Clippings were harvested from each individual plot once per week, using the same mower as used for plot maintenance, and immediately sieved through a 2-mm mesh screen, in order to separate any fertilizer picked up by the mower. Any collected fertilizer was weighed and reapplied to the plot. Fertilizer loss was minimal two weeks after application, so samples were no longer sieved for fertilizer removal. Harvested clippings were forced-air dried at 70°C for 48 hours and weighed for total clipping dry matter yield. Clippings were analyzed via dry combustion for total N using a LECO TruSpec CN (LECO Corp., St. Joseph, MI.).

Soil and thatch temperatures, at 2.54 and 1 cm under the turfgrass surface, respectively, were monitored every ten minutes using a HOBO Pro Series datalogger (Onset Computer Corp., Bourne, MA). Three soil samples were taken from each plot weekly to a 7.62 cm depth below the thatch layer with a 0.95 cm diameter probe. Samples were combined and sieved through a 2-mm screen. Soil samples were extracted with 2 M KCl and analyzed for NH_4-N and NO_3-N concentration colorimetrically (Sims et al., 1995) using a BioTek uQuant Microplate

Spectrophotometer (Winooski, VT). Total N and C in the soil were determined by a dry combustion LECO TruSpec CN (Mulvaney et. al., 2008b).

Shoot, rhizome/stolon, and root densities were taken on 28 July 2009 and on 1 June, 7 July, and 27 July 2010. All densities were measured by taking two cores (6 cm diameter and 6.35 cm deep) with a tubular turf plugger (Turf-Tec International, Tallahassee, Fl.). Shoots were counted by hand, and rhizome/stolons and roots were cleaned of soil, forced-air dried at 70°C for 48 hours, and weighed. When each study was complete, a final measurement of soil microbial biomass was collected using the method described by Parkinson and Paul (1982). Samples were brought to field capacity and fumigated with ethanol-free chloroform and then incubated for 24 hours. The CO_2 evolved was then collected with 1 M NaOH. Samples were incubated for 10 days in the dark. The CO_2 evolution was calculated by titration of the NaOH solution with 1.5 M $BaCl_2$ and 0.25 M HCl.

Laboratory Incubation Study

Laboratory incubation studies to evaluate N mineralization were carried out in 2009 and 2010. Treatments were soil temperatures (15, 25, and 35°C) in combination with nine fertilizer treatments shown in Table 1. An unfertilized control was also included. Each experiment was arranged in a completely random design with four replications of each treatment. Each entire experiment was repeated in time. Thus, there were six 12-week experiments in total, beginning on 20 Jan. 2009 (25°C), 14 Apr. 2009 (25°C), 11 Aug. 2009 (15°C), 15 Dec. 2009 (35°C), 12 Jan. 2010 (15°C), and 6 Apr. 2010 (35°C).

Each 25 and 35°C experiment was conducted in a 0.7 m^3 laboratory incubator (Isotemp, Fisher Scientific, Pittsburgh, PA). The 15°C experiments were conducted in an isolated seed refrigerator room. Microlysimeters (described below) were removed weekly for sample collection, and the experimental units were re-randomized each week within the chamber. Air temperatures were monitored throughout each study via a Hobo temperature sensor.

A Marvyn loamy sand (Fine-loamy, siliceous, thermic Typic Paleudult) was used in each experiment. The soil was collected from the top 7.6 cm of the Auburn University 'Old Rotation'. Initial N and C values were 0.62 and 9.2 g kg^{-1}, respectively. Falcon filter microlysimeters were assembled with fiberglass filters (Becton Dickinson, Franklin Lakes, NJ; Nadelhoffer, 1990). The soil was brought to field capacity (13.4% w/w), and a 13.8 g N m^2 rate of the treatments listed in Table 1 were added to 50 g dry-weight soil. The soil and fertilizer were thoroughly mixed, and then placed into the microlysimeter. Each microlysimeter was extracted with 0.01M $CaCl_2$ on days 0, 1, 3, 5, and 7 after application and then once per week for 10 weeks after the first week.

To extract NH_4-N and NO_3-N in soil solution, the microlysimeters were filled with 100 mL 0.01 M $CaCl_2$ and allowed to equilibrate for one hour (Nadelhoffer, 1990). The soil solution was then extracted, the volume of extract was measured, and a sub-sample taken. The sub-sample was analyzed for NH_4-N and NO_3-N colorimetrically using a spectrophotometer (Sims et al., 1995). After each extraction, the microlysimeters were returned to the incubation chamber and allowed to aerobically incubate until the next extraction. Soil pH was taken at the end of each experiment.

Results and Discussion

Field Study

Fertilizer Removal

In 2009, fertilizer removal was not measured. In 2010, fertilizer removal was included in the study, with all collected fertilizer returned to the plot after measurement. There was significant fertilizer removal with the harvested clippings at one, and in some cases, two weeks after fertilization (Table 5). Bermudagrass fertilized with Sustane® (4-6-4) had greatest fertilizer removal, more than twice as much as any other treatment. Virtually no fertilizer was removed from the urea, Milorganite®, Scotts Turf Builder, or the TOP (fine grade) fertilized plots. The two treatments with greatest fertilizer loss in week 1 still had measureable fertilizer loss in week 2 (Sustane® 4-6-4 and Sustane® 8-2-4).

On a creeping bentgrass (*Agrostis palustris* Huds.) putting green, greatest loss of fertilizer due to clipping harvest was found from an IBDU source, followed by Polyon®, and then Milorganite (Landschoot and Mancino, 2000). The authors noted that differences in fertilizer removal were due to solubility, size and density of the materials. In our study, both solubility and size affected removal, as no fertilizer was harvested from the soluble urea plots, while the treatment with greatest removal (Sustane® 4-6-4) was both a slow-release and large product, with the largest SGN (average particle size diameter multiplied by 100) (Table 1).

Turf Color Response

In both years the bermudagrass responded quickly to applications of urea, with significant greenup in both visual color (Tables 6 and 7; Figures 1 and 2) and chlorophyll meter readings (Tables 8 and 9; Figures 3 and 4) within 5 days. In 2010, plots fertilized with Scotts Turf Builder® also showed a more rapid greenup than all other treatments. This treatment was not included in the 2009 study. Rapid greenup from the TurfBuilder would be expected, as the majority of that products' N is soluble urea and only 0.9% is slow-release (methylene urea). Application of NatureSafe Starter produced a significantly greener turf (as compared to the control) within two weeks after application (2009 and 2010). Application of any fertilizer produced greener turf than observed in the control by week 4 in 2009 and by week 3 in 2010. Urea and NatureSafe Starter consistently produced the greenest turf after week 4 in 2009. In 2009, application of any N source produced greener turf (compared to the control) at 28 days after treatment (DAT). In 2010, the application of any N source created greener turf at 21 DAT.

Application of urea, NatureSafe Starter, NatureSafe StressGuard, Sustane® (8-2-4), and Scotts Turf Builder consistently produced the highest visual color ratings after week 4 in 2010. Application of Top (fine and regular) and Sustane® (4-6-4) often produced higher color ratings than observed in the control plots, but differences within these sources were not observed at 4, 5, and 6 weeks after application. Any difference in visual color due to fertilization was largely gone by week 10 in 2009 and week 9 in 2010. In both years there was never a slow-release organic product that provided any longer color response than that observed in bermudagrass fertilized with urea.

Chlorophyll meter readings for Sustane® (4-6-4) or Top (fine grade) were not statistically different from those measured in the control for the entirety of the 2009 study (Table 8). Chlorophyll meter readings for urea, Milorganite, NatureSafe Starter, and Top (regular grade) were all significantly higher than those measured in the control for the entire twelve week study (2009). NatureSafe StressGuard also had higher ratings than observed in the control plots for all measurement dates, except for the first two weeks. As with the relative visual color ratings, application of urea produced higher chlorophyll meter readings that were as long lived as those measured in plots fertilized with slow-release sources. For example, at 12 week after application (2009) plots fertilized with urea, Milorganite, NatureSafe Starter, NatureSafe StressGuard and Top (regular grade) all had similarly high chlorophyll meter readings, which were greater than measured in the unfertilized plots (Table 8).

In 2010, the chlorophyll meter readings for plots fertilized with urea, Scotts Turf Builder, NatureSafe Starter, and NatureSafe StressGuard were significantly higher than those measured in the control plots through week 8. Data collected from the Top (fine and regular grade) treated plots was generally higher, but not significantly different than that measured in the control (Table 9). Plots fertilized with the Sustane® products had a similar response as Top fertilized plots, except that there was an extended greening response to the Sustane® products, with greener turf (as compared to the control) in weeks 6, 7, and 8 of the study. There were no significant differences in chlorophyll meter readings amongst treatments after week 8 (2010) (Table 9).

Although hand-held chlorophyll meters have become a commonly used research tool, there is little data which examines their correlation with commonly used indices such as turf color. Figures 5 and 6 show correlations between visual turf color and chlorophyll meter readings, for all data collected in each study period. Correlations in 2009 were stronger with an R^2 of 0.81, while in 2010 there was a weaker relationship, with an R^2 of 0.43. Visual ratings sometimes detected differences for a greater period of time, with significant differences in color lasting for 84 and 77 days after application in 2009 and 2010, respectively. In these same years significant differences in chlorophyll meter reading were observed for the entire 84 day period in 2009, but differences were gone by 56 days after application in 2010 (Table 9).

A recent paper which examined relationships between normalized difference vegetation index (NDVI) and visual quality found different relationships due to turf species and mowing height (Lee et al., 2011). They found a lack of precision in the ability of NDVI to predict visual quality and recommended that data be compared within the same species and mowing height. By comparisons, others found significant correlations between hand-held reflectance meters and turfgrass chlorophyll and concluded that hand-held meters could be a useful tool for N management (Mangiafico and Guillard, 2005).

Clipping Yield and Tissue Nitrogen

At two weeks after application, plots treated with urea had significantly greater clipping yield any other treatment (2009) (Table 10). Differences were less distinct in 2010, with urea and Scotts Turf Builder plots both having greatest yield at 3 weeks after application (Table 11). Plots fertilized with organic products often produced a lower clipping yield, and in many cases yield did not differ from that measured in the unfertilized plots. For example, in 2009 plots that were fertilized with organic N products produced no significant increase in clipping yield (as compared to the control) at weeks 3 through 8. The only exception to this was the organic product NatureSafe Starter, which did produce more clippings than measured in the control (Table 10).

In 2009, as with clipping yield, tissue N significantly increased in bermudagrass fertilized with urea (Table 12). Fertilization with the N source NatureSafe Starter also often increased tissue N above that measured in the control, with a significant increase in tissue N (above the control) at weeks 1 through 5 after application. By 9 weeks after application there were few differences in tissue N as affected by N source (Table 12).

In 2010 application of urea or Scotts Turf Builder increased tissue N the most, followed by application of NatureSafe Starter (Table 13). These treatments had greater leaf N for the first 5 weeks after application. In both 2009 and 2010, the organic product NatureSafe StressGuard increased leaf N (as compared to the control) in later weeks of the study, with significantly more tissue N at weeks 3 through 5 in 2009 and weeks 4 and 5 in 2010 (Tables 12 and 13). In 2010, by 7 weeks after application there were few differences in tissue N as affected by N source (Table 13).

Soil Nitrogen, Carbon, and Microbial Biomass

In 2009, there was little significant difference in soil extractable inorganic N (NH_4-N plus NO_3-N) between all treatments (Table 14). Plots fertilized with urea had higher soil inorganic N levels than all other plots 1 week after application. Plots fertilized with Milorganite, Sustane® (4-6-4), TOP (regular grade), and NatureSafe StressGuard had a 132, 120, 113, and 71% increase in extractable soil N between 3 and 4 WAT. Plots fertilized with TOP (fine grade), urea, and NatureSafe Starter had a 162, 148, and 110% increase in soil N levels between weeks 4 and 6 after application. By week 6 all plots including the control had much higher soil N levels than at week 1, indicating that mineralization of N from organic residue such as clippings or thatch was occurring. Ammonium accounted for about 90% of soil extractable inorganic N, and soil NO_3 was low in all plots during the 2009 study (Tables 15 and 16).

In 2010, there were few consistent differences in inorganic N due to N source (Table 17). Application of any product increased extractable soil inorganic N over that measured in the control at 1 week after application. Unlike 2009 data, about half of the N was in NH_4-N form (Table 18) and about half was in the NO_3-N form (Table 19).

` Soil total N and C values were rarely affected by N source in 2009 and 2010 studies (Tables 20, 21, 22, and 23). There was no major difference in total N amongst all treatments as compared to the control (Tables 20 and 21). Studies have shown that mature established bermudagrass turf can sustain growth from naturally mineralized N located in the thatch layer and soil organic N pools, releasing between 60 to 154 kg N ha^{-1} growing $season^{-1}$ (Lee et al., 2003). Lee et al. (2003) also determined that substantial growth from the unfertilized plots of bermudagrass showed evidence of sufficient mineralization for turf nutrition.

This research consisted of two one-year studies, and any significant affect on soil organic N or C would be unlikely in this short time period. A similar study found no differences in microbial populations or total N when hybrid bermudagrass was fertilized with natural organic fertilizer or IBDU (Elliott and Des Jardin, 1999).

Soil microbial biomass was measured at the end of the 2010 study (Table 24). Most of the true organic treatments had a greater numerical microbial biomass compared to the control; however, no treatments were statistically different. The bermudagrass plots were established 13 and greater than 14 years ago for the 2009 and 2010 studies, respectively. Studies suggest that soil type does not affect soil microbial biodiversity, due to abundance of food from carbohydrates and C in the soil (Yao et al., 2006). Studies also suggest that as turfgrass maturity increases natural soil N mineralization efficiency also increases, and mature unfertilized turfgrass can mineralize from 60 to 154 kg N ha^{-1} growing $season^{-1}$. Nitrifying soil microbes are at peak activity between 30 and 35°C, and these temperatures were reached each week (Table 25) during the 2010 study (Shi et al., 2006a).

Roots, Shoots, and Rhizome/Stolons

In 2009, root weight and rhizome/stolon weight were never affected by fertilizer treatments (Table 26). Rhizomes, stolons and roots are the storage organs for turf carbohydrates, and often are less likely to respond to N, as compared to variables such as shoot density or turf color (Guertal and Hicks, 2009). The following treatments produced a significantly higher shoot density, as compared to the control: urea, Milorganite, NatureSafe StressGuard, and TOP (regular grade). Sources with the smallest particle size had the highest shoot densities (urea, Milorganite, NatureSafe StressGuard, and TOP (regular)), and were often sources that produced best color. NatureSafe Starter had the smallest rhizome/stolon diameter, while Milorganite and Sustane® (4-6-4) had the largest rhizome/stolon diameter. All other treatments were not different from either group (other fertilizers or the control).

In 2010, there were no differences in root weight among treatments until the last sampling date (Table 27). At that sampling, 12 weeks after application, bermudagrass fertilized with Milorganite had a greater root weight than plots fertilized with Scotts Turf Builder or NatureSafe. Other treatments were not statistically different from either group. Bermudagrass shoot densities were affected by N source at the first sampling date, 4 weeks after application.

Plots fertilized with urea had the highest shoot density, although not significantly different from the control. Most treatments generally produced a higher shoot density at all three sampling dates, but they were not statistically different from the control. Guertal and Hicks (2009) reported that N source did not affect shoot density. There were differences in rhizome diameter for the first and second sampling dates (4 and 9 WAT); however, results were inconsistent.

Laboratory Incubation Study

Mineralization

All N mineralization incubation studies were significantly affected by N source and a N source x temperature interaction (Tables 28 and 29). The data generally show a large release of inorganic N within the first two weeks after application followed by a steady, low rate of mineralization and N release. The 'transition' day (intercept of two statistical N release models), is where the initial rapid mineralization rate changes to a steady-state mineralization rate (Table 30). Excluding NatureSafe StressGuard (15°C), all treatments completed the initial mineralization phase within two weeks. Recovery of mineralized N ranged from 8.5 to 46.3% during the initial phase and 16.6 to 66.5% for the entire study for all treatments and temperature regimes. During the initial phase, mineralization produced mainly NH_4-N and little if any NO_3-N, but during the steady state phase NO_3-N was the dominant species produced (Figures 7-13).

As temperature increased, the 'transition' day generally decreased, indicating a higher mineralization rate, most likely due to higher microbial activity. Total inorganic N recovery increased for all treatments from 15 to 25°C, except for the Sustane® (4-6-4) fertilizer. Sustane® (4-6-4) has a larger particle size (Table 1) than any other treatment, which may explain the low recovery. Sustane® (4-6-4) had its largest percent of N recovery at 35°C, in which at least 30% more inorganic N was recovered than at 15 and 25°C.

The Sustane® (4-6-4) and urea treatments (Figures 7 and 11) had an overall low inorganic N recovery. The low percent of N recovery from lysimeters fertilized with urea is somewhat unexpected, but may be a function of NH_3 volatilization. Urea has been shown to volatilize upwards of 50% of its N within the first few days after application (Knight et al., 2007). Urea N loss through volatilization increases with higher temperatures and larger N application rates (Overrein and Moe, 1966). In our study we had a high temperature treatment (35°C) (Table 31), which would increase N loss through volatilization. Except for Sustane® (4-6-4) and urea, all other treatments had a decrease in inorganic N recovery as the temperature increased from 25 to 35°C (Figure 17). This is in agreement with Lee et al. (2001) where optimum mineralization rates occurred between 28 and 38°C.

Treatments (urea, Sustane®(4-6-4), and TOP (fine grade)) that had a low recovery (less than 30% N mineralized), generally had a transition in N release at or before 7 days after application (Figures 7, 11, and 12). TOP (regular grade) had a slightly higher increase in days required to reach the transition point, as compared to the TOP (fine grade) (Figures 12 and 13). TOP (regular grade) had a slightly higher recovery (about 10 to 13%) than TOP (fine grade), which would explain the slight increase to reach the transition. The particle size of TOP (regular grade) (Table 3) is about 58% larger than TOP (fine grade), because these two treatments have identical ingredients and N solubility ratings, this may give indication of a reduced volatility due to particle size.

All other treatments (Milorganite, NatureSafe Starter and StressGuard), with the exception of Milorganite at 35°C, had a larger percent of N mineralized (35 to 70% N mineralized), which increased the transition day beyond the one week mark. These treatments have the largest ratio of insoluble N, possibly slowing N release while reducing NH_3 volatilization, and thus allowing for an increase in N recovery, In order from highest to lowest inorganic N recovery for all temperature regimes: NatureSafe Starter, NatureSafe StressGuard, Milorganite, TOP (regular and fine grade), Sustane® (4-6-4), and urea.

Summary

Field Study

Two separate three-month studies evaluated the effects of organic fertilizers on hybrid bermudagrass growth and performance. In general, application of sources with large portions (or 100%) of soluble N (urea and Scotts Turf Builder) produced turf with a dark green color, higher shoot density, and greater clipping yield. Although organic fertilizers are often touted as maintaining color for longer periods of time, it was not the case in this study, as urea provided consistent quality color for the same 8-10 week period as the organic sources. There were few differences in soil N, C, or microbial biomass.

Laboratory Incubation Study

Six individual ten-week studies (two repetitions per temperature) were performed at 15, 25, and 35°C. Mineralization of organic N was observed, and it was significantly affected by treatment and a treatment x temperature interaction. Optimum mineralization was observed at 25°C, with the least amount of mineralization occurring at 15°C. Ammonium-N was largely produced during the first two weeks after application, switching to NO_3-N after that. In some cases, reduced N production at the highest soil temperature was likely due to N loss via NH_3 volatilization.

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Table 1. Initial soil-test values (Mehlich 1 extractant) for the two research areas, TGRU, Auburn, AL. 0 - 5 cm sampling depth.

	Experiment 1	Experiment 2
	28 April 2009	5 May 2010
	mg kg^{-1} soil	
P	28	48
K	47	30
Mg	36	56
Ca	273	432
soil N	259	542
soil C	7360	10550
soil pH	6.6	6.1

Table 2. Maintenance fertilizer, fungicides and herbicides applied to the two field studies, TGRU, 2009 and 2010.

	Fertilizer	Date Applied	Fungicide	Date Applied	Pesticide	Date Applied
Experiment 1 28 April 2009	0-0-60 40 lb K A^{-1}	4/9/2009	Rubigan 1 lb ai A^{-1} (W)	6/11/2009	Escalade 2 1.5 qt A^{-1}	4/20/2009
			Tartan 2 oz 1000ft^{-2} (W)	6/18/2009	Escalade 2 1.5 qt A^{-1}	5/1/2009
					Manor 0.5 oz A^{-1} (W)	5/1/2009
					Manor 0.5 oz A^{-1} (E)	7/2/2009
					Merit 1.5 pt A^{-1} (W)	7/12/2009
					Escalade 2 1.5 qt A^{-1} (E)	7/13/2009
Experiment 2 5 May 2010	0-0-60 80 lb K A^{-1}	1/20/2010	Pro Star 4.5 oz. 1000ft^{-2}	4/29/2010	Revolver 0.4 oz 1000ft^{-2} (S)	4/9/2010
	0-46-0 1.0 lb P 1000ft^{-2}	1/27/2010			Revolver 0.4 oz 1000ft^{-2} (S)	5/7/2010
					Trimec southern 1.5 pt A^{-1}	6/5/2010
					MSMA 1.5 1b ai A^{-1}	6/5/2010
					Trimec southern 1.5 pt A^{-1}	6/17/2010
					MSMA 1.51b ai A^{-1}	6/17/2010

Table 3. Selected fertilizer treatments used in both laboratory incubation and field research studies.

Trade Name/Treatment	Analysis	%N w/w †	SGN ‡
	N-P_2O_5-K_2O	AMM/WSN/WIN	
Milorganite (MILORG)	6-2-0	0/0.75/5.25	90
Nature Safe Starter (NSS)	5-6-6	0.2/0.3/4.5	170
Nature Safe StressGuard (NSSG)	8-3-5	0.2/0.6/7.2	160
Scotts Turf Builder (STB)	32-0-10	2.8/9.6/0.9 12.7% urea N	90
Sustane® (ST4)	4-6-4	0.4/0.4/3.2	200
Sustane® (ST8)	8-2-4	0.4/0.4/7.2	100
Fine/Regular (TOPF/TOPR)	4-2-2	0.0/0.42/3.58	100/170
Urea (UREA)	46-0-0	46% urea N	110

† AMM = ammoniacal nitrogen, WSN = water soluble nitrogen, WIN = water insoluble nitrogen

‡ SGN = Size Guide Number, which is the average particle diameter in millimeters, multiplied by 100.

Table 4. Organic ingredients in selected fertilizer treatments used in both laboratory incubation and field research studies.

Trade Name/Treatment	Manufacturer	Derived from:
Milorganite (MILORG)	Milorganite Milwaukee, WI	composted sewage sludge
Nature Safe Starter (NSS)	Griffin Industries, Inc. Cold Spring, KY.	meat, blood, bone, and fish meals, and langbeinite
Nature Safe StressGuard (NSSG)	Griffin Industries, Inc. Cold Spring, KY.	hydrolyzed feather, meat, bone, poultry, and fish meals, and langbeinite
Scotts Turf Builder (STB)	The Scotts Company LLC. Marysville, OH	methylene urea
Sustane® (ST4)	Sustane Natural Fertilizer, Inc. Cannon Falls, MN.	aerobically composted turkey litter, feather meal, sulfate of potash
Sustane® (ST8)	Sustane Natural Fertilizer, Inc. Cannon Falls, MN.	aerobically composted turkey litter, hydrolyzed feather meal, and sulfate of potash
Fine/Regular (TOPF/TOPR)	Organic Growing Systems, Inc. Alpharetta, GA.	poultry litter and feather meal
Urea (UREA)	Tri-State Plant Food Inc. Dothan, Al	$(NH_2)_2CO$

Table 5. Fertilizer pickup by mower (g per plot) as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application) g plot^{-1}	
	May 11 (1)	May 17 (2)
UREA	0.0 c	0.0 c
MILORG	0.5 c	0.0 c
NSS	16.8 bc	0.0 c
NSSG	1.4 c	0.0 c
ST4	41.8 a	10.5 a
TOPF	7.9 bc	0.0 c
TOPR	1.5 c	0.0 c
ST8	21.9 b	4.3 b
STB	0.5 c	0.0 c
CNTRL	0.0 c	0.0 c

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 6. Visual color ratings (1:brown - 9:dark green) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (days after application)								
	April 28 (1)	April 30 (3)	May 2 (5)	May 5 (7)	May 12 (14)	May 19 (21)	May 26 (28)	June2 (35)	June 9 (42)
UREA	2.00 b	2.75 a	3.00 a	4.50 a	5.00 a	5.25 a	6.00 a	5.75a	6.50 a
MILORG	2.50 ab	2.50 a	2.50 ab	2.50 bc	3.25 bc	4.00 b	4.50 cd	4.25cd	5.25 bc
NSS	2.50 ab	2.25 a	2.00 b	3.00 bc	4.00 b	4.25 b	5.50 ab	5.50a	6.25 a
NSSG	2.00 b	2.00 a	2.00 b	2.00 c	2.75 c	4.25 b	5.00 bc	5.25ab	5.50 b
ST4	2.25 ab	2.75 a	2.50 ab	2.25 bc	3.25 bc	3.50 bc	3.50 e	3.75de	4.50 cd
TOPF	2.50 ab	2.50 a	2.50 ab	2.75 bc	3.50 bc	3.50 bc	3.50 e	4.00de	5.25 bc
TOPR	2.75 a	2.75 a	3.00 a	3.50 ab	3.50 bc	4.00 b	4.00 de	4.75bc	5.25 bc
CNTRL	2.50 ab	2.25 a	2.25 ab	2.00 c	2.75 c	2.75 c	2.75 f	3.50 e	4.25 d

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 6, cont'd. Visual color ratings (1:brown - 9:dark green) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (days after application)					
	June 16 (49)	June 23 (56)	June 30 (63)	July 7 (70)	July 14 (77)	July 21 (84)
UREA	7.00 a	7.00 a	6.50 abc	7.00 ab	6.50 ab	5.75 ab
MILORG	6.00 abc	6.75 ab	6.75 ab	7.25 ab	6.50 ab	6.00 ab
NSS	6.50 ab	7.00 a	7.00 a	7.50 a	6.75 a	6.25 a
NSSG	6.00 abc	6.25 ab	6.50 abc	7.00 ab	6.75 a	6.25 a
ST4	5.50 bc	6.25 ab	6.25 abc	6.00 bc	5.75 ab	5.50 ab
TOPF	5.25 c	5.75 b	6.00 bc	6.00 bc	6.50 ab	5.50 ab
TOPR	5.50 bc	6.25 ab	6.25 abc	7.00 ab	6.50 ab	6.00 ab
CNTRL	5.25 c	6.00 ab	5.75 c	5.25 c	5.50 b	5.25 b

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 7. Visual color ratings (1:poor - 9:lush green) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (days after application)								
	May 5 (1)	May 7 (3)	May 9 (5)	May 11 (7)	May 17 (14)	May 24 (21)	June 1 (28)	June 7 (35)	June 14 (42)
UREA	3.50 a	4.50 a	4.50 a	4.75 a	7.75 ab	8.00 a	7.75 ab	8.00 a	6.50 a
MILORG	3.00 a	3.00 b	3.25 b	3.50 b	5.25 c	6.25 bc	6.25 cd	6.50 cd	5.25 bc
NSS	3.25 a	3.00 b	3.25 b	3.00 bc	6.75 b	7.75 a	8.00 a	7.75 ab	6.00 abc
NSSG	3.00 a	3.00 b	3.00 b	3.00 bc	4.50 cd	6.50 b	7.00 abc	8.00 a	6.25 ab
ST4	3.00 a	3.00 b	3.00 b	3.00 bc	4.50 cd	5.25 cd	5.50 de	6.75 bcd	5.75 abc
TOPF	3.00 a	3.00 b	3.00 b	3.25 bc	4.25 cd	4.50 d	5.00 ef	6.00 d	5.25 bc
TOPR	3.00 a	3.00 b	3.00 b	3.25 bc	5.25 c	6.00 bc	6.25 cd	7.00 abc	5.00 cd
ST8	3.25 a	3.50 b	3.00 b	3.00 bc	4.25 cd	5.75 bc	6.75 bc	7.75 ab	6.75 a
STB	3.00 a	4.25 a	4.50 a	4.75 a	8.25 a	8.50 a	7.75 ab	7.75 ab	5.25 bc
CNTRL	3.00 a	3.00 b	2.75 b	2.75 c	3.75 d	3.00 e	4.25 f	4.25 e	4.00 d

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), , TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10)CNTRL-unfertilized control

Table 7, cont'd. Visual color ratings (1:poor - 9:lush green) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (days after application)					
	June 21 (49)	June 28 (56)	July 6 (63)	July 12 (70)	July 19 (77)	July 27 (84)
UREA	6.25 a	6.75 ab	7.00 a	6.00 a	6.75 ab	7.00 a
MILORG	5.75 ab	5.75 ab	5.50 ab	5.75 a	6.00 ab	6.75 a
NSS	6.50 a	7.00 ab	5.25 ab	5.25 a	6.50 ab	7.25 a
NSSG	6.75 a	7.25 a	6.00 ab	6.25 a	7.00 ab	7.75 a
ST4	6.25 a	6.50 ab	6.00 ab	5.25 a	6.50 ab	7.25 a
TOPF	5.25 ab	5.75 ab	5.5 ab	5.00 a	6.50 ab	7.00 a
TOPR	6.00 ab	5.50 ab	4.5 b	5.25 a	5.25 b	6.00 a
ST8	6.75 a	6.75 ab	5.75 ab	5.00 a	7.25 a	7.00 a
STB	6.50 a	6.50 ab	5.50 ab	5.75 a	6.50 ab	7.00 a
CNTRL	4.50 b	5.25 b	4.25 b	5.75 a	5.75 ab	6.50 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), , TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10)CNTRL-unfertilized control

Table 8. Chlorophyll meter (reflectance) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)
UREA	153.0 a	148.5 a	179.8 a	250.3 a	247.3 a	237.8 a
MILORG	138.3 ab	137.8 ab	149.0 c	196.5 bc	198.5 c	197.3 b
NSS	143.8 ab	136.8 b	169.5 ab	247.5 a	230.0 ab	234.8 a
NSSG	129.0 b	123.5 cd	150.0 bc	221.8 ab	221.8 b	225.8 a
ST4	131.5 b	120.3 d	123.3 d	162.5 d	154.3 d	160.5 c
TOPF	139.0 ab	127.8 bcd	133.8 cd	181.3 cd	165.0 d	180.3 bc
TOPR	147.0 ab	135.0 bc	150.3 bc	205.3 bc	196.0 c	201.5 b
CNTRL	135.5 ab	130.5 bcd	123.8 d	152.8 d	152.0 d	160.8 c

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 8, cont'd. Chlorophyll meter (reflectance) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	251.8 a	258.0 a	219.5 ab	261.8ab	236.3 ab	226.5 ab
MILORG	218.8 bc	251.5 a	216.0 ab	259.8ab	240.0 a	234.3 a
NSS	245.3 ab	267.0 a	233.8 a	273.5 a	255.8 a	239.5 a
NSSG	248.5 ab	253.0 a	225.0 ab	264.0 ab	252.8 a	234.0 a
ST4	178.3 d	197.5 c	179.8 c	220.0 c	204.8 c	201.3 c
TOPF	194.8 cd	219.8 bc	195.0 bc	239.3 bc	214.0 bc	209.5 bc
TOPR	227.0 ab	245.3 ab	216.8ab	255.0 ab	249.5 a	235.8 a
CNTRL	176.8 d	210.3 c	178.0 c	222.8 c	212.8 c	204.8 bc

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 9. Chlorophyll meter (reflectance) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	May11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)
UREA	330.3 a	406.3 a	368.0 a	370.2 ab	383.5 a	350.8 abc
MILORG	291.5 b	327.8 bc	300.8 bc	310.5 de	279.8 bcd	317.5 cd
NSS	288.3 b	349.8 b	324.0 b	358.5 abc	321.8 abc	356.5 ab
NSSG	267.3 b	299.3 cd	303.5 bc	339.8 bcd	331.3 ab	368.5 a
ST4	278.3 b	290.8 de	282.3 cd	316.0 de	277.8 bcd	322.0 bcd
TOPF	285.5 b	306.5 cd	275.0 cd	302.3 de	259.0 cd	303.8 d
TOPR	284.3 b	306.8 cd	271.8 cd	290.8 e	273.5 bcd	302.8 d
ST8	270.8 b	302.3 cd	276.0 cd	325.8 cde	311.0 bc	332.5 abcd
STB	328.3 a	408.3 a	370.3 a	388.0 a	341.5 ab	358.3 a
CNTRL	264.8 b	264.8 e	244.8 d	251.5 f	234.5 d	264.0 e

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 9, cont'd. Chlorophyll meter (reflectance) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	264.0 abc	322.3 abcd	324.3 a	309.8 a	336.5 a	382.5 a
MILORG	258.8 abcd	308.0 bcd	303.5 a	308.8 a	312.8 a	373.8 a
NSS	280.5 ab	336.5 a	308.0 a	305.3 a	328.0 a	374.8 a
NSSG	284.3 a	335.0 ab	307.5 a	317.7 a	337.0 a	391.3 a
ST4	274.8 abc	324.0 abcd	308.3 a	304.5 a	330.3 a	376.3 a
TOPF	250.8 cd	311.3 abcd	303.5 a	298.8 a	330.5 a	381.3 a
TOPR	256.3 bcd	303.8 cd	296.3 a	301.0 a	306.3 a	365.0 a
ST8	268.8 abc	328.0 abc	306.3 a	296.8 a	339.0 a	375.3 a
STB	281.0 ab	329.5 abc	301.8 a	312.8 a	331.0 a	391.8 a
CNTRL	233.3 d	298.8 d	298.3 a	317.8 a	322.5 a	382.8 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 10. Clipping yield (grams per plot) of hybrid bermudagrass as affected by N source, 2009,Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	10.8 ab	1.9 a	1.9 a	4.2 a	9.1 a	3.8 a	5.0 a	4.8 a	6.7 a	7.5 ab	2.0 ab	2.4 a
MILORG	11.2 ab	0.9 bcd	0.6 b	1.3 b	4.7 b	2.0 c	3.8 abc	3.3 ab	4.6 abc	5.1 abc	1.7 abc	1.8 ab
NSS	14.3 a	1.3 b	0.9 b	3.7 a	6.7 a	3.4 ab	4.5 ab	4.5 a	6.4 a	7.9 a	2.3 a	2.5 a
NSSG	8.7 b	0.5 d	0.8 b	2.2 b	5.3 b	2.3 bc	3.7 abc	3.4 ab	5.7 ab	5.7 abc	2.1 ab	2.2 ab
ST4	9.5 ab	0.5 d	0.4 b	1.0 b	3.8 b	1.1 c	1.6 d	2.0 b	2.6 c	4.0 c	1.1 c	1.3 b
TOPF	9.9 ab	0.9 bcd	0.3 b	1.4 b	3.9 b	1.5 c	1.8 d	2.2 b	3.3 bc	5.1 abc	1.3 bc	1.4 b
TOPR	12.6 ab	1.1 bc	0.6 b	2.3 b	4.8 b	2.0 c	3.2 bcd	2.5 b	4.5 abc	5.9 abc	1.9 abc	2.0 ab
CNTRL	12.5 ab	0.7 cd	0.4 b	1.3 b	4.2 b	2.1 bc	2.4 cd	2.5 b	2.8 c	4.7 bc	1.1 c	1.7 ab

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 11. Clipping yield (grams per plot) of hybrid bermudagrass as affected by N source, 2010,Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	66.5 a	54.0 a	47.8 a	40.7 a	45.5 ab	37.5 ab	14.6 ab	94.2 ab	51.4 a	20.9 a	27.3 a	36.9 a
MILORG	66.7 a	33.3 ab	22.3 bc	19.0 cde	27.5 def	19.3 def	7.1 ab	58.5 b	34.8 bc	14.7 a	18.5 a	21.2 a
NSS	73.8 a	44.8 ab	30.1 b	32.3 b	40.3 bc	30.2 bcd	14.2 ab	63.0 b	42.2 abc	17.2 a	21.9 a	27.2 a
NSSG	39.7 a	25.7 b	21.4 bc	22.9 cd	32.7 cd	31.7 abc	13.4 ab	57.5 b	42.0 abc	17.3 a	20.1 a	29.5 a
ST4	56.7 a	36.5 ab	19.0 bc	15.8 cde	20.2 ef	16.1 ef	7.0 ab	59.3 b	37.4 abc	15.0 a	20.0 a	22.5 a
TOPF	61.7 a	47.9 ab	22.2 bc	19.4 cde	26.1 def	14.6 ef	6.8 ab	54.4 b	38.8 abc	16.5 a	19.0 a	28.6 a
TOPR	28.3 a	29.5 b	19.6 bc	14.7 de	18.6 ef	15.9 ef	4.1 b	50.3 b	35.6 bc	14.7 a	17.7 a	23.5 a
ST8	63.9 a	34.9 ab	26.6 bc	24.0 c	29.2 de	23.7 cde	12.7 ab	46.9 b	42.8 abc	17.4 a	20.6 a	30.0 a
STB	41.1 a	41.8 ab	44.6 a	41.6 a	54.0 a	42.9 a	18.9 a	121.2 a	49.0 ab	21.2 a	26.7 a	34.3 a
CNTRL	50.5 a	31.3 b	16.8 c	12.5 e	17.4 f	10.2 f	3.2 b	64.3 b	31.9 c	15.1 a	19.7 a	26.6 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 12. Tissue N (g N kg^{-1} tissue) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	29.0 a	35.5 a	32.0 a	34.6 a	31.3 a	26.9 a	27.1 a	25.5 a	24.7 a	21.3 a	21.0 a	20.8 b
MILORG	23.9 bcd	28.8 c	28.9 bc	30.9 cd	27.9 c	25.8 a	25.4 abcd	24.7 abc	25.6 a	21.3 a	21.9 a	23.0 ab
NSS	24.4 bc	32.4 b	30.1 ab	33.5 ab	30.1 ab	21.6 a	26.2 ab	25.4 ab	25.5 a	20.4 a	22.1 a	23.7 a
NSSG	22.9 cd	30.7 bc	28.6 bc	32.5 bc	29.0 bc	27.1 a	25.7 abc	24.7 abc	24.9 a	20.1 a	19.4 a	22.3 ab
ST4	23.0 cd	28.1 c	26.9 cd	28.4 e	25.3 d	24.8 a	23.6 d	23.1 d	23.8 a	20.5 a	21.2 a	20.9 b
TOPF	24.9 b	28.3 c	26.4 d	29.3 de	25.9 d	25.0 a	25.0 bcd	24.0 bcd	24.5 a	21.1 a	20.5 a	21.5 ab
TOPR	24.5 bc	29.0 c	27.2 cd	30.1 de	27.2 cd	25.8 a	25.4 abcd	24.8 abc	24.5 a	16.5 a	21.2 a	22.3 ab
CNTRL	22.5 d	27.8 c	26.2 d	28.4 e	25.2 d	24.1 a	24.0 cd	23.4 cd	23.3 a	18.5 a	19.6 a	20.7 b

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 13. Tissue N (g N kg^{-1} tissue) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	34.2 a	35.6 a	33.2 a	31.7 a	32.5 a	33.1 ab	34.8 a	32.9 a	35.3 a	34.3 a	31.4 a	30.2 a
MILORG	28.2 bc	30.3 bc	29.7 abc	27.7 bcd	28.6 c	33.7 ab	34.5 a	32.6 a	34.4 a	32.1a	29.6 a	27.2 cd
NSS	30.7 b	32.2 b	32.0 ab	30.5 ab	31.5 ab	34.0 ab	34.5 a	32.8 a	34.4 a	33.0 a	31.6 a	27.8 bcd
NSSG	28.6 bc	29.5 bc	29.9 abc	30.2 abc	32.7 a	34.0 ab	35.0 a	32.6 a	34.8 a	32.5 a	31.8 a	27.6 bcd
ST4	29.6 bc	29.2 bc	30.5 abc	28.7 abc	29.2 c	33.1 ab	34.5 a	31.5 a	34.4 a	32.6 a	30.2 a	28.8 abcd
TOPF	28.0 c	29.8 bc	27.4 c	26.9 cd	28.2 c	32.1 ab	33.7 a	33.2 a	27.3 a	32.6 a	31.3 a	28.9 abcd
TOPR	28.7 bc	29.3 bc	27.6 c	24.3 d	28.4c	31.5 b	33.2 a	31.5 a	33.9 a	32.0 a	29.3 a	26.8 d
ST8	28.6 bc	29.9 bc	28.6 bc	28.9 abc	29.8 bc	35.6 a	34.3 a	33.5 a	34.3 a	32.8 a	31.8 a	29.6 ab
STB	34.7 a	36.8 a	33.4 a	31.3 a	32.6 a	33.8 ab	34.0 a	31.7 a	34.5 a	33.8 a	29.8 a	29.3 abc
CNTRL	27.8 c	27.9 c	27.0 c	25.2 d	25.7 d	31.7 b	32.8 a	32.2 a	34.2 a	32.7 a	31.3 a	28.7 abcd

† within each sampling date means followed by the same letter are not significantly different from each other via means separation at $\alpha = 0.05$.
*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 14. Inorganic N (mg N kg^{-1} soil) (NO_3-N + NH_4-N) (2M KCl extract) soil content as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June2 (5)	June 9 (6)
UREA	8.48 a	7.46 a	5.27 a	4.79 a	9.39 a	11.86 ab
MILORG	5.54 b	6.54 ab	4.39 a	10.18 a	9.02 a	10.74 ab
NSS	5.65 b	6.89 ab	5.20 a	5.24 a	9.27 a	11.01 ab
NSSG	4.45 b	6.51 ab	5.12 a	8.76 a	8.80 a	7.99 b
ST4	4.35 b	5.54 ab	4.15 a	9.15 a	8.91 a	9.62 ab
TOPF	5.20 b	5.33 b	4.55 a	5.34 a	8.47 a	13.97 a
TOPR	5.18 b	5.46 ab	4.44 a	9.47 a	10.30 a	10.24 ab
CNTRL	4.50 b	5.42 ab	4.40 a	4.94 a	7.56 a	10.36 ab

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 14, cont'd. Inorganic N (mg N kg^{-1} soil) (NO_3-N + NH_4-N) (2M KCl extract) soil content as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)					
	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	10.47 a	4.23 a	7.53 a	3.76 ab	5.89 ab	4.30 a
MILORG	8.67 ab	4.68 a	8.39 a	3.21 ab	5.72 ab	4.28 a
NSS	9.10 ab	5.31 a	8.20 a	5.75 ab	5.77 ab	4.46 a
NSSG	5.86 b	4.01 a	8.07 a	6.50 a	5.74 ab	4.55 a
ST4	9.00 ab	8.17 a	7.30 a	2.53 b	5.17 b	4.05 a
TOPF	8.19 ab	7.29 a	6.87 a	2.45 b	5.56 ab	4.92 a
TOPR	8.75 ab	7.11 a	7.91 a	4.92 ab	7.60 a	4.08 a
CNTRL	7.46 ab	5.06 a	7.68 a	4.47 ab	4.64 b	3.85 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 15. Ammonium-N (mg N kg^{-1} soil) (NH_4-N) (2M KCl extract) soil content as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	7.12 a	7.16 a	4.93 a	4.22 a	5.56 a	11.10 a	10.47 a	4.23 a	7.47 a	2.17 b	5.63 ab	3.71 a
MILORG	4.96 ab	6.02 ab	4.08 a	4.69 a	6.82 a	9.81 a	8.62 ab	4.68 a	8.38 a	1.81 b	5.04 b	3.82 a
NSS	5.24 ab	6.37 ab	4.99 a	4.46 a	6.60 a	8.80 a	8.93 ab	5.31 a	7.80 a	3.04 b	5.13 b	4.07 a
NSSG	4.21 b	5.66 ab	4.68 a	4.56 a	5.70 a	7.19 a	5.84 b	4.01 a	7.99 a	5.43 a	5.52 ab	4.05 a
ST4	4.05 b	5.19 ab	3.89 a	3.94 a	7.08 a	9.01 a	9.00 ab	7.67 a	6.96 a	1.38 b	4.57 b	3.33 a
TOPF	4.96 ab	5.17 ab	4.17 a	4.69 a	6.45 a	11.19 a	8.19 ab	7.29 a	6.65 a	1.32 b	5.03 b	4.55 a
TOPR	4.70 ab	5.07 b	4.29 a	4.47 a	8.07 a	8.65 a	8.75 ab	7.11 a	7.91 a	2.78 b	7.33 a	3.51 a
CNTRL	4.11 b	5.12 ab	4.09 a	4.65 a	6.00 a	8.97 a	7.46 ab	4.46 a	7.64 a	2.04 b	4.33 b	3.47 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 16. Nitrate-N (mg N kg^{-1} soil) (NO_3-N) (2M KCl extract) soil content as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	1.36 a	0.30 ab	0.34 a	0.58 a	3.83 a	0.77 a	0.00 b	0.00 a	0.06 a	1.59 a	0.26 a	0.60 a
MILORG	0.58b	0.52 ab	0.31 a	5.49 a	2.21 b	0.93 a	0.05 ab	0.00 a	0.01 a	1.39 a	0.68 a	0.46 a
NSS	0.41 b	0.52 ab	0.21 a	0.78 a	2.66 ab	2.21 a	0.17 a	0.00 a	0.40 a	2.71 a	0.64 a	0.38 a
NSSG	0.23 b	0.85 a	0.44 a	4.20 a	3.10 ab	0.80 a	0.00 b	0.00 a	0.08 a	1.07 a	0.22 a	0.50 a
ST4	0.30 b	0.35 ab	0.26 a	5.21 a	1.83 b	0.61 a	0.00 b	0.50 a	0.34 a	1.15 a	0.61 a	0.72 a
TOPF	0.24 b	0.16 b	0.37 a	0.65 a	2.02 b	2.78 a	0.00 b	0.00 a	0.22 a	1.12 a	0.53 a	0.38 a
TOPR	0.48 b	0.39 ab	0.15 a	5.00 a	2.23 b	1.59 a	0.00 b	0.00 a	0.00 a	2.14 a	0.28 a	0.57 a
CNTRL	0.38 b	0.30 ab	0.31 a	0.12 a	1.56 b	1.39 a	0.00 b	0.59 a	0.04 a	2.43 a	0.31 a	0.38 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 17. Inorganic N (mg N kg^{-1} soil) (NO_3-N + NH_4-N) (2M KCl extract) soil content as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	6.13 ab	6.64 ab	5.20 a	6.25 a	6.07 b	8.56 a	9.72 a	9.83 a	7.19 a	4.29 bc	7.56 a	7.65 a
MILORG	6.70 ab	6.51 ab	4.14 a	5.52 a	8.77 a	9.72 a	8.61 a	7.41 b	6.61 a	3.96 bc	9.02 a	6.91 a
NSS	8.08 a	8.74 a	4.55 a	6.20 a	7.27 ab	8.39 a	8.58 a	7.81 ab	7.00 a	4.62 abc	12.83 a	6.25 a
NSSG	7.71 a	8.09 ab	5.65 a	6.25 a	5.14 b	9.61 a	9.80 a	7.43 b	7.37 a	4.39 bc	11.81 a	5.99 a
ST4	6.01 ab	7.10 ab	4.86 a	5.63 a	5.79 b	7.98 a	8.93 a	7.30 b	7.35 a	3.82 c	8.58 a	6.30 a
TOPF	6.29 ab	5.59 b	4.34 a	4.93 a	7.03 ab	9.85 a	8.61 a	8.08 ab	7.69 a	4.35 bc	8.06 a	7.18 a
TOPR	5.70 ab	5.61 b	4.72 a	5.14 a	5.83 a	7.48 a	8.04 a	6.42 b	6.23 a	3.80 c	8.43 a	6.59 a
ST8	7.29 ab	8.40 a	5.61 a	6.39 a	7.39 ab	10.09 a	8.07 a	8.25 ab	7.30 a	5.04 ab	11.22 a	6.49 a
STB	7.97 a	6.95 ab	4.54 a	6.12 a	6.18 b	9.24 a	7.96 a	7.57 ab	8.09 a	5.54 a	10.36 a	7.19 a
CNTRL	5.07 b	6.43 ab	4.19 a	4.99 a	6.74 ab	8.38 a	7.33 a	7.00 b	7.40 a	4.17 bc	8.16 a	6.27 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 18. Ammonium-N (mg N kg^{-1} soil) (NH_4-N) (2M KCl extract) soil content as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	2.78 c	2.71 abc	2.24 a	1.66 a	1.76 a	6.94 a	5.58 a	4.55 a	4.61 a	0.29 b	4.89 b	5.93 a
MILORG	4.07 abc	2.72 abc	2.12 a	2.21 a	3.42 a	7.38 a	4.92 a	2.56 a	4.34 a	0.54 ab	6.23 ab	5.27 a
NSS	4.84 a	4.29 a	2.56 a	1.82 a	3.04 a	6.78 a	5.89 a	4.41 a	5.76 a	0.97 a	9.70 a	4.66 a
NSSG	4.60 ab	2.91 abc	3.02 a	1.66 a	2.60 a	6.82 a	4.70 a	2.73 a	4.06 a	0.61 ab	8.61 ab	4.32 a
ST4	3.23 abc	2.09 bc	2.42 a	2.15 a	2.14 a	5.24 a	3.89 a	3.02 a	4.62 a	0.43 b	5.34 ab	4.31 a
TOPF	3.64 abc	2.04 c	1.88 a	1.51 a	2.13 a	5.80 a	4.37 a	2.94 a	4.94 a	0.45 ab	5.09 ab	5.28 a
TOPR	3.01 bc	1.88 c	2.49 a	1.99 a	1.89 a	5.62 a	4.41 a	1.93 a	4.08 a	0.63 ab	5.50 ab	4.84 a
ST8	4.45 abc	3.68 ab	3.06 a	1.86 a	2.50 a	7.18 a	5.36 a	2.38 a	4.73 a	0.55 ab	8.35 ab	4.62 a
STB	3.44 abc	1.84 c	2.15 a	2.03 a	2.09 a	6.49 a	3.95 a	2.86 a	4.73 a	0.80 ab	6.87 ab	5.42 a
CNTRL	3.09 bc	1.65 c	2.21 a	1.83 a	2.21 a	6.13 a	4.41 a	3.16 a	4.63 a	0.72 ab	5.97 ab	4.62 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 19. Nitrate-N (mg N kg^{-1} soil) (NO_3-N) (2M KCl extract) soil content as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	3.34 b	3.94 a	2.96 a	4.59 a	4.31 ab	1.62 a	4.13 ab	5.28 ab	2.58 ab	4.00 abc	2.68 a	1.73 a
MILORG	2.63 bc	3.79 a	2.01 a	3.31 a	5.35 a	2.34 a	3.69 ab	4.85 abc	2.27 ab	3.42 c	2.79 a	1.65 a
NSS	3.23 b	4.45 a	1.99 a	4.38 a	4.24 ab	1.61 a	2.69 b	3.40 c	2.24 ab	3.65 bc	3.13 a	1.60 a
NSSG	3.11 bc	5.18 a	2.64 a	4.59 a	2.54 b	2.79 a	5.11 a	4.69 abc	3.31 a	3.78 abc	3.20 a	1.67 a
ST4	2.78 bc	5.01 a	2.44 a	3.48 a	3.65 ab	2.74 a	5.03 a	4.27 bc	2.73 ab	3.39 c	3.24 a	1.99 a
TOPF	2.65 bc	3.55 a	2.46 a	3.42 a	4.90 a	4.05 a	4.24 ab	5.14 ab	2.75 ab	3.90 abc	2.97 a	1.90 a
TOPR	2.69 bc	3.73 a	2.23 a	3.15 a	3.93 ab	1.85 a	3.63 ab	4.49 abc	2.17 b	3.17 c	2.93 a	1.76 a
ST8	2.84 bc	4.73 a	2.55 a	4.53 a	4.89 a	2.91 a	2.72 b	5.87 a	2.57 ab	4.49 ab	2.86 a	1.88 a
STB	4.53 a	5.11 a	2.39 a	4.08 a	4.09 ab	2.75 a	4.01 ab	4.71 abc	3.36 a	4.74 a	3.49 a	1.77 a
CNTRL	1.87 c	4.78 a	1.98 a	3.16 a	4.53 ab	2.25 a	2.92 ab	3.84 bc	2.78 ab	3.45 c	2.19 a	1.66 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 20. Total soil N ((inorganic + organic) g N kg^{-1} soil) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	0.53 a	0.39 a	0.67 a	0.46 a	0.41 ab	0.58 a	0.74 a	0.89 a	0.73 a	0.71 b	0.60 b	0.70 a
MILORG	0.29 a	0.32 a	0.68 a	0.40 a	0.40 ab	0.57 a	0.72 a	0.96 a	0.72 a	0.69 b	0.62 ab	0.74 a
NSS	0.58 a	0.37 a	0.66 a	0.41 a	0.39 ab	0.58 a	0.76 a	0.91 a	0.79 a	0.82 ab	0.71 ab	0.73 a
NSSG	0.39 a	0.31 a	0.61 a	0.44 a	0.42 ab	0.54 a	0.67 a	0.97 a	0.74 a	0.91 a	0.70 ab	0.74 a
ST4	0.55 a	0.35 a	0.83 a	0.47 a	0.50 a	0.76 a	0.78 a	1.00 a	0.74 a	0.75 ab	0.84 a	0.66 a
TOPF	0.77 a	0.28 a	0.67 a	0.47 a	0.39 ab	0.63 a	0.77 a	1.03 a	0.68 a	0.70 b	0.69 ab	0.75 a
TOPR	0.45 a	0.43 a	0.59 a	0.45 a	0.41 ab	0.51 a	0.70 a	1.01 a	0.78 a	0.77 ab	0.63 ab	0.70 a
CNTRL	0.36 a	0.38 a	0.69 a	0.44 a	0.32 b	0.56 a	0.72 a	0.98 a	0.75 a	0.73 b	0.64 ab	0.72 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 21. Total soil N ((inorganic + organic) g N kg^{-1} soil) of hybrid bermudagrass as affected by N source, 2010,Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	0.56 a	0.40 a	1.02 ab	0.92 a	0.93 a	0.85 bc	0.66 a	0.97 ab	0.40 a	0.12 a	0.00 b	0.22 ab
MILORG	0.65 a	0.40 a	1.00 ab	0.88 a	0.96 a	1.03 a	0.77 a	0.80 ab	0.30 a	0.24 a	0.55 ab	0.32 ab
NSS	0.57 a	0.48 a	1.01 ab	0.72 a	0.89 a	0.83 c	0.76 a	1.09 a	0.34 a	0.29 a	0.42 a	0.00 b
NSSG	0.67 a	0.58 a	0.81 ab	1.20 a	0.93 a	0.95 abc	0.78 a	0.84 ab	0.51 a	0.22 a	0.64 a	0.28 ab
ST4	0.74 a	0.64 a	1.06 ab	0.83 a	1.00 a	0.93 abc	0.66 a	1.04 ab	0.50 a	0.32 a	0.77 a	0.17 ab
TOPF	0.56 a	0.56 a	1.05 ab	0.98 a	0.93 a	0.88 abc	0.72 a	0.93 ab	0.51 a	0.11 a	0.34 a	0.50 a
TOPR	0.49 a	0.37 a	0.97 ab	0.88 a	1.01 a	0.87 abc	0.45 a	0.76 ab	0.45 a	0.21 a	0.43 a	0.21 ab
ST8	0.62 a	0.51 a	1.00 ab	2.35 a	1.04 a	0.90 abc	0.64 a	0.72 b	0.63 a	0.24 a	0.57 a	0.16 ab
STB	0.72 a	0.57 a	0.75 b	0.97 a	0.94 a	1.02 a	0.43 a	0.96 ab	0.34 a	0.11 a	0.43 b	0.32 ab
CNTRL	0.53 a	0.41 a	1.15 a	0.74 a	0.93 a	1.00 ab	0.62 a	0.96 ab	0.47 a	0.09 a	0.41 ab	0.22 ab

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 22. Soil C (g C kg^{-1} soil) of hybrid bermudagrass as affected by N source, 2009, Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 5 (1)	May 12 (2)	May 19 (3)	May 26 (4)	June 2 (5)	June 9 (6)	June 16 (7)	June 23 (8)	June 30 (9)	July 7 (10)	July 14 (11)	July 21 (12)
UREA	9.09 a	8.18 a	9.38 a	6.90 a	6.51 a	8.27 ab	7.55 a	9.53 a	8.94 ab	7.23 ab	6.61 b	8.37 a
MILORG	7.71 a	8.31 a	8.41 a	6.68 a	6.76 a	7.90 b	8.18 a	10.70 a	8.74 ab	7.73 ab	7.49 ab	9.34 a
NSS	8.62 a	8.82 a	8.12 a	6.53 a	6.42 a	8.36 ab	7.71 a	10.50 a	10.36 ab	8.94 ab	8.55 a	9.46 a
NSSG	7.86 a	8.67 a	8.66 a	7.16 a	6.84 a	8.45 ab	6.93 a	11.23 a	10.51 a	9.51 a	7.98 ab	9.62 a
ST4	8.12 a	8.18 a	7.63 a	6.73 a	7.16 a	11.75 a	8.44 a	10.77 a	8.32 b	7.95 ab	7.63 ab	7.98 a
TOPF	8.70 a	7.89 a	8.12 a	7.06 a	6.77 a	8.98 ab	8.12 a	11.86 a	8.45 ab	7.04 b	7.32 ab	9.28 a
TOPR	8.76 a	7.98 a	7.90 a	7.92 a	7.08 a	7.34 b	7.45 a	11.90 a	9.86 ab	7.53 ab	7.62 ab	8.90 a
CNTRL	8.40 a	9.03 a	9.29 a	6.99 a	6.06 a	7.75 b	7.58 a	10.40 a	8.86 ab	7.62 ab	7.77 ab	8.52 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 23. Soil C (g C per kg soil) of hybrid bermudagrass as affected by N source, 2010,Auburn, AL.

N Source	Harvest Date (weeks after application)											
	May 11 (1)	May 17 (2)	May 24 (3)	June 1 (4)	June 7 (5)	June 14 (6)	June 21 (7)	June 28 (8)	July 6 (9)	July 12 (10)	July 19 (11)	July 27 (12)
UREA	10.86 a	10.50 ab	14.26 a	11.88 a	10.30 a	12.28 ab	15.49 a	15.58 a	9.52 a	7.61 a	7.05 a	8.88 ab
MILORG	11.30 a	10.50 ab	11.78 a	11.73 a	12.86 a	13.73 a	15.22 a	13.73 ab	8.06 a	9.38 a	12.86 a	9.31 ab
NSS	10.70 a	10.77 ab	12.06 a	9.95 a	11.36 a	11.40 b	14.00 a	15.13 ab	10.29 a	10.10 a	11.52 ab	6.25 b
NSSG	12.21 a	12.49 a	12.32 a	11.60 a	11.27 a	11.86 ab	16.19 a	14.18 ab	10.73 a	8.66 a	14.16 a	7.93 ab
ST4	12.28 a	12.57 a	13.98 a	11.11 a	12.16 a	11.83 ab	14.23 a	15.53 a	10.93 a	10.12 a	13.68 a	8.98 ab
TOPF	12.13 a	11.91 ab	13.30 a	10.61 a	11.70 a	11.38 b	14.81 a	15.35 ab	9.71 a	8.06 a	10.86 ab	11.42 a
TOPR	10.78 a	10.22 ab	12.24 a	10.96 a	12.75 a	12.65 ab	12.75 a	14.05 ab	10.06 a	9.85 a	11.69 a	8.23 ab
ST8	11.78 a	11.11 ab	10.95 a	12.31 a	12.31 a	13.03 ab	13.48 a	15.20 ab	10.46 a	9.48 a	12.99 a	7.58 b
STB	12.22 a	11.82 ab	10.71 a	12.31 a	10.16 a	13.15 ab	12.67 a	12.88 b	8.92 a	7.99 a	12.22 a	9.83 ab
CNTRL	10.39 a	9.83 b	13.90 a	11.29 a	12.07 a	12.53 ab	12.65 a	13.23 ab	8.99 a	8.34 a	11.22 ab	7.78 ab

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 24. Soil microbial biomass (μg C per g soil) of hybrid bermudagrass as affected by N source, 27 July 2010, Auburn, AL.

N Source	μg C per g soil
UREA	171.6 a
MILORG	217.0 a
NSS	154.4 a
NSSG	241.8 a
ST4	222.4 a
TOPF	217.3 a
TOPR	210.0 a
ST8	181.7 a
STB	214.4 a
CNTRL	180.4 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 25. Weekly maximum and minimum temperatures of hybrid bermudagrass, 2010, Auburn, Al.

Weeks After Application	soil†		thatch‡	
	T_{min}	T_{max}	T_{min}	T_{max}
	°C			
1	17.5	28.3	38.8	70.9
2	18.3	28.7	60.6	68.3
3	21.0	30.7	29.9	69.1
4	22.1	31.1	38.3	66.6
5	23.6	31.9	39.2	65.8
6	24.4	34.4	36.1	68.3
7	25.6	35.3	31.5	67.4
8	27.9	34.9	27.1	66.6
9	17.1	33.2	34.4	62.7
10	26.3	31.9	19.8	66.6
11	27.5	31.9	25.6	49.0
12	27.1	32.8	26.0	59.2

†probe inserted at 5 cm depth

‡probe inserted at 2.5 cm depth

Table 26. Root and shoot measurements (average of two 57 mm diameter cores) of hybrid bermudagrass as affected by N source, 21 July 2009, Auburn, AL.

N Source	root weight (g)	shoot density (shoots per core)	rhizome/stolon weight (g)	rhizome/stolon diameter (mm)
UREA	0.78 a	102 a	5.7 a	1.5 ab
MILORG	0.84 a	102 a	6.0 a	1.6 a
NSS	0.77 a	94 ab	6.0 a	1.3 b
NSSG	0.87 a	107 a	5.0 a	1.6 ab
ST4	0.66 a	91 ab	5.0 a	1.6 a
TOPF	0.70 a	92 ab	5.0 a	1.5 ab
TOPR	0.83 a	99 a	6.0 a	1.6 a
CNTRL	0.84 a	79 b	5.0 a	1.5 ab

† within each sampling date means followed by the same letter are not significantly different from each other via means separation at α = 0.05.
*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Table 27. Root and shoot measurements (averaged of two 57 mm diameter cores) of hybrid bermudagrass as affected by N source, 2010, Auburn, AL.

N Source	Harvest Date (weeks after application)								
	root weight (g)			shoot density (shoots per core)			rhizome/stolon diameter (mm)		
	June 2 (4)	July 6 (9)	June 27 (12)	June 2 (4)	July 6 (9)	June 27 (12)	June 2 (4)	July 6 (9)	June 27 (12)
UREA	8.3 a	6.5 a	5.3 b	170 a	138 a	140 a	1.4 ab	1.3 abc	1.2 a
MILORG	7.6 a	6.2 a	7.7 a	159 ab	138 a	129 a	1.3 abc	1.2 bc	1.2 a
NSS	7.2 a	5.8 a	5.9 ab	150 ab	144 a	132 a	1.3 abc	1.3 ab	1.2 a
NSSG	8.0 a	5.6 a	5.4 b	156 ab	141 a	128 a	1.2 bc	1.1 c	1.2 a
ST4	7.7 a	6.3 a	6.3 ab	141 ab	167 a	126 a	1.3 abc	1.1 bc	1.3 a
TOPF	7.0 a	6.6 a	7.2 ab	133 b	152 a	135 a	1.1 c	1.4 a	1.1 a
TOPR	8.4 a	6.3 a	5.9 ab	130 ab	133 a	124 a	1.3 abc	1.2 bc	1.2 a
ST8	8.9 a	5.9 a	6.7 ab	159 ab	160 a	136 a	1.4 ab	1.2 bc	1.2 a
STB	6.7 a	5.2 a	5.6 b	144 ab	137 a	134 a	1.4 ab	1.3 abc	1.3 a
CNTRL	8.3 a	5.8 a	6.9 ab	142 ab	137 a	114 a	1.5 a	1.2 abc	1.2 a

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

*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Table 28. Laboratory mineralization study, analysis of variance table, Auburn, AL.

	Effect	Degrees of Freedom		F Value	P > F Values	
					Day 0	Day 70
NH_4	Temp	2	3	1.0	0.5	1.0
	Trmt	6	118	46.0	0.0*	0.0*
	Temp x Trmt	12	118	4.8	0.0*	0.0*
NO_3	Temp	2	3	0.5	0.7	0.6
	Trmt	6	118	3.7	0.0*	0.0*
	Temp x Trmt	12	118	4.6	0.0*	0.0*
Total N (NH_4-N + NO_3-N)	Temp	2	3	0.8	0.5	0.8
	Trmt	6	118	26.5	0.0*	0.0*
	Temp x Trmt	12	118	1.2	0.3	0.0*

*denotes a significant effect at $\alpha = 0.05$.

Table 29. P-values for organic fertilizer treatments used in mineralization study, Auburn, AL.

	N Source	% recovery	Std. Err.	Adjusted P-value						Std. Err.	LSD 0.05
				NSS	NSSG	ST	TOPF	TOPR	UREA		
15°C	MILORG	37.3	6.1	0.0*	0.0*	0.0*	0.2	1.0	0.0*	2.77	5.48
	NSS	62.3	6.1	.	0.7	0.0*	0.0*	0.0*	0.0*	2.77	5.48
	NSSG	58.0	6.1	.	.	0.0*	0.0*	0.0*	0.0*	2.77	5.48
	ST4	20.1	6.1	.	.	.	0.0*	0.0*	1.0	2.77	5.48
	TOPF	30.6	6.1	.	.	.	.	0.1	0.0*	2.77	5.48
	TOPR	38.2	6.1	.	.	.	.	.	0.0*	2.77	5.48
	UREA	18.4	6.1	.	.	.	.	.	.		
25°C	MILORG	49.5	6.1	0.0*	0.0*	0.0*	0.0*	0.7	0.0*	2.77	5.48
	NSS	66.5	6.1	.	0.5	0.0*	0.0*	0.0*	0.0*	2.77	5.48
	NSSG	61.4	6.1	.	.	0.0*	0.0*	0.0*	0.0*	2.77	5.48
	ST4	16.6	6.1	.	.	.	0.0*	0.0*	0.0*	2.77	5.48
	TOPF	38.7	6.5	.	.	.	.	0.8	0.0*	3.50	6.93
	TOPR	43.9	6.5	.	.	.	.	.	0.0*	3.50	6.93
	UREA	27.4	6.1	.	.	.	.	.	.		
35°C	MILORG	43.9	6.1	0.0*	0.0*	0.0*	0.0*	0.4	0.0*	2.77	5.48
	NSS	60.1	6.1	.	0.8	0.0*	0.0*	0.0*	0.0*	2.77	5.48
	NSSG	56.2	6.1	.		0.0*	0.0*	0.0*	0.0*	2.77	5.48
	ST4	31.7	6.1	.		.	0.7	0.2	0.0	2.77	5.48
	TOPF	27.3	6.1	.	.	.	.	0.0*	1.0	2.77	5.48
	TOPR	38.3	6.1	.	.	.	.	.	0.0*	2.77	5.48
	UREA	29.9	6.1				.	.	.	.	.

*denotes significant effect at α = 0.05

†UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)

Table 30. Transition day and percent recovery for mineralization study, Auburn, AL.

	N Source	15°C	25°C	35°C
Days at transition	UREA	7.4	5.6	5.4
	MILORG	9.8	8.8	5.4
	NSS	12.2	9.0	7.1
	NSSG	31.7	10.7	8.3
	ST4	9.4	3.1	4.1
	TOPF	5.2	9.2	7.3
	TOPR	8.0	12.3	7.6
% recovery (inorganic N) at transition	UREA	15.3	21.7	24.1
	MILORG	23.6	28.4	29.5
	NSS	40.0	46.3	45.0
	NSSG	45.3	40.4	39.8
	ST4	12.8	8.5	21.2
	TOPF	22.8	23.5	19.0
	TOPR	19.2	25.3	24.0
% recovered (total inorganic N)	UREA	18.4	27.4	29.9
	MILORG	37.3	49.5	43.9
	NSS	62.3	66.5	60.1
	NSSG	58.0	61.4	56.2
	ST4	20.1	16.6	31.7
	TOPF	30.6	38.7	27.3
	TOPR	38.2	43.9	38.3

†transition point is the intercept of two predicted models of mineralization

‡ UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-NatureSafe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)

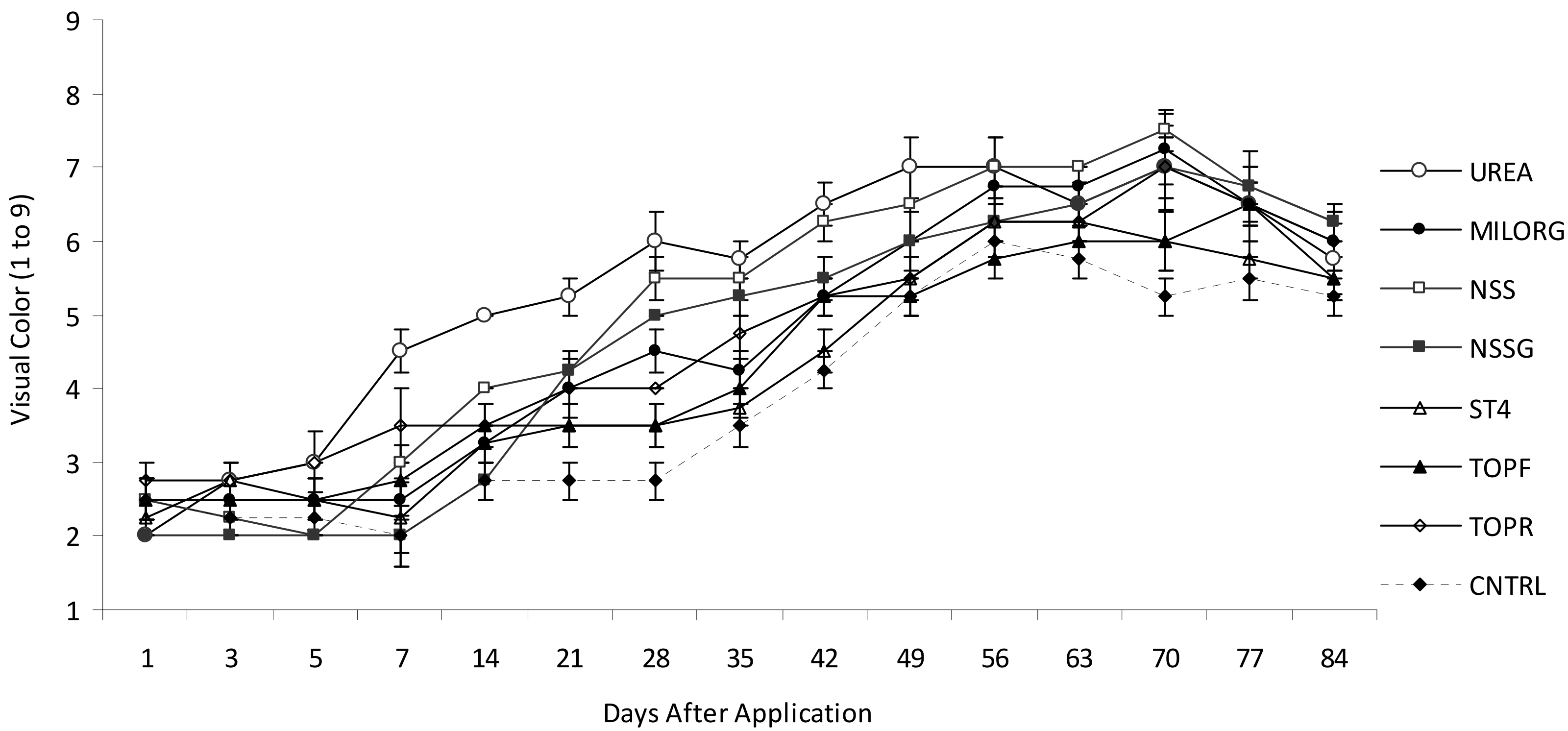
Table 31. Weekly maximum and minimum air temperatures for incubation study (15 and 35°C), 2010.

	15°C Rep 2		35°C Rep 1		35°C Rep 2	
Weeks After Application	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
1	15.62	12.55	*	*	36.13	29.90
2	15.62	12.55	*	*	35.27	32.76
3	15.62	12.55	*	*	34.85	34.01
4	15.62	12.93	34.85	34.01	35.27	32.34
5	15.62	12.93	34.85	31.52	35.27	32.34
6	15.62	12.55	34.85	32.34	35.27	32.76
7	15.62	12.93	34.85	29.90	35.27	28.70
8	15.62	12.93	34.85	29.50	35.27	28.70
9	15.62	12.93	34.85	32.34	35.27	27.91
10	15.62	12.93	35.27	34.01	35.27	29.10

* missing data; all 25°C and 15°C rep 1 data was lost

Figure 1. Visual color rating (1 to 9) of hybrid bermudagrass as affected by N source, applied on April 27, 2009, Auburn, AL.

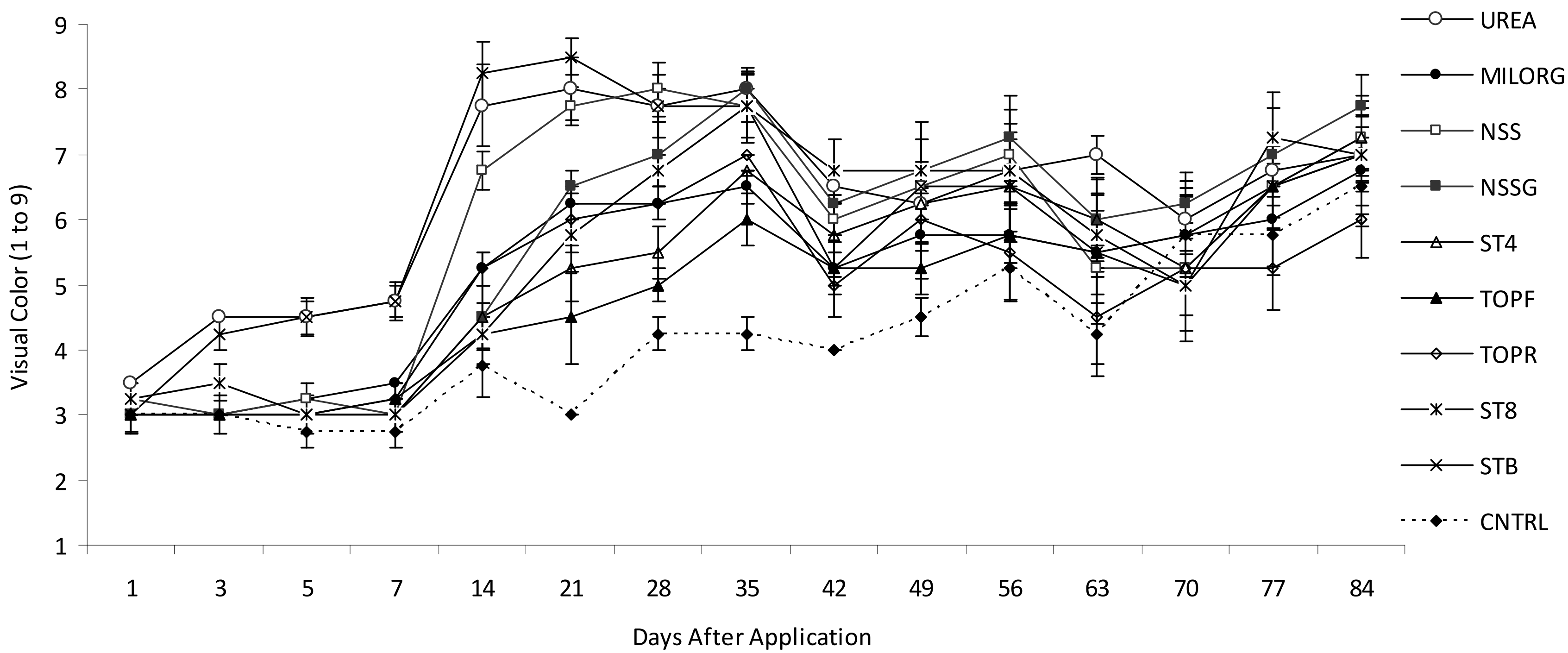
Vertical bars represent the standard error.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Figure 2. Visual color rating (1 to 9) of hybrid bermudagrass as affected by N source, applied on May 4, 2010, Auburn, AL.

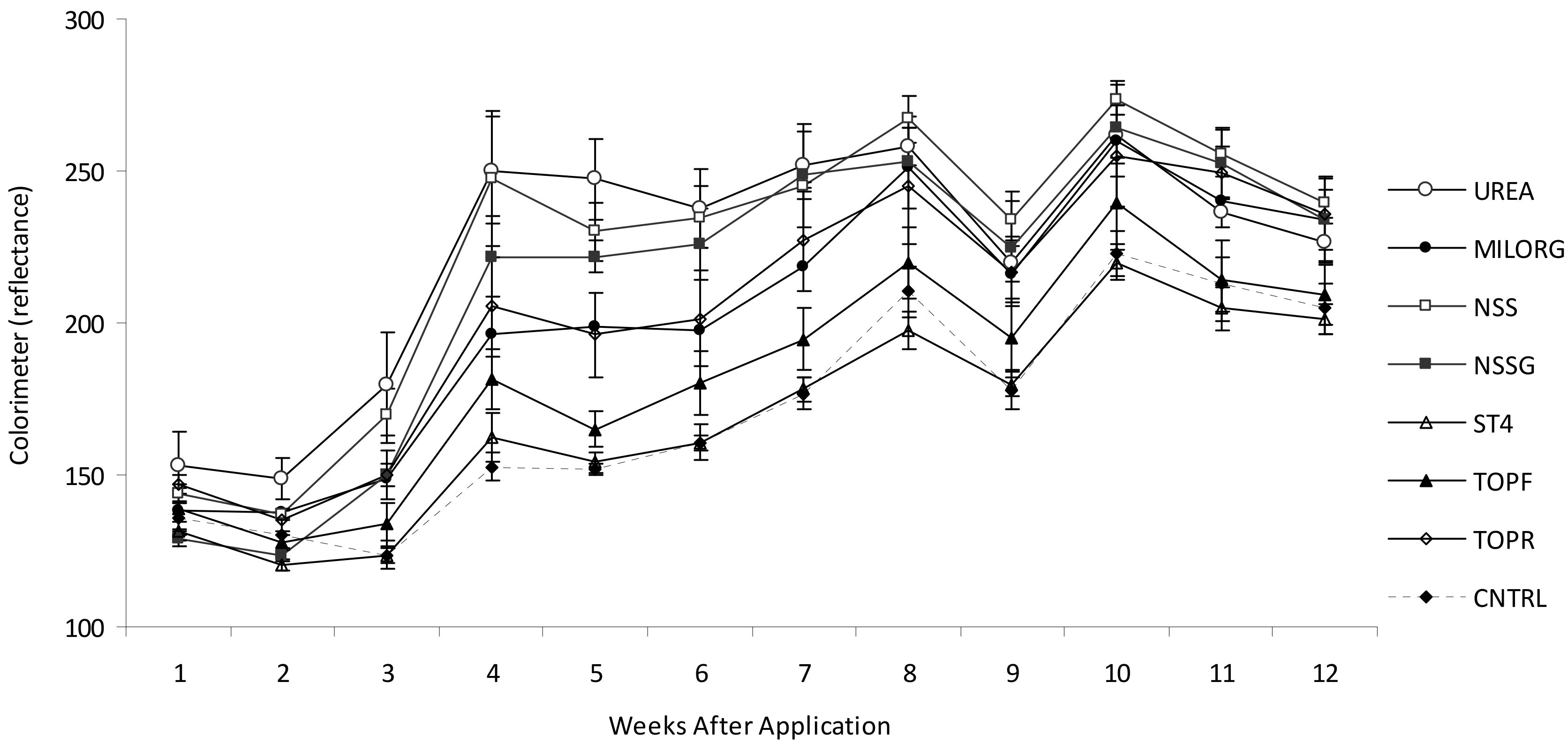
Vertical bars represent the standard error.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Figure 3. Colorimeter reflectance of hybrid bermudagrass as affected by N source, applied on April 27, 2009, Auburn, AL.

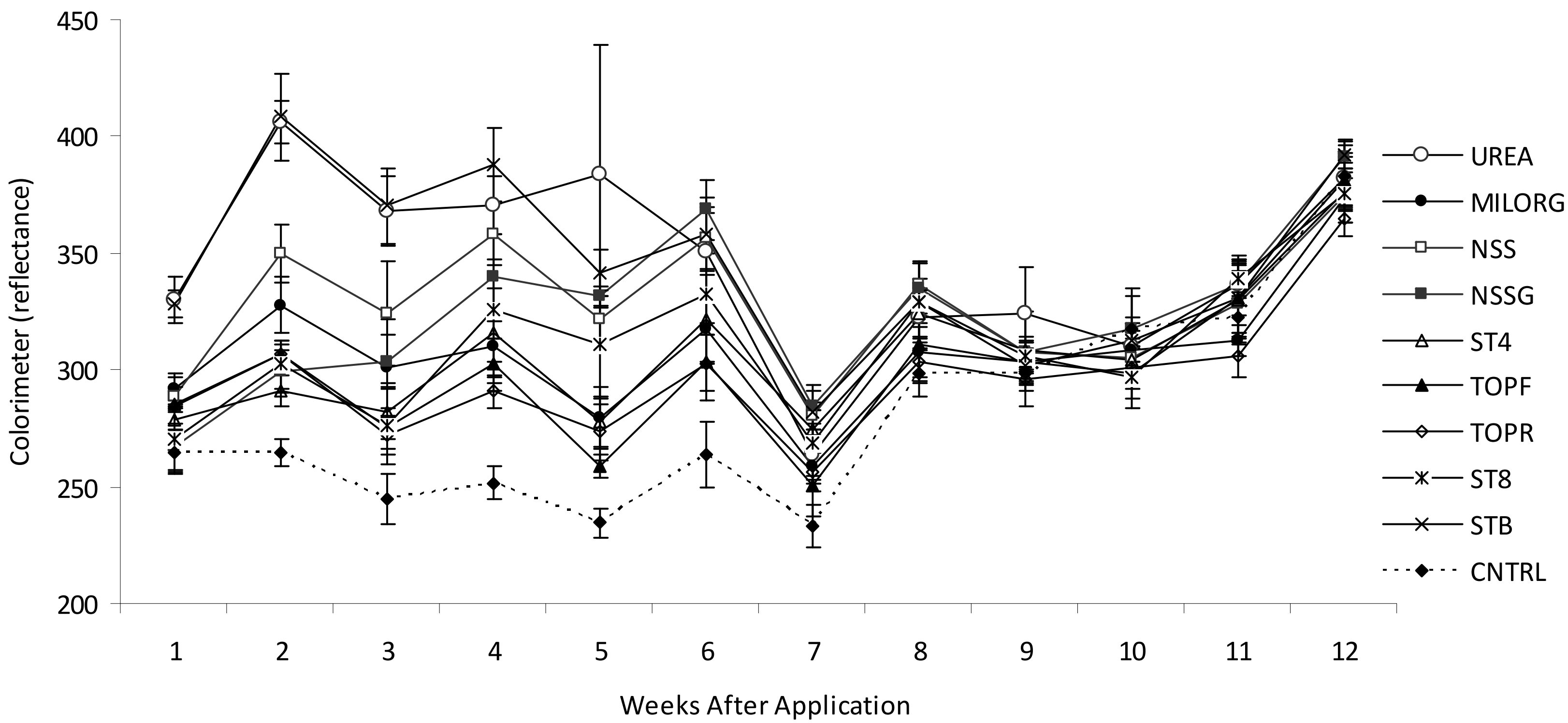
Vertical bars represent the standard error.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), CNTRL-unfertilized control

Figure 4. Colorimeter reflectance of hybrid bermudagrass as affected by N source, applied on May 4, 2010, Auburn, AL.

Vertical bars represent the standard error.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2), ST8-Sustane® (8-2-4), STB-Scotts Turf Builder (32-0-10), CNTRL-unfertilized control

Figure 5. Correlation between visual color and chlorophyll meter readings as affected by N source, 2009, Auburn, AL.

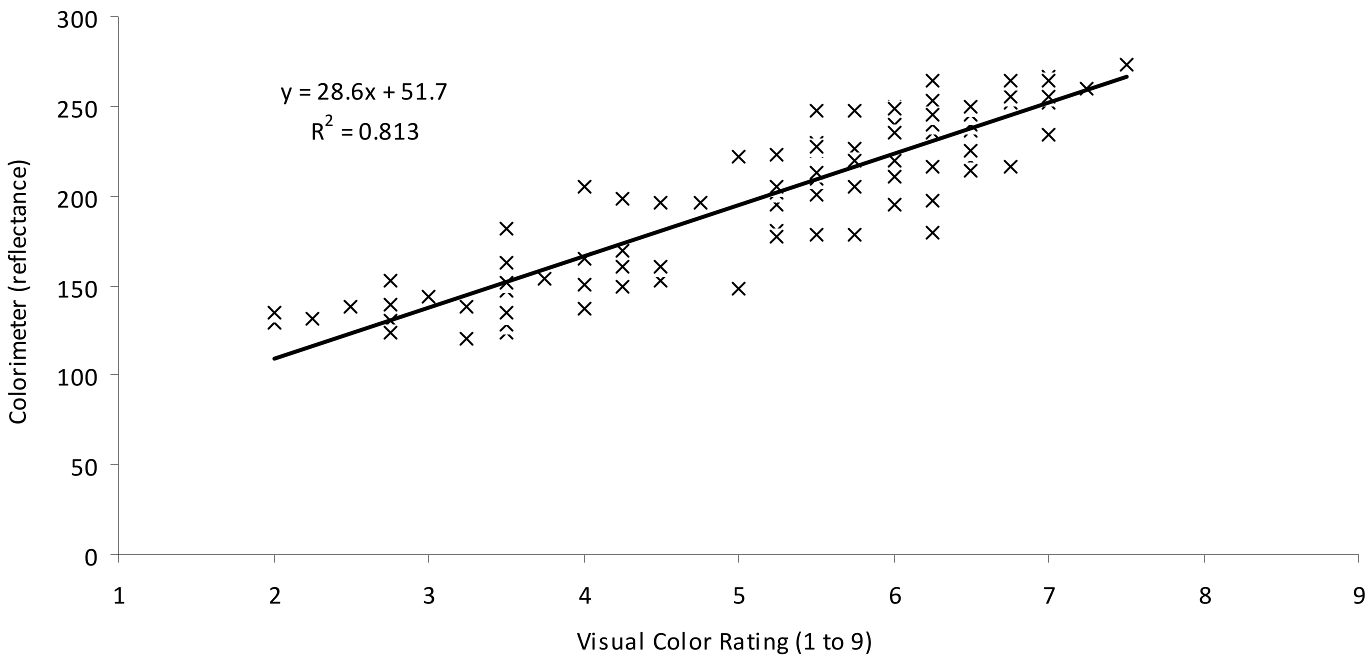


Figure 6. Correlation between visual color and chlorophyll meter readings as affected by N source, 2010, Auburn, AL.

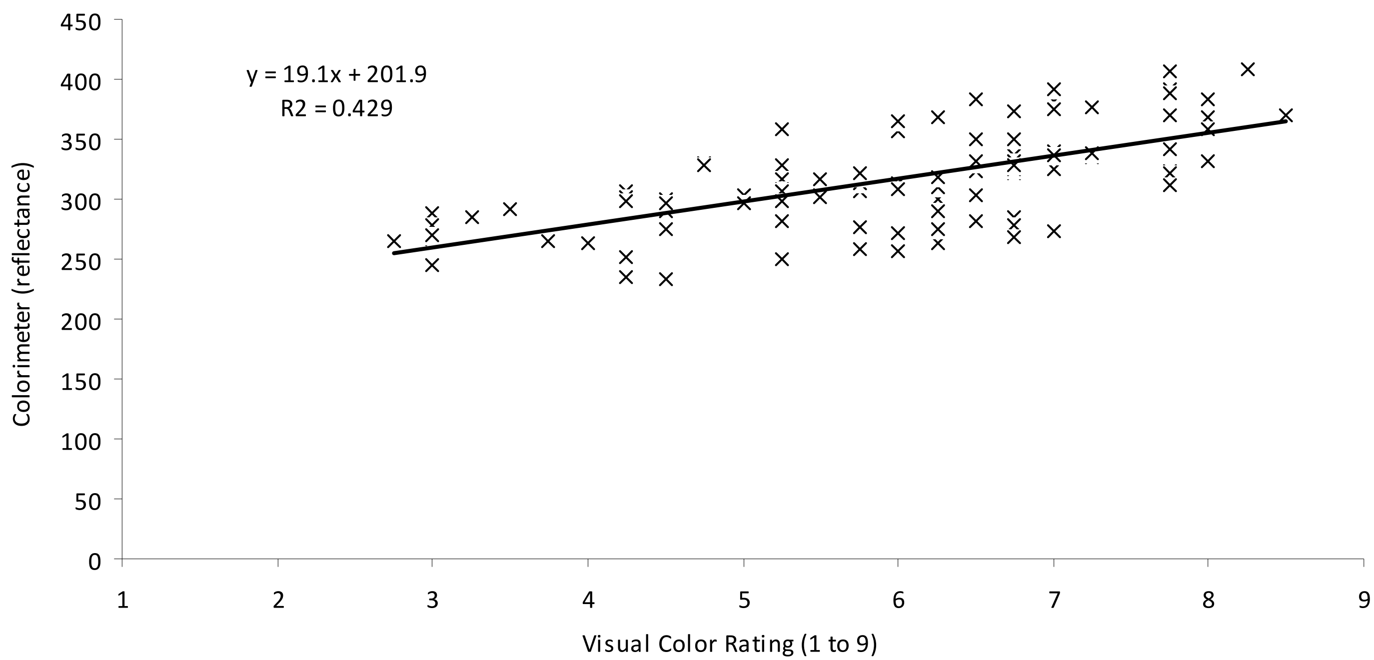
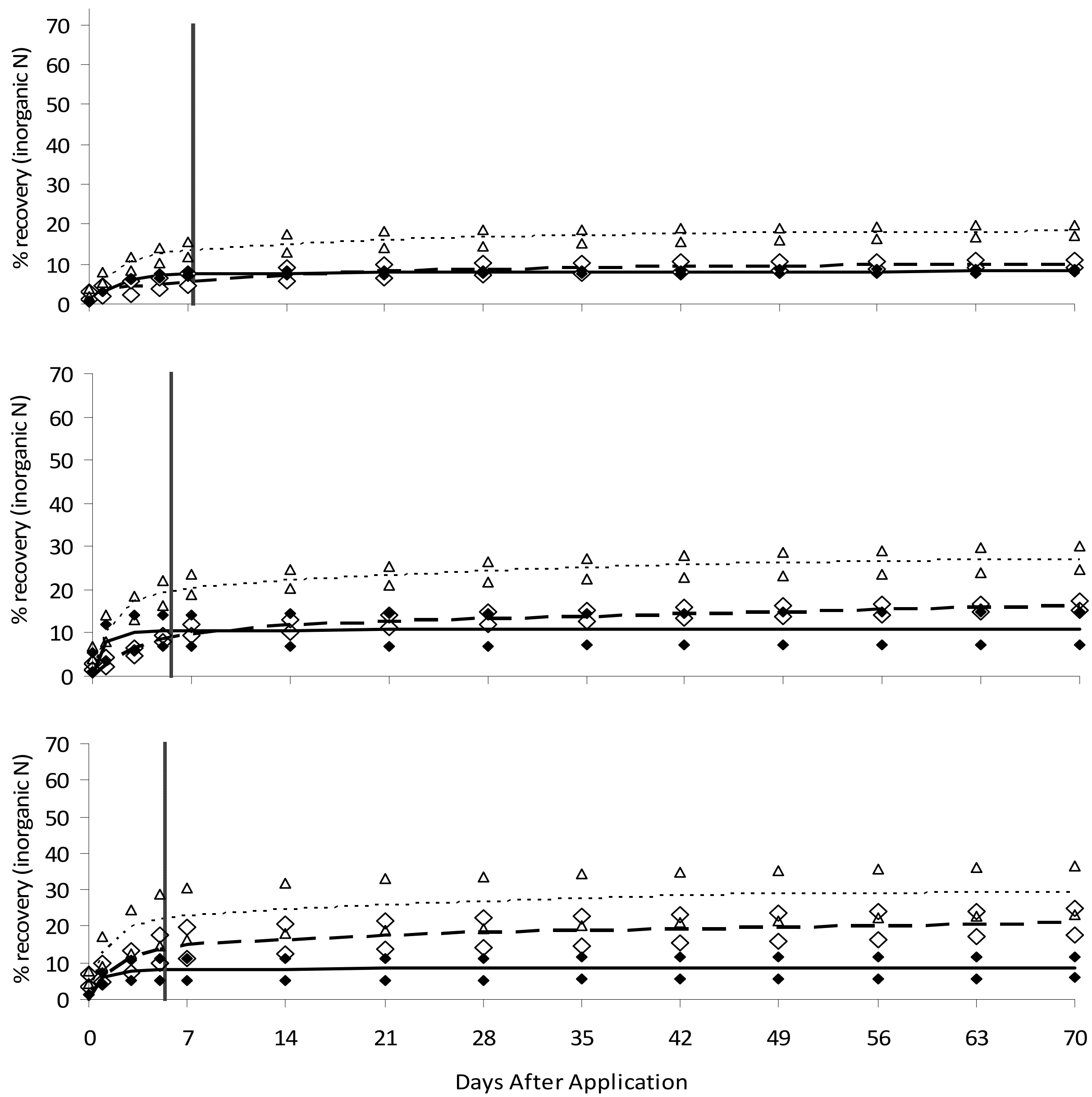
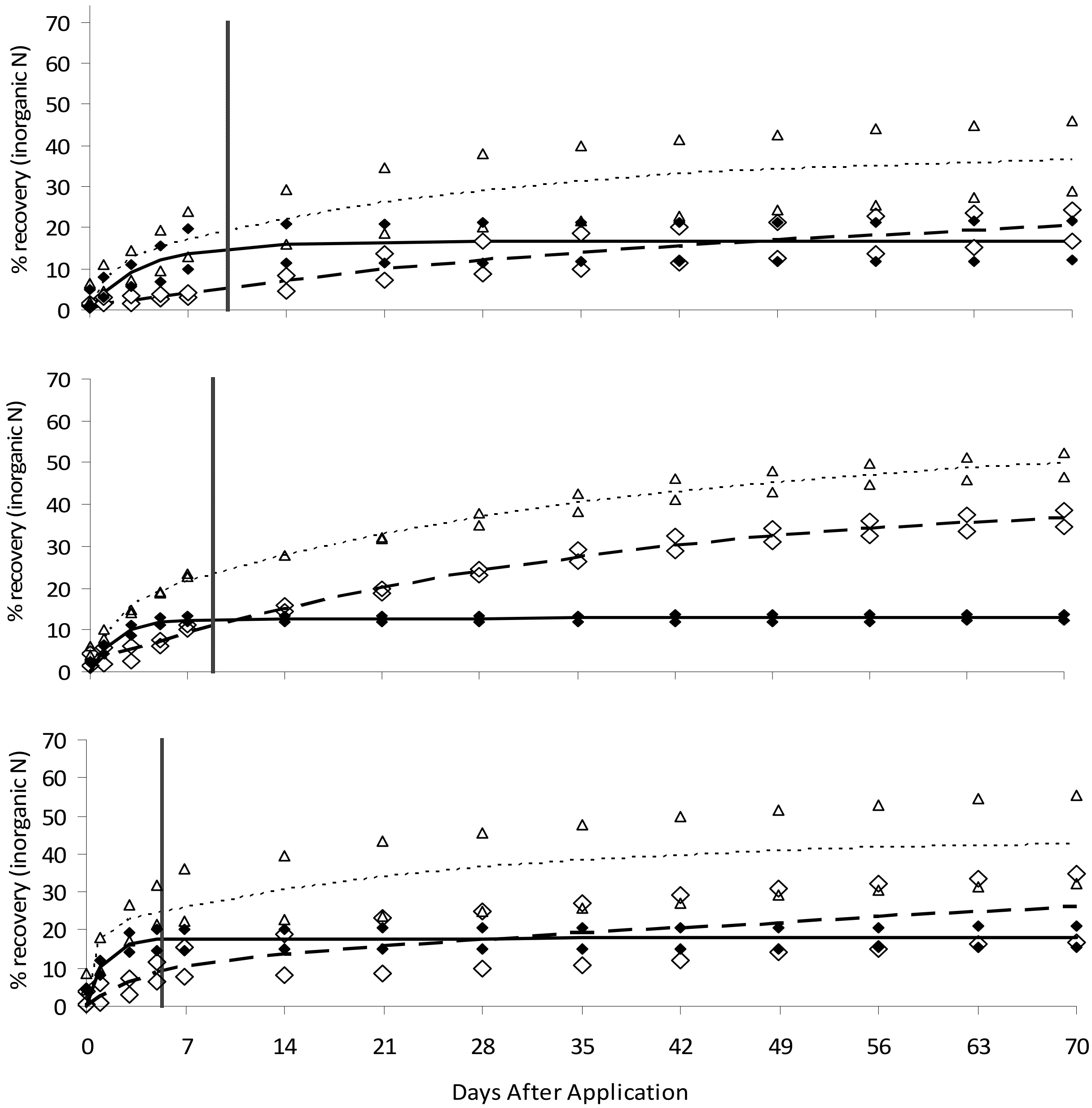


Figure 7. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a urea application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



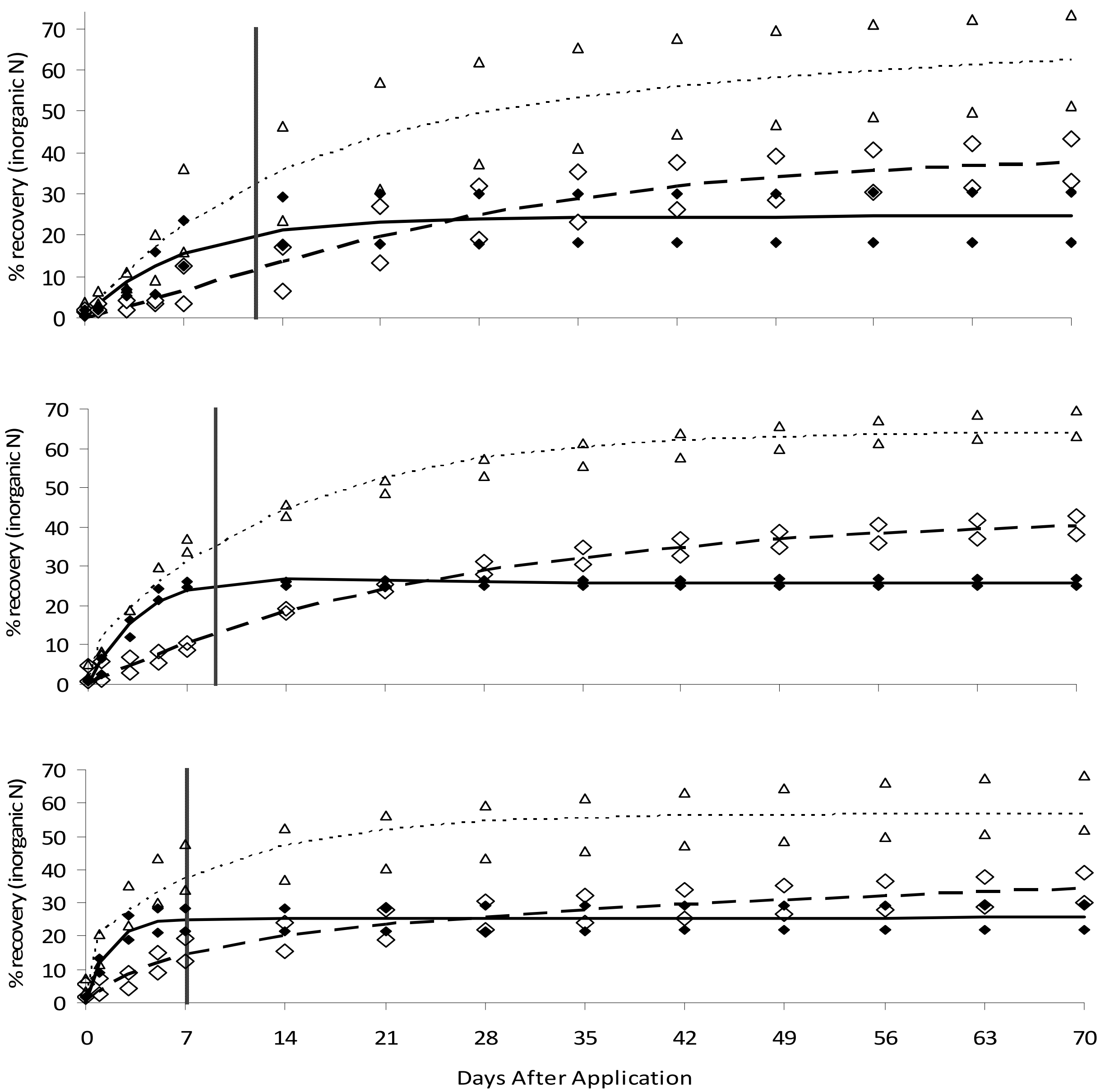
* Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted); vertical bar (transition day)

Figure 8. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a Milorganite application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



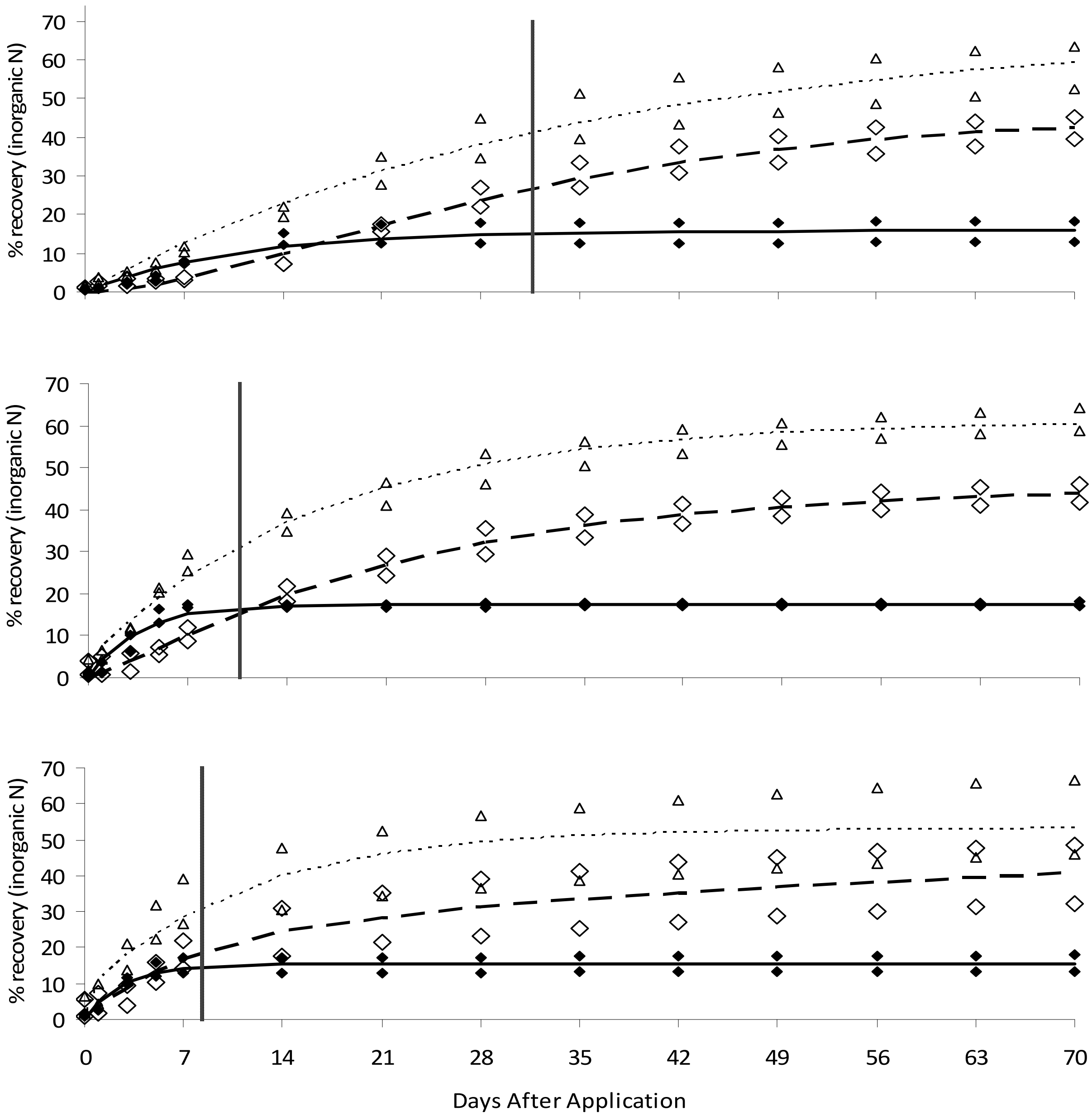
* Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted); vertical bar (transition day)

Figure 9. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a NatureSafe Starter application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



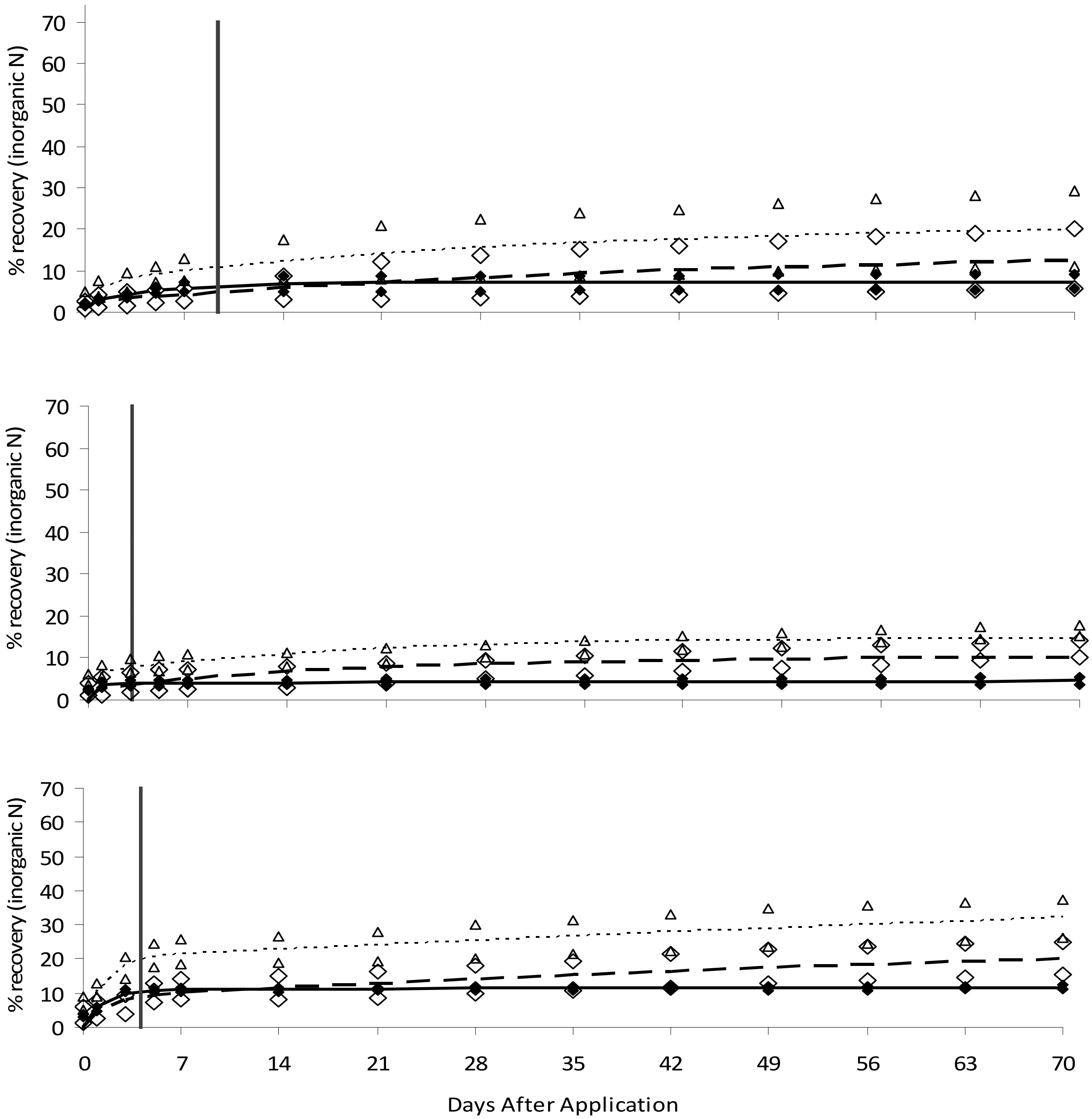
* Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted), vertical bar (transition day)

Figure 10. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a NatureSafe StressGuard application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



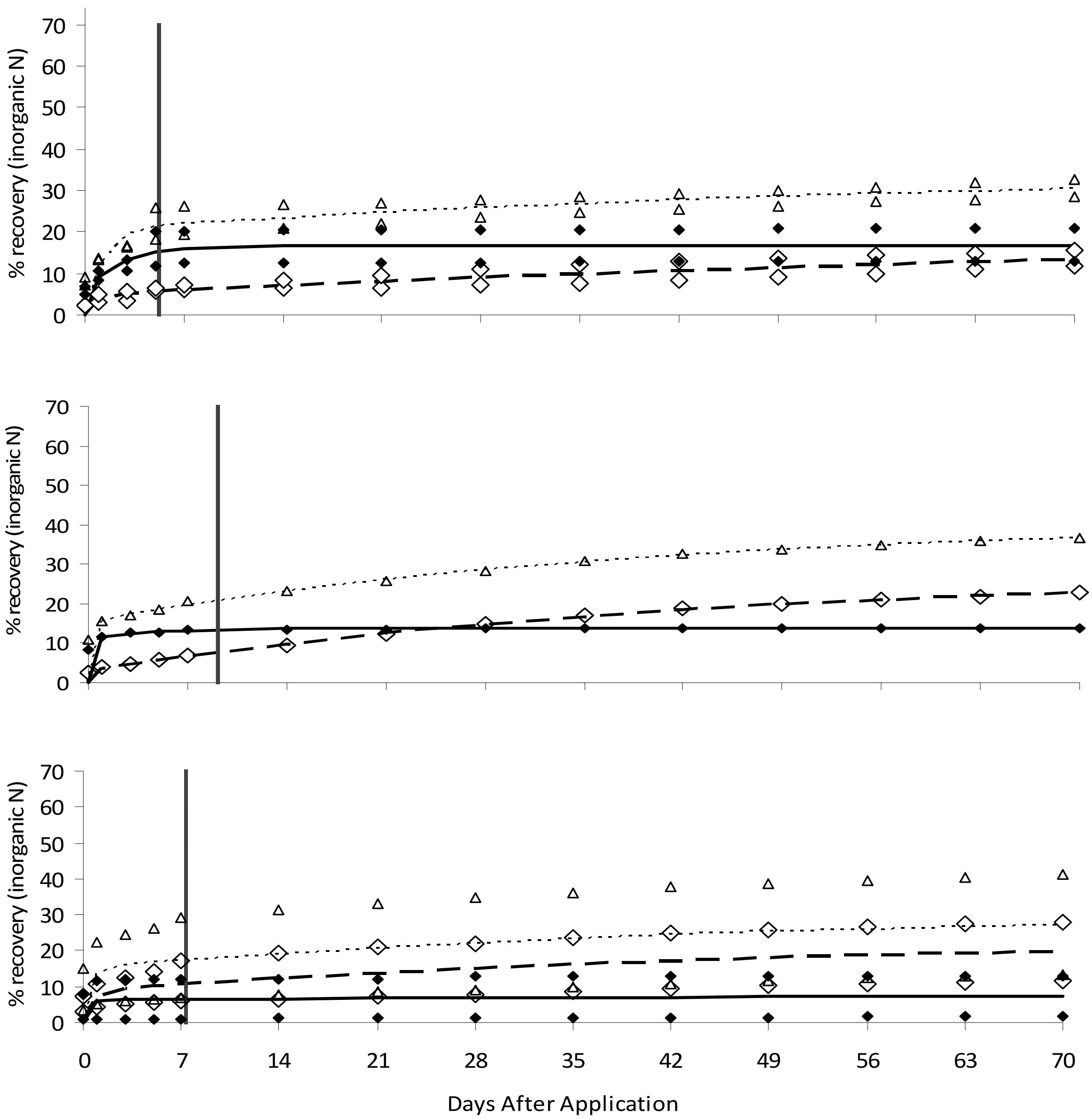
*Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted); vertical bar (transition day)

Figure 11. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a Sustane® (4-6-4) application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



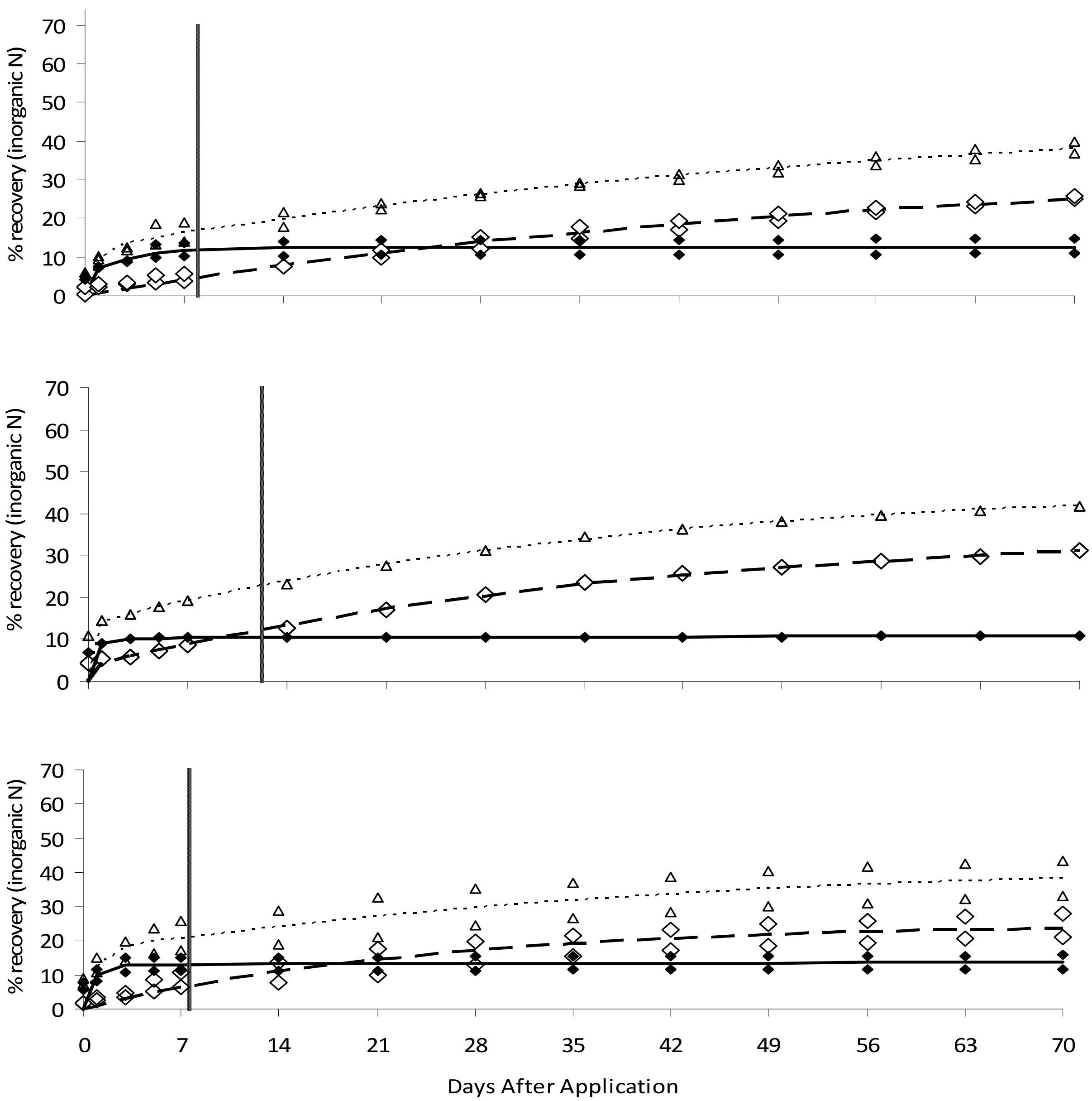
* Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted), vertical bar (transition day)

Figure 12. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a TOP (fine grade) application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



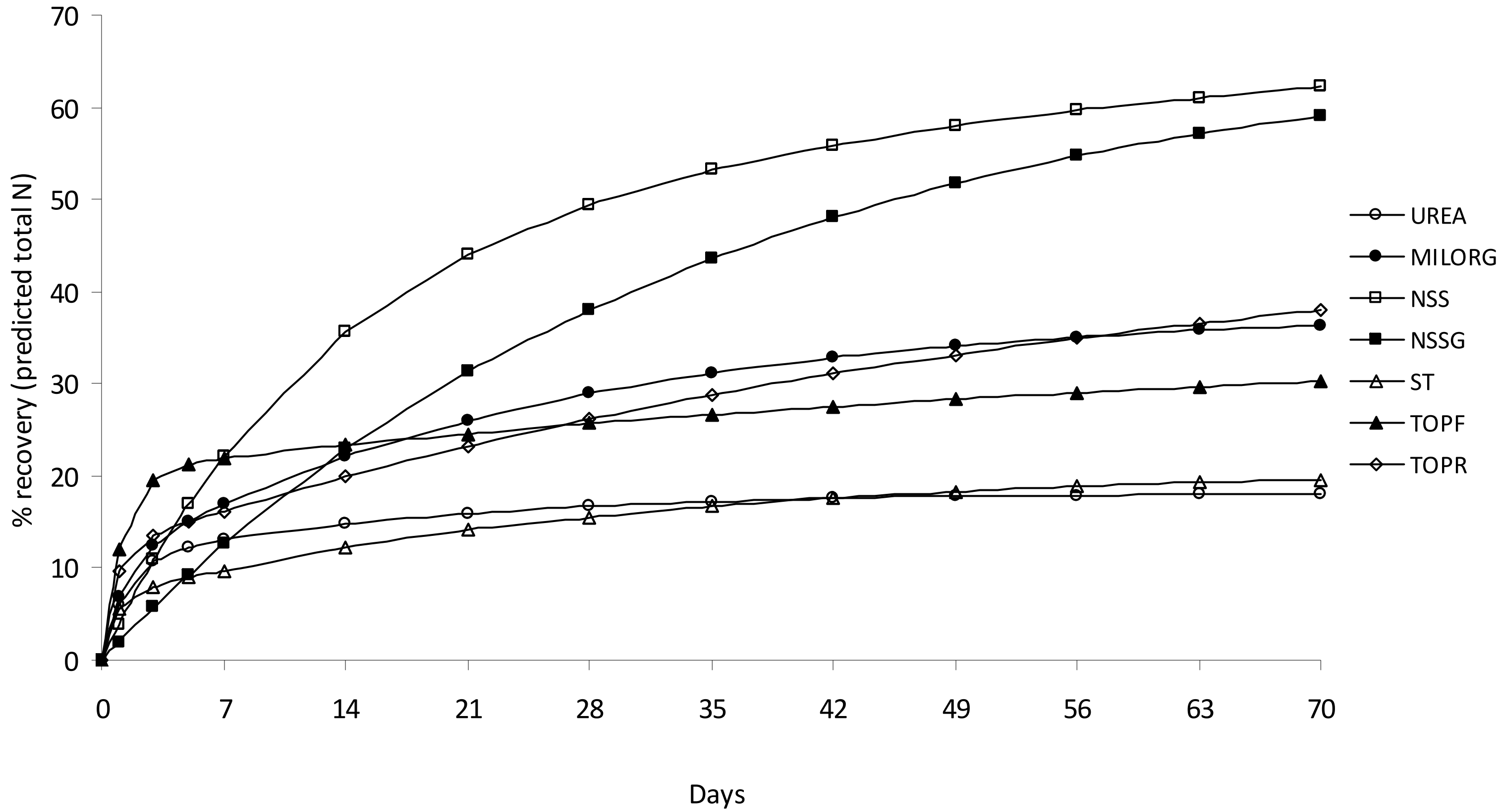
*Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted); vertical bar (transition day)

Figure 13. Cumulative inorganic N (NH_4-N and NO_3-N) recovery from a TOP (regular grade) application to a Marvyn loamy sand with soil temperatures at 15 (top), 25 (middle), and 35°C (bottom), respectively.



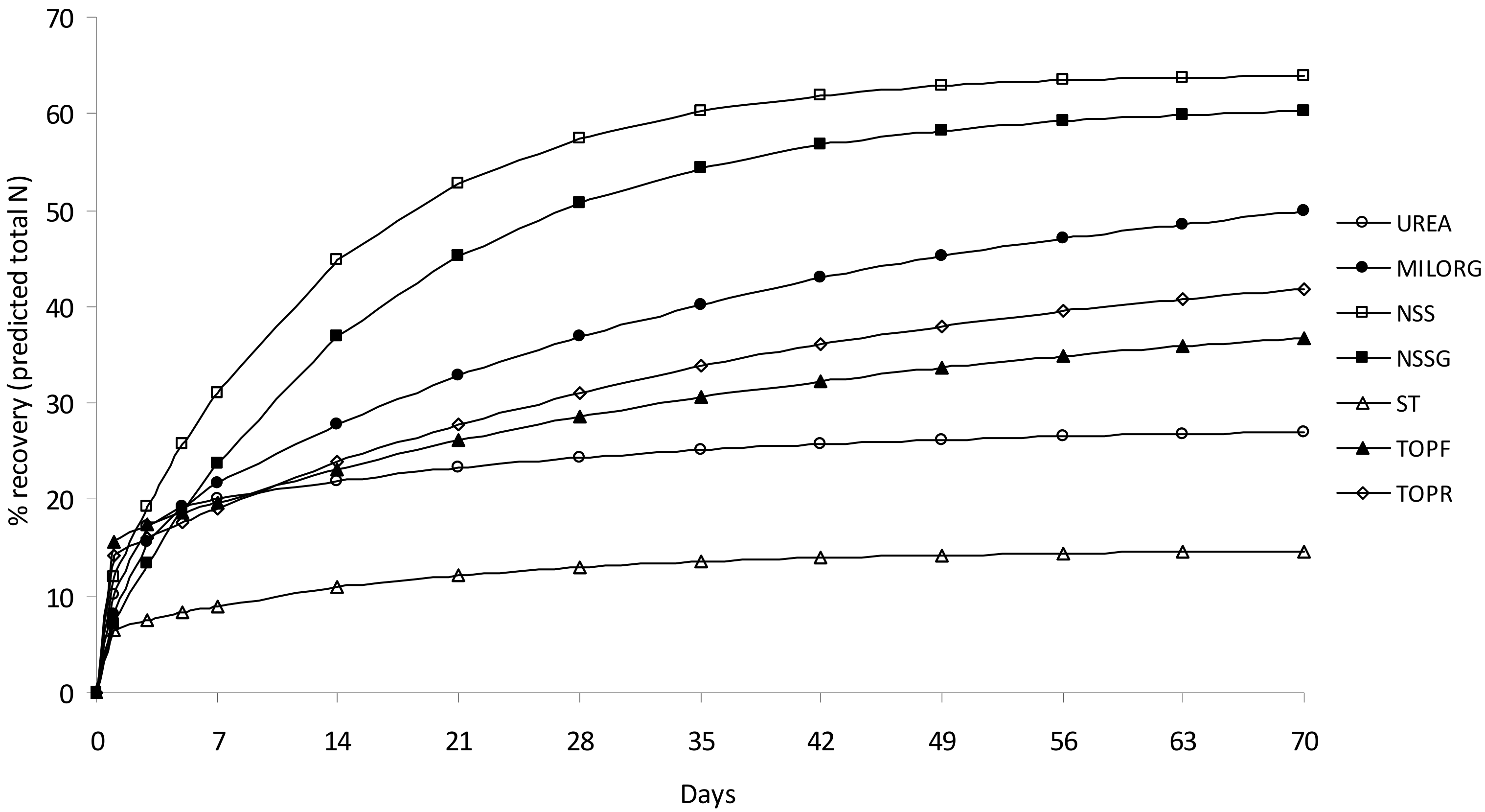
*Solid diamond (NH_4-N); open diamond (NO_3-N); solid line (NH_4-N predicted); dashed line (NO_3-N predicted); open triangle (total inorganic N); dotted line (total inorganic N predicted); vertical bar (transition day)

Figure 14. Percent of inorganic N (NH_4-N +NO_3-N) recovery from organic fertilizer sources applied to a Marvyn loamy sand incubated at 15°C, 2009, Auburn, AL.



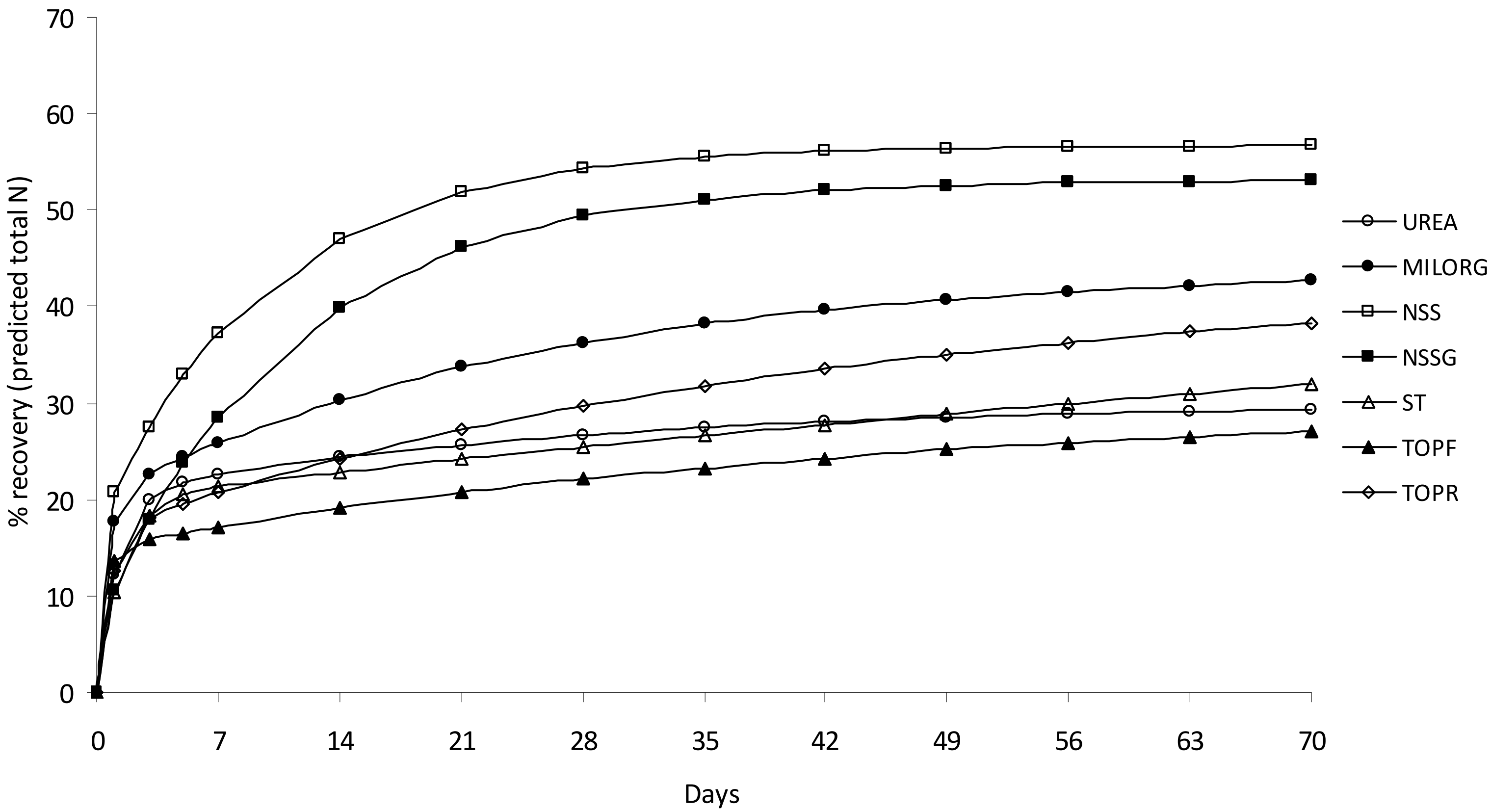
*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-NatureSafe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)

Figure 15. Percent of inorganic N (NO_3-N + NH_4-N) recovery from organic fertilizer sources applied to a Marvyn loamy sand incubated at 25°C, 2009 and 2010, Auburn, AL.



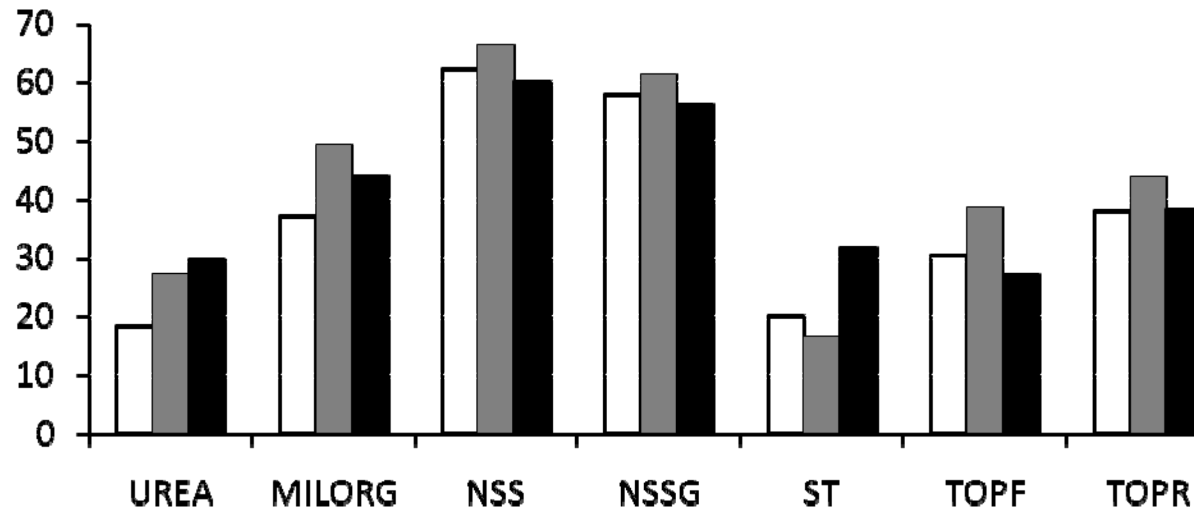
*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)

Figure 16. Percent of inorganic N (NO_3-N + NH_4-N) recovery from organic fertilizer sources applied to a Marvyn loamy sand incubated at 35°C, 2009 ad 2010, Auburn, AL.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)

Figure 17. Day 70 percent recovery of inorganic N (NH_4-N + NO_3-N) from organic fertilizers applied to a Marvyn loamy sand at 15, 25, and 35°C, respectively.



*UREA-Urea (46-0-0), MILORG-Milorganite (6-2-0), NSS-Nature Safe Starter (5-6-6), NSSG-Nature Safe StressGuard (8-3-5), ST4-Sustane® (4-6-4), TOPF-Top Organic Fine Grade (4-2-2), TOPR-Top Organic Regular Grade (4-2-2)