

MOWING AND NITROGEN SOURCE EFFECTS ON AMMONIA VOLATILIZATION
FROM FERTILIZERS APPLIED TO TURFGRASS

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FROM FERTILIZERS APPLIED TO TURFGRASS

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THESIS ABSTRACT

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Although ammonia (NH_3) volatilization can be a pathway of nitrogen (N) loss from turfgrass systems, the magnitude of this loss has not been well quantified, especially from N sources other than urea. The objective of this research was to evaluate NH_3 volatilization as affected by N source and mowing. The laboratory study consisted of two mowing treatments (mowed or not mowed) and six N sources: 1) urea (46-0-0), 2) sulfur coated urea (39-0-0); 3) polymer coated urea (41-0-0), 4) methylene urea (40-0-0), 5) ammonium nitrate (34-0-0), and 6) composted sewage sludge (6-0-0). The 12 treatments were applied at a N rate of 14.7 g m^{-2} to the surface of a 10 cm diameter bentgrass plug contained in 1 L jars. Jars were sealed, and NH_3 volatilization over 10 days was measured via boric acid trapping. Two experiments were conducted, each with a

different soil: a loamy sand (Exp. 1), and an 80% sand/20% peat (v/v) greensmix (Exp. 2). In Exp. 1, mowing never affected NH_3 volatilization, so mowing was eliminated from Exp. 2. Over the ten day measurement period, urea had greatest total NH_3 volatilization, with most released in the first two days. Polymer coated urea released the least NH_3 , with greatest release nine and ten days after treatment. In descending order, amounts of NH_3 volatilization were: urea, sulfur coated urea, methylene urea, composted sewage sludge, ammonium nitrate, and polymer coated urea.

The objective of the field study was to determine the amount of nitrogen (N) lost through NH_3 volatilization from three N sources previously used in the laboratory experiment. Treatments were applied to existing turfgrass stands of Tifway hybrid bermudagrass, Emerald zoysiagrass, and both bermudagrass and zoysiagrass in fall 2005, spring 2006, and fall 2006, respectively, near Tuskegee, AL. Fertilizer treatments included: urea (46-0-0), methylene urea (40-0-0), and polymer coated urea (41-0-0) and were applied at a rate of 14.7 g m^{-2} of N. Ammonia was captured using a passive micrometeorological system and differences in N sources were observed over a 10-d period. In 2005, urea released the highest proportion of applied N (11.7 %). Mass of NH_3 released from methylene urea (7.4 %) was not different from that released from urea ($P \leq 0.10$). Polymer-coat urea differed from urea in the amount of NH_3 volatilized, but did not differ from methylene urea ($P \leq 0.10$). In spring 2006, NH_3 volatilization from N sources was in the order: urea (20.1%) > methylene urea (7.4%) > polymer coated urea (4.4%) ($P \leq 0.10$). Nitrogen sources followed the same trend in fall 2006: urea (15.7%) > methylene urea (4.2%) = polymer coated urea (4.4%) ($P \leq 0.10$).

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I. LITERATURE REVIEW

Introduction

In Genesis 1:11-12, God commanded that the earth produce seed-bearing vegetation, and so it was that the first plants were created for man's use and enjoyment. In other passages, such as Peter 1:24 and Deuteronomy 8:7, the Lord compared man to grass and talked of the good land that he had prepared for man's use. These are perhaps some of the first historical references to the use and importance of plants throughout history. Today, plants continue to play important roles in the lives of all humans. They provide food and medicines that are vital to our survival and well-being, as well as providing decorations that improve our overall health and happiness. Recent research confirmed past claims that interior plants improved employee morale, increased productivity, and reduced work absences (Pearson-Mims and Lohr, 2000). Other research showed that patients in a room with a view of trees used less pain medication after surgery (Lohr and Pearson-Mims, 2000).

Turfgrass are plants that form a more or less contiguous ground cover that persists under regular mowing and traffic. The term turfgrass refers only to the plant itself, whereas turf includes a portion of the medium in which the turfgrass are growing (Turgeon, 1985). The grass family (*Gramanieae*) includes over 5,000 species of plants, but only about 40 species are suited for turf use. The characteristic that distinguishes

turfgrass from the other grass species is the ability of turfgrass to persist under regular mowing (Duble, 1996).

Turfgrass are used for a variety of purposes. Utility turfs exist to stabilize the soil, reduce dust and glare, and absorb pollution from road traffic. Lawn turfs serve a decorative function by enhancing the beauty of a landscape and providing arenas for recreational play (Turgeon, 1985). Turfgrasses are the most important feature on golf courses, athletic fields, and other sports fields requiring a resilient playing surface (Duble, 1996).

Golf Course Management

The society of St. Andrew's Golfers recognized the importance of golf course management in 1754. In exchange for privileged start times for paying members, the Society agreed to pay for the maintenance of the golf course. The end of the 1700s also brought the first "greenkeepers" (green referring to the entire golf course, not just the putting greens). The Aberdeen Golf Links recorded the first paid caretaker in 1820. Alexander Moore earned 3 pounds a year for his work in maintaining the links and members' boxes, paying special attention to keeping the holes in good order. By the late 1880s the United States had its first permanent golf course, with seventy-five clubs existing by 1895 (Beard, 1982).

In 2002, there were more than 16,000 golf courses in the United States, with 325 new facilities projected to open that year. In addition, over the last two decades many artificial turf sports fields have been converted to natural turf. The growth in these areas, along with the continued need for skilled professionals in the lawn care sector, has

increased the demand for trained professionals in turf grass management (Christians, 2004).

Importance of N Fertility in Turf

Nitrogen is an essential plant nutrient and has several roles in plant and soil fertility. The importance of maintaining balanced N fertility in a turfgrass maintenance program has been emphasized in studies (Bowman et. al, 2002). However, balancing N fertility for maximum value (aesthetic and playability), a healthy environment, and disease control has become increasingly important. There are fine lines between applying adequate N to maximize aesthetic value and playability and over-fertilizing with N, creating turf health problems and environmental concerns.

Nitrogen is the element that is usually needed in the greatest quantity on golf courses (Christians, 2004). When maintained at adequate levels, N promotes vigor, visual quality, recovery from damage, and overall health (Bowman et al, 2002). Nitrogen is used to increase green color of grasses on putting greens, and this can lead to over-fertilization because players and superintendents want aesthetically pleasing turf on which to play. Razmjoo et al (1996) found that both high N rate and increased mowing height significantly increased the color of creeping bentgrass, but high N rate was more effective than mowing height.

Fate of N Applied to Turf

Nitrogen primarily enters the turf system as fertilizer and exits via gaseous losses, leaching, clipping removal, and under some conditions, surface runoff (Bowman et al, 2002). Uptake of N is influenced by several factors including temperature and moisture

that affect plant growth rate, available N pool, N source and rate, and the genetic potential differences between species and/or cultivars (Petrovic, 1990).

High leaching losses are associated with several factors, including irrigation management, turfgrass establishment, and species or cultivar selection. Bowman, et al. (2002) found that there were significant genotypic differences in N use among six warm season turfgrasses. In this study, nitrate and ammonium readily leached from all species shortly after planting, but leaching was reduced as the root systems were developed. This study highlights the importance of carefully managing both fertility and irrigation when establishing warm-season grasses from sod.

Factors affecting NH_3 volatilization include soil type (texture, pH, CaCO_3 content, and urease activity), environmental factors (temperature, soil water content, rainfall pattern, wind speed, and relative humidity), and fertilizer management (timing, placement, and irrigation regime) (Bouwmeester et al., 1985). Increased temperature and soil water content have been both shown to increase the rate of NH_3 volatilization (Clay et al., 1990). Further, the absence or presence of thatch is a characteristic of turfgrass culture that has a dramatic impact on NH_3 volatilization. Urease activity, which is needed to convert urea to NH_3 , has been noted in the thatch layer, explaining the role thatch plays in NH_3 volatilization (Bowman et al., 1987).

Since the position of N affects volatilization rate, and position is influenced by rainfall or irrigation, irrigating after application moves urea out of the shoots and thatch layer and into underlying soil. Irrigation of 1.2-cm 72 h after application reduced volatilization (Titko et al., 1987). Choosing a fertilizer that requires urea to be released in a different way than that of urea alone can also reduce the amount of volatilization that

occurs. The source, rate, and form of N influence the pool of NH_3 available for volatilization. Rate of urea volatilized can be decreased by decreasing the rate. Studies also suggest that using a different form of urea, such as sulfur-coated urea can further reduce ammonia volatilization (Torello et al., 1983 and Titko et al., 1987). It has been shown that isobutylidene diurea (IBDU), which requires urea to be liberated by hydrolysis, increases the amount of N recovered from cores both with and without thatch, as opposed to using just urea (Petrovic, 1990).

Common N Sources for Turf

There are several ways of classifying the different types of turf fertilizers. They can be broadly divided as readily or slowly available (Puhalla et al., 1999), or as inorganic or organic (Christians, 2004).

Readily available N fertilizers, also known as water soluble nitrogen (WSN), provide rapid turfgrass growth and green-up responses because they are quickly released into the soil and are readily available for plant uptake. However, because of their ready availability and quick response, soluble N sources can potentially burn the grass. They are also prone to leaching, requiring more frequent application rates than other sources. Examples of readily available N fertilizer sources are the synthetic organic material urea (45-0-0), and the inorganic sources ammonium nitrate (34-0-0) and ammonium sulfate (21-0-0). Urea is considered a synthetic organic fertilizer (contains C), but is mentioned here because it is soluble and thus readily available for plant use (Puhalla et al., 1999).

The other broad category is slow- or controlled-release fertilizers. Although these products have a wide-range of N release rates, products are generally considered to be slow release if they contain 35% or more of water insoluble nitrogen (WIN). While these

products may cost more than soluble products, they offer less risk of burn, leaching, or runoff. Turfgrass can utilize N from these slow-release sources over several weeks or months. Slow-release N sources may be further divided into natural organics, synthetic organics, and coated fertilizers (Puhalla et al., 1999).

Natural organic N sources originate from plant and animal sources (Christians, 2004), have very low nutrient analysis, and may contain small concentrations of micronutrients (Puhalla et al., 1999). All natural organic sources require that soil conditions (temperature, moisture, pH) be conducive to microbial activity, whether they contain actual microbes or promote the growth of beneficial microbes. Examples of organic fertilizers include Milorganite[®], Ringer[®], and Harmony[®], which are made from composted sewage sludge, stockyard waste, and chicken litter, respectively.

Synthetic organics include IBDU, urea formaldehyde (UF) and methyleneureas (MU) such as MethEX 40[®]. These combinations of urea and formaldehyde are slow release because plant available N must be released via hydrolysis. Most of these products, while effective, are often not the only N source applied, because of their higher price (Puhalla et al., 1999; and Christians, 2004).

The other general group of fertilizers that is slow release are those that are slow release due to a physical barrier or coating. The earliest method, which is still commonly used today, involves a spray application of molten sulfur onto a urea prill. The release mechanism depends upon water penetration through micropores in the fertilizer's coating. Some sulfur-coated products may be sealed with wax, which must then be broken down microbially in order for N release to begin. Sulfur-coated urea can only be

applied in the granular form. However, it is still a viable slow release option, and is fairly inexpensive (Puhalla et al., 1999; Christians, 2004).

The latest in coated fertilizer technology is polymer coated urea. Although other granular fertilizers (such as potassium sulfate) may be covered with a polymer, urea is the most common material used because it is a smooth, round material that coats well. Polymers provide better control of N release than sulfur-coated products, and have provided granular fertilizers with very precise N rates that may be delayed for months after application. These products, although available for several years now, have seen limited use in the turf industry because of the more expensive price. Other technologies have used a combination of sulfur and polymer coatings, providing a more affordable source of effective turf fertilizers with very predictable responses. Examples of coated fertilizer sources are sulfur-coated urea (SCU), Polyon[®], and Scott's Poly-S[®].

Ammonia Volatilization

Loss of N from agricultural systems has long been studied. Both production and environmental consequences have been evaluated, with the loss paths of denitrification, volatilization, immobilization, and leaching all under research scrutiny. In turfgrass, N loss via clipping removal is also a path by which N exits the system (Bowman et al., 2002).

Atmospheric loss by NH₃ volatilization is a major category of the N cycle and a possible fate of N applied to turfgrass. In the presence of urease and water, urea hydrolyzes to form ammonium (NH₄), raising soil pH (Kissel and Cabrera, 1988). As a result of urea hydrolysis, N loss as gaseous NH₃ may occur when urea is applied at or near the soil surface (Pepper et al., 1996). Several factors increase the rate of NH₃

volatilization, the first being increased soil pH (He et al., 1999; Fan and McKenzie, 1993). It was found that NH_3 volatilization was minimal at a soil pH of 3.5, but increased rapidly as soil pH increased to 8.5 (He et al., 1999). Addition of diammonium phosphate increased NH_3 volatilization from urea because of a resulting high pH (Fan and Mckenzie, 1993). Others also found increases in NH_3 volatilization associated with increases in soil pH (Clay et al., 1990).

Ammonia volatilization was a cause of N loss from urea applied to Coastal bermudagrass (*Cynodon dactylon* L.) sod on Houston Black clay, resulting in decreased fertilizer efficiency (Hargrove and Kissel, 1979). Decreased fertilizer efficiency due to NH_3 volatilization was the most important factor affecting high pH-alkaline rice fields, where N was the most limiting nutrient in production (Singandhupe and Rajput, 1989). Significant losses of NH_3 were also observed in wheat production (Morgan and Parton, 1989; and Gezgin and Baykrall, 1995). Losses of 16.7%, 8.2%, and 5.5% were observed when ammonium sulfate, urea, ammonium nitrate, respectively, were applied to calcareous soils (Gezgin and Baykrall, 1995). Other environmental concerns associated with NH_3 volatilization include ammonia deposition (Rao et al., 1993), eutrophication (Boyd, 2000), and odor and health concerns from application of animal manures (Moore et al., 1995; Keener and Elwell, 2001).

Increased soil temperature has also been identified as a factor that increases NH_3 volatilization (Clay et al., 1990; He et al., 1999; and Titko et al., 1987). Maximum NH_3 volatilization occurred at a maximum soil temperature of about 30 C, and decreasing soil temperature from that maximum value resulted in decreased NH_3 volatilization (Clay et al., 1990). Having a residue cover on the soil surface reduced soil temperature, also

reducing volatilization loss. Ammonia volatilization from granular and dissolved urea was significantly higher when temperature increased from 10 to 22 C, but did not further increase when temperatures rose from 22 to 32 C (Titko et al., 1987). Ammonia volatilized sooner at 32 C due to high urease activity and rapid hydrolysis of urea, but the total amount lost over 90 hours was not greater than that lost at 22 C. The effect of increasing temperature was attributed to an increase in microbial activity at higher temperatures and temperature dependent enzyme activity (Titko et al., 1987).

Surface application of urea also increased the rate at which NH_3 volatilized (Volk, 1959; Gezgin and Bayrakll, 1995). Ammonia losses from surface-applied ammonium sulfate, ammonium nitrate, and other ammoniacal materials were high from soils with pH above 7.5 (Volk, 1959). Volatile loss of ammonia following surface application of pelleted or crystal urea to sods or light sandy soils was considerable, and it was recommended that urea be washed into the soil or covered by tillage within a few hours of application to minimize losses (Volk, 1959). Gezgin and Baykrakll (1995) determined that NH_3 volatilization losses from surface-applied ammonium sulfate, ammonium nitrate, and urea were as high as 16.7% of total N applied. On noncalcareous soils, urea had the highest rate of volatilization compared to ammonium sulfate and ammonium nitrate (Gezgin and Baykrakll, 1995).

Wind speed also affects the rate of NH_3 volatilization, but conclusions as to the exact reason for the loss vary. Some suggest that increasing wind speed increases NH_3 volatilization because it removes water from the soil and stimulates the production of NH_3 (Sommer et al., 1991). The drying effect of wind impeded volatilization of NH_3 , because dry topsoil reduced the rate at which underlying urea moved back to the soil

surface (Bouwmeester et al., 1985). Wind speed was closely associated with soil water content, and increased soil water content increased urease activity, with a subsequent increase in NH_3 volatilization (Bouwmeester et al., 1985). Ammonia volatilization was low when urea was applied to dry soil, but after soil wetting, urease activity and the rate of NH_3 volatilization increased (McInnes et al., 1986). Rapid soil drying rapidly decreased the rate of NH_3 loss from soil, and reduced the amount of hydrolyzed urea in the period between 42 and 72 hours to nearly zero (Ferguson and Kissel, 1986).

When a series of different wind, rainfall, and air humidity conditions were simulated in a wind tunnel, highest N losses were recorded when wet soil conditions were maintained by air humidities between 80 and 95%, with essentially no rainfall. Conversely, lowest losses were recorded with either frequent low-intensity rainfall, or high wind velocities. Results also indicated that wind had a general drying effect on soil, impeding volatilization because the dry top soil reduced the rate at which underlying urea moves back to the soil surface (Bouwmeester et al, 1985).

Relevance of this Study

There are no published studies that examine the impact of mowing on NH_3 volatilization. Mowing may have a direct impact on turf fertilizers, as high quality turfgrass management on putting greens combines low mowing heights and specialty fertilizers. Such fertilizers include coated slow-release products that may be impacted by the rotating blades of mowers. One study that examined the impacts of mowing did so by evaluating fertilizer loss via clipping removal (Mancino et al., 2001). Total percentages lost ranged from 75.4% to 1.9%, with fertilizer loss being most related to water-solubility. Coated and organic products were most likely to be collected in clippings. It

was also noted that prill size and density could be factors contributing to loss. The study did not directly measure N loss due to volatilization.

Previous studies have examined N loss from turf systems, but few have focused on the process of volatilization. Studies have concluded that NH₃ volatilization occurs to a limited extent in turfgrass stands growing on an acidic soil (Torello et al., 1983). The studies that did measure NH₃ volatilization studied environmental effects, such as temperature, wind speed, and soil water content, on urea, and rarely included other N sources, specifically those used in the turf industry (Bowman and Paul, 1990; Lightner et al., 1990; Wesley et al., 1987; Nelson et al., 1980; Sheard and Beauchamp, 1985). Results from these studies ranged from 0% to 50% of applied N lost to volatilization. Most previous studies were also conducted on cool season grasses (usually Kentucky bluegrass (*Poa pratensis*) cultivars), and not the warm season grasses commonly used in the Southeast (Bowman and Paul, 1990; Bowman et al., 1987; Wesley et al., 1987). For example, Bowman and Paul (1990) conducted their study on 'A-34 Bensun' Kentucky bluegrass sodded on a Yolo loam (Typic Xerorthent) soil with a pH of 7.3. Other studies were conducted on orchardgrass (*Dactylis glomerata*) sod on a Xenia silt loam soil (Lightner et al., 1990) and 'Park' Kentucky bluegrass grown on a Sharpsburg silty clay loam (Wesley et al., 1987).

Given the increased use of N fertilizer sources other than urea, and the fact that mowing of putting greens is frequent and low, research that examines potential N loss via volatilization is needed. Some slow-release N sources consist of coated urea, where any crack or fissure in the coating could affect N loss, or make the surface-applied urea susceptible to loss via volatilization. Thus, the objectives of this study were to determine

the effects of mowing on ammonia volatilization from fertilizers applied to turfgrass, and to determine differences in volatilization among N sources.

II. EFFECTS OF MOWING AND N SOURCE ON AMMONIA VOLATILIZATION FROM FERTILIZERS APPLIED TO TURFGRASSES

Abstract

Although ammonia volatilization can be a pathway of nitrogen (N) loss from turfgrass systems, the magnitude of this loss has not been well quantified, especially from N sources other than urea. The objective of this research was to evaluate NH₃ volatilization as affected by N source and mowing of those N sources. The study consisted of mowing treatments (mowed or not mowed) and N sources: 1) urea, 2) sulfur coated urea, 3) polymer coated urea, 4) methylene urea, 5) ammonium nitrate, and, 6) composted sewage sludge. Mowing treatments were applied by mowing the N sources, which had been applied to bentgrass (*Agrostis palustris* Huds.) putting greens. The fertilizers were collected and taken to the laboratory for ammonia volatilization measurements, without additional watering. Treatments were applied at an N rate of 14.7 g m⁻² to the surface of bentgrass plugs contained in 1 L jars. Ammonia volatilization over 10 days was measured via boric acid trapping. Two experiments were conducted: one with loamy sand (Exp. 1), and one with an 80/20 sand-peat (v/v) greensmix (Exp. 2). In Exp. 1, mowing never affected ammonia volatilization, so mowing was eliminated from Exp. 2. Over the ten day measurement period, urea had greatest total ammonia volatilization, with most released in the first two days. Polymer coated urea released the

least ammonia, with greatest release nine and ten days after treatment. In descending order, amounts of ammonia volatilization were: urea, sulfur coated urea, methylene urea, composted sewage sludge, ammonium nitrate, and polymer coated urea.

Introduction

Losses of nitrogen (N) from agricultural systems have long been studied, with the loss pathways of denitrification, volatilization, plant uptake, leaching, ammonia fixation and immobilization all receiving scrutiny in a wide range of agricultural systems. In turfgrass, losses of N via leaching (Brown, et al., 1977; Starr and DeRoo, 1981; Morton et al., 1988; Mancino and Troll, 1990; Geron et al., 1993; Miltner, et al., 1996; Pare et al., 2006; Frank et al., 2006) and clipping removal (Johnson et al., 1987; Bowman, et al., 2002; Kopp and Guillard, 2002; Fagerness, et al., 2004) have been studied most intensively. Despite real environmental concerns, pathways of gaseous loss of N (volatilization and denitrification) have been less studied in turfgrass systems. Environmental issues associated with ammonia volatilization include ammonia deposition (Rao, et al., 1993), eutrophication (Boyd, 2000), and odor concerns from application of animal manures (Moore, et al., 1995; Keener and Elwell, 2001).

Ammonia volatilization is most likely to occur when urea is applied to the surface of turf, where the urea hydrolyzes in the presence of water and urease to form ammonium (Torello, et al., 1983; Kissel and Cabrera, 1998). This ammonium can be converted to gaseous ammonia, which may be lost to the atmosphere via volatilization. Factors that increase ammonia volatilization include increased soil pH (Clay, et al., 1990; He, et al., 1999; Fan and McKenzie, 1993), increased soil temperature (Clay et al., 1990; He, et al., 1999; and Titko, et al., 1987), increased soil water content (Bouwmeester, et al., 1985;

McInnes, et al., 1986; Ferguson and Kissel, 1986), and increased wind speed (Sommer, et al., 1991; Ferguson and Kissel, 1986).

Method of fertilizer application and fertilizer source also affect ammonia volatilization. When ammonia volatilization from turf was studied, selected N sources were urea (Bowman et al., 1987; Nelson et al., 1980; Sheard and Beauchamp, 1985; Titko et al., 1987; Torello et al., 1983), isobutylidene diurea (IBDU) (Nelson, et al., 1980), sulfur-coat urea (Torello, et al., 1983) and ureaformaldehyde (Torello et al., 1983). Typically, fertilizers were applied as granular materials, with the presence or absence of irrigation (Titko, et al., 1987; Bowman, et al., 1987) or the inclusion of liquid urea formulations (Volk, 1959; Torello, et al., 1983; Wesely, et al., 1987; Titko, et al., 1987) as treatment variables. Although turf-type fertilizers were included in some additional studies, they were not applied to turf, but rather to bare soil (Hargrove and Kissel, 1979; Kissel and Cabrera, 1988) or pasture grasses (Hargrove and Kissel, 1979; Lightner et al., 1990). Such results, while valuable, may not directly apply to the specialized environments of closely mown turf.

Methodologies for measuring ammonia volatilization from turf varied, but in most cases they were short term studies (3 - 21 d; Petrovic, 1990) which utilized laboratory or greenhouse methods, or small-scale field devices. A typical collection device used a chamber to hold fertilized soil or turf, a trap to collect volatilized ammonia, and a vacuum pump to pull air through (Hargrove and Kissel, 1979). Because nonfield and closed system field studies prevented normal air movement across the turf surface (Hargrove and Kissel, 1979), results from such closed experiments were typically used to

compare treatment effects (Petrovic, 1990), and quantified N loss over a short period of time.

There are no published studies which have examined ammonia volatilization from warm season turfgrasses. In fact, the published research has been conducted on one species: Kentucky bluegrass (*Poa pratensis* L.). Rates of ammonia volatilized from a Kentucky bluegrass turf ranged from 1.1 to 10.3% of applied N, with the greater amount volatilizing from urea, and less from a SCU product (Torello, et al., 1983). Volatilization was greater when the same rate of urea ($49 \text{ kg ha}^{-1} \text{ N}$) was applied as a liquid spray, compared to a prill formulation (Torello, et al., 1983). Conversely, others found greater volatilization from urea applied in a granular form as compared to that applied in a solution, except when irrigation immediately followed the urea application (Titko, et al., 1987). In these 84-h greenhouse studies using Kentucky bluegrass, as much as 60% of applied N was lost via volatilization, when temperatures and relative humidity were high ($32 \text{ }^{\circ}\text{C}$ and 68%), and the turf was not irrigated after application (Titko, et al., 1987). When irrigation followed the urea application ammonia volatilization was reduced to 2% of total N applied (Titko, et al., 1987). When urea was applied to Kentucky bluegrass as a foliar application at 1.7 and 3.4 g m^{-2} of N, volatilized N was 35 and 31% of the total applied, respectively, with maximum ammonia losses occurring at 25-h after treatment (Wesely, et al., 1987). As little as 1.0 cm of irrigation water reduced such volatilization losses from spray-applied urea, with 5-cm of irrigation reducing volatilization losses to around 1% of total N applied (Bowman et al., 1987). Volatile loss of ammonia from urea sprays applied to Kentucky bluegrass was relatively small ($< 10\%$), and most loss occurred within the first 8 h. Reductions in volatile loss of ammonia between 8 and 21 h

after application were hypothesized as the result of biological immobilization of applied N (Bowman and Paul, 1990).

In summary, N losses from ammonia volatilization in turfgrass systems have been shown to vary from almost zero to as great as 60% of total N applied. Losses were greatest when irrigation was not applied following application (Titko, et al., 1987) and when volatilization from thatch was separated from soil (Nelson et al., 1980). When slow release fertilizer sources were evaluated, volatilization losses of ammonia from IBDU and SCU were 2% of total N applied, much less than measured in comparable urea treatments (Nelson, et al., 1980; Torello, et al., 1983).

There are no published studies that examine the impact of mowing on ammonia volatilization, especially on close-mown turf such as putting greens. Mowing may have a direct impact on turf fertilizers, as high quality turfgrass management on putting greens combines low mowing heights and specialty fertilizers such as resin-coated ureas. Previous research has shown that such fertilizers are susceptible to pickup via clipping removal (Mancino, et al., 2001). In that work, total percentages of fertilizers lost via clipping removal ranged from 75.4% to 1.9%, with fertilizer loss being most related to water-solubility. Coated and organic products were most likely to be collected in clippings (Mancino, et al., 2001). If such fertilizers could be removed via mowing, our hypothesis is that the products could be nicked or chipped in the mowing process, especially in the first few mowings when fertilizer prills are sitting higher in the turf canopy, and have not moved into the underlying canopy. Coated urea products that have been chipped might be prone to increased N loss from ammonia volatilization, as exposed urea would be sitting on the turf surface.

Thus, the objectives of this study were to determine the effects of mowing fertilizer prills on ammonia volatilization from fertilizers applied to turfgrass, and to determine differences in volatilization among N sources that have not been evaluated in previous research. This study was intended as an initial assessment of potential ammonia volatilization losses in the first 10 d after mowing, and not to quantify losses over the entire release period of a slow-release fertilizer source.

Materials and Methods

Two experiments were performed. Both included the same six fertilizer sources (Table 1), plus an unfertilized control. Coated or slow-release products were specifically sized for application to low-cut turf such as putting greens. The other products (SCU, ammonium nitrate and urea) were not sized as greens grade fertilizers (Table 1).

The first experiment was conducted using 10 cm diameter cores collected from a four-year-old Marvyn loamy sand (Fine-loamy, siliceous, thermic Typic Paleudult) putting green with 'G-2' creeping bentgrass. A total of 16 cores were extracted using a conventional cup cutter, and soil removed so that a 2.5 cm layer remained below the thatch. Average thatch depth of cores was 1.3 cm, underlying soil pH was 6.0, soil cation exchange capacity was $2.0 \text{ cmol}_c \text{ kg}^{-1}$, and average soil-water content was 15.9%. Cores were removed the morning (after dew had dried) that mowing treatments were applied, and cores were moved to the laboratory for subsequent fertilizer treatment applications. This same procedure of core removal and transport to the laboratory was also used for Exp. 2, except those cores were removed from a three-year-old putting green of 80% sand and 20% reed-sedge peat (v/v). Average thatch depth of those cores was 1.0 cm,

underlying soil pH was 5.9, soil cation exchange capacity was $1.8 \text{ cmol}_c \text{ kg}^{-1}$, and average soil-water content was 15.3%.

In Exp. 1, mowing was a treatment variable. To apply this treatment, the N sources were applied to the surface of the same putting green from which the cores had been removed. The six fertilizer sources (Table 1) were hand spread in six individual blocks (2 x 2 m) at a rate to ensure that fertilizer prills could easily be detected for removal from the green (an N rate of $\sim 30 \text{ g m}^{-2}$). Half of each block (1 x 2 m) was mowed by making seven passes across the block, simulating a week of mowing. These 7 passes were applied at one time, using a Toro walking greens mower with a 3.2 mm mowing height, without grooming reels or clipping collection baskets. The other half of each block remained unmowed, with fertilizers on the surface. Both mowed and unmowed N sources were collected with a small air vacuum immediately after the 7 mowing passes were applied, stored in sealed glass jars, and immediately transferred to the lab for application to the surface of the previously harvested cores. No additional irrigation was applied after fertilizer application, nor was any additional water applied during the 10 d experiment period.

Harvested grass cores were placed into 1L glass canning jars, with the turf lying flat in the bottom of each jar. The volatilization experiment was conducted on a lab bench with 24 hr standard room lighting, and no additional environmental modifications. Average room temperature during the experiment was $27.4 \text{ }^\circ\text{C}$. Due to the nature of the experiment (sealed glass jars with no ability to trim the turf) the experiments were conducted for a 10 d period only. This is a typical time length for volatilization experiments, as previous research demonstrated most ammonia release within the first

days of experiment initiation (Petrovic, 1990). Fertilizers collected from the un-mowed and mowing treatments were applied by hand at 14.7 g m^{-2} of N across the top of the turf surface in each jar.

The seven N sources and two mowing treatments were combined factorially, and two empty jars for determining background ammonia were included, resulting in 16 experimental units per replication. There were four replications of each experiment, with replication occurring over time in the controlled laboratory setting.

Exp. 2 was conducted exactly as Exp. 1, except that the mowing treatment was eliminated. This was because mowing never affected ammonia volatilization in Exp. 1, so it was eliminated as a treatment variable in Exp. 2.

To collect ammonia an ammonia trap system was used, following the method of O'Halloran (1993). A schematic is shown in Fig. 1. Air flow was generated by passing 1000 mL min^{-1} air stream through a 5N sulfuric acid air scrubber and across each jar, with resultant NH_3 trapped in 100 mL of 0.01 N boric acid. The boric acid trap was changed each day for 10 days, with collected samples titrated to the original pH of the boric acid using 0.01 N sulfuric acid. Mass and percent of volatilized NH_3 were calculated using the formulas:

$$\text{mg-N} = \text{mLs acid} * \underline{\text{N}} \text{ acid} * 14, \text{ where } 14 \text{ is the equivalent weight of N} \quad [1]$$

and

$$\% \text{ N volatilized} = (\text{total mg-N for each treatment}/118) * 100, \text{ where } 118 \text{ is the mg N per jar.} \quad [2]$$

In the laboratory, treatments were arranged in a complete randomized design, with the empty background jars also included in that randomization. The data was

analyzed using standard statistical procedures (SAS, 2006), with analysis of variance used to test for the significance of treatment effects (N source, mowing) and their interaction. Means separation (Duncan's) or use of standard error bars were used to determine differences in ammonia volatilization as affected by N source, with a p-value of 0.05.

Results and Discussion

Background ammonia was never detected at any measurable level at any time during the experiment period. In Exp. 1, mowing never affected NH₃ volatilization (Fig. 2) (nor was the interaction of mowing and N source significant), so mowing was eliminated from Exp. 2. There was a nonsignificant trend for greater volatilization in the mowed SCU treatments, as compared to SCU treatments that were not mowed. This fertilizer material was the only coated product that had a larger Size Guide Number (SGN), which is defined as the average particle size in millimeters multiplied by 100 (Table 1). In practice, a material with a larger SGN would not have been applied to a close mown surface such as a putting green. Although not significant, this result does suggest that the impact of fertilizer prill size on N losses by volatilization should be examined in greater detail.

In both experiments N source significantly affected ammonia volatilization (Figs 3 and 4). In both experiments significant loss of N occurred from only two N sources, urea and SCU, and the majority of this loss occurred in the first 4 days after experiment initiation. Such results are consistent with previous work, which showed that N losses from volatilization mostly occurred within the first few days of experiment initiation (Nelson, et al., 1980; Torello, et al., 1983; Petrovic, 1990).

Although losses of N due to volatilization are often greater in soils with a higher pH (Bouwmeester, et al., 1985; He et al., 1999), losses observed in our study occurred from treatments applied to soils with pHs of 5.9 and 6.0. Ammonia volatilization from acid soils is consistent with previous findings, where volatile loss of N was measured from two soils with pHs of 5.2 and 6.0 (Fan and Mackenzie, 1993). In that work it was noted that there was less N volatilized from the soil with a pH of 5.2 than from the soil with a pH of 6.0. Others have observed N loss due to volatilization from soils or turfed soils with initial pHs of 6.8 (Clay, et al., 1990) and 6.0 (Lightner, et al., 1990), respectively.

Urea released the greatest amount of ammonia, with 40.0% and 35.5% of applied N lost via volatilization in Exp. 1 and 2 over the 10 d period, respectively (Figs. 5 and 6). Such amounts are similar to that reported in previous research, with N loss ranging from 0 to 61% of total N applied (Petrovic, 1990). Research with higher percent N losses (35 to 39%) typically occurred in studies in which irrigation was not applied, or only lightly applied after application (Bouwmeester, et al., 1985; Wesley, et al., 1987). In our study, irrigation was not applied after fertilizer application, which would account for the relatively high N loss in some treatments.

In Exp. 1, at the end of 10 days, mean volatilization loss of ammonia from urea and SCU were not different (Fig. 5). In Exp. 2, urea and SCU differed in the amount of NH_3 volatilized (Fig. 6). Compared to other slow-release sources, greater loss of N from SCU in Exp. 1 might be the result of an uneven coating process, or loss of N from cracks or fissures in the prills. In both experiments urea had significantly greater loss of NH_3

than polymer coated urea, ammonium nitrate, methylene urea, or composted sewage sludge (Figs 5 and 6).

Polymer coated urea released the lowest total percentage of applied N, but the amount was not significantly different from that released from methylene urea, ammonium nitrate, or composted sewage sludge (Fig. 5). When N was volatilized from polymer coated urea (Exp. 1) it was released at nine and ten DAT, but it was small (0.76% of total N applied), and not different from the control. Delayed ammonia volatilization from slow release products was also noted in an earlier study with the slow-release product SCU, where slight amounts of ammonia were released from SCU-treated turf for up to 21-d after application (Torello, et al., 1983). In Exp. 2, there was no measurable ammonia volatilization from the polymer coated urea (Fig. 6).

The slight evidence offered in this paper (resin coated) and one other (Torello, et al., 1983) that slow-release sources might continue to release N for volatilization suggests that new methods for long term measurement of ammonia volatilization in turf should be developed. Current methods that could be used in an 8 wk experiment could only be adjusted for bare soil, as the closed chamber system does not allow for watering or turf maintenance. This limits the inclusion of treatment variables such as mowing or irrigation regimes. Large-scale field systems (Wood, et al., 2000), or modification of a system used for denitrification measurement (Horgan, et al., 2002) may offer a solution, and research is currently underway to test this hypothesis.

Conclusions

Nitrogen loss via ammonia volatilization was affected by N source, but not mowing, in our 10 d laboratory evaluations. Nitrogen sources with greatest N loss were urea and

SCU, with only negligible amounts lost from ammonium nitrate, polymer coated urea, methylene urea, or composted sewage sludge. In both experiments only two N sources, urea and SCU, had N losses greater than the control, and the majority of this loss occurred in the first four days after experiment initiation. Levels of N lost via volatilization were similar in both the native loamy sand putting green and the 80/20 sand-peat greensmix. Our laboratory method precluded long-term evaluation; but the slow-release nature of products such as polymer coated urea and methylene urea would make 8 to 12 wk evaluations the next step of this research.

Table 1. Nitrogen sources used in the laboratory examination of NH₃ volatilization.

Fertilizer	Analysis	SGN [†]	Trade Name/Manufacturer
urea	46-0-0	110	Tri-State Plant Food Inc., Dothan, AL
sulfur coated urea	39-0-0	210	Poly Plus SCU/ Lesco, Rocky River, OH
polymer coated urea	41-0-0	100	Polyon / Pursell Industries, Sylacauga, AL
ammonium nitrate	34-0-0	150	Red Fox Fertilizer, Dothan, AL
methylene urea	40-0-0	90	Meth-Ex / Lebanon Seaboard Corp., Lebanon, PA
dehydrated sewage sludge	6-0.9-0	90	Milorganite / Milorganite, Milwaukee, WI

[†] SGN = Size Guide Number, which is the average particle size in millimeters multiplied by 100.

Fig. 1. Diagram of complete laboratory set up with jars, pump, and air scrubbers, following the procedure of O'Halloran (1993). The glass manifold is connected to an opening in each jar with silicon tubing.

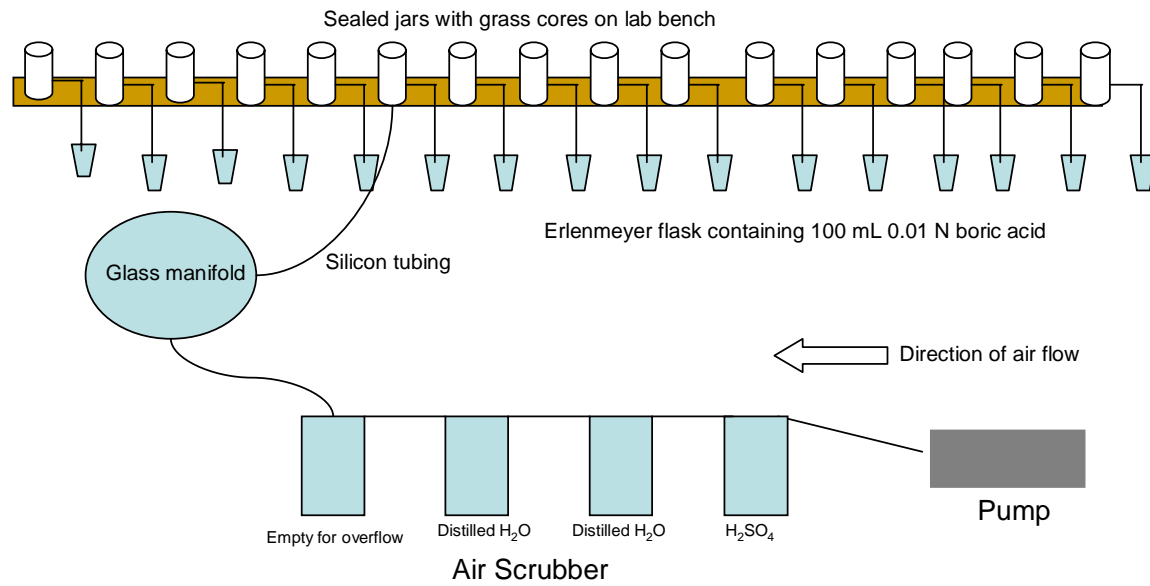


Fig. 2. Effect of mowing (M) and N source on % N volatilized in Exp.1. Comparisons are within fertilizers (mowed or unmown). There was no significant difference in NH₃ volatilization due to mowing.

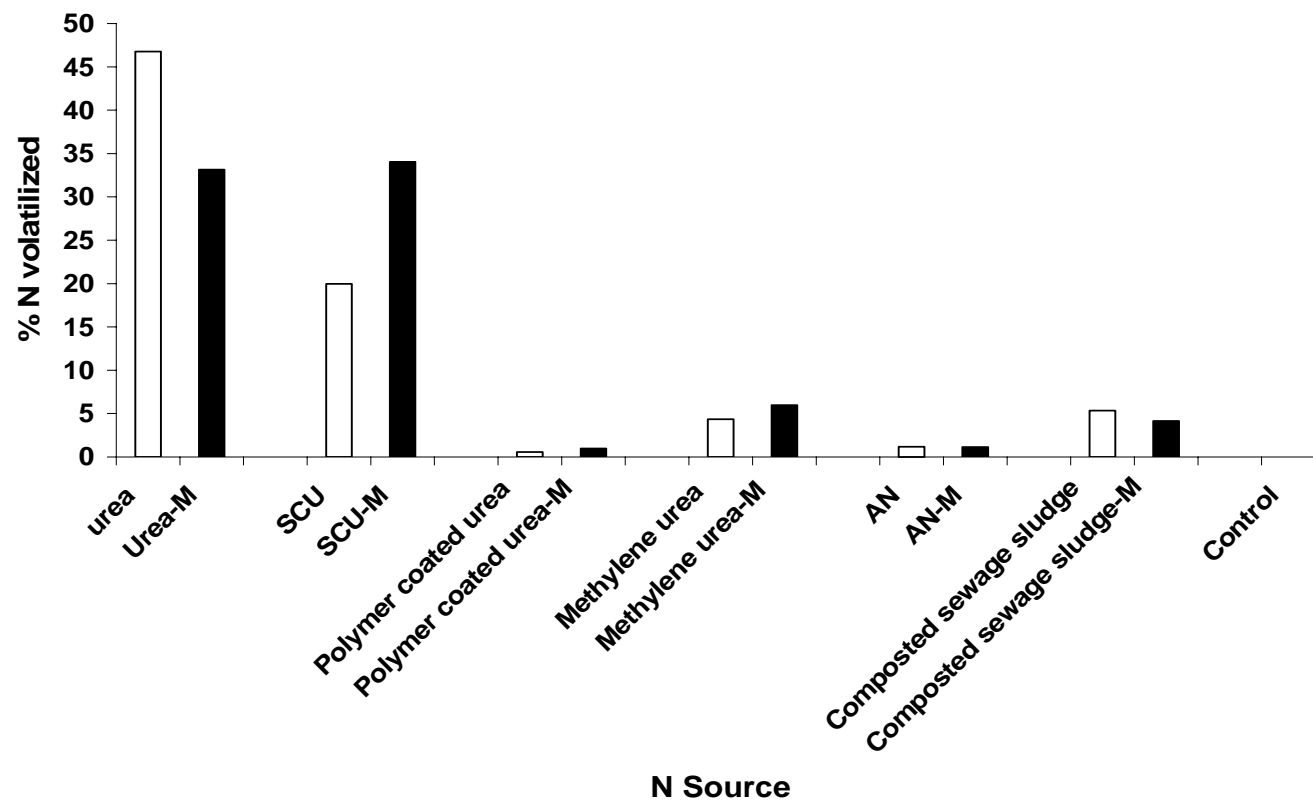


Fig. 3. Ammonia volatilization as affected by N source and sampling day, Exp. 1.

Vertical bars are the standard error

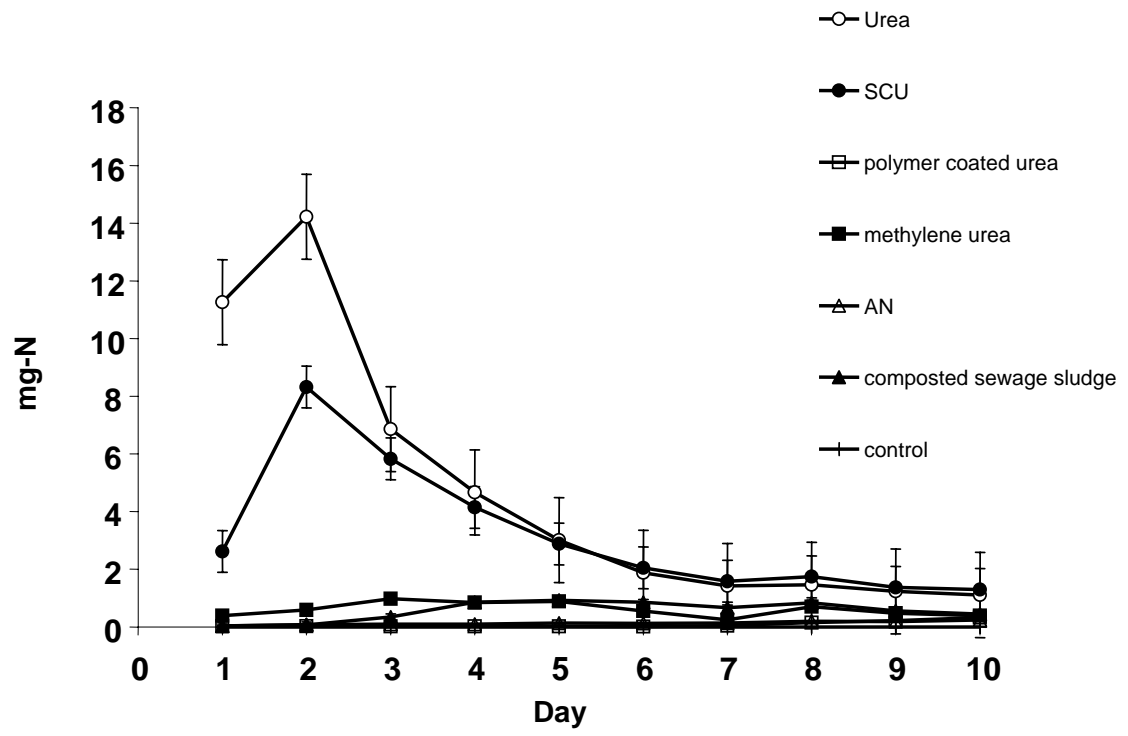


Fig. 4. Ammonia volatilization as affected by N source and sampling day, Exp. 2.

Vertical bars are the standard error.

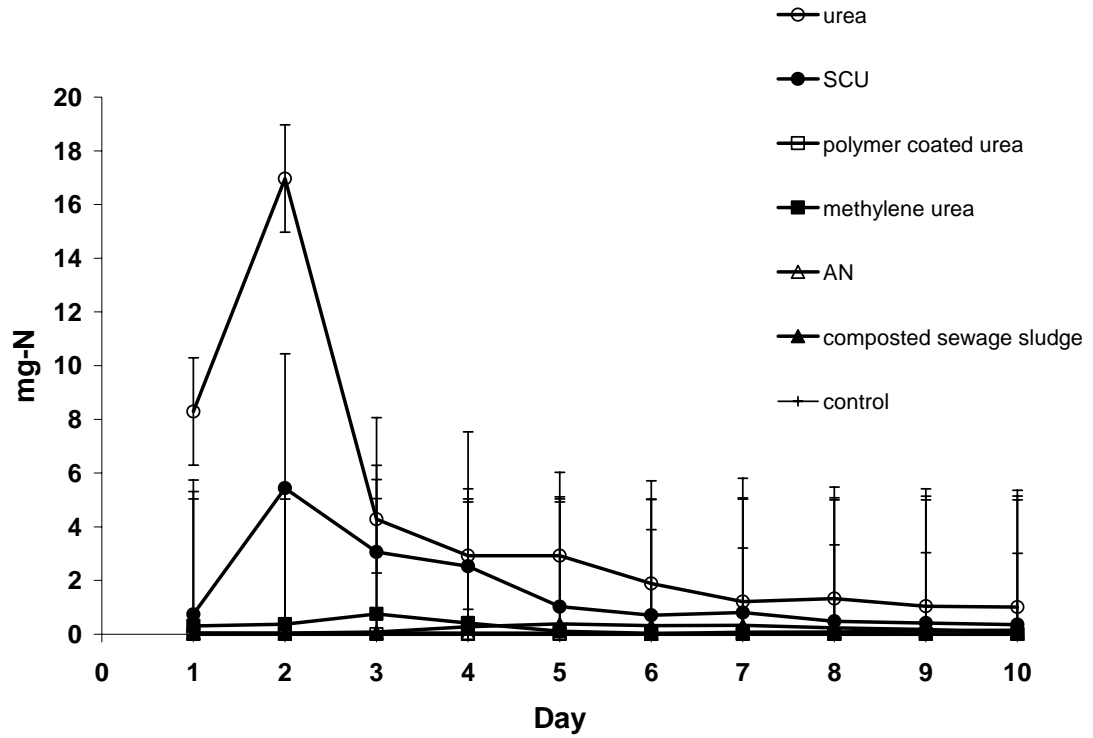


Fig. 5. Total cumulative N loss due to NH₃ volatilization over a 10 d period as affected by N source, Exp. 1. Columns with different letters are significantly different from each other ($\alpha=0.05$).

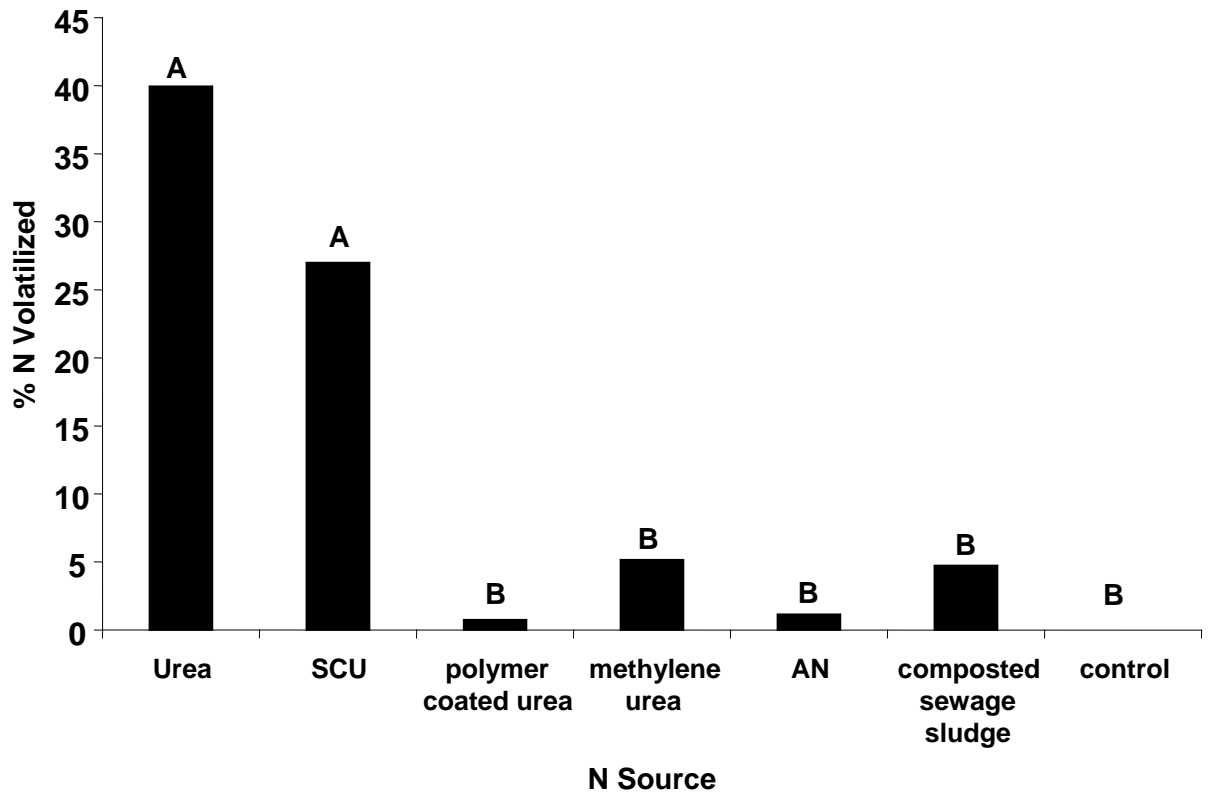
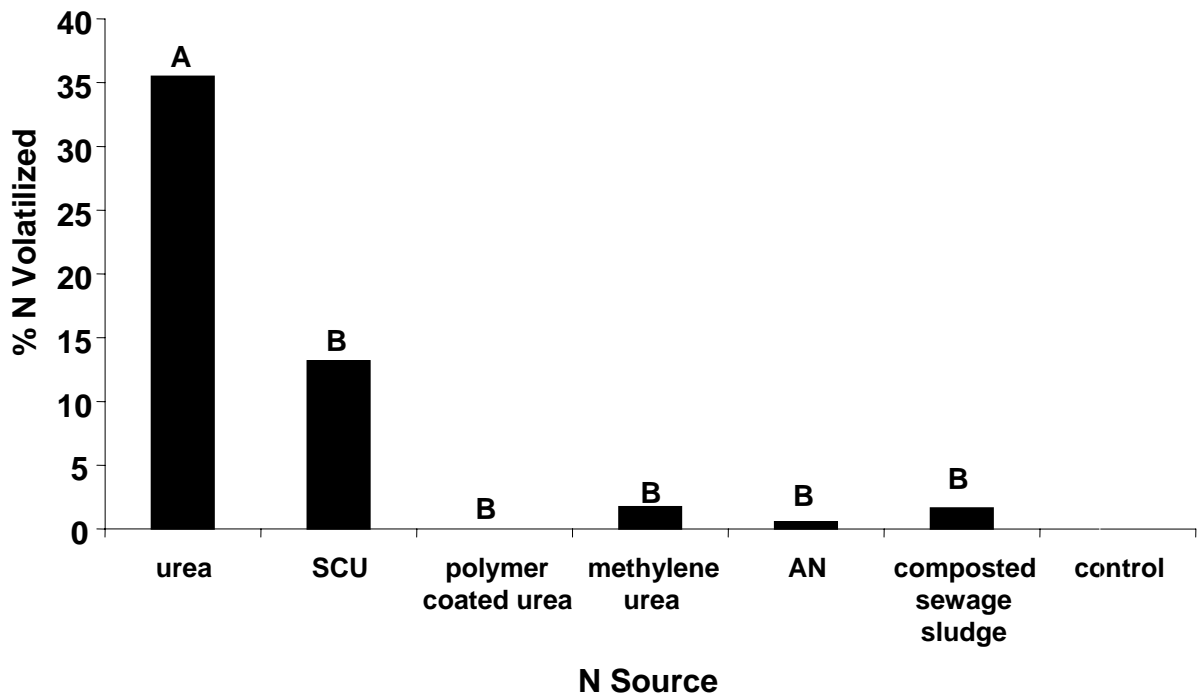


Fig. 6 Total cumulative N loss due to NH₃ volatilization over a 10 d period as affected by N source, Exp. 2. Columns with different letters are significantly different from each other ($\alpha=0.05$).



III. NITROGEN SOURCE EFFECTS ON AMMONIA VOLATILIZATION FROM FERTILIZERS APPLIED TO TURFGRASS IN THE FIELD

Abstract

Few studies have addressed ammonia (NH_3) volatilization from coated fertilizers applied to turfgrasses in the field. The objective of this study was to determine the amount of nitrogen (N) lost through NH_3 volatilization from three N sources applied to existing turfgrass stands. Treatments were applied to Tifway hybrid bermudagrass, Emerald zoysiagrass, and both bermudagrass and zoysiagrass in fall 2005, spring 2006, and fall 2006, respectively, near Tuskegee, AL. Fertilizer treatments were applied at the rate of 14.7 g m^{-2} of N and included: urea (46-0-0), methylene urea (40-0-0), and polymer coated urea (41-0-0). Ammonia was captured using a passive micrometeorological system and differences in N sources were observed over a 10 day period. In 2005, urea released the highest proportion of applied N (11.7 %). The mass of NH_3 released from methylene urea (7.4 %) was not different from that released from urea ($P \leq 0.10$). Polymer-coat urea differed from urea in the amount of NH_3 volatilized, but did not differ from methylene urea ($P \leq 0.10$). In spring 2006, NH_3 volatilization from N sources was in the order: urea (20.1%) > methylene urea (7.4%) > polymer coated urea (4.4%) ($P \leq 0.10$). Nitrogen sources followed the same trend in fall 2006: urea (15.7%) > methylene urea (4.2%) = polymer coated urea (4.4%) ($P \leq 0.10$). Urea releases a greater proportion of N applied than the slow-release sources methylene urea and polymer coated urea.

Polymer-coated urea appears to be superior to methylene urea as a slow-release N source the first 10 days after application.

Introduction

Through a complex cycle, N enters and exits a cropping system. Nitrogen may enter a cropping system via several pathways, including inputs from the atmosphere and animal waste, but primarily a turfgrass system through the addition of fertilizers (Bowman, et al., 2002). Nitrogen may also exit a turfgrass system via several pathways, such as through leaching, runoff, clipping removal, plant uptake, and gaseous pathways (Bowman, et al., 2002). Minimizing these losses and increasing N efficiency is a concern for turfgrass managers because N is the nutrient typically needed in the highest quantity in turfgrass maintenance programs (Christians, 2004).

In turfgrass, losses of N via leaching (Brown, et al., 1977; Starr and DeRoo, 1981; Morton et al., 1988; Mancino and Troll, 1990; Geron et al., 1993; Miltner, et al., 1996; Pare et al., 2006; Frank et al., 2006) and clipping removal (Johnson et al., 1987; Bowman, et al., 2002; Kopp and Guillard, 2002; Fagerness, et al., 2004) have been studied most intensively. Despite real environmental concerns, fewer have studies focused on pathways of gaseous N loss (volatilization and denitrification) in turfgrass systems. Environmental issues associated with ammonia volatilization include ammonia deposition (Rao, et al., 1993), eutrophication (Boyd, 2000), and odor concerns from application of animal manures (Moore, et al., 1995; Keener and Elwell, 2001).

Ammonia volatilization is the gaseous loss of N that occurs when urea is hydrolyzed in the presence of water and urease to form NH_4 (Torello, et al., 1983; Kissel

and Cabrera, 1998). Environmental factors that affect NH₃ volatilization include increased soil pH (Clay, et al., 1990; He, et al., 1999; Fan and McKenzie, 1993), increased soil temperature (Clay et al., 1990; He, et al., 1999; and Titko, et al., 1987), increased soil water content (Bouwmeester, et al., 1985; McInnes, et al., 1986; Ferguson and Kissel, 1986), and increased wind speed (Sommer, et al., 1991; Ferguson and Kissel, 1986).

Bowman and Paul (2000) showed urea spray-applied to bluegrass turf underwent very rapid transformations depending on its position in the turfgrass profile. Volatilization from urea positioned deeper in the profile (2 mm) was approximately twice that from urea positioned mainly on the leaves and shoots (0.5 mm). In a different study, cumulative 4-day NH₃ volatilization losses from urea applied to foliage of Kentucky bluegrass (*Poa pratensis* L.) were 35% and 31% at rates of 1.7 and 3.4%, respectively (Wesley, et al., 1987). While these studies show NH₃ volatilization to be a significant cause of loss from bluegrass turf systems, a study performed on Coastal bermudagrass (*Cynodon dactylon* L.) had conflicting results (Hargrove and Kissel, 1979). On a Houston Black clay soil, NH₃ losses measured directly in the field were 0 to 9% of applied N, which were small when compared to losses in the laboratory of up to 31%. While these results are important findings, the experiments did not examine warm season grasses for turf or fertilizer sources common to the turfgrass industry. Therefore, the objective of this field study was to determine the amount of N lost through NH₃ volatilization from three fertilizers applied to an established turfgrass stand.

Materials and Methods

Effects of N source on NH₃ volatilization were examined in the field near Tuskegee, AL, on a commercial turfgrass farm. The experiment was performed three times, each for a 10 d interval. In 2005, the experiment was initiated on October 3 and ended on October 13. Fertilizer treatments were applied to approximately 18-month-old Tifway hybrid bermudagrass sod fields. In spring 2006 the experiment was initiated on May 9 and ended on May 19. Fertilizer treatments were applied to a 12-month-old Emerald zoysiagrass sod field. The experiment was initiated a third time on September 20, 2006 and ended September 30. Two replications of fertilizer treatments were applied to a Emerald zoysiagrass sod field; and one replication was applied to a two-year-old Tifway hybrid bermudagrass sod field. For all three experiments, soil type was a Marvyn, fine-loamy sand (thermic Typic Kanhapludult).

All research areas were maintained by sod farm personnel, with plot areas mowed approximately every 3 d, and irrigation supplied as needed via a center pivot system in each field. Details regarding dates of mowing and irrigation/precipitation can be found in Table 5.

There were three fertilizer treatments for the experiments, each replicated three times, for a total of nine plots. Treatments were the N fertilizer sources urea (46-0-0), polymer coated urea (41-0-0), and methylene urea (40-0-0). Details about each product are provided in Table 1 in this thesis. Treatments were applied to 15 m radius circular turfed plots (Wood et al., 2000) using a walk-behind drop fertilizer spreader (Gandy Company, Owatonna, MN) calibrated to apply a rate of 14.7 g N m⁻².

Following the technique of Wood, et al. (2000), NH₃ was captured using a passive micrometeorological system. In this system, a three m high rotating mast is placed in the

center of the 15 m circular plot. A wind vane is located at the top of the mast, ensuring that NH₃ collection tubes always face the prevailing wind. Five NH₃ collection tubes are inserted perpendicular to the mast at 5 heights along the mast: 40, 70, 150, 220, and 300 cm above the soil surface. Tubes were 200 mm long, with a 7 mm inside diameter, and were coated inside with 3% w/v in acetone oxalic acid in the laboratory prior to their insertion in the field. All tubes were capped before and after insertion, ensuring that the only time the coated tubes could absorb NH₃ was when they were in the treated plots.

Tubes were collected twice a day (morning and afternoon) for the first three days and once a day for the remaining seven days of the 10 day observation period, a total of 13 collections. To collect the tubes, the mast was removed from the treated plot area, tubes taken from the mounting holes, and the ends of each tubes capped to prevent contamination. Capped tubes were returned to the lab and stored at 4 C until extraction. The next, fresh set of tubes was inserted into the mast, and the mast was remounted. Average time to process one mast was 5 min.

Every time collection tubes were swapped, pH measurements were determined at the soil surface using a flat-pH electrode. To collect pH measurements the electrode was held flush to the soil surface, approximately 10 mL of distilled water added, and pH determined. Ten random sample spots were measured for pH at each sampling. Soil samples were also collected (0-3 inch depth) by taking 10 samples per plot using a 2.5 cm soil sampler, combining the 10 samples.

At the end of 10 days, NH₃ was extracted from each tube by adding two mL deionized water and shaking for five min. Extracts were analyzed colorimetrically using a microplate technique (Sims et al., 1995). Soil samples were extracted by using 2 M KCl

and analyzed colorimetrically using microplate techniques for measuring soil ammonium and nitrate content (Sims et al., 1995). Equations used by Wood, et al. (2000) were also used for calculations in this study. Data was analyzed with Microsoft Excel and SAS statistical software (SAS, 2006). Results were converted to total mg-N volatilized and percent of applied N volatilized.

Results and Discussion

Differences in the amount of NH_3 volatilized from the three N sources used in the field experiment were observed. Average surface pH, soil NO_3 , and soil NH_4 of urea, methylene urea, and polymer coated urea in fall 2005, spring 2006, and fall 2006 are listed in Tables 2 – 4, respectively.

Periodic wetting and drying of the soil surface was shown to increase NH_3 volatilization from surface applied urea because of the effect on urea hydrolysis (Titko et al., 1987). In fall 2005, rain occurred three, four, and five days after treatment (DAT), totaling 4.17 in. of precipitation (Table 5). The highest proportion of N loss from urea was observed in the first three days after treatment, with another increase in loss at six days after treatment (following the period of precipitation) (Fig. 7). In spring 2006, a total of 2.49 in. of precipitation occurred zero (day treatments applied), three, six, and seven DAT (Table 5). The highest proportion of N loss was observed during the first three days after treatment (Fig. 7). After a decrease in volatilization, an increase was observed six and seven days after treatment (Fig. 7). Days of precipitation in fall 2006 were zero, three, and five days after treatment. (Table 5). Highest proportion of N loss during this experiment was observed during the first three days after treatment (Fig. 7), with another increase in amount released six and seven days after treatment. Average temperatures at

the experiment site were 26.2 C, 21.8 C, and 27.2 C in 2005, spring 2006, and fall 2006 respectively. Table 6 shows daily minimum and maximum temperatures for the three experiments.

In 2005, urea released the highest proportion of applied N (11.7 %) (Fig. 8). The mass of NH₃ released from methylene urea (7.4 %) was not different from the amount released from urea at $P \leq 0.10$. Polymer-coat urea differed from urea in the amount of NH₃ volatilized, but did not differ from methylene urea ($P \leq 0.10$).

In spring 2006, NH₃ volatilization from N sources was in order of urea (20.1%) > methylene urea (7.4%) = polymer coated urea (4.4%)($P \leq 0.10$). Nitrogen sources followed the same trend in fall 2006: urea (15.7%) > methylene urea (4.2%) = polymer coated urea (4.4%) ($P \leq 0.10$). These findings are similar to those in our previous laboratory study (Knight, et al, 2007, in press).

Conclusions

Urea released a greater proportion of applied N in the field than methylene urea and polymer coated urea. These differences may be attributed primarily to coating characteristics of the three fertilizers. Polymer coated urea appears to be superior to methylene urea as a slow-release N source in the first 10 days after treatment. Periods of precipitation and subsequent drying increased NH₃ volatilization from fertilizer sources. Because these slow-release sources are designed to release N over several weeks, further examination as to the significance of these differences over a longer time period is needed.

Table 2. Irrigation and mowing schedule for NH₃ volatilization field study for 2005 and 2006.

Precipitation											
	Day										
	0	1	2	3	4	5	6	7	8	9	10
2005	0.00	0.00	0.00	1.62	0.71	1.84	0.00	0.01	0.00	0.00	0.00
Spring2006	0.21	0.01	0.00	1.95	0.00	0.00	0.27	0.05	0.00	0.00	0.00
Fall 2006	0.03	0.00	0.00	0.23	0.00	0.30	0.00	0.00	0.00		

2005 Mowing[†]											
	Day 0	1	2	3	4	5	6	7	8	9	10
Plot 1	X		X				X		X		
2	X		X				X		X		
3	X		X				X		X		
4	X		X				X		X		
5	X		X				X		X		
6	X		X				X		X		
7	X		X				X		X		
8	X			X				X		X	
9	X			X				X		X	
10	X			X				X		X	

[†] plots were not mowed in 2006 during the observation period.

Table 3. 2M KCl extractable NO₃ and NH₄, and surface pH at each sample time as affected by N source Fall 2005.

	Days after fertilization									
	1	2	3	4	5	6	7	8	9	10
N Source	NO₃ (mg kg⁻¹)									
Urea	4.46	0.00	0.00	4.66	8.28	1.90	0.00	3.28	6.97	3.40
Methylene urea	7.69	3.82	0.00	1.71	1.17	3.62	2.62	2.32	2.32	1.42
Polymer coated urea	8.20	3.19	0.00	0.00	3.41	0.00	-0.90	2.10	2.34	1.86
background	13.27	8.73	7.47	4.42	4.47	5.85	7.28	4.68	4.35	5.92
	NH₄ (mg kg⁻¹)									
Urea	6.17	6.82	0.00	8.71	6.95	1.84	3.99	2.97	3.73	2.31
Methylene urea	6.94	4.81	1.31	1.02	0.66	1.15	0.00	1.03	0.00	0.00
Polymer coated urea	6.42	3.21	0.00	0.00	2.82	1.46	0.00	1.66	1.69	0.38
background	0.00	5.48	5.47	5.05	3.28	1.59	3.26	1.28	2.70	4.10
	pH (surface)									
Urea	7.26	7.23	7.06	6.85	6.06	6.70	6.39	5.49	5.41	7.58
Methylene urea	6.75	6.75	6.68	6.61	5.76	6.48	6.22	5.38	5.41	7.32
Polymer coated urea	6.08	6.10	6.50	6.85	5.98	6.36	6.27	5.46	5.64	7.04
background	5.78	5.78	6.67	6.62	5.74	6.30	6.40	5.61	5.84	6.79

Table 4. 2M KCl extractable soil NO₃ and NH₄, and surface pH at each sample time as affected by N source, Spring 2005.

	Days after fertilization									
	1	2	3	4	5	6	7	8	9	10
N Source	NO₃ (mg kg⁻¹)									
Urea	57.35	23.61	28.78	15.52	16.57	14.07	27.13	83.56	5.18	6.43
Methylene urea	9.38	6.75	6.06	5.03	0.00	57.65	22.72	0.00	8.28	8.34
Polymer coated urea	37.34	37.18	21.12	25.88	24.45	22.40	21.29	1.07	17.55	12.16
background	11.62	7.32	7.85	9.36	12.98	12.34	--	12.27	9.64	6.72
	NH₄ (mg kg⁻¹)									
Urea	23.50	9.67	7.27	6.07	3.41	0.57	10.50	6.61	5.40	3.59
Methylene urea	3.54	4.70	4.85	3.96	0.40	1.78	9.63	4.72	4.97	3.29
Polymer coated urea	13.36	9.94	6.35	7.21	7.16	0.69	9.46	5.19	10.62	5.01
background	13.39	4.74	4.77	5.47	7.56	9.37	--	2.74	0.41	1.63
	pH (surface)									
Urea	7.81	8.18	7.81	7.34	7.04	7.40	7.14	6.32	6.56	6.14
Methylene urea	6.62	7.11	7.07	6.55	6.00	6.41	6.41	6.17	6.17	6.21
Polymer coated urea	6.14	6.65	6.32	6.09	5.70	6.11	6.30	6.43	5.68	5.83
background	6.50	6.51	6.62	7.31	6.35	7.04	7.30	6.30	6.71	7.06

Table 5. 2M KCl extractable NO₃ and NH₄, and surface pH at each sample time as affected by N source, Fall 2005.

	Days after fertilization									
	1	2	3	4	5	6	7	8	9	10
	NO₃ (mg kg⁻¹)									
Fertilizer										
Urea	97.64	69.20	37.07	20.38	8.50	21.08	19.75	7.58	13.44	11.63
Methylene urea	0.00	0.00	3.27	3.41	2.12	0.00	0.02	5.24	4.28	7.84
Polymer coated urea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.68
background	26.75	27.38	9.10	6.99	3.87	15.41	16.98	6.77	12.92	-0.18
	NH₄ (mg kg⁻¹)									
Urea	90.42	61.87	28.32	17.33	6.69	12.37	20.65	5.35	11.20	4.23
Methylene urea	2.30	0.85	0.43	4.91	3.14	2.32	6.54	3.70	6.43	4.91
Polymer coated urea	0.00	0.00	0.00	0.98	0.00	2.65	0.85	0.19	3.46	2.76
background	9.26	8.84	5.74	1.96	1.61	2.22	2.40	2.32	1.21	-0.39
	pH (surface)									
Urea	8.01	6.82	7.68	7.05	6.87	7.17	6.38	6.91	--*	--
Methylene urea	7.58	5.73	6.20	6.47	6.30	6.64	6.29	5.99	--	--
Polymer coated urea	6.14	5.61	5.76	6.08	6.36	6.66	6.11	5.75	--	--
background	6.64	4.94	5.63	5.82	6.42	6.07	5.47	5.78	--	--

*pH electrode broken, unable to collect data

Table 6. Daily maximum and minimum air temperature for 2005 and 2006 at Beck's Turf Farm.

DAT	2005		Spring 2006		Fall 2006	
	T _{max}	T _{min}	T _{max}	T _{min}	T _{max}	T _{min}
	C					
0	86	69	79	64	80	58
1	85	70	80	60	77	55
2	86	68	71	61	80	61
3	83	69	74	63	86	70
4	77	70	72	50	90	72
5	78	60	72	49	85	64
6	67	60	68	57	78	57
7	64	61	74	57	78	54
8	79	62	69	50	81	70
9	80	66	72	52	--	--
10	78	62	73	53	--	--

Fig. 7 Ammonia volatilization as affected by N source and sampling day, Fall 2005 (top), Spring 2006 (middle), and Fall 2006 (bottom).

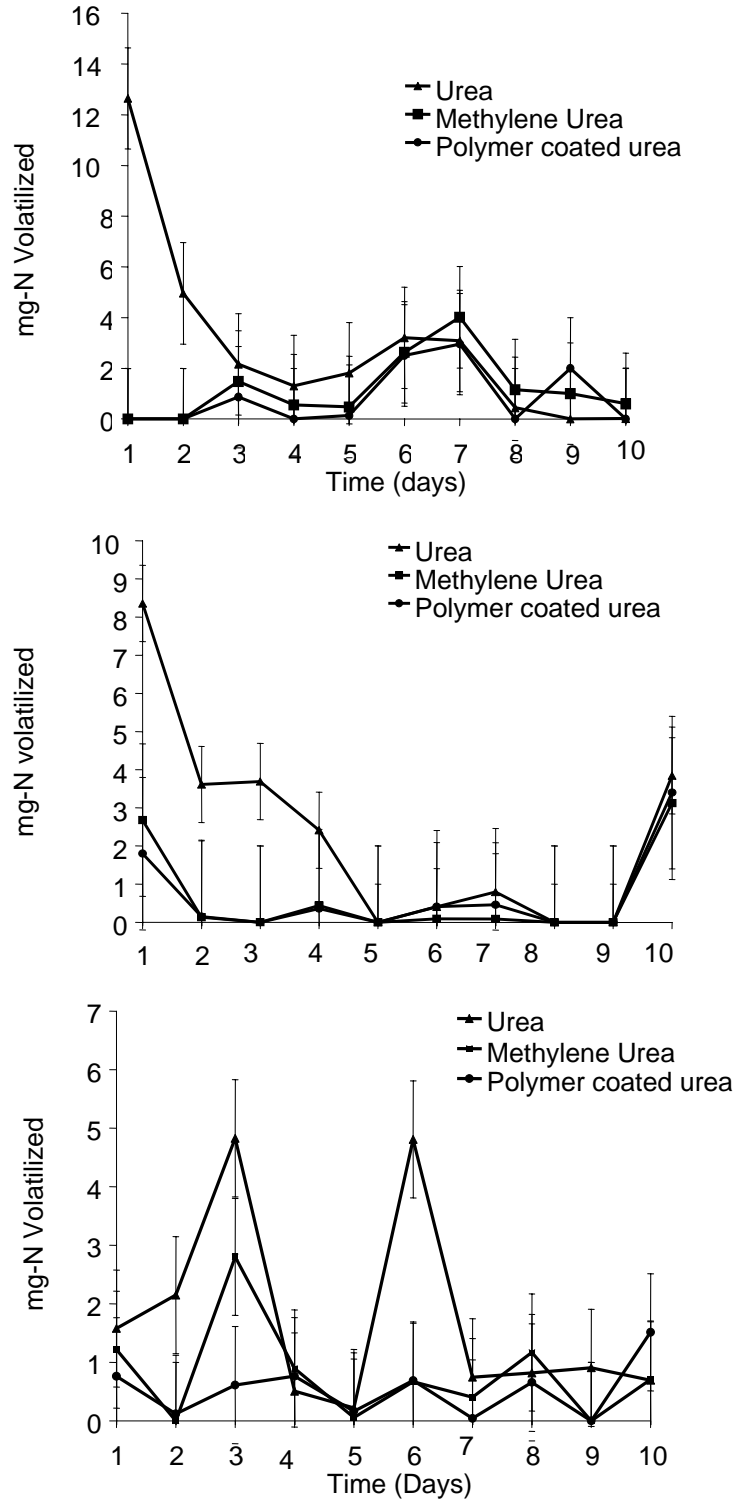
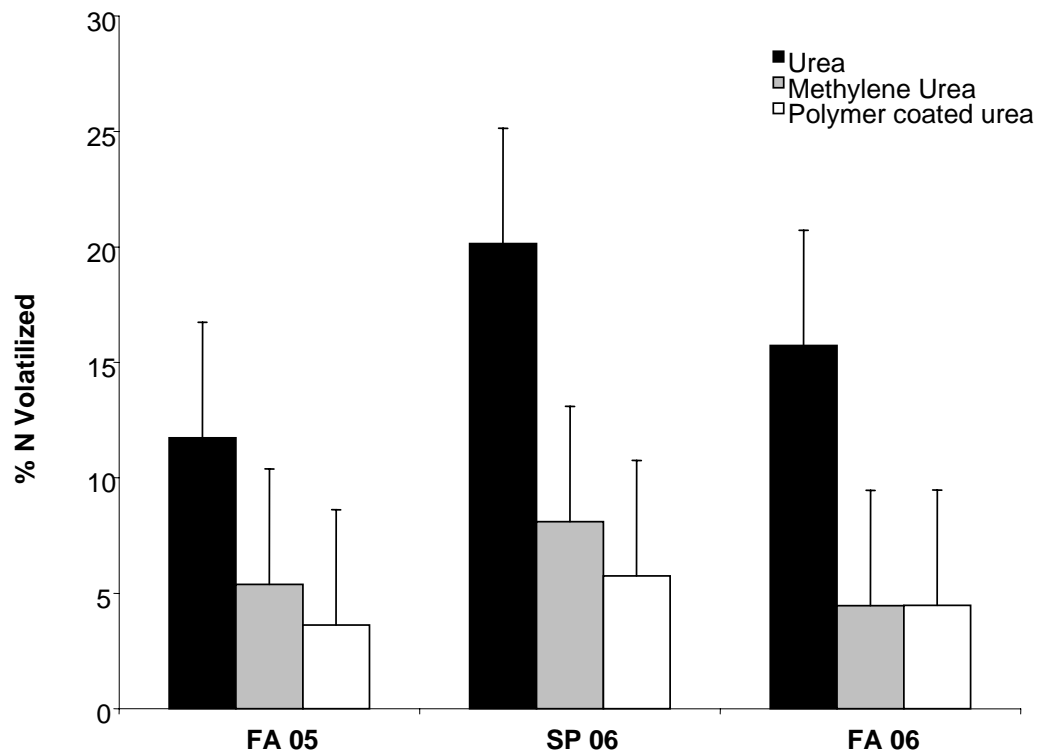


Fig. 8 Total cumulative N loss due to NH₃ volatilization over a 10 d period as affected by N source in the field, fall 2005, spring 2006, and fall 2006. Vertical lines represent the standard error.



IV. SUMMARY

This study was a preliminary examination of the effects of mowing and N source on NH_3 volatilization from fertilizers applied to warm season turfgrass in the laboratory and field. Results from the laboratory indicate that mowing has no effect on the amount of N lost to volatilization from the six fertilizers used, at least in the first 10 days. Results from the laboratory and field did show differences in the amount of NH_3 volatilization from the different N sources. Polymer coated urea and methylene urea have higher N contents than composted sewage sludge and release less NH_3 to volatilization than urea, sulfur coated urea, and ammonium nitrate. Therefore, polymer coated urea and methylene urea would be superior choices for slow release N sources in a turfgrass maintenance program than urea, sulfur coated urea, ammonium nitrate, and composted sewage sludge. These results warrant further, longer-term, investigation to determine how significant the differences are in an overall turfgrass management program.

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