ABSTRACT

PROCTOR, CYNTHIA LAMBERT. Effect of fertilizer nitrogen rate and time of application on growth and performance of six herbaceous perennials and soil solution nitrogen concentration in a simulated landscape. (Under the direction of Stuart L. Warren)

Herbaceous perennials are planted worldwide in public gardens, and commercial and home landscapes. Little research based information exists on response of herbaceous perennials to fertilizer nitrogen (FN) rate and timing and the potential for loss of applied N via leaching. Therefore, we constructed simulated landscapes and installed canna lily (*Canna* L. 'President'), coreopsis (*Coreopsis verticillata* L. 'Moonbeam'), purple coneflower (*Echinacea purpurea* L. 'Magnus'), iris (*Iris siberica* L. 'Caesar's Brother'), switchgrass (*Panicum virgatum* L. 'Shenandoah'), sedum (*Sedum* L. 'Herbstfreude'), and sage (*Salvia* x *sylvestris* L. 'East Friesland') to determine how FN rate and timing affected growth and performance of herbaceous perennials and potential N leaching. Porous ceramic cup lysimeters were installed *in situ* in each landscape plot 38 cm below the soil surface to examine the effects of FN rate and timing on soil solution N concentrations. The experiment was a 4 x 4 factorial in a randomized complete block design with four replications. Four rates of FN: 0, 7, 14, and 28 $g{\bullet}m^{-2}$ N were divided equally into two applications and applied at the following times: 1) winter (Jan. 15 and Feb.15), 2) spring (Apr. 15 and May 15), 3) summer (June 15 and July 15), or 4) fall (Sept. 15 and Oct.15) beginning 2001. Soil solution samples were collected approximately every 2 weeks from Jan. 30, 2002 to Nov. 3, 2003 and analyzed to determine soil N (NO_3^- and NH_4^+) concentrations. Data collected in 2002 and 2003 for each species included the following number of flowers, plant visual evaluations, growth index (GI), and

top dry weight. In 2003, mineral nutrient concentration was determined for each species. Plant response to treatments varied in 2002 and 2003. Our results indicated that despite statistical significance differences, many differences were small and FN treatments had little impact on the growth and ornamental qualities of these species. However, applying no N may not advisable, as some perennials species did benefit from an FN application during a specific time. Soil N concentrations remained above 10 mg•L^{-1} for 110 days, 62 days, 52 days, and 192 days when applied during January/February, April/May, June/July, 2002 and September/October in 2001 respectively. In 2003, soil N concentrations from FN rates of 7 g•m^{-2} N (1.5 lbs•1000 ft^{-2}) and 14 g•m^{-2} N (3.0 lbs•1000 ft^{-2}) applied in January/February, June/July, April/May and September/October remained below 10 mg•L^{-1} until the end of the study (Oct. 14, 2003). Nitrogen concentrations increased to 19 mg•L^{-1}, 38 mg•L^{-1}, and 21 mg•L^{-1}, after 28 g•m^{-2} N (6.0 lbs•1000 ft^{-2}) was applied in January/February, April/May, and June/July, respectively. To cover the needs of a wide variety of perennial species that usually exists in one landscape as well as minimize N concentrations in the soil solutions, we recommend a low to moderate rate of FN (5 g•m^{-2} to 15 g•m^{-2}) be applied in split applications in spring and early fall.

Effect of fertilizer nitrogen rate and time of application on growth and performance of six herbaceous perennials and soil solution nitrogen concentration in a simulated landscape

by

CYNTHIA LAMBERT PROCTOR

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

HORTICULTURAL SCIENCE

Raleigh

2005

APPROVED BY:

Robert L. Mikkelsen — Dennis J. Werner

Stuart L. Warren
Chair of Advisory Committee

Biography

Cynthia Faye Lambert was born in St. Louis, MO to Martha Faye and J.D. Wooster Lambert Jr. on October 29, 1966. Cindy stayed in St. Louis with her mother after her parents divorced in 1972. She attended local schools in St. Louis and became interested in sports, especially volleyball and basketball in high school. After high school graduation she moved to Charlotte, NC to attend University of North Carolina in Charlotte and to spend more time with her father and his family. Cindy has a total of 9 brothers and sisters, three half brothers, two half sister, two step brothers, and two stepsisters.

Cindy received an undergraduate degree in Business Administration with a concentration in Finance in 1991. Her love for plants began when she started working part time for a small landscape firm, Brenda Cathey Landscape Design, doing simple job tasks like pine needling and annual installations while still in school. Cindy loved returning to job sites where she previously had helped install landscapes, prune plant material, or plant little annual flowers. It wasn't long until she was promoted to foreman of several crews. After graduation, she was asked to become a partner in charge of establishing new commercial and residential clientele, and improving current operations. Unlike other landscape companies, Brenda Cathey Landscape Design did not maintain any turf but focused on pruning, renovation, plant installation, and high customer service.

By 1994, Cindy moved to Greensboro, NC to work with New Garden Landscaping and Nursery, in charge of logistics and operations of their satellite retail operation. The high volume of plant material that moved in and out of the store, preparing full-time and support staff for seasonal changes and retail trends further defined Cindy's people and organizational skills. She realized however, she loved training and coaching the staff in doing their job description. However, she wasn’t sure how to match horticulture and training.

In 1998, Cindy decided to attend NC State to go back to school to explore more about what the horticulture industry had to offer personally and professionally. During her undergraduate degree, Cindy involved herself as much as possible in the Horticulture Club and ALCA type activities. In addition, she traveled to three department chaperoned European garden tours to England, Wales, Scotland, and France, and one domestic garden tour that visit explore gardens in Virginia, Pennsylvania, and Delaware. In an attempt to investigate teaching, Cindy served as an assistant to a Garden Center Management class and two Plant Identification classes. Furthermore, she did a small research project to sense what graduate school might be like.

Cindy started the master’s program at NC State University in the fall of 2001 and worked as a teaching assistant for Tree and Grounds Maintenance and Plant Identification. In fall 2004, Cindy taught Landscape Management while Stu Warren was on sabbatical. Cindy pursued a minor in Soil Science while she worked on her master’s project. In 2002, she married Austin K. Proctor and they had a son Jack Clemson born February 20, 2005. Cindy plans to raise her son and teach horticulture related classes at a community college level.

Acknowledgements

I would like to thank my committee members, Drs. Stuart Warren, Dennis Werner, and Rob Mikkelsen for serving on my committee and for all their advice and instruction throughout my MS Program. I enjoyed working with each and every one of you. I would like to especially thank Stuart Warren for his incredible patience and guidance throughout the pursuit of this degree. I have gained many professional skills from you; research, teaching, and time management, although I doubt that we ever stop learning how to master time management. You truly are a great leader and an asset to the horticulture industry.

To fellow graduate students, I loved getting to know all of you and treasure our friendships. To my dear friend Denny Crowe; thank-you for pushing me to achieve greater things in life, personally and professionally. I will always treasure our friendship and I look forward to breaking more ornaments in the future.

Much appreciation for all the help I received from our research group. I particularly value the camaraderie among us, especially in trying to figure out our research and class woes. A very special thanks to William Reece for all of his help throughout this experiment. I enjoyed our conversations, and all the laughs we had during this experiment. I would also like to thank Peggy Longmire for the technical assistance in the Soil Science department. I could have never used the equipment in the lab without your help and it would have never been as much fun without you.

To my husband, Austin who has been a great companion and I have loved sharing my life with you and I look forward to discovering what the future holds for the both of us. I love you and our wonderful son, Jack and I want you to know how much I appreciate all your support in my pursuit of this degree. To my sweet baby Jack. Thanks my little one for being such a good baby and a joy to raise.

Table of Contents

List of Tables

List of Figures

List of Figures cont.

List of Figures cont.

General Introduction

The overall objective of these studies was to establish the fertilizer nitrogen (FN) requirements of herbaceous perennials in a landscape setting and determine its effects on nitrogen losses. This objective was addressed in two main areas:

I. Nitrogen requirement of perennials

II. The effects of fertilizer nitrogen on nitrogen leaching in the landscape

I. Nitrogen requirement of perennials

Nitrogen (N) is the fertilizer element required in the greatest quantity by most plants to maximize yields, maintain health, and promote growth. Current fertilizer recommendations for herbaceous perennials vary dramatically regarding nitrogen rate and timing (Brown, 1996; Evans, 2000; Kessler, 2002; Relf and Ball, 2002; Thomas, 1999). One of the myths surrounding herbaceous perennials is that they do not require fertility management. The uncertainty is not surprising since existing research is conflicting. For example, a study comparing several herbaceous perennial species reported that *Achillea* and *Gypsophila* plants did not respond to FN when grown in a Windsor sandy loam with high P and K levels while *Heuchera sanguinea* 'Splendens' used in the same study did require high rates of FN [35.3 $g•m^{-2}$ N (7.2 lbs•1000 ft^{-2})] to maximize top dry weights (Duarte, 1986). Field-grown purple coneflower (*Echinacea purpurea* L.) grown as an annual crop needed FN rates up to 147 $g•m^{-2}$ (30 lbs•1000 ft^{-2}) to maximize height and top dry weight (Shalaby et al., 1997). In addition, 41 $g•m^{-2}$ N (8.5 lbs•1000 ft^{-2}) were needed to maximize biomass of field-grown switchgrass (*Panicum virgatum* L.) (Muir et al., 2001). Container production studies have also examined the effects of N rate on growth of herbaceous perennials, however, these results bear little resemblance to the landscape (Cabrera, 2003; Dubois et al., 2000; Perry and Adam, 1990).

Varying responses to FN rates occur in perennial species such as woody ornamentals and fruit bearing plants. Recent studies with red raspberry (*Rubus idaeus* L. 'Meeker') (Rempel et al., 2004), fraser fir [*Abies fraseri* (Pursh) Poir] (Hinesley and Snelling, 2000), and river red gum (*Eucalyptus camaldulensis*) (Cockerham, 2004) have shown these species to have a low FN requirement whereas, southern magnolia (*Magnolia grandiflora* L.) required 4.4 g•m^{-2} N (~ 1.0 lbs N•1000 ft^{2})] applied monthly from February to October to maximize height over a 4-year period (Gilman et al., 2000).

. Other perennial studies have demonstrated that response to FN varied with time of application. Lovatt (2001) examined the response of 'Hass' avocado *(Persea americana* Mill. 'Hass') after increasing the FN rate at two significant phenological timings over four years. The FN rate of 5.6 g•m^{-2} (1.2 lbs •1000 ft^{-2}) applied in mid-November (flower bud initiation) and 5.6 g•m^{-2} (1.2 lbs •1000 ft^{-2}) applied in mid-April (flower anthesis and vegetative shoot flush) significantly increased fruit weight and number of large sized fruit compared to 2.8 g•m^{-2} (0.6 lbs •1000 ft^{-2}) applied in January, February, April, June, July, and November. However, FN timing did not influence tree performance of mature (~ 4 years) peach [*Prubus persica* (L.) Batsch 'O' Henry'] trees. No significant differences existed when fruit growth, yield, or vegetative growth were compared between fall or spring applications of 20 g•m^{-2} (4 lbs •1000 ft^{-2}) of FN (Niederholzer et al., 2001). Incorrect timings of FN applications may increase seed development and vegetative growth thereby reducing flowering or reoccurrence of flowering. Gariglio et al., (2000) demonstrated that monthly applications of FN to strawberry (*Fragaria* x *ananassa*) increased foliage size as well as runner production while decreasing the expected harvest index. Furthermore, excess FN may encourage tender plant growth that may be more susceptible to plant diseases and lodging. Fall FN application may prevent perennials from "hardening off" before cold weather occurs (Brady and Weil, 1999).

Several herbaceous perennial studies monitored N uptake patterns during growth. Hood et al. (1993) reported uptake of nutrients by snapdragon (*Antirrhinum majus* L.) grown hydroponically was highest from visible bud to anthesis and suggested that supplemental fertilizer during this stage of growth would be beneficial. Similarly, rapid uptake of N by chrysanthemum (*Dendranthema* x *grandiflorum* L.) grown hydroponically from cuttings was greatest 40 to 50 days after root formation up to flower bud formation (King et al., 1995). In contrast, Kaximirova (1994) reported that nutrient uptake by carnation was greatest during full flower and seed development, however, N uptake was high throughout growth, suggesting available N throughout the plant's life cycle was necessary for maximum growth and flowering. Most herbaceous perennial gardens include various species that will flower throughout the year thus, these gardens may vary in their N absorption. Mengal and Kirby (1981) report that most plants require more N during the vegetative stage whereas, in the generative phase N uptake is low and the retranslocation of organic N is high. Similarly Huett (1996) stated that efficient N uptake occurs during periods of active growth and depends on active photosynthesis.

Differences in N uptake patterns and N reserves also appear in woody perennial plants as indicated by ^{15}N studies. Their patterns of N accumulation may reflect their demand for N and can be useful in timing N fertilization for greatest N-use (Weinbaum et al., 1992). In grapevines, FN absorption was most rapid at flower initiation compared to budbreak and N demand of stems and leaves were met by current season adsorption when N was applied between bloom and veraison (Hanson and Howell, 1995; Williams, 1991). In addition, after fruit harvest to leaf fall, trunks and roots of grapevines accumulated N reserves that supported early growth during the following year (Conradie, 1991). Similarly, summer N fertilization of apple trees (*Malus* x *domestica* Borkh.) sustained the following year's spring vegetative growth (Toselli et al., 2000). Acuna-Maldonado et al. (2003) reported that pecan (*Carya illinoinensis* Wangenh. C. Koch) N absorption was greatest between budbreak and the end of shoot expansion. They also reported, however, that substantial N was absorbed between leaf fall and budbreak. Rempel et al. (2004) stated that 24% to 37% of the N in new growth of red raspberry came from FN. Thus, the remaining N (63% to 76%) was derived from soil mineralization and plant reserves. Other N uptake and N storage studies found that most N in new growth was from remobilization of N stored in other plant parts (Ledgard and Smith, 1992; Sanchez et al., 1991; Toselli et al., 2000). Unlike woody perennials, the root system is the only portion of herbaceous plants that remains during the dormant season to store N reserves for vegetative growth the next spring. Therefore, if herbaceous perennials require N reserves for spring growth, N is most likely stored in the root systems until retranslocation during vegetative growth.

In addition to growth, FN rate and time of application can affect ornamental quality. A turfgrass mixture of perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.), creeping red fescue (*Festuca rubra* var. *rubra* L.), and chewing fescue

(*Festuca rubra* var *commutate* Gaud) grown in Turkey had more uniform color and sustained turf quality throughout the growing season (April to September) when 5 g•m^{-2} (1 lb•1000 ft^{-2}) N was applied in April and May compared to 15 g•m^{-2} (3.3 lbs•1000 ft^{-2}) applied in April and September (Oral and Acikgoz, 2001). Rate of growth and top growth, however, were more uniform when 5 g•m^{-2} N (1.0 lb•1000 ft^{-2}) or 10 g•m^{-2} (2.0 lb•1000 ft^{-2}) of FN were applied in April, June, and August.

Obviously fertility management across all perennials is a complex task and protocols differ depending on the species and whether the plant is grown to produce yields or preserve ornamental qualities. However, inconsistent FN recommendations may result in over application of N for fear of developing a nutrient deficient or poor performing plant and therefore may lead to excess N in groundwater. Furthermore, excess FN may lead to a high shoot:root ratio (Bowman, 2003). More top growth may increase a plants demand for water. Examining N requirements of perennials alone is not enough to develop a fertility management plan. Current fertility management recommendations need to balance plant performance against reducing potential N losses.

II. The effects of fertilizer nitrogen on leaching in the landscape

Excessive N loading to watersheds promotes changes in harmful algal blooms, hypoxia, anoxia, and fish kills. Nitrate leaching comes from several non-point sources such as agricultural and urban runoff, septic fields, atmospheric deposited N, and municipal and industrial discharges. Nitrate leaching is the largest source of degradation to surface water quality in the U.S. and as a result, the United States Environmental Protection Agency has established a maximum contaminant level (MCL) of 10 mg•L^{-1} NO_3-N for watersheds throughout the U.S. (U.S. Environmental Protection Agency, 2000). Although the underlying sources of elevated N in watersheds remains unclear, one possibility includes FN runoff and leaching from residential and commercial landscapes, where FN is used routinely to promote strong, healthy landscapes. Loss of FN through leaching commonly constitutes the main channel of loss from field soils (Allison, 1966). With the growing public interest regarding groundwater contamination by N and the MCL of 10 mg•L^{-1} NO_3-N, the landscape industry needs to reevaluate fertility management practices.

Current agricultural studies have developed thorough fertility management programs that center on planting times, growth stages, and N uptake patterns while minimizing N leaching (Owens et al., 2000; Toth and Fox, 98; Upendra et al., 1999). Similarly, researchers have examined the effects of FN applied at various rates and timings on a variety of turf species by measuring top growth, vigor, color intensities, and rooting architecture while comparing FN concentrations found at various depths in the soil profile (Bowman, 2003; Bowman and Paul, 1991; Lee et al., 2003; Petrovic, 1990; Roy et al., 2000). These studies discovered that most turfgrass species are efficient in N uptake because of dense root systems and frequent removal of grass clippings that contain N.

Existing FN studies on landscape ornamentals and trees have correlated FN rates with several growth parameters, however, little research has observed the leaching effects of these FN inputs (Appleton and Kauffman, 1999; Good and Weir, 2004; Rose and Smith 2001; Rosen et al., 2004). Current FN recommendations are based on early research when maximizing fertilizer response was the primary goal and N losses was a secondary consideration. Therefore, it is currently unclear how some landscape management practices may affect the environment.

It is not surprising that little research exists for landscape ornamentals since many ornamental landscapes usually have a combination of woody and herbaceous perennials, evergreens, and annual plantings. To complicate matters further, it is not likely that all plants were installed at the same time and therefore may have various FN requirements. This was suggested by Erickson et al., (2001) who found soil N concentrations differences after applying various FN rates at various timings to a mixed species landscape and a St. Augustine turf [(*Stenotaphrum secundatum* (Walt.) Kuntze]. Soil N concentration under St. Augustine never exceeded 0.4 mg L^{-1} after six 5 g•m^{-2} N (1 lb•1000 ft^{-2}) was applied in separate applications in February, April, June, August, October, and December. In contrast, the mixed landscape with 12 ornamental species contained soil N concentrations ranging from < 0.2 to 15.2 mg L^{-1} in percolate sampled daily after three separate N application of 5 g•m^{-2} (1 lb•1000 ft^{-2}) applied in April, August, and December. However, these N concentrations may be misleading since plants from this study were installed in Dec. 1998 and fertilization began the following February. Newly installed landscape plants may have different fertility requirements than established plantings.

In recent years, fruit crop researchers have developed new fertility programs based on the rate and timing of FN application relative to the nutritional demands of the plant to reduce N leaching. Retamales and Hanson (1989) discovered that mature (22 years) highbush blueberries (*Vaccinium corymbosum* L.'Bluecrop') required 18 g•m^{-2} (3.6 lb•1000 ft^{-2}) less FN than the commercially recommended rate. Traditionally, field-grown plants were fertilized in the spring and fall so N would be readily available for uptake (Rose, 1999). However, Niederholzer et al., (2001) found that more than three-fourths of the N ultimately absorbed by fall-fertilized trees persisted in the soil over winter and was absorbed during the subsequent spring and summer. In contrast, pecan (*Carya illinoinensis* Wangenh. C. Koch.) tree studies have found that N adsorption takes place during dormancy (November to April) as well as spring before shoot and leaf development (Acuna-Maldonado et al., 2003).

The degree of nitrate leaching can be influenced by irrigation practices and/or rainfall amounts. Application of FN near the fall season in some parts of the country has shown to leach due to heavy fall and winter precipitation (Petrovic, 1990; Roy et al., 2000; Snyder et al., 1984). Drier summers could limit a plant's use of FN since the absorption of nitrate is highly dependent on soil moisture levels (Roy et al., 2000). If high FN rates exceed crop needs, excess N may remain in the soil profile during dry conditions. Heavy rainfall may initiate a wetting front containing high concentrations of nitrate. If these concentrations reach the water table as a single pulse, groundwater could test well over the MCL (Roy et al., 2000).

Unlike field-grown perennial crops, ornamentals in an urban landscape have another source of N unique to landscapes, mulch. Organic mulches that are frequently used are pine-bark, hardwood, cypress, and pine needles. There use in ornamental landscapes is to suppress weeds, retain soil moisture, and moderate soil temperatures. Even though organic mulches may offer plant available nutrients they are not commonly applied to fertilize plants. Nutrients that exist in mulch are generally not readily soluble for plant uptake and are less predictable due to their various chemical properties and carbon to nitrogen (C: N) ratios.

Organic mulches greater than 30:1, C:N decrease N mineralization, making microbes scavenge for available N thus reducing soil N availability for plant growth. In contrasts, N mineralizes if C:N ratio are low, enough soil N exists to support microbial and plant growth. (Barbarick, 1999).

A recent study conducted by Lloyd et al. (2002) illustrated that composted yard waste applied as mulch can serve as an organic fertilizer. Lloyd (2001) examined the effects of three mulches [composted yard waste (a mixture of wood chips, leaves, and grass clippings, C:N ratio = 20), ground wood pallets (C:N ratio = 100), and no mulch (bare soil)] on growth of river birch (*Betula nigra* 'Cully' Heritage) and rhododendron (*Rhododendron* 'Pioneer Silvery Pink'). All three mulch treatments received no FN (0 N) or 14 $g•m^{-2}$ N (3 $lbs•1000\ ft^{-2}$) applied in split applications (at budbreak and early October) yearly from 1998 to 2000. Fertilizer N increased growth and foliar N concentrations of river birch and rhododendron when mulched with ground wood pallets or no mulch (bare soil) compared to plants receiving no FN. However, growth and foliar N concentrations of rhododendron and river birch were similar when grown with composted yard waste with or without FN. Lloyd (2001) also reported soil N concentrations were similar in the composted yard waste treatment receiving no FN compared to the soil N concentration in the ground wood pallets and no mulch (bare soil) treatment receiving FN indicating that composted yard waste can serve as a high-quality organic fertilizer. Nitrogen measured in the soil solution under the composted yard mulch receiving no FN averaged 30 $mg•L^{-1}$ N compared to 10 $mg•L^{-1}$ N with no mulch (bare soil) receiving FN. Not all organic materials decompose at the same rate

(Duryea et al., 1999) therefore, mulch should not be used as the sole N source for landscape plants unless C:N testing was performed by landscapers and homeowners.

Soil organic matter may alter the effects of FN due to microbe activity. Switchgrass (*Panicum virgatum* L. 'Cave-n-Rock') biomass increased only 12% in a soil that contained 2.7 $g \bullet kg^{-1}$ of native soil N within the 0-15 cm of soil profile after 8.4 $g \bullet m^{-2}$ N (1.7 $lbs \bullet 1000\ ft^{-2}$) was applied. In this same study, FN significantly increased switchgrass biomass (74%) planted in other soils that contained < 1.3 $g \bullet kg^{-1}$ of native soil N (Stout and Jung, 1995). Mass balance studies have documented that some FN was incorporated into the microorganisms or organic residues of the soil (Rempel et al., 2004; Retamales and Hanson, 1989). Soil organic matter has many benefits for plants by positively influencing soil structure, bulk density, water infiltration rates, and water and air movement within the soil (Tisdale, 1993). Another study showed that application of FN to sweet corn (*Zea mays* L.) can be reduced by half [146 vs. 73 $g \bullet m^{-2}$ (15 vs. 30 $lbs \bullet 1000\ ft^{-2}$) if 2.5 cm (1 in) of leaf compost is incorporated into the soil (Maynard, 2002). However, compost was incorporated annually in this study. Incorporating soil organic matter is an option during installation of landscapes but not practical for established plantings. Nonetheless, careful consideration should be exercised when using organic matter as fertilizer since N from this source can still be subject to leaching under certain environmental conditions (Stout et al., 1997).

Landscape professionals should better understand the impact of landscape fertilization practices on growth and performance of landscape plants and how these practices impact N leaching. Currently, research has not adequately examined urban soil nitrogen status, but urban soils are commonly perceived to be nitrogen deficient (Scharenbroch and

Lloyd, 2004). Adapting FN recommendation from other systems is convenient but of little value for managing N in the landscape environment. Furthermore, in light of concerns of over applying FN, N demands to increase growth may differ from demands to maintain healthy, vigorous, aesthetic plants. For this, research is needed that examines how FN rate and time of application affects plant growth and N losses for ornamentals in the landscape.

Literature Cited

Acuna-Maldonado, L.E., M.W. Smith, N.O. Maness, B. Cheary, and B. Carroll. 2003. Influence of nitrogen application time on nitrogen absorption, partitioning, and yield of pecan. J. Amer. Soc. Hort. Sci. 128:155-162.

Allison, F.E. 1966. The fate of nitrogen applied to soils. Adv. Agron. 18:219-258.

Appleton, B. and K. Kauffman 1999. Fertilizing landscape trees and shrubs. Virginia Coop. Ext. Serv. Publ. 430-018.

Barbarick, K.A. 1999. Organic materials as nitrogen fertilizers. Colorado State Univ. Coop. Ext. No. 546.

Bowman, D.C. 2003. Daily vs. periodic nitrogen addition affects growth and tissue nitrogen in perennial ryegrass turf. Crop Sci. 43(2):631-638.

Bowman, D.C.and J.L. Paul. 1991. Absorption of three slow-release nitrogen fertilizers by perennial ryegrass turf. Fert. Res. 29(3):309-316.

Brady, N.C. and R.R. Weil. 1999. The Nature and Properties of Soils. 12th ed. Prentice Hall, Upper Saddle River, N.J.

Brown, S.P., L. Hodyss, and D. Marshall. 1996. Flowering perennials in Florida. Florida Sta. Univ. Bul. ENH-68.

Cabrera, R.I. 2003. Less is more. Amer. Nurseryman. 197:40-45.

Cockerham, S.T. 2004. Irrigation and planting density affect river red gum growth. California Agric. 58(1):40-43.

Conradie, W.J. 1991. Distribution and translocation of nitrogen absorbed during early summer by two year old grapevines grown in sand culture. Amer. J. Enol. Viticult. 42(3):145-148.

Cookson, W.R., J.S. Rowarth, and K.C. Cameron. 2000. The response of a perennial ryegrass (*Lolium perenne* L.) seed crop to nitrogen fertilizer application in the absence of moisture stress. Grass For. Sci. 55: 314-325.

Duarte, M. 1986. Herbaceous perennial production systems for *Achillea*, *Gypsophila*, and *Heuchera*, M.S. Thesis, Univ. of Vermont, Burlington.

Dubois, J.J.B., S.L. Warren, and F.A. Blazich. 2000. Nitrogen nutrition of containerized *Anemone* x *hybrida*. J. Environ. Hort. 18(3):145-148.

Duryea, M.L., J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: chemical, allelopathic, and decomposition properties. J. Abor. 25(2):88-96.

Environmental Protection Agency. 2000. National management measures to control non-point source pollution from agriculture. [http://www.epa.gov/owow/nps/agmm/index.html] *(last accessed 04/20/04)*.

Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustine turf and alternative residential landscape. Crop Sci. 41:1889-1895.

Evans, E. 2000. Perennials: Maintaining. North Carolina State Univ. Coop. Ext. Serv. [http://www.ces.ncsu.edu/depts/hort/consumer/factsheet/perennials/text_maintaining.html] *(last accessed 01/04/05)*.

Good, G. and R. Weir. 2004. Suggested practices for planting and maintaining trees and shrubs. Cornell Coop. Ext. Publ. Bul. 24.

Hanson, E.J.and G.S. Howell. 1995. Nitrogen accumulation and fertilizer use efficiency by grapevines in short-season growing areas. HortScience. 30:504-507.

Hood, T.M., H.A. Mills, and P.A. Thomas. 1993. Developmental stage affects nutrient uptake by four snapdragon cultivars. HortScience. 28:1008-1010.

Gariglio, N.F., R.A. Pilatti, and B.L. Baldi. 2000. Using nitrogen balance to calculate fertilization in strawberries. HortTechnology. 10(1):147-150.

Gilman, E.F., T.H. Yeager, and D. Kent. 2000. Fertilizer rate and type impacts magnolia and oak growth in sandy landscape soils. J. Abor. 26(3):177-181.

Hinesley, L.E.and L.K. Snelling. 2000. Nitrogen increases fresh weight and retail value of fraser fir christmas trees. HortScience. 35(5):860-862.

Huett, D.O. 1996. Prospects for manipulating the vegetative-reproductive balance in horticultural crops through nitrogen nutrition: a review. Austral. J. Agr. Res. 47:47-66.

Kaximirova, R.N. 1994. Chemical plant analysis for determining the fertilizer requirements of carnations. Austral. J. Agr. Res. 34(5):691-697.

Kessler, J.R., J.D. Williams, and B. Clendenen. 2002. Herbaceous perennials in Alabama AN-566.

King, J.J., L.A. Peterson, and D.P. Stimart. 1995. Ammonium and nitrate uptake throughout development in *Dendranthema* x *grandiflorum*. HortScience. 30:499-503.

Ledgard, S.F. and G.S. Smith. 1992. Fate of ^{15}N-labelled nitrogen fertilizer applied to kiwifruit (*Actinidia deliciosa*) vines. Plant Soil. 147:59-68.

Lee, D.J., D.C. Bowman, D.K. Cassel, C.H. Peacock, and J. Thomas W. Rufty. 2003. Soil inorganic nitrogen under fertilized bermudagrass turf. Crop Sci. 43:247-257.

Lloyd, J.E. 2001. Trophic cascades in ornamental landscapes mediated by soil organic matter: Effects of mulch and fertilization on microbial activity, nutrient cycling, plant carbon allocation, and insect herbivores. PhD Diss., Ohio State Univ., Columbus.

Lovatt, C.J. 2001. Properly timed soil-applied nitrogen fertilizer increases yield and fruit size of 'Hass' avocado. J. Amer. Soc. Hort. Sci. 126(5):555-559.

Maynard, A.A. 2002. Leaf compost reduces fertilizer use for corn. BioCycle. 43(3):56-59.

Mengel, K.and E. Kirby. 1981. Principles of plant nutrition. 3rd ed., Intl. Potash Inst. Worblaugen-Bern,Switzerland.

Muir, J.P., M.A. Sanderson, W.R. Ocumpaugh, R.M. Jones, and R.L. Reed. 2001. Biomass production of 'Alamo' switchgrass in response to nitrogen, phosphorus, and row spacing. Agron. J. 93:896-901.

Niederholzer, F.J.A., T.M. DeJong, J.L. Saenz, T.T. Muraoka, and S.A. Weinbaum. 2001. Effectiveness of fall versus spring soil fertilization of field-grown peach trees. J. Amer. Soc. Hort. Sci. 126:644-648.

Oral, N.and E. Acikgoz. 2001. Effects of nitrogen application timing on growth and quality of a turfgrass mixture. J. Plant Nutr. 24:101-109.

Owens, L.B., R.W. Malone, M.J. Shopitalo, W.M. Edwards, and J.V. Bonta. 2000. Lysimeter study of nitrate leaching from a corn-soybean rotation. J. Environ. Qual.29:467-474.

Perry, L.P.and S.A. Adam, Jr. 1990. Nitrogen nutrition of container grown *Hemerocallis* x 'Stella de Oro'. J. Environ. Hort. 8(1):19-21.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1-14.

Relf, K.and E. Ball. 2002. Perennials: culture, maintenance and propagation. Virginia Coop. Ext. Bul. 426-203.

Rempel, H.G., B.C. Strik, and T.L. Righetti. 2004. Uptake, partitioning, and storage of fertilizer nitrogen in red raspberry as affected by rate and timing of application. J. Amer. Soc. Hort. Sci. 129:439-448.

Retamales, J.B.and E.J. Hanson. 1989. Fate of 15N-labeled urea applied to mature highbush blueberries. J. Amer. Soc. Hort. Sci. 114(6):920-923.

Rose, M.A. 1999. Nutrient use patterns in woody perennials: implications for increasing fertilizer efficiency in field-grown and landscape ornamentals. HortTechnology. 9(4):613-617.

Rose, M.A. and E. M. Smith. 2001. Fertilizing landscape plants. Ohio State Univ. Coop. Ext. Serv. Bul. HYG-1002-96.

Rosen, C. J., P.M. Bierman, and R.D. Eliason. 2004. Soil test interpretation and fertilizer management for lawns, turf, gardens, and landscape plants. Univ. Minnesota.Ext. Serv. Publ. BU-1731.

Roy, J.W., G.W. Parkin, and C. Wagner-Riddle. 2000. Timing of nitrate leaching from turfgrass after multiple fertilizer applications. J. Water Qual. Res. 35:735-752.

Sanchez, E.E., T.L. Righetti, D. Sugar, and P.B. Lombard. 1991. Recycling of nitrogen in field-grown 'Comice' pears. J. Hort. Sci. 66:479-486.

Scharenbroch, B.C.and J.E. Lloyd. 2004. A literature review of nitrogen availability indices for use in urban landscapes. J. Abor. 30(4):214-229.

Shalaby, A.S., S.E. El-Gengaihi, E.A. Agina, A.S. El-Khayat, and S.F. Hendawy. 1997. Growth and yield of *Echinacea purpurea* L. as influenced by planting density and fertilization. J. Herbs, Spices, Med. Plants. 5:69-76.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in bermudagrass turf. Agron. J. 76:964-969.

Stout, W.L., S.L. Fales, L.D. Muller, R.R. Schnabel, W.E. Priddy, and G.F. Elwinger. 1997. Nitrate leaching from cattle urine and feces in northeast U.S. Soil Sci. Am. J. 61:1787-1794.

Stout, W.L.and G.A. Jung. 1995. Biomass and nitrogen accumulation in switchgrass: Effects of soil and environment. Agron. J. 87:663-669.

Thomas, P.A. 1999. Flowering perennials for Georgia gardens. Univ. Georgia Coop. Ext. Serv. Bul. 944.

Tisdale, S.L. 1993. Soil fertility and fertilizers. 5th ed. Macmillan, New York, N.Y.

Toselli, M., J.A. Flore, C. Zavalloni, and B. Marangoni. 2000. Nitrogen partitioning in apple trees as affected by application time. HortTechnology 10:136-141.

Toth, J.D.and R.H. Fox. 98. Nitrate losses from a corn-alfalfa rotation: Lysimeter measurement of nitrate leaching. J. Environ. Qual. 27:1027-1033.

Upendra, S.M., B.P. Singh, S. Rahman, and V.R. Reddy. 1999. Soil nitrate-nitrogen under tomato following tillage, cover cropping, and nitrogen fertilization. J. Environ. Qual. 28:1834-1844.

Weinbaum, S.A., S.A. Merwin, and T.T. Muraoka. 1978. Seasonal variation in nitrate uptake efficiency and distribution of absorbed nitrogen in non-bearing prune trees. J. Amer. Soc. Hort. Soc. 103:516-519.

Williams, L.E. and R.J. Smith. 1991. The effect of rootstock on the partitioning of dry weight, nitrogen, and potassium, and root distribution of cabernet sauvignon grapevines. Amer. J. Enol. Viticult. 42:118-122.

Chapter 1

Effect of fertilizer nitrogen rate and timing on growth and performance of six herbaceous perennials in a simulated landscape

(In the format appropriate for submission to the

Journal of Environmental Horticulture)

Effect of fertilizer nitrogen rate and time of application on growth and performance of six herbaceous perennials in a simulated landscape[1]

Cynthia L. Proctor[2], Stuart L. Warren[3], Robert L. Mikkelsen[4], and Dennis J. Werner[3]

Department of Horticulture Science

North Carolina State University

Raleigh, NC 27695-7609

Abstract

Herbaceous perennials are planted worldwide in public gardens, and commercial and home landscapes. Little research has been conducted, however, examining the fertility needs of herbaceous perennials in landscapes. This experiment included four rates of FN: 0, 7, 14, and 28 g•m^{-2} (0, 1.5, 3.0, and 6.0 lbs•1000 ft^{-2}) and four timings of FN application. Each FN rate was divided equally into two applications and applied at the following times: 1) winter (Jan. 15 and Feb.15), 2) spring (Apr. 15 and May 15), 3) summer (June 15 and July 15), or 4) fall (Sept. 15 and Oct. 15). *Canna* L. 'President' (canna lily), *Coreopsis verticillata* L. 'Moonbeam' (thread leaf coreopsis), *Echinacea purpurea* L. 'Magnus' (purple coneflower), *Iris siberica* L. 'Caesar's Brother' (Siberian iris), *Panicum virgatum* L. 'Shenandoah' (switchgrass), and *Sedum* L. 'Herbstfreude' ('Autumn Joy' sedum) were planted in October, 2000 in a simulated landscape. Treatments were initiated in September, 2001. In 2002, number of flowers and height of *Canna* L. 'President' increased linearly with increasing FN

rate when FN was applied in April/May whereas *Canna* L. 'President' was unaffected by FN when applied at the remaining times. All growth and measured ornamental characteristics of *Canna* L. 'President' were unaffected by FN rate and timing in 2003. Foliar N concentration ≥ 3.0% was adequate for growth of *Canna* lily. *Coreopsis verticillata* 'Moonbeam' was unaffected by FN rate and timing in 2002, whereas in 2003 number of flowers, visual evaluations, growth index (GI), and top dry weight all increased linearly with increasing rate of FN. Growth index was greater when FN was applied in January/February and April/May compared to June/July. Foliar N concentration ≥ 1.9% was adequate for growth of *Coreopsis.* For optimum performance of *Coreopsis* we recommend 7 $g•m^{-2}$ to 14 $g•m^{-2}$ N (1.5 lbs•1000 ft^{-2} and 3 lbs•1000 ft^{-2}) applied in late winter to early spring. In 2002, total number of flowers per *Iris siberica* 'Caesar's Brother' increased linearly with increasing FN rate applied in September/October. Number of *Iris* flowers were unaffected by FN rate applied in January/February and April/May. FN applied in September/October increased visual evaluation of iris on Apr. 24 compared to all other timings. In 2003, regardless of FN timing, top dry weight increased quadratically with increasing rates of FN with maximum top dry weight at 15.5 $g•m^{-2}$ N (3.1 lb•1000 ft^{-2}). Foliar N concentration ≥ 1.22% was adequate for growth of *Iris siberica* 'Caesar's Brother'. Thus for optimum performance of *Iris* we recommend 7 $g•m^{-2}$ to 14 $g•m^{-2}$ N (1.5 lbs•1000 ft^{-2} and 3 lbs•1000 ft^{-2}) applied from late summer to early fall. All measured parameters except height of *Panicum virgatum* 'Shenandoah' was unaffected by FN rate and timing in 2002 and 2003. On June 25 and July 25, height of *Panicum* increased quadratically with increasing FN rates with maximum plant height at 11.3 $g•m^{-2}$ (2.3 lb•1000 ft^{-2}) and 6•7 $g·m^{-2}$ (1.4 lb•1000 ft^{-2}), respectively when N was applied in January/February. FN applied at the other timings did not affect plant height. Foliar N concentration of ≥ 0.92% dry wt was adequate for plant growth. A low rate of FN [< 14 g•m^{-2} (3.0 lb•1000 ft^{-2})] applied anytime during the year was adequate to maximize performance of *Panicum virgatum* 'Shenandoah'. In 2002, all measured parameters of *Sedum* L. 'Herbstfreude' were unaffected by FN rate and timing. On July 2, 2003 visual evaluations were significantly greater when FN was applied in April/May compared to all other timings. On Aug. 4, 2003 FN applied in September/October (the previous season) advanced cyme coloration of *Sedum* L. 'Herbstfreude' compared to all other timings. By Aug. 15, FN applied in September/October continued to advance cyme coloration compared to FN applied in January/February and April/May. By Sept. 17, visual evaluations were significantly greater when FN was applied in September/October compared to all other N timings. From June 26 to July 24, GI was significantly greater when FN was applied in April/May compared to June/July and September/October. By Aug. 4, 20 days after June/July fertilization, GI was similar among all FN timings that received FN in 2003 (January/February, April/May, and June/July). Cyme coloration, visual evaluation and GI were unaffected by rate of FN suggesting that *Sedum* ''Herbstfreude' would benefit from a low rate of FN applied in both fall and spring. Foliar N concentrations increased linearly with increasing FN rate when FN was applied in April/May and June/July. Foliar N concentration ≥ 1.4% was adequate for plant growth. To cover the needs of a wide variety of perennial species that usually exists in one landscape as well as minimize N concentrations in the soil solutions, we recommend a low to moderate rate of FN [5 g•m^{-2} to 15 g•m^{-2} (1 lb•1000 ft^{-2} to 3 lb•1000 ft^{-2})] be applied in split applications in spring and early fall.

Index words: *Canna* L. 'President', *Coreopsis verticillata* L. 'Moonbeam', *Iris siberica* L. 'Caesar's Brother', *Panicum virgatum* L. 'Shenandoah', *Sedum* L. 'Herbstfreude'

Significance to the Nursery Industry

Herbaceous perennials are planted worldwide in public gardens, and commercial and home landscapes. Little research has been conducted, however, examining the fertility needs of herbaceous perennials in landscapes. It is uncertain how FN rate and timing affects growth, performance, and foliar mineral nutrient concentrations of herbaceous perennials in the landscape. Data herein suggests that FN applied to herbaceous perennials had little effect on growth and ornamental qualities. However, applying no N may not advisable, as some perennials species did benefit from an FN application during a specific time. In addition, choice of mulch may affect mineralization which may impact the availability of N in the landscape. Applying FN at a low to moderate rate of FN [5 $g{\bullet}m^{-2}$ to 15 $g{\bullet}m^{-2}$ (1 $lb{\bullet}1000\ ft^{-2}$ to 3 $lb{\bullet}1000\ ft^{-2}$)] equally divided and applied in split applications in spring and early fall will maintain adequate plant performance.

[1]Received for publication__________________and in revised from____________________.
This research was supported in part by a grant from the Perennial Plant Association, 3383 Schirtzinger Rd., Hilliard, Ohio 43026. Special thanks to William Reece for technical Assistance and William Swallow for statistical guidance. From a thesis submitted by C.L.P. in partial fulfillment of the requirements for the M.S. degree.

[2]Graduate Teaching Assistant

[3]Professor

[4]Dr. Robert Mikkelsen, Western U. S. Director, Potash and Phosphate Institute, Davis, Calif

Introduction

Herbaceous perennials are planted worldwide in public gardens, and commercial and home landscapes. Trade journals have used herbaceous perennials repeatedly as their cover story in recent years (Ashmun, 2003; Cohen, 2000; Lauderdale, 2003). In 1999, perennials accounted for 27% of all U.S. plant sales, with $642 million wholesale value among 7,391 producers (Hamrick, 2000).

Much information exists for tradesmen and homeowners concerning herbaceous perennials and most recommendations on topics such as pruning and planting techniques are similar (Armitage, 1997; Still, 1994). Recommendations regarding FN rate and timing, however, vary dramatically (Holmes et al., 2001; Phillips and Burrell, 1999). For herbaceous perennials in the southeastern United States FN rate recommendations range from 0 to 25 $g \bullet m^{-2}$ N (0 to 5 $lbs \bullet 1000\ ft^{-2}$) while recommendations for FN timing vary from split applications (i.e., early spring and mid-summer), once at budbreak or simply apply "in the growing season" (Brown, 1996; Evans, 2000; Kessler, 2002; Relf and Ball, 2002; Thomas, 1999). The lack of continuity regarding recommended FN rate and timing may be due to the little research examining the fertility needs of herbaceous perennials in landscapes.

Currently, it is assumed that herbaceous perennials are N-limited in the landscape. Therefore growth and performance (flower number, aesthetic quality) would suffer without FN application. This is supported by results from Duarte and Perry (1988) who reported it required 35.3 $g \bullet m^{-2}$ N (7.2 $lbs \bullet 1000\ ft^{-2}$) to maximize top dry weight of field-grown *Heuchera sanguinea* 'Splendens' growing in a Windsor sandy loam with high P and K levels in Vermont. Biomass of field-grown switchgrass (*Panicum virgatum* L.) peaked at 41 $g \bullet m^{-2}$

N (8.5 lbs•1000 ft^{-2}) when applied annually in the spring (Muir et al., 2001). In addition, a field study in Egypt with purple coneflower (*Echinacea purpurea* L.), grown as an annual crop found that plant height and top dry weight increased with increasing FN rates up to 147 g•m^{-2} (30 lbs•1000 ft^{-2}) (Shalaby et al., 1997). In contrast, *Achillea* and *Gypsophila* plants did not respond to FN when grown in a Windsor sandy loam with high P and K levels (Duarte and Perry, 1988). Cabrera (2003) also reported that herbaceous perennials appeared to have a very low FN requirement. Other field-grown perennial crops have also been shown to have very low FN requirements: red raspberry (*Rubus idaeus* L. ‘Meeker’) (Rempel et al., 2004), strawberry (*Fragaria* x *ananassa Duch*) (Strik, 2004), and river red gum (*Eucalyptus camaldulensis*) (Cockerham, 2004).

In addition to rate of FN, applying FN at the appropriate time for maximum uptake is important since low recovery of FN by landscape plants (low efficiency) may necessitate the use of higher FN rates to supply plants with sufficient N and contribute nitrate to surface or groundwater. The authors are unaware of any research examining the effect of FN timing on the growth response of herbaceous perennials in landscapes. Since most plants need more N during the vegetative stage whereas in the generative phase the N uptakes are low and the retranslocation of organic N is high (Mengel and Kirby, 1981), N absorption of perennial plants may vary during the year. Miner et al. (1997) reported greatest yield of 'Chandler' strawberry with a split application of FN in spring and fall. Hood et al. (1993) reported uptake of nutrients by snapdragon (*Antirrhinum majus* L.) grown hydroponically was highest from visible bud to anthesis, and suggested that supplemental fertilizer during this stage of growth would be beneficial. Similarly, rapid uptake of N by chrysanthemum (*Dendranthema* x *grandiflorum* L.) grown hydroponically from cuttings was greatest 40 to 50 days after root formation up to flower bud formation (King et al., 1995). Generally, woody perennial plants do not begin absorbing N efficiently until after rapid top growth begins (Weinbaum et al., 1978). Acuna-Maldonado et al. (2003) reported that pecan (*Carya illinoinensis* Wangenh. C. Koch) N absorption was greatest between budbreak and the end of shoot expansion. They also reported, however, that substantial N was absorbed between leaf fall and budbreak. Working with grapevines (*Vitas* sp.), Hanson and Howell (1995) and Williams and Smith (1991) reported that N absorption was most rapid between flower and veraison. In addition, after fruit harvest to leaf fall, trunks and roots of grapevines accumulated N reserves that supported early growth during the following year (Conradie, 1991).

In addition to growth, FN rate and timing can affect ornamental quality. A turfgrass mixture of perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.), creeping red fescue (*Festuca rubra* var. *rubra* L.), and chewing fescue (*Festuca rubra* var *commutate* Gaud) grown in Turkey had more uniform color and sustained turf quality throughout the growing season (April to September) when 5 g•m^{-2} (1 lb•1000 ft^{-2}) N was applied in April and May compared to 15 g•m^{-2} (3.3 lbs•1000 ft^{-2}) applied in April and September (Oral and Acikgoz, 2001). Rate of growth and top growth, however, were more uniform when 5 g•m^{-2} N (1.0 lb•1000 ft^{-2}) or 10 g•m^{-2} (2.0 lb•1000 ft^{-2}) of FN were applied in April, June, and August. Cookson et al. (2000) working in New Zealand reported vegetative growth and seed yields of perennial ryegrass were increased by applying 12.5 g•m^{-2} (2.5 lb•1000 ft^{-2}) N in fall and late winter in combination with a N application of 37 g•m^{-2} (8 lbs•1000 ft^{-2}) in the spring compared to applying 12.5 g•m^{-2} (2.5 lb•1000 ft^{-2}) of N in late winter and spring and a fall N application of 37 g•m^{-2} (8 lbs•1000 ft^{-2}).

Over-application of FN is costly to the homeowner/landscaper and may have negative effects on the environment and plant performance (Tisdale, 1993). Therefore, characterizing FN needs for herbaceous perennials within the landscape, to match FN application to plant N needs, is important for both improved plant performance and decreased environmental risk. To optimize plant growth and performance while minimizing N losses more information concerning FN rate and timing is required. Thus, the objective of this study was to determine the effect of FN rate and timing on growth, performance, and foliar mineral nutrient concentrations of seven selected herbaceous perennials.

Materials and Methods

The experiment was conducted at the Horticulture Field Laboratory, North Carolina State University, Raleigh, from Oct. 2000 to Oct. 2003. Prior to planting, the Cecil clay soil (clayey, kaolinitic, thermic Typic Hapludult) was amended by incorporating 2.5 cm (1 in) of milled pine bark [< 1.3 cm (< 0.5 in)] and pH, phosphorus (P), and potassium (K) were adjusted to levels recommended by the North Carolina Dept. of Agric. (NCDA) (Raleigh). To create individual landscapes, raised beds were constructed and individual plots 2.4 x 3.4 m (8 x 11 ft) were laid out and a plastic barrier was installed to a depth of 61 cm (24 in) between plots to maintain treatment integrity. In addition, there was a 1.5 m (5 ft) sod (*Festuca arundinacea* 'K-31', K-31 tall fescue) buffer between each block. The following perennials from 2.8 L (#1) containers were planted in Oct. 2000: two *Coreopsis verticillata* L. 'Moonbeam' (thread leaf coreopsis), one *Echinacea purpurea* L. ‘Magnus’ (purple coneflower), one *Iris siberica* L. 'Caesar's Brother' (Siberian iris), two *Panicum virgatum* L. 'Shenandoah' (switchgrass), and one *Sedum* L. 'Herbstfreude' ('Autumn Joy' sedum) and one *Salvia* x *sylvestris* L. 'East Friesland' (hybrid sage) in each plot. Three rhizomes of *Canna* L. 'President' (canna lily), were planted in each plot at the same time (Fig. 1). In August 2001, canna rhizomes were thinned to one in each plot. All plots received 5 cm (2 in) of mulch (composted yard waste) after planting. If rainfall did not supply 2.5 cm (1 in) of water weekly, supplemental irrigation was applied via drip emitters, (Xeri-bug, Rain Bird, Glendora CA) at a rate of 1.9 L•hour^{-1} (0.5 gal•hour^{-1}). Additional soil testing was performed by the NCDA for each plot in Mar. 2002 and 2003 and the pH, P, and K levels were adjusted accordingly. Weeds were controlled by hand or by directed applications of glyphosate weekly during the growing season and monthly during the dormant season.

The experiment was a 4 x 4 factorial in a randomized complete block design with four replications. Treatments included four rates of FN: 0, 7, 14, and 28 g•m^{-2} (0, 1.5, 3.0, and 6.0 lbs•1000 ft^{-2}) and four timings of application. Each FN rate was divided equally into two applications and applied at the following times: 1) winter (Jan. 15 and Feb.15), 2) spring (Apr. 15 and May 15), 3) summer (June 15 and July 15), or 4) fall (Sept. 15 and Oct. 15). All FN was applied as granular ammonium nitrate (NH_4NO_3) with handheld shakers beginning Sept. 15, 2001 and the last FN application was applied July 15, 2003. Prior to this study, no FN had been applied to this site since 1997.

In 2001, no plant data was collected. In 2002, data collected for each species included the following: number of flowers was counted every three days, plant visual evaluations, GI, and top dry weight. Flowers of each species were monitored as described below:

Canna 'Mr. President': A flower was counted when the staminodes were open showing color. A flower was no longer counted once it lost its aesthetic appearance.

Coreopsis verticillata 'Moonbeam': A flower was counted when all rays were completely unfurled and the disk exposed. When five flowers were present on the entire plant, the plant was considered to be in flower. Flowers were no longer counted when each plant had < 5 flowers. A flower was no longer counted when it lost its aesthetic appearance. To estimate total number of flowers, three 10 cm^2 (1.6 in^2) openings were placed diagonally 20 cm (8 in) apart on a 0.5 m x 1.2 m (1.5 ft x 4 ft) foam board with the corner of the foam board placed at the northeast corner of each plant. Total number of flowers in each opening was added together and divided by three, providing us with number of flowers per 10 cm^2. To determine total number of flowers per plant, the following formula was used:

$$\text{Total flower number} = \text{number of flowers} \big/ 10\,\text{cm}^2 \times \left(\frac{\text{total plant cm}^2}{100} \right) \quad [1]$$

Total plant cm^2 was determined by maximum plant width (cm) x perpendicular width (cm).

Echinacea purpurea 'Magnus': Data collection for *Echinacea* will not be included in this manuscript.

Iris siberica 'Caesar's Brother': A flower was counted when falls (outer 3 petals) were partially reflexed, exposing its purple coloration. Flower number was recorded daily in lieu of every 3 days due to the short life of *Iris* flowers. A flower was no longer counted once it lost its aesthetic appearance. Total number of flowers was determined by counting remaining seed pods.

Panicum virgatum ‘Shenandoah’: Length of flowering was recorded in lieu of flower number. When > 50% of the flowers on each plant turned a coppery color (visual evaluation) the plant was recorded as in flower. The plant was no longer in flower when > 50% of the coppery color (visual observation) on each plant turned brown.

Sedum ‘Herbstfreude’: Length of flowering was recorded in lieu of flower number. When > 20% of the cymes displayed a pink coloration (visual observation) the plant was recorded as in flower. All plants remained in flower until harvest.

Salvia x *sylvestris* ‘East Friesland’: No data was collected due to its marginal performance in all treatments.

Plants were evaluated visually for landscape performance based on health of foliage, percent flower coverage, and overall vigor (density and uniformity). Based on a visual assessment of those characteristics, a single numeric rating from 1 to 5 (5 being optimum) was recorded for each species. Plant visual evaluations for each species began when flowering commenced and every two weeks thereafter until flowering ended. Thereafter, visual evaluations were taken every month until Sept. 15.

GI was measured Oct. 1 and calculated as follows:

$$GI = \underset{\text{(included flower)}}{\text{plant height}} + \left(\frac{\text{maximum plant width} + \text{perpendicular width}}{2} \right) \qquad [2]$$

Tops (leaves, stems, and flowers) of every plant were harvested Oct. 15 and dried at 65C (150F) for 7 days and weighed, except for *Canna* ‘Mr. President’ where fresh weight of the tops was recorded. Expired flowers remained on all perennials until harvest.

Based on the 2002 results, data collection for 2003 included the following: number of flowers were recorded as described above but only counted weekly except for *Iris* which was counted daily. Growth index was measured starting May 20, 2003 for all plants every 14 days, until GI remained unchanged for two subsequent measurements (*Canna* ‘Mr. President’ May 20 to Aug. 3, *Coreopsis verticillata* 'Moonbeam' May 20 to Aug. 3, *Iris siberica* ‘Caesar’s Brother’ May 20 to July 22, Panicum *virgatum* ‘Shenandoah’ May 20 to July 22, and *Sedum* ‘Herbstfreude’ May 20 to Aug. 3).

On Aug. 15, 2003, recently matured leaves were collected from all plants to determine mineral nutrient concentration before sinensis except for *Coreopsis*. Due to the small nature of its leaves, *Coreopsis* samples included stems and leaves. Leaves were dried at 65 C (150 F) for 7 days and weighed. After drying, leaves were ground in a Cyclotec grinder (Analytical instruments, LLC, Golden Valley, MN) to pass a 40 mesh (0.635 mm) screen. All samples were analyzed for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Na, and Zn by NCDA. On Oct. 7 all tops (stems, leaves, and flowers) of each species were harvested and dried at 65C (150F) for 7 days and weighed except for *Canna* ‘Mr. President', where fresh weight was recorded. Weights of leaves harvested on Aug. 15 were combined with dry weights of tops to determine total top dry weights. After the final harvest (Oct. 7, 2003) soil was excavated parallel to the root system of each plant to determine approximate rooting depth of each species.

All data were subjected to analysis of variance procedures (ANOVA) ($P \leq 0.05$) and regression analysis ($P \leq 0.05$) where appropriate. Treatments means were separated by Fisher’s protected least significant difference (LSD), P= 0.10, where appropriate. Alpha was set to 0.10 due to the variable nature of field experiments, and to avoid making Type II statistical errors (Marini, 1999). When there was a significant FN rate x FN timing interaction ($P \leq 0.05$) the data is presented appropriately. When the FN rate x FN timing was nonsignificant, however, FN rate is presented averaged over FN timing and FN timing is presented averaged over FN rate.

Results and Discussion

Canna 'Mr. President'. *2002*: Canna was in flower from May 8 to Sept. 19. Number of flowers increased linearly on May 26, May 29, June 1, and June 4 with increasing FN rates when FN was applied in April/May (only June 1 data presented) (Fig. 2). Number of flowers (mean = 3.6 ±0.08 SE) was unaffected by FN rate when applied in January/February, June/July, or September/October (data not presented). Since the number of flowers did not increase after FN applications in winter, summer or fall these results suggest that FN uptake may be maximized during active spring growth. Many perennial plants exhibit a high rate of N uptake during active growth (Hanson and Howell, 1995). In addition, height of *Canna* at the end of the 2002 growing season was significantly taller when N was applied in April/May compared to all other timings regardless of the FN rate (Table 1).

After June 4, number of flowers were unaffected by FN rate regardless of N timing with the number of flowers/plant/week per *Canna* averaging five from June 15 to Sept. 18 (data not presented). Top fresh weight [mean = 10.5 kg ±0.48 SE (23.0 lbs)] and visual evaluations (mean = 3.2 ±0.04 SE), however, were unaffected by FN rate and timing (data not presented). Total N concentrations found 38 cm (15 in) below the soil surface were 82 $mg \cdot L^{-1}$ (May 23) and 59 $mg \cdot L^{-1}$ (June 10), after split N application of 28 $g \cdot m^{-2}$ (6 $lbs \cdot 1000\ ft^{-2}$) in April/May (Proctor et al., 2006). Even though flower number increased with increasing rate of FN from May 26 to June 4 when applied in April/May, the lack of response of fresh weight and visual evaluations to FN combined with potential N leaching losses at the high rates of FN, landscapers/homeowners will need to balance maximizing plant performance and environmental consequences of high rates of FN application.

2003: *Canna* was in flower from June 2 to Sept. 15. Peak number of flowers occurred July 1, twenty-six days later than 2002. The 2002-2003 winter was colder [(18 days < -4C (25F)] compared to 2001-2002 winter [9 days < -4C (25F)] and *Canna* species are listed as zone 7 to 10 for cold hardiness (Armitage, 1997). Thus, the duration of temperatures below 0C (25F) could have delayed plant emergence and flowering potential for *Canna*. Top fresh weight, however, increased 16% in 2003 compared to 2002 (data not presented).

Number of flowers/plant/week (mean = 4 ±0.03 SE), top fresh weight [mean = 12.5 kg ±0.48 SE (27.6 lbs)], visual evaluations (mean = 3.2 ±0.05 SE), height [78 cm ±3.0 SE (2.6 ft)], and GI [118 ±5 SE] were unaffected by FN rate and timing (data not presented). This was surprising based on the 2002 response and since N typically elicits a growth response in plants (Mengel and Kirby, 1981). Other perennial crops, however, have also not responded to FN. River red gum (*Eucalyptus camaldulensis*) was fertilized with 0, 23.5 kg•ha^{-1} (21 lbs•a^{-1}), and 47 kg•ha^{-1} N (42 lbs•a^{-1}) annually for six years (Cockerham, 2004). Tree height, diameter, and top fresh weight were unaffected by FN. Mature summer-bearing red raspberry (*Rubus idaeus* L. 'Meeker') plants were grown for two years with FN applied: singularly at 0, 4, or 8 g•m^{-2} N (0.8 or 1.6 lbs•1000 ft^{-2}) applied at budbreak, or split 4 g•m^{-2} N (0.8 lbs•1000 ft^{-2}) applied at budbreak and 4 g•m^{-2} N (0.8 lbs•1000 ft^{-2}) applied eight weeks later (Rempel et al., 2004). Total plant dry weight was unaffected by FN rate and timing. Similarly, one-year-old strawberry (*Fragaria* x *ananasis* 'Totem') plants received FN from 0 to 55 $kg{\bullet}ha^{-1}$ N (49.1 $lbs{\bullet}a^{-1}$) applied at various timings during the growing season for two years, total plant dry weight was unaffected by FN (Strik, 2004).

Field-grown perennial plants obtain N for new growth from residual N, soil mineralization, plant reserves, and FN, if applied. No FN had been applied to the soil in this study since 1997 so we propose that residual N would be at a minimum. The quantity of N available from soil mineralization is primarily soil dependent. With an average humic matter of 1.0% (data not presented), the soil in this study should have a low rate of N available from soil mineralization. Plant reserves are a very important N source for perennial plants (Rempel et al., 2004). Rempel et al. (2004) reported 24% to 37% of the N in new growth of red raspberry came from FN. Thus, the remaining N (63% to 76%) was derived from soil mineralization and plant reserves. Sixty percent of the N present in new growth in kiwifruit (*Actinidia deliciosa*) was from remobilization of N stored in the vines (Ledgard and Smith, 1992). Research with apples (*Malus x domestica* Borkh.'Mutsu') and pear ('Comice'/'Provence' quince BA29) have reported similar results (Sanchez et al., 1991; Toselli et al., 2000). In addition, N mobilization may have become more important in this study as plants moved from the 2nd to the 3rd growing season. The more N available from soil mineralization and N mobilization the less of a response that one might expect from FN.

Unlike field-grown perennial crops, herbaceous perennials in a landscape setting have another source of N unique to landscapes, mulch. Five cm (2.5 in) of composted yard waste was applied as mulch at planting in this study. Nitrogen in composted yard waste can range from 0.7% to 2.0% (Lloyd, 2001). Lloyd (2001) examined the effects of three mulches [composted yard waste (a mixture of wood chips, leaves, and grass clippings, C:N ratio = 20), ground wood pallets (C:N ratio = 100), and no mulch (bare soil)] on growth of river birch (*Betula nigra* 'Cully' Heritage) and rhododendron (*Rhododendron* 'Pioneer Silvery Pink'). All three mulch treatments received no FN (no N) or 14 g•m^{-2} N (3 lbs•1000 ft^{-2}) applied in split applications (budbreak and early October) yearly from 1998 to 2000. Nitrogen fertilization increased growth and foliar N concentrations of river birch and rhododendron when mulched with ground wood pallets or no mulch (bare soil) compared to plants receiving no FN. However, growth and foliar N concentrations of rhododendron and river birch were similar when grown with composted yard waste with or without FN. Lloyd (2001) also reported soil solution total N concentrations were similar under the unfertilized composted yard waste compared to the soil solution total N concentration found under the fertilized ground wood pallets and the fertilized no mulch (bare soil) indicating that composted yard waste can serve as a high-quality organic fertilizer. Total N measured in the soil solution under the composted yard mulch receiving no FN averaged 30 mg•L^{-1} N compared to 10 mg•L^{-1} N with no mulch (bare soil) receiving FN. Proctor et al. (2006) reported an average of 15 mg•L^{-1} of total-N in the soil solutions during the growing season in the control treatments (no FN) in this study. In the absence of a response to FN, N mineralization from composted yard mulch along with soil mineralization, and plant N mobilization may have provided adequate N for plant growth and performance. These results do not necessarily support the hypothesis that *Canna's* do not require FN for maximum growth and performance rather that adequate N can be provided through other means.

Landscapers/homeowners utilizing composted yard waste as mulch may not need additional FN to support plant growth of herbaceous perennials.

Foliar mineral nutrient concentrations of N, P, K, Mg, and Mn were affected by FN rate and/or timing (Fig. 3, Fig. 4, and Fig. 5) whereas foliar concentrations of Ca (mean = 0.53% dry weight ±0.01 SE), S (mean = 0.19% dry weight ±0.01 SE), B (mean = 15.7 $mg•kg^{-1}$ ±0.27 SE), Cu (mean = 15.6 $mg•kg^{-1}$ ±0.23 SE), Fe (mean = 79 $mg•kg^{-1}$ ±0.01 SE), Na (mean = 0.01 $mg•kg^{-1}$ ±0.001 SE), and Zn (mean = 38.4 $mg•kg^{-1}$ ±0.65 SE) were not (data not presented). Foliar concentrations of N increased linearly with increasing FN rate regardless of FN timing (Fig. 3). Increasing foliar N concentration with increasing rates of FN is reported commonly with perennials crops (Macz et al., 2001; Rempel et al., 2004; Simonne et al., 1999). Since top fresh weight of *Canna* was unaffected by FN rate, increasing foliar N concentration was probably luxury consumption. The increase, however, was small from 3.0% to 3.2% dry weight from 0 to 28 $g•m^{-2}$ (6 $lbs•1000\ ft^{-2}$), respectively. Furthermore, Mill and Jones (1996) reported that a foliar N concentration of 2.9% dry weight for landscape-grown cannas was adequate which is similar to the 3% reported for the 0 FN (no N) in this study. The similarity of foliar N concentrations combined with no differences in fresh weight suggests that similar quantities of N were absorbed regardless of FN rate supporting the hypothesis that adequate N was present in the soil solution regardless of FN rate and timing.

Foliar concentration of Mn increased linearly with increasing FN rate regardless of FN timing (Fig. 3). Since uptake of Mn increases with decreasing pH (Mengel and Kirby, 1981) decreasing soil pH with increasing FN rates probably increased foliar Mn concentrations. Soil pH values were negatively correlated (*P*=0.001, *R*=0.84) with increasing FN rates (data not presented). All foliar Mn concentrations were lower than the 675 mg•kg^{-1} reported by Mills and Jones (1996) for landscape-grown cannas.

Foliar K concentrations increased quadratically with increasing FN rates when FN rate was applied in January/February and June/July with maximum occurring at 10 g•m^{-2} and 14 g•m^{-2} N (2 lbs•1000 ft^{-2} and 2.8 lbs·1000 ft^{-2}), respectively (Fig. 4). Foliar concentration of K was unaffected by FN rate when applied in April/May and September/October. These data support the hypothesis that environmental conditions in combination with the physiologically state of the plant affect K uptake. All foliar K concentrations were higher than the 3.62% dry weight reported by Mills and Jones (1996). Similar to foliar K concentrations, foliar Mg concentrations increased quadratically with increasing FN rates when FN rate was applied in June/July and September/October with maximum occurring at 15 g•m^{-2} and 14 g·•m^{-2} (3 lbs•1000 ft^{-2} and 2.8 lbs·1000 ft^{-2}), respectively (Fig. 4). These results were surprising since nutrient acquisition of K and Mg are usually influence negatively by ammonium as they compete for binding sites (Marschner, 2002). Dubois et al. (2000) working with container-grown *Anemone* x *hybrida*, reported that foliar concentrations of K decreased linearly with increasing N rates whereas foliar concentration of Mg was unaffected by increasing rate of N. All foliar Mg concentrations were lower than the 0.51% dry weight reported by Mills and Jones (1996).

Foliar P concentration decreased linearly with increasing FN rate when fertilized in January/February, whereas when FN was applied in June/July and September/October P concentrations increased quadratically with increasing FN rates with maximum P concentrations at FN rates of 15 g•m^{-2} (3 lbs•1000 ft^{-2}) at both June/July and September/October (Fig. 5). Foliar P concentration was unaffected by FN rate when applied in April/May. Smith (1962) reported that increasing FN rate suppressed P uptake which happened when FN was applied in January/February. However, more recent studies with container-grown *Anemone* x *hybrida* and woody perennial plants have reported foliar P concentration increased quadratically with increasing FN rates (Dubois et al., 2000; Griffin et al., 1999; Stubbs et al., 1997) similar to the results reported for June/July and September/October. Results herein suggest that P uptake in response to FN applications may vary depending upon timing of the FN application. Under field conditions, increased concentrations of P are often observed with ammonium based fertilizers due to their acidifying effects (Mills and Jones, 1996). These data suggest that environment conditions (temperature, soil moisture) that exist at time of FN application in combination with the physiological condition of the plant play a role in the resultant P uptake of the plant. All reported foliar P concentrations, however, reported herein are less than the 0.34% dry weight reported by Mills and Jones (1996) for landscape-grown *Cannas*.

From this we concluded that foliar N concentration ≥ 3.0% was adequate for plant growth. For all other nutrients (P, K, Ca, Mg, S, B, Cu, Fe, Mn, Na, and Zn), reported means or range of values for foliar concentrations observed in this study should be considered indicative of good plant vigor, although optimal levels were not determined directly. Mineral nutrient concentrations of Ca and Na reported herein, however, were lower that the average values listed in Mills and Jones (1996). The remaining mineral nutrients (S, B, Cu, Fe, and

Zn) had similar or higher concentrations than the reported foliar concentrations in Mills and Jones (1996).

Coreopsis verticillata 'Moonbeam'. *2002*: *Coreopsis* was in flower from June 13 to Sept. 17 and exhibited several peak flowering times in June, July, and August (data not presented). Top dry weight [mean = 243.0 g ±8.9 SE (0.56 lb)], GI [mean = 65.2 ±1.3 SE] visual evaluation (mean = 3.5 ±0.5 SE), and number of flowers (mean = 5.0/10 cm^2 ±0.9 SE) were unaffected by FN rate and timing (data not presented). Similar to *Canna's* results, the authors are not suggesting that no new N is required for plant growth. With no response to FN, however, we are purposing that adequate N was available from plant reserves, soil mineralization, and mineralization of the mulch. In addition, all of the fertility needs (excluding N) and pH of the soil were maintained at optimum levels throughout the study. *2003*: *Coreopsis* was in flower from May 30 to Aug. 15. Number of flowers per plant increased linearly with increasing FN rate on June 24 and July 1 (Fig. 6). Number of flowers was unaffected by timing of FN application. This is in contrast to the *Canna* results where only FN applied in April/May increased number of flowers. Visual evaluations also increased linearly with increasing FN rates on June 1, June 14, and July 2 (Fig. 7) which is probably a reflection of increasing flowers with increasing FN rate. By June 14, visual evaluations of *Coreopsis* receiving FN in January/February and April/May were significantly greater than June/July and Sept./Oct. This data suggests that an application of FN the previous summer or fall will not maintain visual quality of coreopsis through rapid spring growth. Thus, it appears that visual quality of *Coreopsis* will benefit from a spring application of FN.

The GI increased linearly with increasing FN rates on June 1 and every two weeks thereafter until Aug. 3 (Fig. 8). In addition, applying FN in January/February and April/may significantly increased GI from June 25 to Aug. 3 compared to FN applied in June/July (Table 3). It is of interest that FN applied the previous late summer/early fall maintained a similar growth rate to the FN applied in winter and spring. Acuna-Maldonado (2003) working with pecan and Conradie, (1991), Hanson and Howell (1995), and Williams and Smith (1991) all working with rapes also reported that N absorbed in late summer and early fall supported growth during the following year.

Top dry weight also increased linearly with increasing FN (Fig. 9). The significant response of number of flowers, visual evaluations, GI, and top dry weight is in marked contrast to the data reported previously for *Canna*. It is similar, however, to switchgrass (Muir et al., 2001) and *Heuchera* 'Splendens' (Duarte and Perry, 1988) that responded to increasing rates of FN. With a 100% increase in plant dry weight from 2002 [243 g (0.56 lb)] to 2003 [521 g (1.1 lb)] *Coreopsis* may have required more N in 2003 than plant reserves, and soil and mulch mineralization could provide resulting in a response to FN. In addition, soil solution total-N concentration in the controls (no FN) in 2003 ranged from 2 to 17 $mg\bullet L^{-1}$ which was a decrease from 2002 (Proctor et al., 2006). The decrease in soil solution N concentration may have been a consequence of not applying mulch in 2003. Thus for optimum performance of *Coreopsis* we recommend 7 $g\bullet m^{-2}$ to 14 $g\bullet m^{-2}$ N (1.5 lbs•1000 ft^{-2} and 3 lbs•1000 ft^{-2}) applied from late winter to early spring.

Foliar mineral nutrient concentrations of P and Mn were affected by FN rate and/or timing (Table 4, Fig. 10) whereas foliar concentrations of N (mean = 1.9% dry wt ±0.04 SE), K (mean = 1.1% dry wt ±0.02 SE), Ca (mean = 0.8% dry wt ±0.20 SE), Mg (mean ± 0.2 % dry wt ±0.01 SE), S (mean = 0.2% dry wt ±0.01 SE), B (mean = 31.8 $mg•kg^{-1}$ ±1.0 SE), Cu (mean = 11.9 $mg•kg^{-1}$ ±0.5 SE), Fe (mean = 212.9 $mg•kg^{-1}$ ± 66.7 SE), Na (mean = 0.01 $mg•kg^{-1}$ ±0.001 SE) and Zn (mean = 73.9 $mg•·kg^{-1}$ ±3.0 SE)] were unaffected by FN rate and timing (data not presented). Even though *Coreopsis* had significant growth and flower responses to FN rate and timing it was not reflected in the foliar mineral nutrient concentrations. Although, it would appear to be unusual for foliar N concentration not to increase with increasing rates of FN, Strik et al. (2004) working with strawberry, Rempel et al. (2004) working with red raspberry, and Jull et al. (1994) working with *Cryptomeria japonica* 'Elegans Aurea' also reported that foliar N concentration did not increase with increasing rates of FN. Cabrera and Devereaux (1999) working with container-grown crape myrtle (*Lagerstroemia indica* x *fauriei* 'Tonto') also reported that most macro- and micro-nutrients were unaffected by increasing rates of FN.

Similar to *Canna*, foliar P concentration decreased linearly when N was applied in January/February (y = -0.0008x + 0.22, R^2 = 0.95) and April/May (y = -0.003x + 0.24, R^2 = 0.73) with increasing FN rates (Table 4) whereas Mn concentration increased linearly with increasing FN rate (Fig. 10). All of the foliar P concentrations reported herein, however, were within the range of 0.2% to 0.25% dry wt reported by Hipp et al. (1988) to maximize growth of *Salvia greggii* Gray. (autumn sage). Plants that primarily take up ammonium-N may induce a low rhizosphere pH promoting Mn uptake and suppress P (Mills and Jones, 1996). Plant preference for ammonium and/or nitrate uptake is rhizosphere pH dependent and species specific (Kraus et al., 2002; Mengel and Kirby, 1981).

From this we concluded that foliar N concentration ≥ 1.9% was adequate for plant growth. *Leucophyllum candidum* (violet Texas ranger), *Melampodium lecanthum* Ton. and Gray (blackfoot daisy), and *Salvia greggii* required foliar N concentrations of >1.7%, >1.5%, and ≥2.2% dry wt. for maximum growth, respectively (1988; Hipp et al., 1989). Mills and Jones (1996) reported a higher foliar N concentration (2.49% dry weight) for container-grown *Coreopsis verticillata* 'Zagreb'. For all other nutrients (P, K, Ca, Mg, S, B, Cu, Fe, Mn, Na, and Zn) reported means or range of values for foliar concentrations observed in this study should be considered indicative of good plant vigor, although optimal levels were not determined directly. Mineral nutrient concentrations of P, K, Ca, Mg, S, Mn reported in the study were lower that the average values listed in Mills and Jones (1996). However, no visual deficiency symptoms were observed throughout the entire study. The remaining mineral micro-nutrients (B, Cu, Fe, and Zn) had similar or higher concentrations than the reported foliar concentrations in Mills and Jones (1996).

Echinacea purpurea L. ‘Magnus’: Results for purple coneflower will not be included in this manuscript.

Iris siberica ‘Caesar’s Brother’. *2002*: *Iris* was in flower from Apr. 23 to May 4. On Apr. 26 and 27, number of flowers per plant increased linearly with increasing FN rate applied in September/October (Fig. 11). Number of flowers were unaffected by FN rate applied in January/February and April/May (data not presented). (The FN for June/July had not been applied.) In addition, FN applied in September/October increased visual evaluations on Apr. 24 compared to all other timings (Table 5). *Iris siberica* 'Caesar's Brother' fertilized in September/October had the highest visual evaluations and flower numbers indicating that fall FN application was favorable for N uptake. This is similar to pecan (*Carya illinoinensis* Wangenh. C. Koch) where FN applied during the fall was absorbed and assimilated more efficiently than spring applied FN, resulting in accelerated flower development and increased fruit set the following spring (Acuna-Maldonado et al., 2003). Top dry weight [mean = 222 g ±9.5 SE (0.49 lb)], GI [mean = 54 ± 1.2 SE], total number of flowers (mean = 10 ±0.6 SE), and daily flower number (mean = 3 ±0.02 SE), however, were unaffected by FN rate and timing (data not presented).

2003: *Iris* was in flower from Apr. 30 to May 12. Total number of flowers increased 600% from 2002 but was unaffected by FN rate and timing (data not presented). Regardless of FN timing, top dry weight increased quadratically with increasing rates of FN with maximum top dry weight at 15.5 $g•m^{-2}$ N (3.1 lb•1000 ft^{-2}) (Fig. 12), which was 14% greater than the control (no FN). Rates of FN > 15.5 $g·m^{-2}$ (3.1 lb•1000 ft^{-2}) decreased top dry weight indicating Iris did not respond to high rates of FN. Total number of flowers (mean = 74 flowers ±2.7 SE), daily flower number (mean = 11.5 ±0.6 SE) and GI [mean = 127 ±1.8 SE], however, were unaffected by FN rate and timing (data not presented). Visual evaluations were also unaffected by FN rate and timing with a mean of 4.0 (± 0.04 SE) indicating good flower coverage and overall vigor for all plants. As herbaceous perennials increase in size they may become less dependent upon FN as a greater percentage of N needs may be met by N remobilization. After flowering (May 12 to harvest), *Iris* foliage remained upright with some lodging towards the end of the season, however lodging was unaffected by FN treatments (visual observation).

Foliar mineral nutrient concentrations of P, K, S, and B were affected by FN rate (Fig. 13) whereas foliar concentrations of N (mean = 1.22% dry wt ±0.02 SE), Ca (mean = 1.0% ±0.01 SE), Mg (mean = 0.15% dry wt ±0.02 SE), Cu (mean = 3.7 mg•kg^{-1} ±0.08 SE), Fe (mean = 64.9 mg•kg^{-1} ±4.3 SE), Mn (mean = 48.2 mg•kg^{-1} ±1.9 SE), Na (mean = 0.01 mg•kg^{-1} ±0.001 SE), and Zn (mean = 33.6 mg•kg^{-1} ±0.64 SE) were unaffected by FN rate and timing (data not presented). Foliar P concentration decreased linearly with increasing FN, whereas foliar K, S, and B concentrations increased linearly with increasing FN rate (Fig. 13). From this we concluded that foliar N concentration ≥ 1.22% dry wt was adequate for plant growth. Mills and Jones (1996) reported a much higher foliar N concentration (1.97% dry wt) for landscape grown *Iris siberica*. For all other nutrients (P, K, Ca, Mg, S, B, Cu, Fe, Mn, Na, and Zn), reported means or range of values for foliar concentrations observed in this study should be considered indicative of good plant vigor, although optimal levels were not determined directly. Foliar mineral nutrient concentrations of P, K, S, Cu, and Na, however, reported herein were lower that the average values listed in Mills and Jones (1996). The remaining foliar mineral nutrients (Ca, Mg, B, Fe, Mn, and Zn) had similar or higher concentrations than the reported foliar concentrations in Mills and Jones (1996). Thus for optimum performance of *Iris* we recommend 7 g•m^{-2} to 14 g•m^{-2} N (1.5 lbs•1000 ft^{-2} and 3 lbs•1000 ft^{-2}) applied from late summer to early fall.

Panicum virgatum ‘Shenandoah’. *2002*: Panicum was in flower from June 25 to Sept. 2. Neither FN rate nor timing affected GI [mean = 146 ±2.6 SE], top dry weight [mean = 124 g ±5.6 SE (0.27 lb)], visual evaluations (mean = 2.9 ±0.04 SE) or initiation of flowering (mean = June 19) (data not presented)

2003: Panicum was in flower from July 1 to Sept. 16. Similar to 2002, visual evaluations (mean = 4.3 ±0.06 SE), top dry weight [mean = 1218 g ± 42 SE (2.7 lb)], and initiation of flowering (mean = June 28) were unaffected by FN rate and timing (data not presented). Top dry weight, however, increased 880% in 2003 compared to 2002 indicating that sufficient N was present in the soil solution without applications of FN. The lack of top dry weight response to FN is in contrast with other studies that have examined *Panicum* biomass for feedstock production. *Panicum* yields increased with increasing FN rates up to 15 $g•m^{-2}$ (3 $lbs•1000\ ft^{-2}$) applied in the spring (Madakadze et al., 1999). Muir et al. (2001) reported similar results when 17 $g•m^{-2}$ (3.4 $lbs•1000\ ft^{-2}$) was applied in April and again in June the following year. These studies, however, were conducted in pasture environments which may differ significantly from our simulated landscapes in regards to mineralization of mulch and plant competition for soil N. Soil solution N concentrations in our control (no FN) plots may have impeded response to N fertilization of *Panicum*. Stout and Jung (1995) found that high soil N concentrations [> 2.0 $g•kg^{-1}$ (0.9 $oz•lb^{-1}$)] reduced biomass accumulation response to FN rates of 8.4 $g•m^{-2}$ (1.7 $lbs•1000\ ft^{-2}$) applied in May.

On June 25 and July 25, FN rates produced a quadratic relationship with maximum plant height at 11.3 $g•m^{-2}$ (2.3 $lb•1000\ ft^{-2}$) and 6•7 $g·m^{-2}$ (1.4 $lb•1000\ ft^{-2}$), respectively when N was applied in January/February (Fig. 14). These responses, however, were small with an average increase of 4% compared to the control (no FN). Plant height was unaffected by the remaining FN rates x timing combinations (data not presented).

Regardless of FN timing, foliar mineral nutrient concentrations of Fe and Zn increased linearly with increasing rate of FN (Fig. 15) whereas foliar concentrations of Mn increased linearly with increasing FN rates in all timings except January/February (Fig. 16). The foliar nutrient concentrations of N (mean = 0.92% dry wt ±0.02 SE), P (mean =0.11% dry wt ±0.01 SE), K (mean = 1.0% dry wt ±0.01 SE), Ca (mean = 0.42% dry wt ±0.01 SE), Mg (mean = 0.16 % dry wt ±0.01 SE), S (mean = 0.09% dry wt ±0.01 SE), Cu (mean = 6.5 $mg \bullet kg^{-1}$ ±0.13 SE), B (mean = 6.8 $mg \bullet kg^{-1}$ ±0.16 SE), and Na (mean = 0.01 $mg \bullet kg^{-1}$ ±0.001 SE) were unaffected by FN rate and timing (data not presented). Vogel et al. (2002) found similar foliar N concentrations when switchgrass samples were taken in August. However, from July 12 to July 27 they reported foliar N concentrations increased linearly with increasing FN rates [0 to 30 $g \bullet m^{-2}$ (6 lbs $1000 \bullet ft^{-2}$)], however, foliar N concentrations from August to October decreased to an average of 0.5% dry weight illustrating how herbaceous perennials such as switchgrass translocate N into bases, tillers, and roots before senescence for reallocation the following spring (Vogel et al., 2002). Similar results were reported by Madakadze et al., (1999) for switchgrass when N concentrations decreased from 1.4% dry weight to 0.5% dry weight from 20 days after fertilization (June 1) to 120 DAF (~Oct. 1) after 15 $g \bullet m^{-2}$ (3 $lbs \bullet 1000 \cdot ft^{-2}$) was applied. Our samples were taken in August. Thus, it appears that a foliar N concentration of 0.92% dry wt was adequate for plant growth. Even though the range of values for foliar macro-nutrient (N, P, K, Ca, and Mg) concentrations reported in Mills and Jones (1996) were taken from field-grown switchgrass, all foliar mineral macro-nutrient concentrations reported herein fall in the range of values reported for *Panicum virgatum*. Mills and Jones (1996) did not report any values for S and micro-nutrients.

Sedum 'Herbstfreude'. *2002:* Sedum was in flower from Aug. 6 to harvest. Cyme coloration, visual evaluations (mean = 3.0 ±04 SE), GI [mean = 89 ±3.8 SE], and top dry weight [mean = 173 g ±14 SE (0.38 lb)] were unaffected by FN rate and timing (data not presented).

2003: Similar to 2002, *Sedum* was in flower from Aug. 4 to harvest. On Aug. 4, FN applied in September/October (the previous season) advanced cyme coloration compared to all other timings (Table 6). Thus, current season FN applications appeared to delay cyme colorations. By Aug. 15, FN applied in September/October continued to advance cyme coloration compared to FN applied in January/February and April/May. In contrast, on July 2, visual evaluations were significantly greater when FN was applied in April/May compared to all other timings (Table 7). By Sept. 17, however, visual evaluations were significantly greater once again when FN was applied in September/October compared to all other N timings. From June 26 to July 24, GI was significantly greater when FN was applied in April/May compared to June/July and September/October (Table 8). While spring FN application increased GI, spring FN may delay the rate of flower formation and anthocyanin pigmentation. By Aug. 4, 20 days after June/July fertilization, GI was similar among all FN timings that had received N in 2003 (January/February, April/May, and June/July). Cyme coloration, visual evaluation and GI were unaffected by rate of FN suggesting that *Sedum* ''Herbstfreude' would benefit from a low rate of FN applied in both fall and spring. Even though top dry weight increased 723% in 2003 [mean = 1424 g ±90 SE (3.1 lb)] compared to 2002, top dry weight of sedum was unaffected by FN rate and timing (data not presented) supporting the hypothesis that N supplied from the mineralization of mulch and N remobilization within the plant provided adequate N for growth.

Foliar mineral nutrient concentrations of N, K, Ca, Mg, and S were affected by FN rate and/or timing (Tables 9 and Table 10;
Fig. 17) whereas foliar concentrations of P (mean = 0.25% dry wt ±0.01 SE), B (mean = 50 mg•kg^{-1} ±1.1 SE), Cu (mean = 7.7 mg•kg^{-1} ±0.30 SE), Fe (mean = 61 mg•kg^{-1} ±1.6 SE), Mn (mean = 49.4 mg•kg^{-1} ±2.0 SE), Na (mean = 0.01mg•kg^{-1} ±0.001 SE) and Zn (mean 69.8 mg•kg^{-1} ±1.6 SE) concentrations were unaffected by FN rate and timing (data not presented). Foliar Mg and Mn concentrations increased linearly with increasing FN rate, whereas foliar K and B concentrations decreased linearly with increasing FN rate (Fig. 17). Foliar N concentrations increased linearly in April/May ($y = 0.04x + 1.19$, $R^2 = 0.80$) and June/July ($y = 0.02x + 1.47$, $R^2 = 0.88$) with increasing FN rates (Table 9). Sedum was the only species which responded in this manner. Foliar N concentrations indicated that N was absorbed in April/May and June/July with increasing FN rates which may have been luxury consumption since top dry weight was unaffected by FN rate (Table 9). Increased N uptake in June/July FN timing may have increased K, Ca, and S concentrations (Table 10). Foliar K, Ca, and S concentrations were significantly greater when N was applied in June/July compared to FN applied in January/February and September/October (Table 10). From this we concluded that foliar N concentration ≥ 1.4% was adequate for plant growth. Mills and Jones (1996), however, reported a higher value (1.78% to 2.48%) for container-grown *Sedum* L. 'Herbstfreude'. Container-grown plant material might be expected to have higher foliar mineral nutrient concentrations. Mineral nutrient concentrations of P, Ca, S, B, Cu, Fe, Mn,

and Zn reported in the study were in the range of values listed in Mills and Jones (1996). The remaining nutrient concentrations (K and Mg) were lower than the reported foliar concentrations in Mills and Jones (1996). However, no visual deficiency symptoms were observed throughout the entire study.

In 2002, *Canna* and *Iris* were affected by FN rate and timing, whereas *Coreopsis*, *Iris*, and *Sedum* responded to FN rate and timing in 2003. Most of the species in this study had large increases in top dry weight between the 2002 and 2003 growing seasons and we do not believe these increases were achieved with no additional N. We propose that the mineralization of the mulch and organic matter in the soil in combination with N remobilization supplied these herbaceous perennials with enough N to support growth. Response to FN is usually reduced as the N content of the soil increases (Mengel and Kirby, 1981). In addition, the research conducted by Lloyd et al. (2002) illustrated that composted yard waste applied as mulch can serve as an organic fertilizer. Even though we did not determine the C:N ratio of the composted yard waste used as mulch in the current study it consisted of the same material (wood chips, leaves, and grass clippings) that Lloyd reported. Proctor (2006) determined the NH_4-N and NO_3-N concentrations in the soil solution at a depth of 38 cm (15 in) every two weeks throughout the entire study. Typically, total-N in the soil solution increased linearly with increasing FN rate regardless of FN timing. Thus, the FN applied was in the soil solution, however, this increase in soil solution N concentration did not typically affect growth or ornamental performance. The treatment receiving zero FN, however, rarely dropped below 10 mg•L^{-1} N which supports Lloyd's data that composted yard waste can act as an organic fertilizer.

The higher rates of FN in this study maintained total-N concentration > 10 $mg{\bullet}L^{-1}$ in the soil solution for 240 and 205 days after FN application in 2002 and 2003, respectively (Proctor, 2006). From an environmental perspective, the concentration of total-N found in soil solution was alarming. Assuming that nitrate concentrations at a depth of 38 cm (15 in) are below the depth of the typical herbaceous perennial root system much of the N may be subject to leaching into the ground water or entering into subsurface water flows to streams and lakes. Therefore care must be taken when applying high rates of FN rates to herbaceous perennials in the landscape.

Our results indicated that despite statistical significance differences, many differences were small and FN treatments had little impact on the growth and ornamental qualities of these species. However, applying no N may not advisable, as some perennials species did benefit from an FN application during a specific time and in addition N was available from mineralization of the mulch. To cover the needs of a wide variety of perennial species that usually exists in one landscape as well as minimize N concentrations in the soil solutions, we recommend a low to moderate rate of FN [5 $g{\bullet}m^{-2}$ to 15 $g{\bullet}m^{-2}$ (1 $lb{\bullet}1000\ ft^{-2}$ to 3 $lb{\bullet}1000\ ft^{-2}$)] be applied in split applications in spring and early fall.

Literature Cited

Acuna-Maldonado, L.E., M.W. Smith, N.O. Maness, B. Cheary, and B. Carroll. 2003. Influence of nitrogen application time on nitrogen absorption, partitioning, and yield of pecan. J. Amer. Soc. Hort. Sci. 128:155-162.

Armitage, A.M. 1997. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 2nd ed. Stipes, L.L.C., Champaign. IL.

Ashmun, B.B. 2003. Bloomin' long. Amer. Nurseryman. 197(3):34-39.

Brady, N.C. and R.R. Weil. 1999. The Nature and Properties of Soils. 12th ed. Prentice Hall, Upper Saddle River, N.J.

Brown, S.P., L. Hodyss, and D. Marshall. 1996. Flowering perennials in Florida. Florida Sta. Univ. Bul. ENH-68.

Cabrera, R.I. 2003. Less is more. Amer. Nurseryman. 197:40-45.

Cabrera, R.I.and D.R. Devereaux. 1999. Crape myrtle post-transplant growth as affected by nitrogen nutrition during nursery production. J. Amer. Soc. Hort. Sci. 124:94-98.

Cockerham, S.T. 2004. Irrigation and planting density affect river red gum growth. California Agric. 58(1):40-43.

Cohen, S. 2000. Perennials go commercial. Amer. Nurseryman. 191(8):26-28.

Conradie, W.J. 1991. Distribution and translocation of nitrogen absorbed during early summer by two year old grapevines grown in sand culture. Amer. J. Enol. Viticult. 42(3):145-148.

Cookson, W.R., J.S. Rowarth, and K.C. Cameron. 2000. The response of a perennial ryegrass (*Lolium perenne* L.) seed crop to nitrogen fertilizer application in the absence of moisture stress. Grass For. Sci. 55: 314-325.

Duarte, M.and L.P. Perry. 1988. Field fertilization of *Heuchera sanguinea* 'Splendens'. HortScience. 23:1084.

Dubois, J.J.B., S.L. Warren, and F.A. Blazich. 2000. Nitrogen nutrition of containerized *Anemone* x *hybrida*. J. Environ. Hort. 18:145-148.

Environmental Protection Agency. 2000. National management measures to control non-point source pollution from agriculture. [http://www.epa.gov/owow/nps/agmm/index.html] *(last accessed 04/20/04)*.

Evans, E. 2000. Perennials: Maintaining. North Carolina State Univ. Coop. Ext. Serv. [http://www.ces.ncsu.edu/depts/hort/consumer/factsheet/perennials/text_maintaining.html] *(last accessed 01/04/05)*.

Griffin, J.J., S.L. Warren, F.A. Blazich, and T.G. Ranney. 1999. Nitrogen nutrition of containerized *Thuja* x 'Green Giant'. J. Environ. Hort. 17:76-79.

Hamrick, D. 2000. Dynamite in gallon pots. Grower Talks. 64(2):40-47.

Hanson, E.J.and G.S. Howell. 1995. Nitrogen accumulation and fertilizer use efficiency by grapevines in short-season growing areas. HortScience. 30:504-507.

Hipp, B.W., B.J. Simpson, and P.S. Graff. 1988. Influence of nitrogen and phosphorus on growth and tissue N and P concentration in *Salvia greggii*. J. Environ. Hort. 6:59-61.

Hipp, B.W., B.J. Simpson, and P.S. Graff. 1989. Influence of phosphorus on nitrogen fertilizer requirements of *Melampodium leucanthum* (Blackfoot Daisy) grown in perlite-vermiculite medium. J. Environ. Hort. 7:83-84.

Holmes, R., R. Buchanan, and F. Tenebaum. 2001. Taylor's master guide to gardening. Houghton Mifflin, New York, NY.

Hood, T.M., H.A. Mills, and P.A. Thomas. 1993. Developmental stage affects nutrient uptake by four snapdragon cultivars. HortScience. 28:1008-1010.

Jull, L.G., S.L. Warren, and F.A. Blazich. 1994. Nitrogen nutrition of containerized *Cryptomeria japonica* 'Elegans Aurea'. J. Environ. Hort. 12:212-215.

Kessler, J.R., J.D. Williams, and B. Clendenen. 2002. Herbaceous perennials in Alabama.

King, J.J., L.A. Peterson, and D.P. Stimart. 1995. Ammonium and nitrate uptake throughout development in *Dendranthema* x *grandiflorum*. HortScience. 30:499-503.

Kraus, H.T., S.L. Warren, and C.E. Anderson. 2002. Nitrogen form affects growth, mineral nutrient content, and root anatomy of Cotoneaster and Rudbeckia. HortScience. 37:126-129.

Lauderdale, C.C. 2003. Purple reign. Amer. nurseryman. 191(11):18-22.

Ledgard, S.F. and G.S. Smith. 1992. Fate of ^{15}N-labelled nitrogen fertilizer applied to kiwifruit (*Actinidia deliciosa*) vines. Plant and soil. 147:59-68.

Lieberman and Weir

Lloyd, J.E. 2001. Trophic cascades in ornamental landscapes mediated by soil organic matter: Effects of mulch and fertilization on microbial activity, nutrient cycling, plant carbon allocation, and insect herbivores. PhD Diss., Ohio State Univ., Columbus.

Macz, O., E.T. Paparozzi, and W.W. Stroup. 2001. Effect of nitrogen and sulfur applications on pot chrysanthemum production and postharvest performance. I. leaf nitrogen and sulfur concentrations. J. Plant Nutr. 24:111-129.

Madakadze, I.C., K.A. Stewart, R.R. Peterson, B.E. Coulman, and D.L. Smith. 1999. Cutting frequency and nitrogen fertilization effects on yield and nitrogen concentration of switchgrass in a short season area. Crop Sci. 39:552-557.

Marini, R.P. 1999. Are nonsignificant differences really not significant? HortScience. 34:761-762.

Marschner, H. 2002. Mineral nutrition of higher plants. 2nd. ed. Academic press, London.

Mengel, K.and E. Kirby. 1981. Principles of plant nutrition. 3rd ed., Intl. Potash Inst. Worblaugen-Bern,Switzerland.

Mills, H.A.and J.B. Jones. 1996. Plant analysis handbook II: A practical sampling, preparation, analysis, and interpretation guide. Micro-Macro, Athens, GA.

Miner, G.S., E.B. Poling, D.E. Carroll, L.A. Nelsen, and C.R. Campbell. 1997. Influence of fall nitrogen and spring nitrogen-potassium applications on yield and fruit quality of 'Chandler' strawberry. J. Amer. Soc. Hort. Sci. 122:290-295.

Muir, J.P., M.A. Sanderson, W.R. Ocumpaugh, R.M. Jones, and R.L. Reed. 2001. Biomass production of 'Alamo' switchgrass in response to nitrogen, phosphorus, and row spacing. Agron. J. 93:896-901.

Oral, N.and E. Acikgoz. 2001. Effects of nitrogen application timing on growth and quality of a turfgrass mixture. J. Plant Nutr. 24:101-109.

Owens, L.B., R.W. Malone, M.J. Shopitalo, W.M. Edwards, and J.V. Bonta. 2000. Lysimeter study of nitrate leaching from a corn-soybean rotation. J. Environ. Qual.29:467-474.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1-14.

Proctor, C.L. 2006. Effect of fertilizer nitrogen rate and timing on growth and performance of six herbaceous perennials and soil solution nitrogen concentration in a simulated landscape. MS Thesis, North Carolina State Univ., Raleigh.

Phillips, E. and C.C. Burrell. 1999. Rodale's illustrated encyclopedia of perennials. 10th ed. Rodale Press, Emmaus, Pa.

Relf, K.and E. Ball. 2002. Perennials: culture, maintenance and propagation. Virginia Coop. Ext. Bul. 426-203.

Rempel, H.G., B.C. Strik, and T.L. Righetti. 2004. Uptake, partitioning, and storage of fertilizer nitrogen in red raspberry as affected by rate and timing of application. J. Amer. Soc. Hort. Sci. 129:439-448.

Rosen, C. J., P.M. Bierman, and R.D. Eliason. 2004. Soil test interpretation and fertilizer management for lawns, turf, gardens, and landscape plants. Univ. Minnesota.Ext. Serv. Publ. BU-1731. Roy, J.W., G.W. Parkin, and C. Wagner-Riddle. 2000. Timing of nitrate leaching from turfgrass after multiple fertilizer applications. J. Water Qual. Res. 35:735-752.

Sanchez, E.E., T.L. Righetti, D. Sugar, and P.B. Lombard. 1991. Recycling of nitrogen in field-grown 'Comice' pears. J. Hort. Sci. 66:479-486.

Shalaby, A.S., S.E. El-Gengaihi, E.A. Agina, A.S. El-Khayat, and S.F. Hendawy. 1997. Growth and yield of *Echinacea purpurea* L. as influenced by planting density and fertilization. J. Herbs, Spices, Med. Plants. 5:69-76.

Simonne, E.H., C.E. Harris, J.O. Sichivitsa, J.E. Altland, C.H. Gilliam, and D.J. Eakes. 1999. A simple format for reporting methods used in nutritional studies: application with *Loropetalum* response to fertilizer rates. J. Plant Nutr. 22:1797-1806.

Smith, P.F. 1962. Mineral analysis of plant tissue. Annu. Rev. Plant Physiol. 13: 81-108.

Still, S.M. 1994. Manual of herbaceous ornamental plants. 4th. Stipes, Champaign,IL.

Stout, W.L. and G.A. Jung. 1995. Biomass and nitrogen accumulation in switchgrass: Effects of soil and environment. Agron. J. 87:663-669.

Strik, B., T. Righetti, and G. Buller. 2004. Influence of rate, timing, and method of nitrogen fertilizer application on uptake and use of fertilizer nitrogen, growth, and yield of June-bearing strawberry. J. Amer. Soc. Hort. Sci. 129:165-174.

Stubbs, H.L., S.L. Warren, F.A. Blazich, and T.G. Ranney. 1997. Nitrogen nutrition of containerized *Cupressus arizonica* var. *glabra* 'Carolina Sapphire'. J. Environ. Hort. 15:80-83.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in bermudagrass turf. Agron. J. 76:964-969Thomas, P.A. 1999. Flowering perennials for Georgia gardens. Univ. Georgia Coop. Ext. Serv. Bul. 944.

Tisdale, S.L. 1993. Soil fertility and fertilizers. 5th ed. Macmillan, New York, N.Y.

Toselli, M., J.A. Flore, C. Zavalloni, and B. Marangoni. 2000. Nitrogen partitioning in apple trees as affected by application time. HortTechnology. 10:136-141.

Toth, J.D.and R.H. Fox. 98. Nitrate losses from a corn-alfalfa rotation: Lysimeter measurement of nitrate leaching. J. Environ. Qual. 27:1027-1033.

Upendra, S.M., B.P. Singh, S. Rahman, and V.R. Reddy. 1999. Soil nitrate-nitrogen under tomato following tillage, cover cropping, and nitrogen fertilization. J. Environ. Qual. 28:1834-1844.

Vogel, K., J.J. Brejda, D.T. Walters, and D.R. Buxton. 2002. Swithgrass biomass production in the midwest USA: Harvest and nitrogen management. Agron. J. 94:413-420.

Weinbaum, S.A., S.A. Merwin, and T.T. Muraoka. 1978. Seasonal variation in nitrate uptake efficiency and distribution of absorbed nitrogen in non-bearing prune trees. J. Amer. Soc. Hort. Soc. 103:516-519.

Williams, L.E. and R.J. Smith. 1991. The effect of rootstock on the partitioning of dry weight, nitrogen, and potassium, and root distribution of cabernet sauvignon grapevines. Amer. J. Enol. Viticult. 42:118-122.

Table 1. Effect of FN applied at various times on height[z] of *Canna* 'Mr. President', 2002.

Nitrogen timing	Height (cm)
January/February	125 b[y]
April/May	136 a
June/July	122 b
September/October	123 b

[z]Height measured Oct.15, 2002.

[y]Means separated by Fisher's protected LSD, $P = 0.10$

Table 2. Effect of FN timing on visual evaluations of *Coreopsis verticillata* 'Moonbeam', 2003.

Nitrogen timing	Date: June 1	Date: June 14
	Visual evaluation	
January/February	3.7 ab[z]	3.7 a
April/May	3.9 a	3.7 a
June/July	2.9 c	2.7 b
September/October	3.2 bc	2.9 b

[z]Means separated by Fishers protected LSD, $P = 0.10$

Table 3. Effect on FN timing on growth index (GI) of *Coreopsis verticillata* 'Moonbeam', 2003.

Nitrogen timing	Date			
	June 25	July 9	July 25	Aug. 3
	GI (cm)			
January/February	64 a[z]	68 a	71 a	83 a
April/May	63 a	68 a	71 a	83 a
June/July	56 b	62 b	64 b	76 b
September/October	57 b	64 ab	68 ab	79 ab

[z]Means separated within columns by Fishers protected LSD, P=0.10.

Table 4. Effect of FN rate applied at various times on foliar phosphorus concentrations of *Coreopsis verticillata* 'Moonbeam', 2003[z].

	N rate ($g \cdot m^{-2}$)					
	0	7	14	28	Significance[y]	
Nitrogen timing	Phosphorus (% dry weight)				L[x]	Q
January/February	0.22 a[w]	0.21 ab	0.21 a	0.20 b	**	NS
April/May	0.26 a	0.20 b	0.18 a	0.17 c	**	NS
June/July	0.21 a	0.21 ab	0.20 a	0.21 b	NS	NS
September/October	0.21 a	0.25 a	0.18 a	0.29 a	NS	NS

[z]Leaves were collected Aug. 15, 2003.

[y]NS, **, * Nonsignificant or significant at $p \leq 0.05$ or $p \leq 0.10$, respectively.

[x]L = linear, Q = quadratic.

[w]Means separated within columns by Fisher's protected LSD, $P = 0.10$.

Table 5. Effect of FN timing on visual evaluation for *Iris siberica* 'Caesar's Brother', 2002.

Nitrogen timing	Apr. 24
	Visual evaluation[x]
January/February	2.8 b[y]
April/May	3.0 b
June/July	-
September/October	3.8 a

[z]Means within columns separated by Fishers protected LSD, $P = 0.10$.

[y]Treatment not applied until June 15, 2002.

[x]Based on a 1-5, 5 being optimal

Table 6. Effect of FN timing on flower color of *Sedum* 'Herbstfreude', 2003[z].

Nitrogen timing	Aug. 4	Aug. 15
January/February	1.3 b[y]	1.7 bc
April/May	1.1 c	1.6 c
June/July	1.3 b	1.9 ab
September/October	1.6 a	2.0 a

[z]Flower color recorded with 1 = No and 2 = Yes based on whether > 20% of the cymes displayed a pink coloration.

[y]Means separated within columns by Fishers protected LSD, $P = 0.10$.

Table 7. Effect of FN timing on visual evaluations[z] on July 2 and Sept. 17 of *Sedum* 'Herbstfreude', 2003.

Nitrogen timing	July 2	Sept. 17
	Visual evaluation	
January/February	3.8 b[y]	2.7 b
April/May	4.3 a	2.1 b
June/July	3.6 b	2.4 b
September/October	3.4 b	3.9 a

[z]Based on a 1-5 scale with 5 being optimal.

[y]Means separated within columns by Fishers protected LSD, $P = 0.10$.

Table 8. Effect of FN timing on growth index (GI) of *Sedum* 'Herbstfreude' at various dates, 2003.

	Date			
	June 26	July 10	July 24	Aug. 4
Nitrogen timing	GI (cm)			
January/February	72 ab[z]	73 ab	86 ab	89 ab
April/May	74 a	76 a	89 a	90 a
June/July	67 b	70 b	81 b	84 ab
September/October	65 b	68 b	80 b	84 b

[z]Means separated within columns by Fisher protected LSD, $P = 0.10$.

Table 9. Effect of FN rates applied at various times on foliar N concentration of *Sedum* 'Herbstfreude', 2003[z].

	N rate ($g \bullet m^{-2}$)					
	0	7	14	28	Significance[y]	
Nitrogen timing	Nitrogen (% dry weight)				L[x]	Q
January/February	1.3 a[w]	1.4 a	1.4 b	1.4 c	NS	NS
April/May	1.4 a	1.4 a	1.6 ab	2.5 a	**	NS
June/July	1.4 a	1.4 a	1.8 a	1.9 b	**	NS
September/October	1.4 a	1.4 a	1.7 ab	1.3 c	NS	NS

[z]Leaves were collected Aug. 15 2003.

[y]NS, **, * Nonsignificant or significant at $p \leq 0.05$ or $p \leq 0.10$, respectively.

[x]L = linear, Q = quadratic.

[w]Means separated within columns by Fisher's protected LSD, $P = 0.10$.

Table 10. Effect of FN timing on foliar nutrient concentrations of *Sedum* ‘Herbstfreude’, 2003.[z]

Nitrogen timing	K	Ca	S
	-----------(% dry weight)-----------		
January/February	1.2 b	3.1 b	0.12 b
April/May	1.3 b	3.3 ab	0.14 a
June/July	1.5 a	3.4 a	0.15 a
September/October	1.3 b	3.1 b	0.13 b

[z]Leaves were collected Aug. 15 2003.

[y]Means separated within columns by Fisher’s protected LSD, $P = 0.10$.

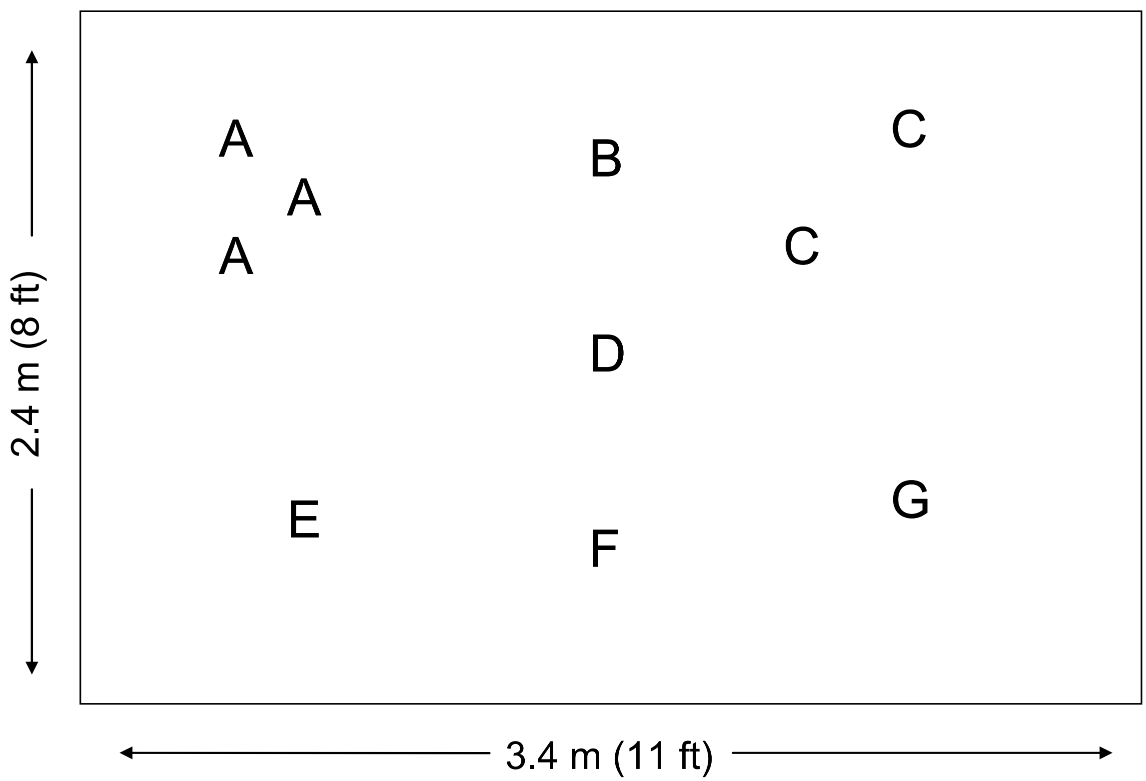

Fig. 1. Placement of perennials planted in a 2.4 x 3.4 m (8 x 11 ft.) plot to simulate a landscape (A) *Canna* ‘Mr. President’, (B) *Panicum virgatum* ‘Shenandoah’, (C) *Coreopsis verticillata* ‘Moonbeam’, (D) *Salvia* x *sylvestris* ’East Friesland’, (E) *Iris siberica* ‘Caesar’s Brother’,(F) *Sedum* ‘Herbstfreude’, (G) *Echinacea purpurea* ‘Magnus’. Plants were installed Oct. 2000.

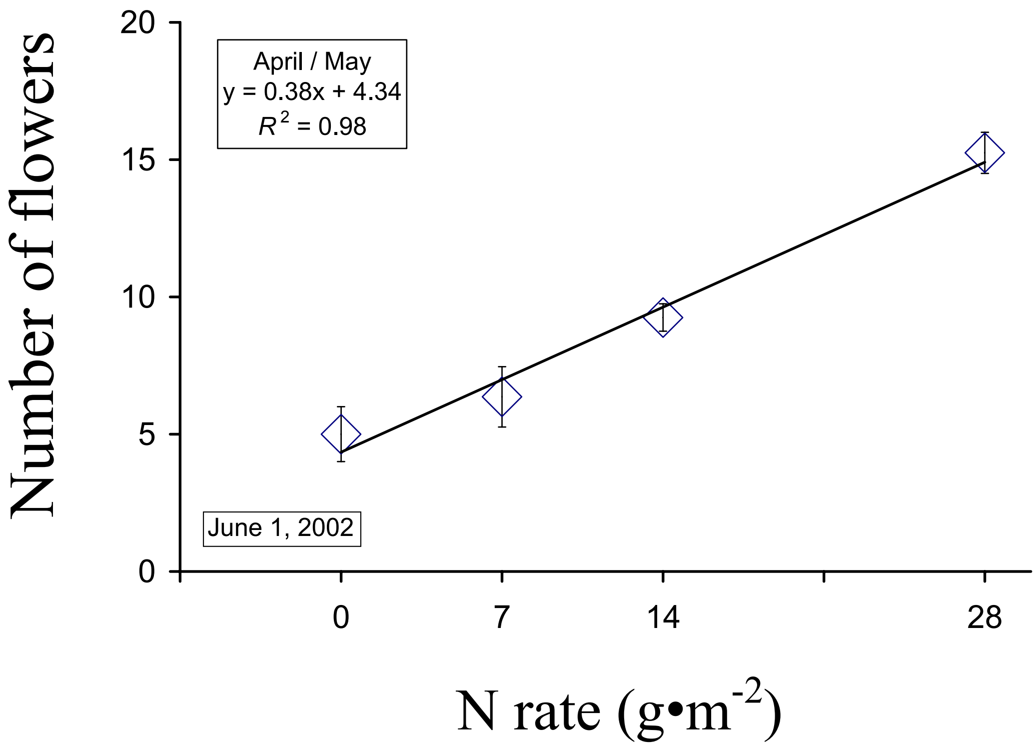

Fig. 2. Effect of FN rate applied in April/May on *Canna* ‘Mr. President’ flower number, June 1, 2002. Each symbol is based on 4 observations and vertical =± SE.

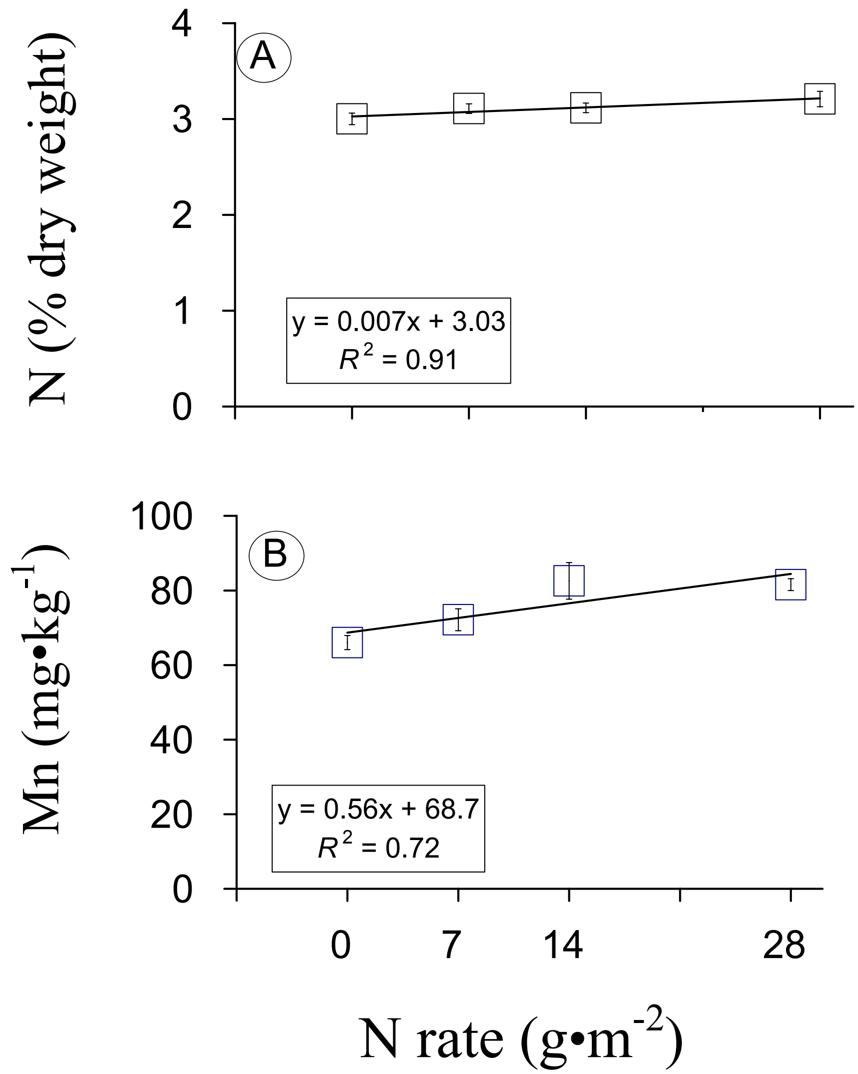

Fig. 3. Effect of FN rate on (A) nitrogen (N) and (B) manganese (Mn) concentrations in leaves collected Aug. 15, 2003, from *Canna* 'Mr. President'. Each symbol is based on 16 observations and vertical bars= ± SE.

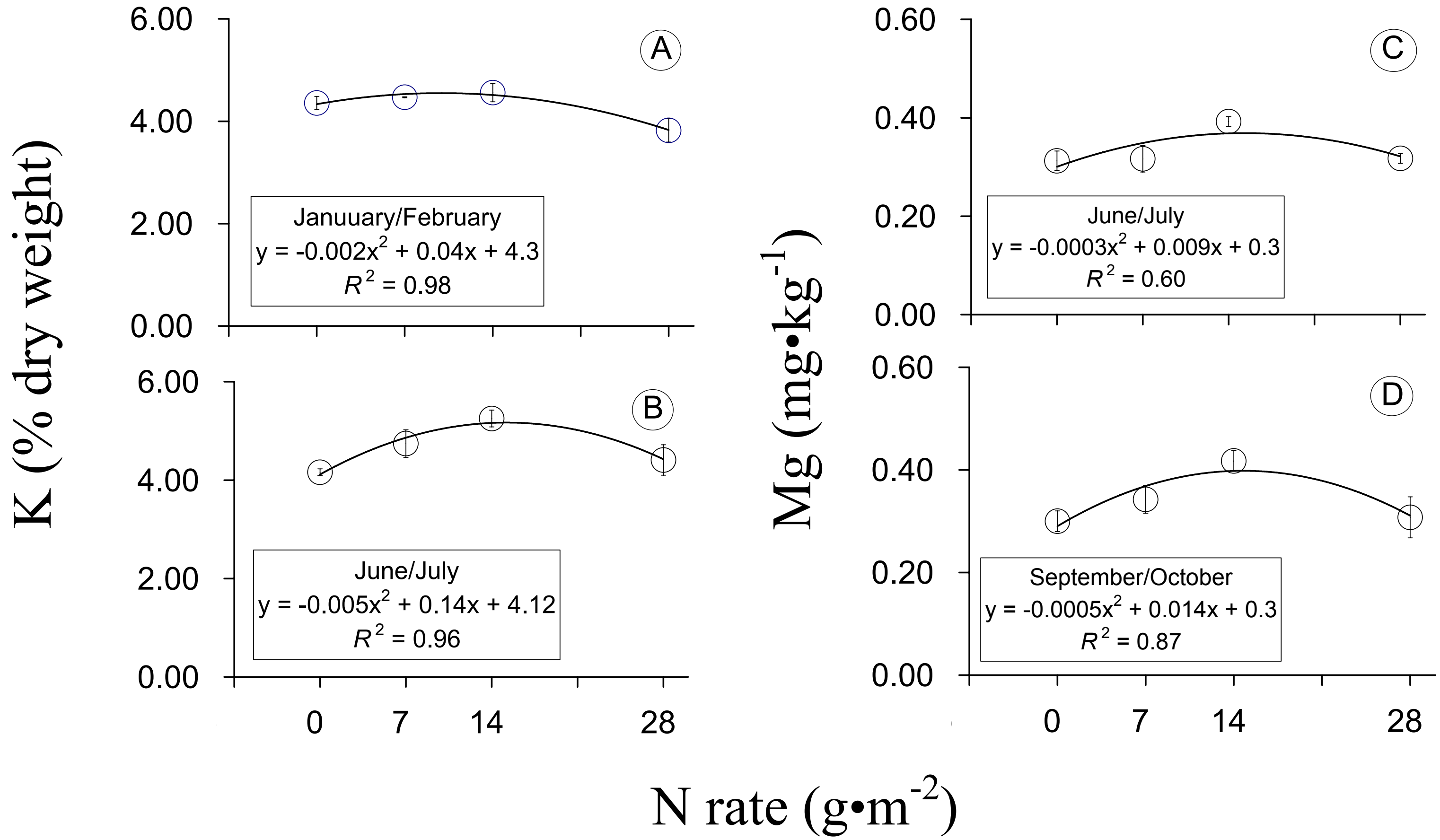

Fig. 4. Effect of N rate applied in (A) January/February and (B) June/July on potassium (K) concentrations. Effect of FN rate applied in (C) June/July and (D) September/October on magnesium (Mg) concentrations. Nutrient concentrations are from *Canna* 'Mr. President' leaves collected Aug. 15, 2003. Each symbol is based on 4 observations and vertical bars = ± SE

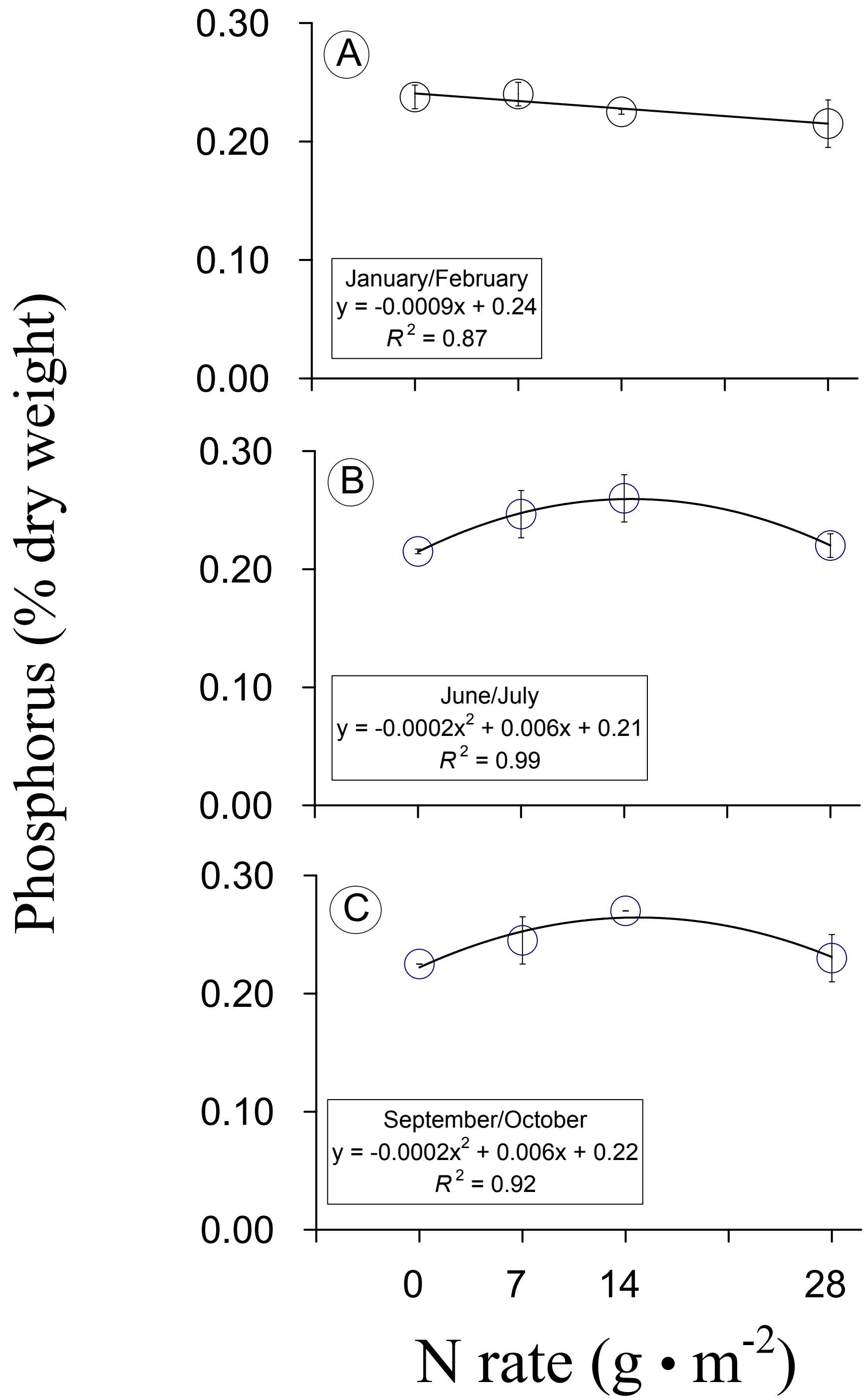

Fig. 5. Effect of FN rate applied (A) January/February, (B) June/July and, (C) September/October on phosphorus concentrations in leaves from *Canna* 'Mr. President' collected Aug. 15, 2003. Each symbol is based on 4 observations and vertical bars =± SE.

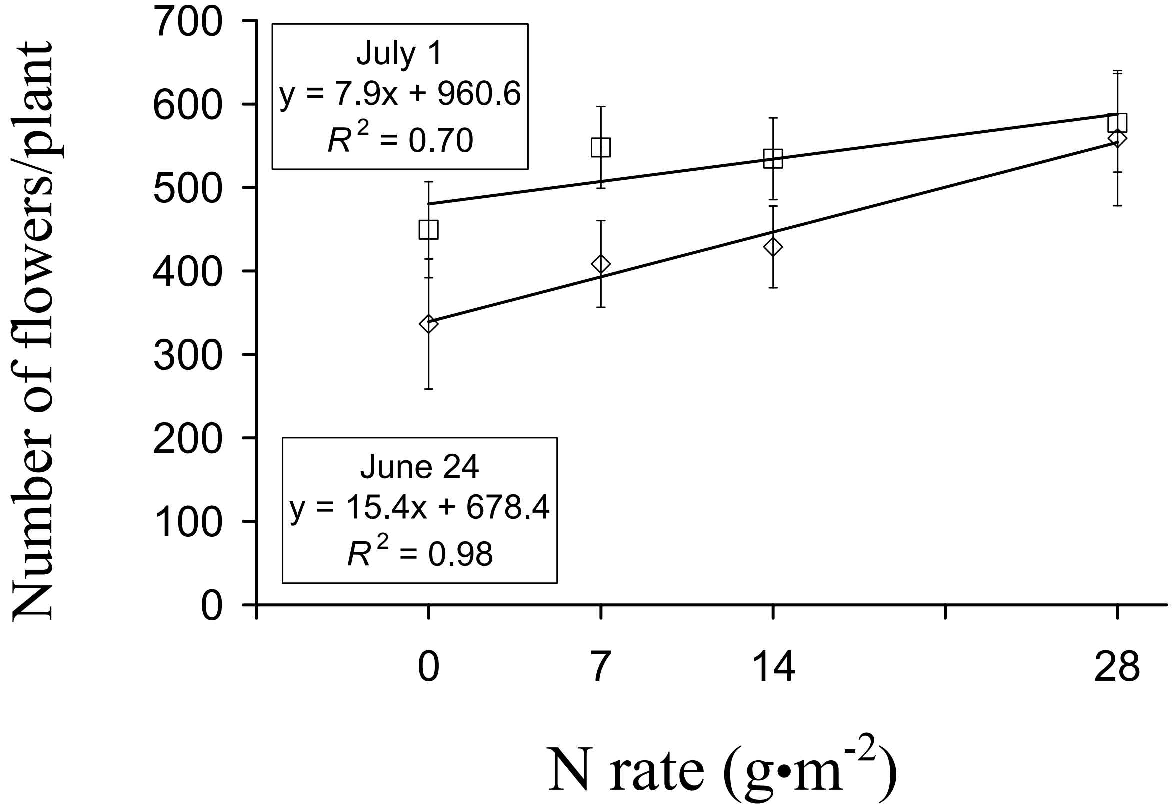

Fig. 6. Effect of FN rate on flower number of *Coreopsis verticillata* 'Moonbeam' on June 24 and July 1, 2003. Each symbol is based on 16 observations and vertical bars = ± SE.

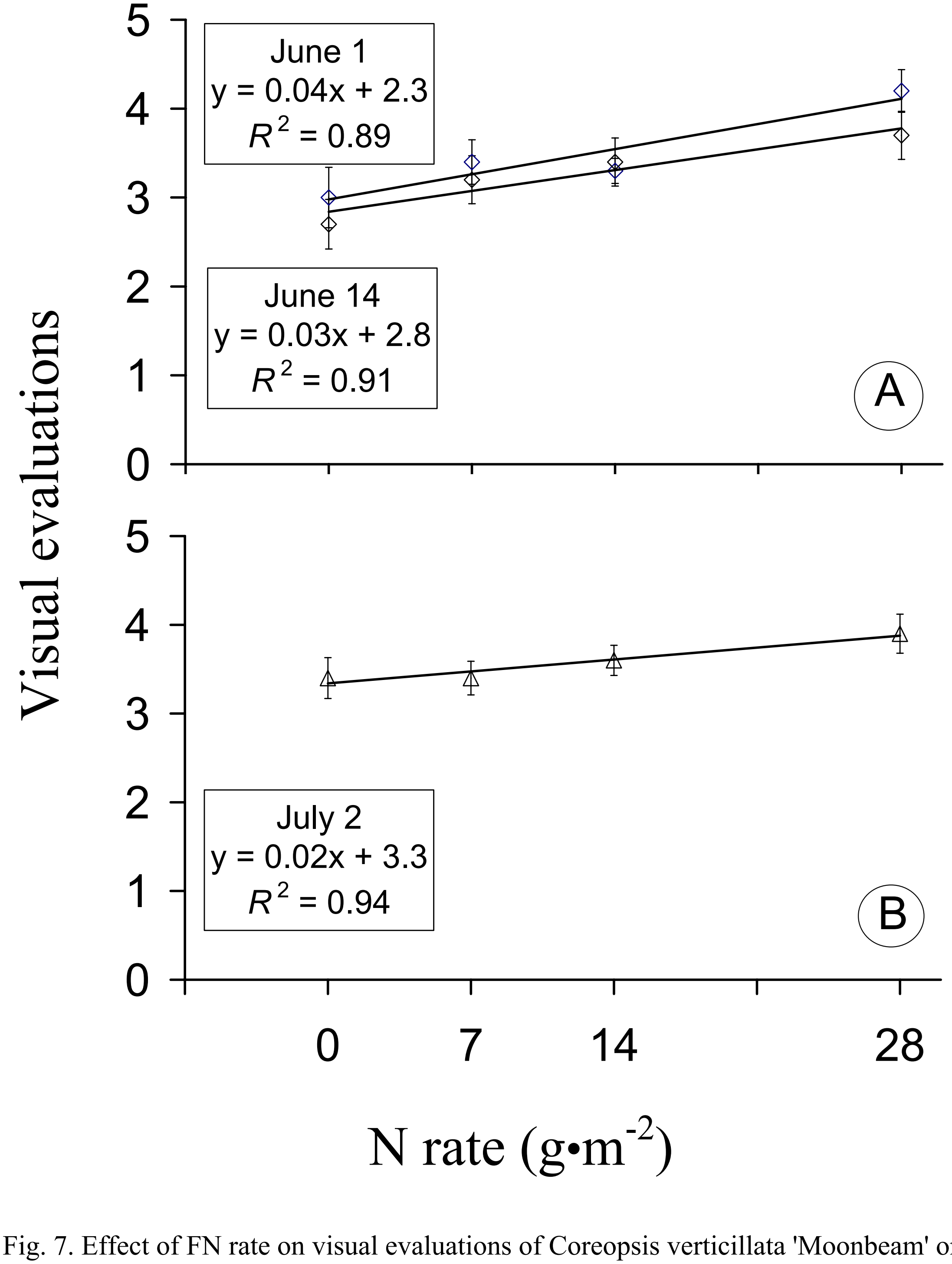

Fig. 7. Effect of FN rate on visual evaluations of Coreopsis verticillata 'Moonbeam' on (A) June 1, June 14, and (B) July 2, 2003. Each symbol is based on 16 observations and vertical bars = ± SE.

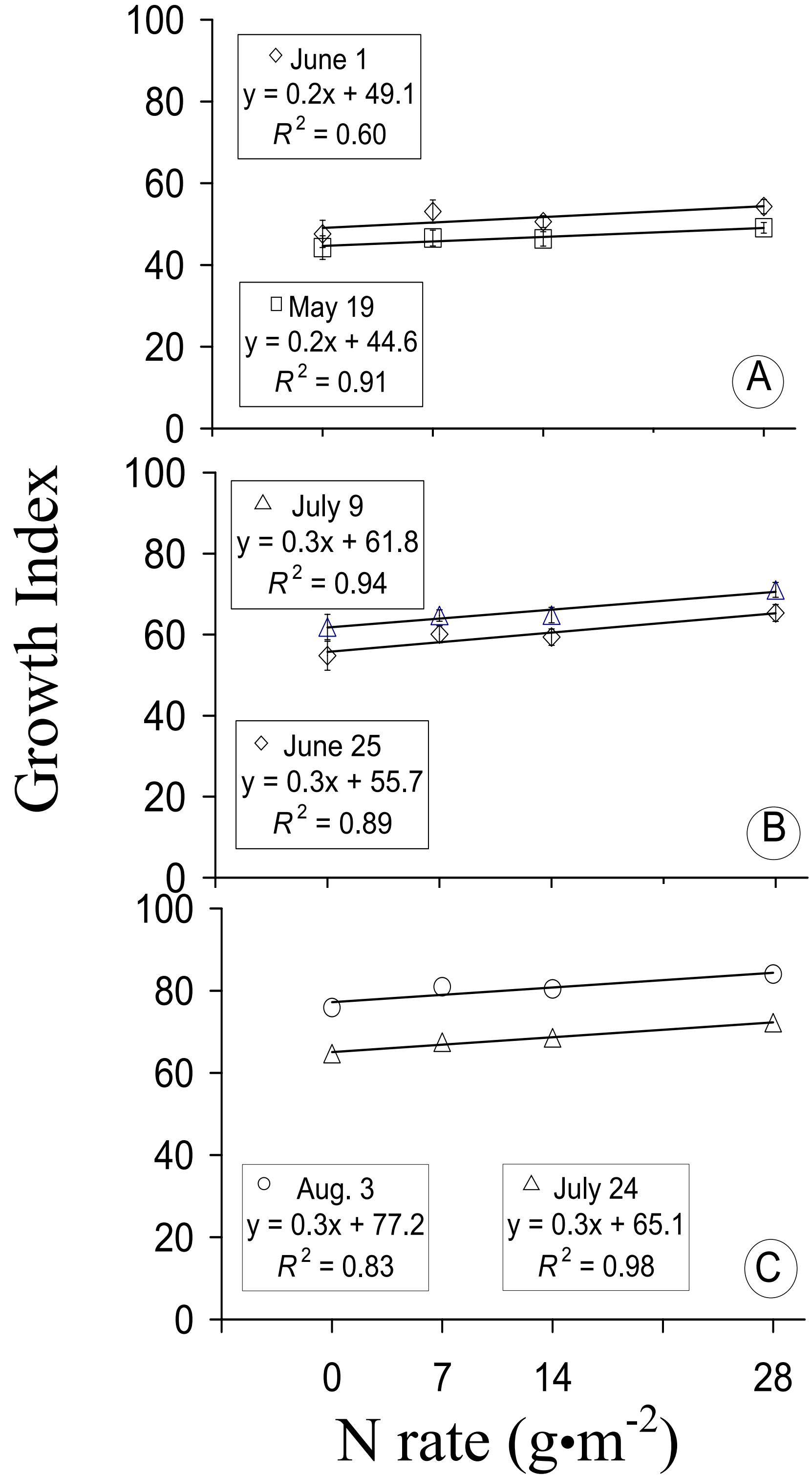

Fig. 8. Effect of FN on GI (growth index) (cm) of *Coreopsis verticillata* 'Moonbeam' on (A) May 19 and June 1, (B) June 25 and July 9, (C) July 24 and Aug. 3 2003, Each symbol is based on 16 observations and vertical bars = ± SE

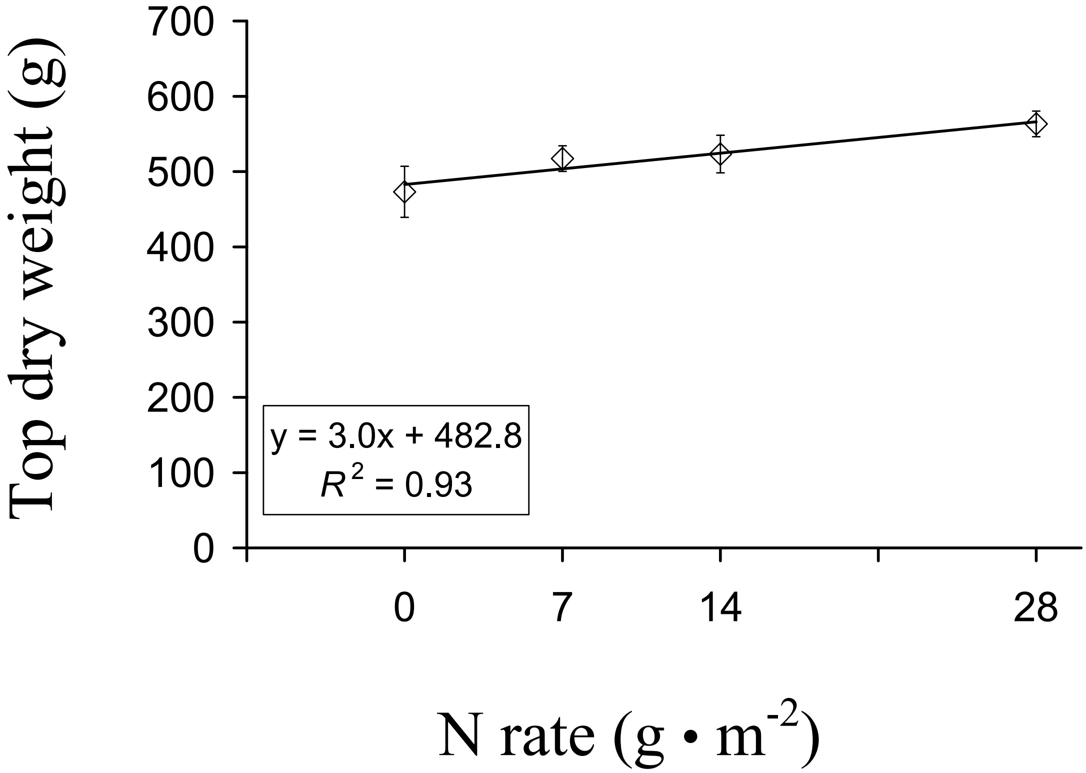

Fig. 9. Effect of FN rate on top dry weight (g) of *Coreopsis verticillata* 'Moonbeam', 2003. Each symbol is based on 16 observations and vertical bars = ± SE.

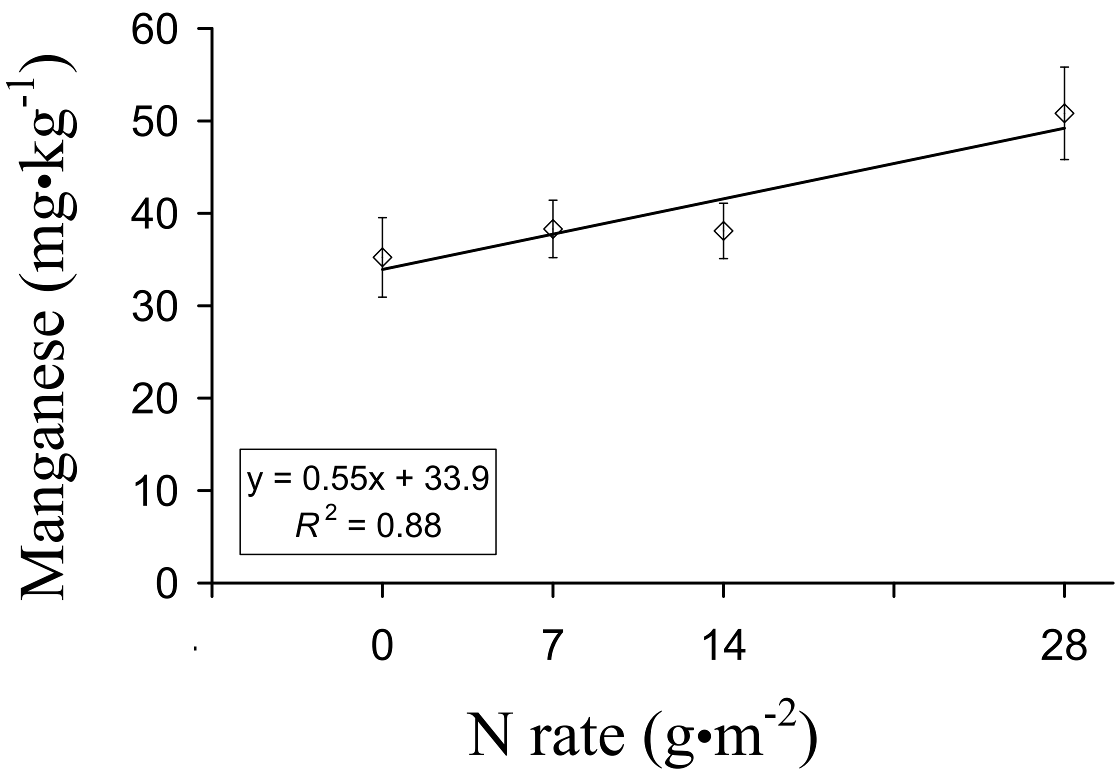

Fig. 10. Effect of FN rate on foliar manganese (Mn) concentrations in leaves collected Aug. 15, 2003, from *Coreopsis verticillata* 'Moonbeam'. Each symbol is based on 16 observations and vertical bars = ± SE.

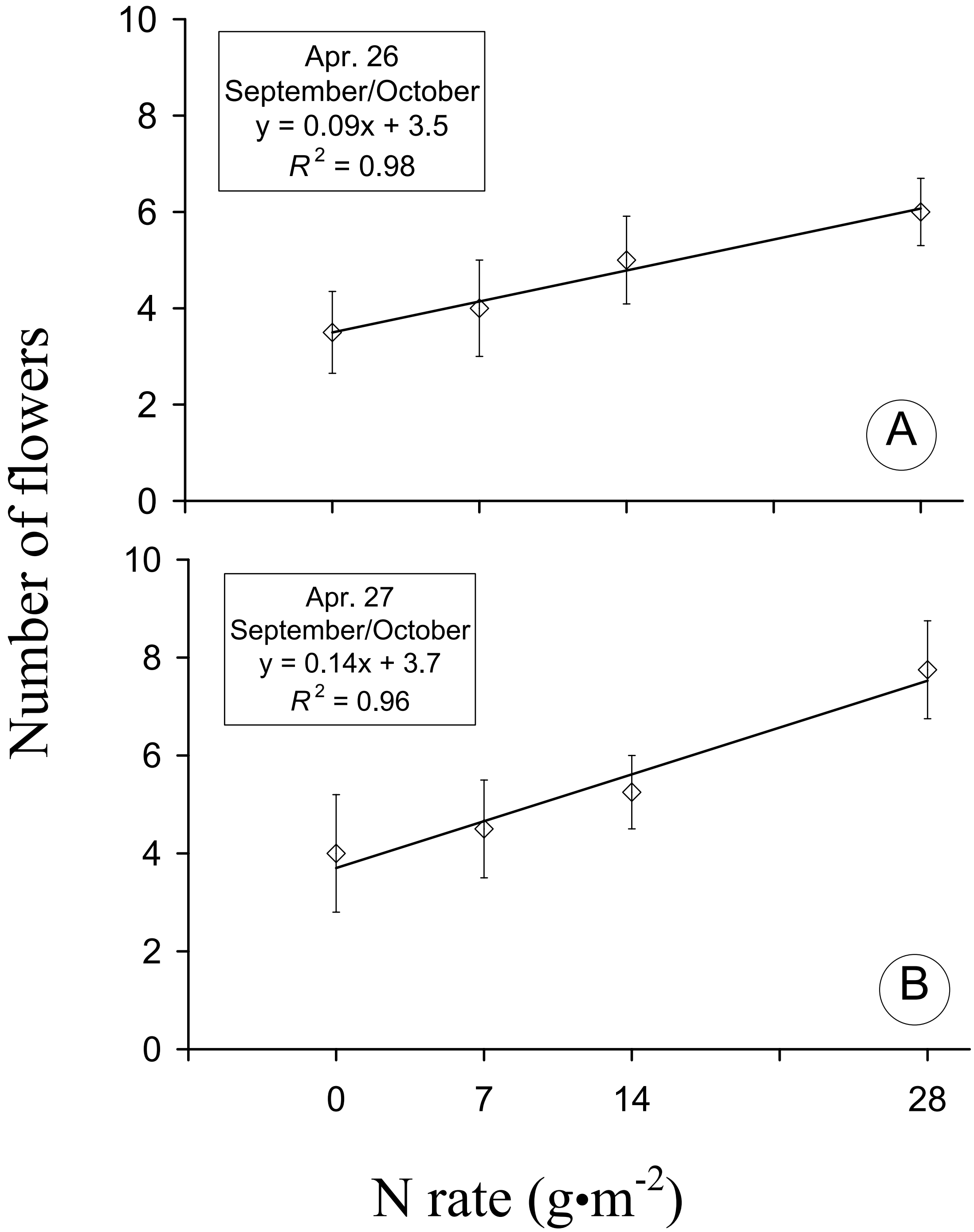

Fig. 11. Effect of FN rate applied in September/October on number of flowers of *Iris siberica* 'Caesar's Brother', (A) Apr. 26 and (B) Apr. 27, 2002. Each symbol is based on 16 observations and vertical bars = ± SE.

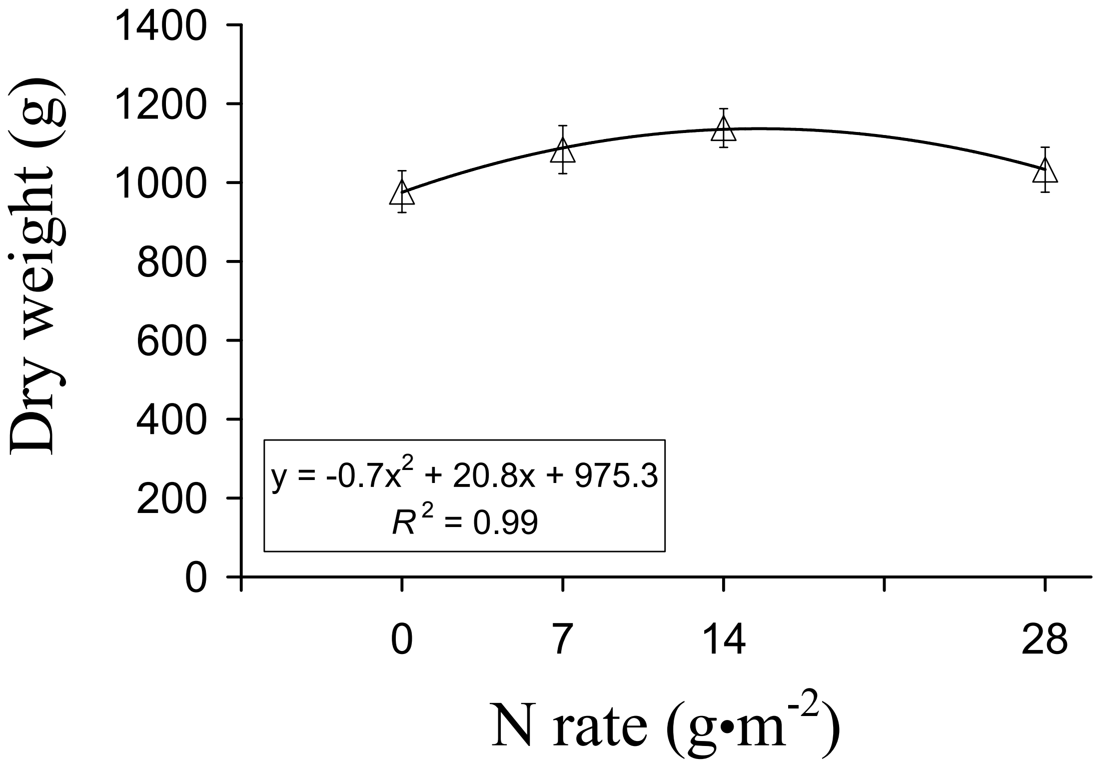

Fig. 12. Effect of FN rate on top dry weight (g) of *Iris siberica* ‘Caesar’s Brother’, 2003. Each symbol is based on 16 observations and vertical bars = ± SE.

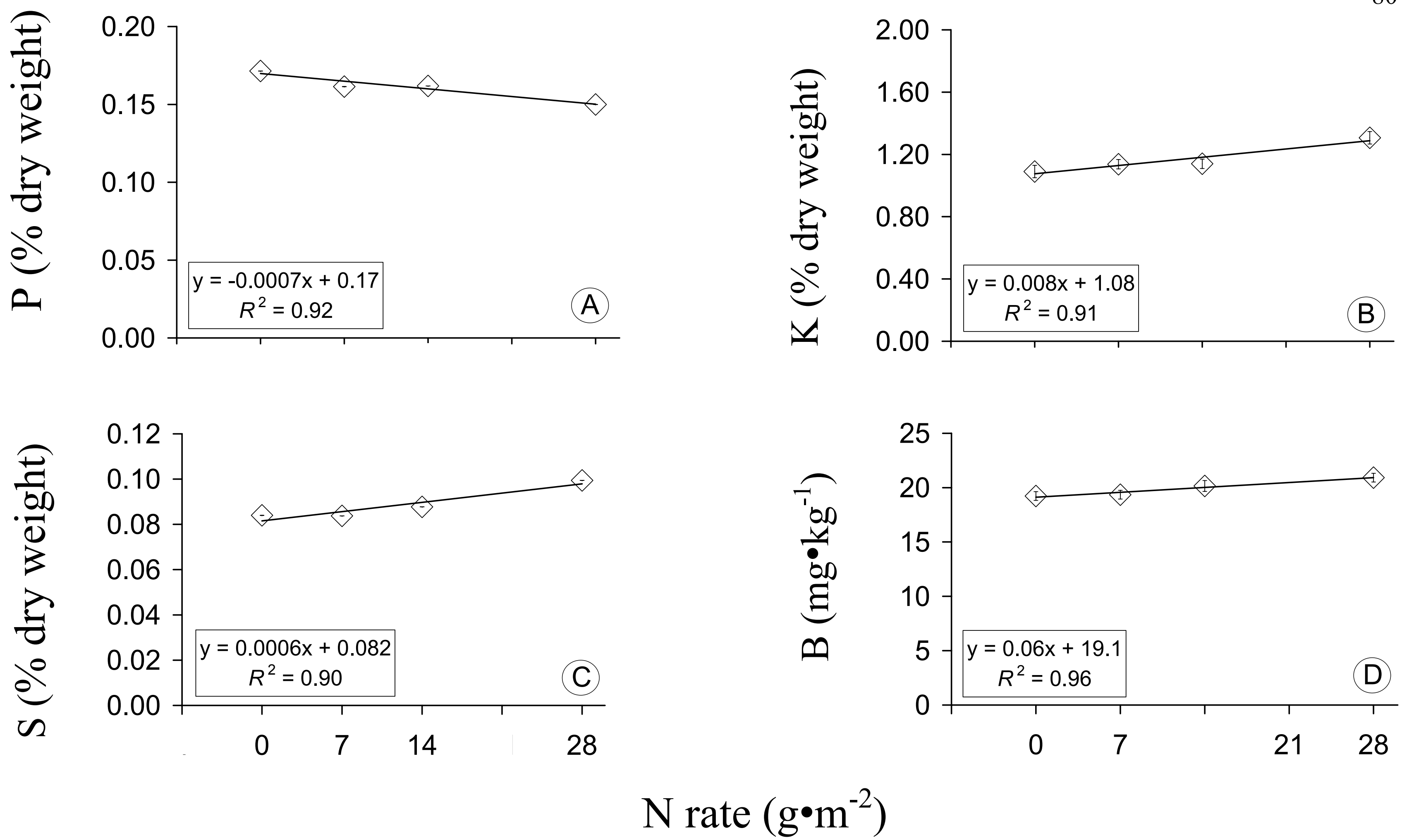

Fig. 13 Effect of FN rate on (A) phosphorus (P), (B) potassium (K), (C) sulfur (S), and (D) boron (B) concentrations in leaves collected Aug. 15, 2003, from *Iris siberica* ‘Caesar’s Brother’. Each symbol is based on 16 observations and vertical bars = ± SE.

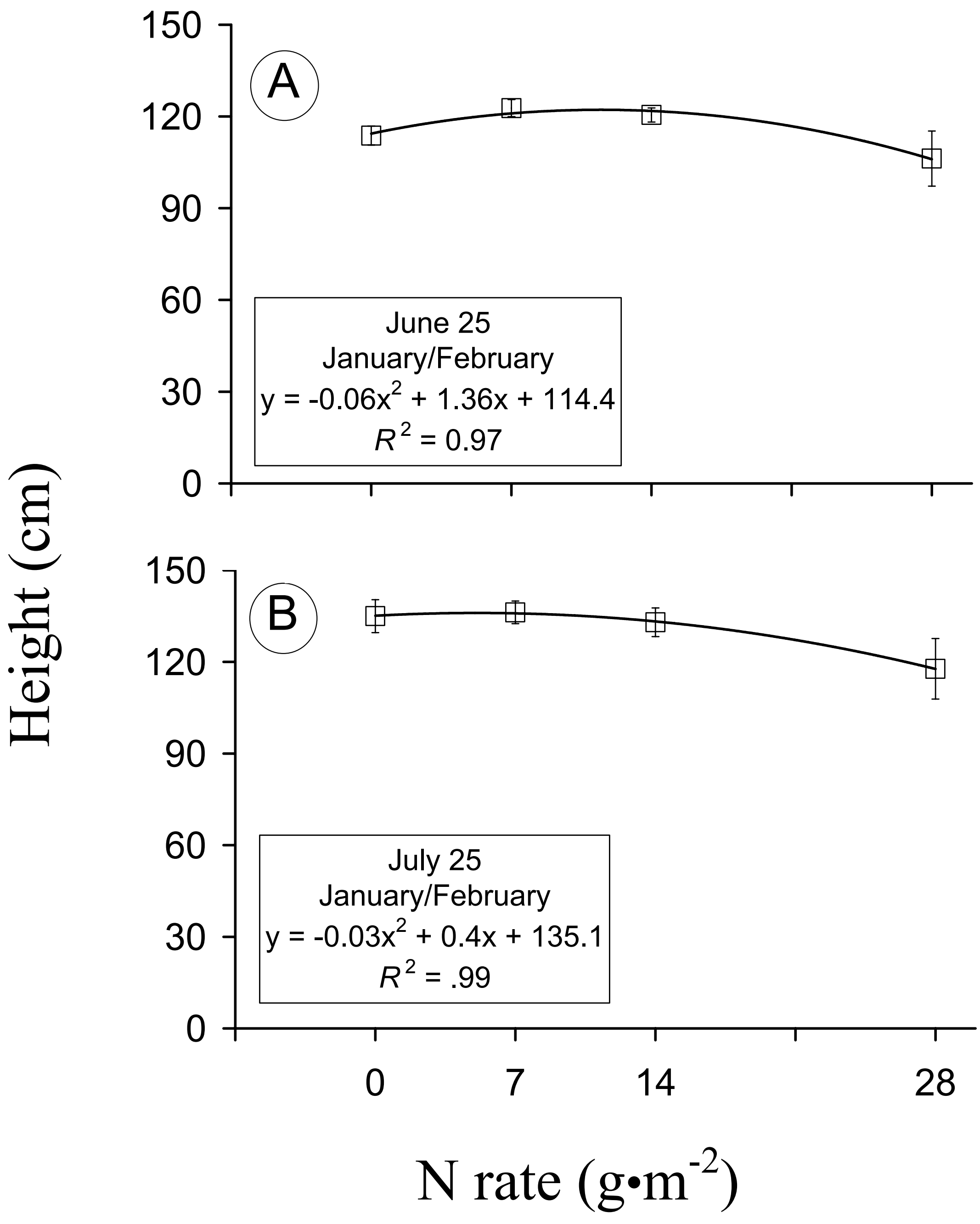

Fig. 14. Effect of FN rate applied in January/February on height of *Panicum virgatum* 'Shenandoah' on (A) June 25 and (B) July 25, 2003. Each symbol is based on 16 observations and vertical bars = ± SE.

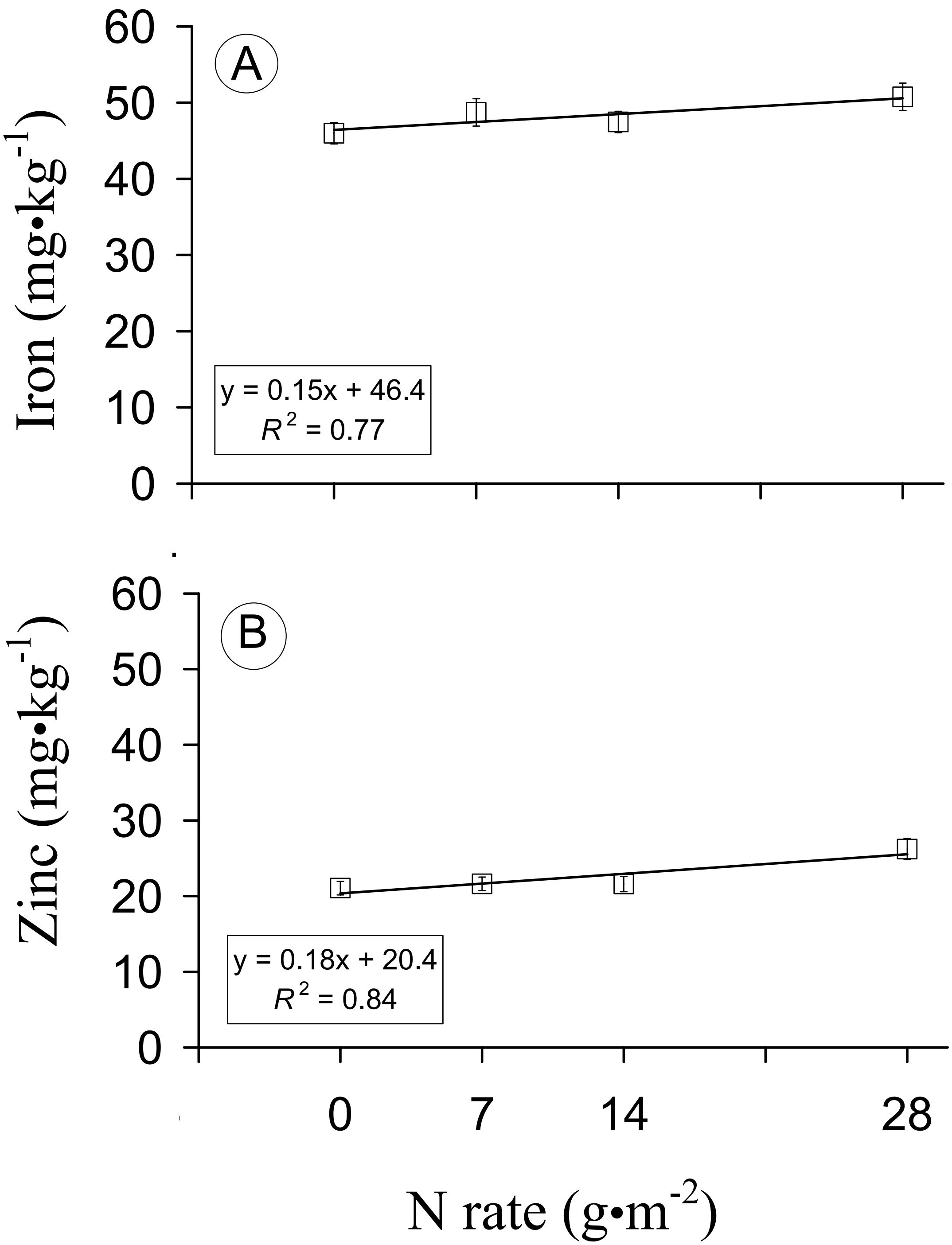

Fig. 15. Effect of N rate on (A) iron (Fe) and (B) zinc (Zn) concentrations in leaves collected Aug. 15, 2003, from *Panicum virgatum* 'Shenandoah'. Each symbol is based on 16 observations and vertical bars = ± SE.

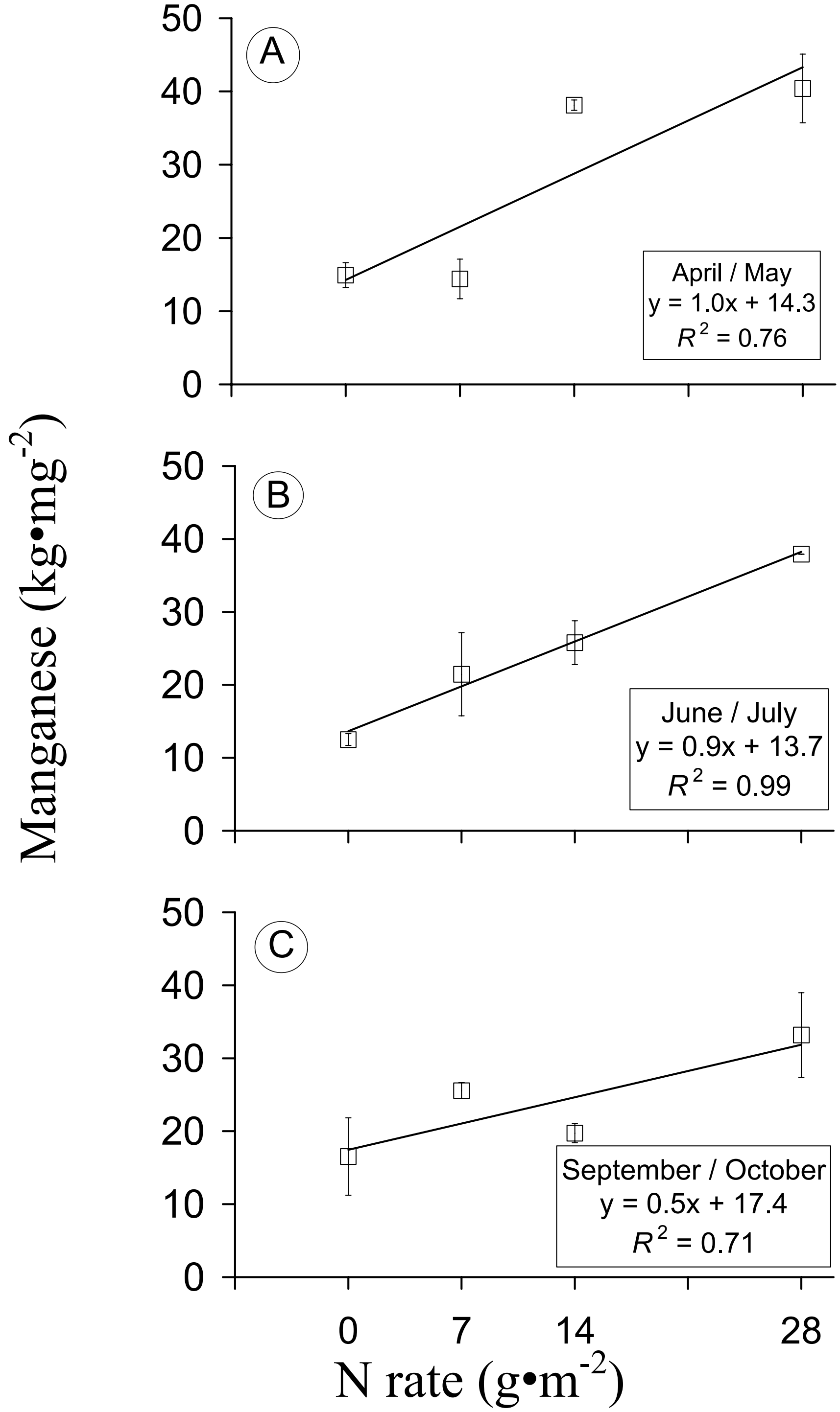

Fig. 16. Effect of FN rate applied in (A) April/May, (B) June/July, and (C) September/October on manganese concentrations (Mn) in leaves collected from Aug. 15, 2003, from *Panicum virgatum* 'Shenandoah'. Each symbol is based on 16 observations and vertical bars = ± SE.

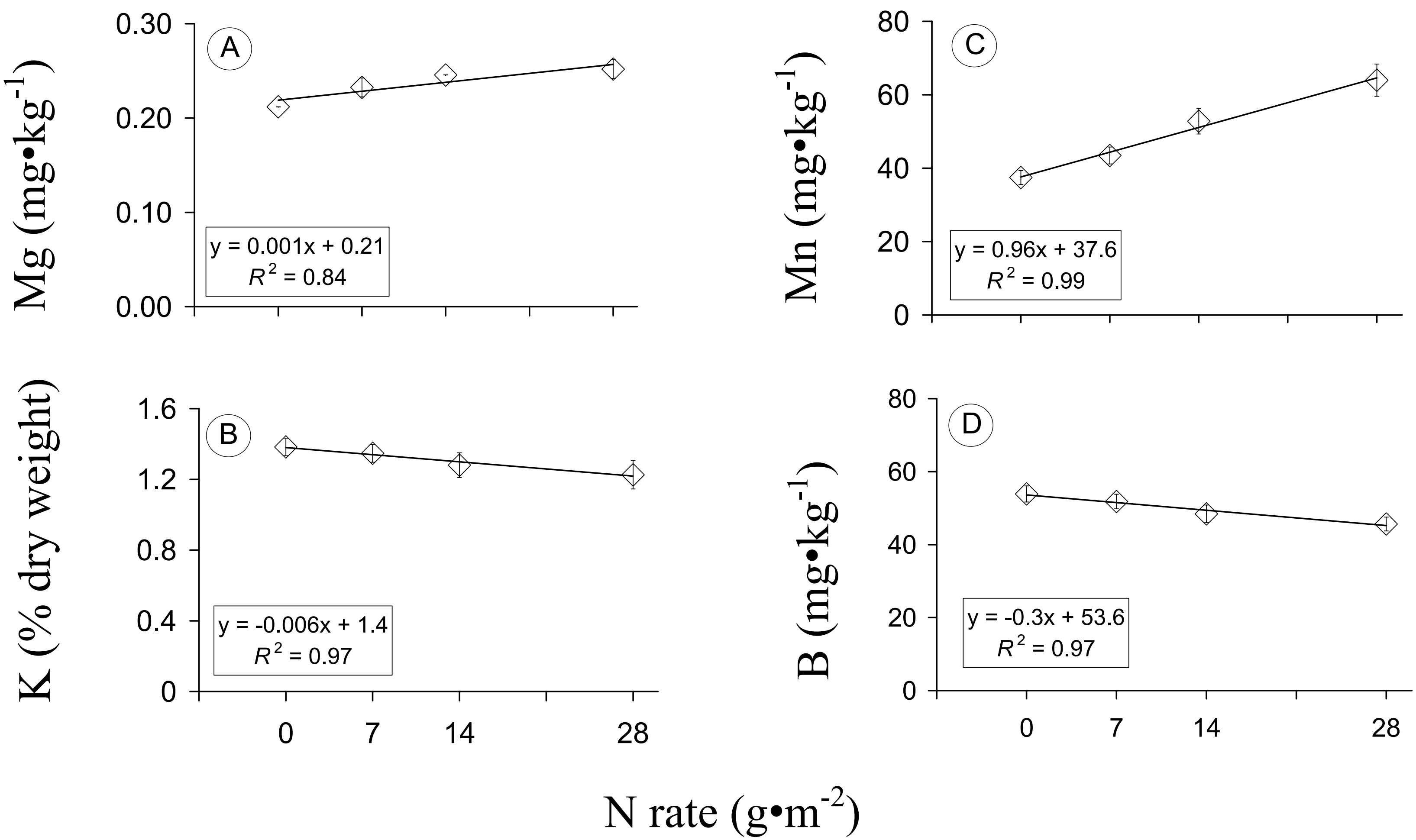

Fig. 17. Effect of FN rate on (A) magnesium (Mg), (B) potassium (K), (C) manganese (Mn) and, D) boron (B) concentrations in leaves collected Aug. 15, 2003, from *Sedum* 'Herbstfreude'. Each symbol is based on 16 observations and vertical bars = ± SE.

Influence of fertilizer nitrogen rate and time of application on soil solution nitrogen concentration in a simulated landscape[1]

Cynthia L. Proctor[2], Stuart L. Warren[3],

and Robert L. Mikkelsen[4]

Department of Horticulture Science
North Carolina State University
Raleigh, NC 27695-7609

[1]Received for publication__________________and in revised form____________________.

This research was supported in part by a grant from the Perennial Plant Association, 3383 Schirtzinger Rd., Hilliard, Ohio 43026 and the Landscape and Ground Management Assoc. of NC, 968 Trinity Rd, Raleigh, NC 27607. Technical assistance of William Reece and Peggy Longmire is gratefully acknowledged. From a thesis submitted by C.L.P. in partial fulfillment of the requirements for the M.S. degree.

[2]Graduate Teaching Assistant.

[3]Professor.

[4]Dr. Robert Mikkelsen, Western U. S. Director, Potash and Phosphate Institute, Davis, Calif.

Abstract

Use of herbaceous perennials in the landscape is common among homeowners, public gardens, and landscape companies. A mixture of species is usually planted together to vary growth habit and time of flowering. Currently there is little research based information on response of herbaceous perennials to FN rate and timing and the potential for loss of applied N via leaching. Therefore, we constructed simulated landscapes and installed *Coreopsis verticillata* L. 'Moonbeam' (thread leaf coreopsis), *Echinacea purpurea* L. ‘Magnus’ (purple coneflower), *Iris siberica* L. ‘Caesar’s Brother’ (Siberian iris), *Panicum virgatum* L. ‘Shenandoah’ (switchgrass), and *Sedum* L. ‘Herbstfreude’ ('Autumn Joy' sedum) and *Salvia* x *sylvestris* L. ’East Friesland’ (hybrid sage) in each plot to determine how FN rate and timing affected growth and performance of herbaceous perennials and potential N leaching. Porous ceramic cup lysimeters were installed *in situ* in each landscape plot 38 cm (15 inch) below the soil surface to examine the effects of FN on soil solution N concentrations. Four rates of FN: 0, 7, 14, and 28 $g•m^{-2}$ N (0, 1.5, 3.0, and 6.0 $lbs•1000\ ft^{-2}$) were divided equally into two applications and applied at the following times: 1) winter (Jan. 15 and Feb.15), 2) spring (Apr. 15 and May 15), 3) summer (June 15 and July 15), or 4) fall (Sept. 15 and Oct.15) beginning 2001. Soil solution samples were collected approximately every 2 weeks from Jan. 30, 2002 to Oct. 14, 2003 and analyzed to determine soil N (NO_3^- and NH_4^+) concentrations. The FN rate x FN timing interaction was never significant. Soil N concentrations remained above 10 $mg•L^{-1}$ for 110 days, 62 days, 52 days, and 192 days when applied during January/February, April/May, June/July, 2002 and September/October in 2001 respectively. The 28 $g•m^{-2}$ N (6.0 $lbs•1000\ ft^{-2}$) elevated N concentrations to 79 $mg•L^{-1}$, 135 $mg•L^{-1}$, and 138 $mg•L^{-1}$, after application was made in January/February, April/May, and June/July,

respectively. In 2003, soil N concentrations from FN rates of 7 g•m^{-2} N (1.5 lbs•1000 ft^{-2}) and 14 g•m^{-2} N (3.0 lbs•1000 ft^{-2}) applied in January/February, June/July, April/May and September/October remained below 10 mg•L^{-1} until the end of the study (Oct. 14, 2003). Nitrogen concentrations increased to 19 mg•L^{-1}, 38 mg•L^{-1}, and 21 mg•L^{-1}, after 28 g•m^{-2} N (6.0 lbs•1000 ft^{-2}) was applied in January/February, April/May, and June/July, respectively. Soil N concentrations increased linearly with increasing FN rates for approximately 180 days after fertilization (DAF) in 2002 and 136 to 150 DAF in 2003. Lower N concentrations during 2003 could have resulted from increased N uptake as the perennials increased in top dry weight from 2002 to 2003 from 16% to 880%. Soil N concentrations may have been subject to leaching during 2003 due to above average rainfall. In addition, the 0 g•m^{-2} N (no FN) maintained higher than expected soil N concentrations throughout the study indicating that mulch might provide plant available N over time. The results indicated that to maintain plant performance and minimize soil N solution concentrations, a low to moderate rate of FN [5 g•m^{-2} to 15 g•m^{-2} (1 lb•1000 ft^{-2} to 3 lb•1000 ft^{-2})] should be equally divided and applied in split applications in late winter/early spring and early fall.

Index words: herbaceous perennials, leaching, landscape.

Significance to the Industry

Use of herbaceous perennials in the landscape is common among homeowners, public gardens, and landscape companies. Since there is little research based information on response of herbaceous perennials to FN rate and timing, current FN recommendations for herbaceous perennials are broad and vague. It is unclear how FN landscape management practices may affect water quality. Data herein suggests that some current recommended rates of FN if applied to herbaceous perennials might lead to N losses. Applying FN at a low to moderate rate of FN [5 g•m^{-2} to 15 g•m^{-2} (1 lb•1000 ft^{-2} to 3 lb•1000 ft^{-2})] equally divided and applied in split applications in spring and early will maintain adequate plant performance and minimize potential N losses to leaching.

Introduction

Most of the N requirements in today's urban landscapes are met by the addition of synthetic fertilizers. The use of nitrogenous chemical fertilizers has benefited plant growth significantly, however, it has also contributed to the nitrate contamination of ground and surface water (U.S. Environmental Protection Agency, 2000). This results mainly from FN application in excess of plant N needs, and is a function of FN rate and the timing of FN application. Excess FN may accumulate in soil and become increasingly vulnerable to a variety of losses such as leaching and denitrification. Several factors influence the degree of leaching including soil type, irrigation, precipitation, N source, N rates, and season of application (timing) (Petrovic, 1990). Currently, the United States Environmental Protection Agency has established a maximum contaminant level (MCL) of 10 mg•L^{-1} NO_3-N (U.S. Environmental Protection Agency, 2000). Excess of this limit may result in a decline in water quality through eutrophication, loss of aquatic biota, and hypoxia (Brady and Weil, 1999).

Leaching of N is a non-point source of pollution and has been identified as the largest source of degradation to water quality in the United States (U.S. Environmental Protection Agency, 2000). Research on the effects of FN rate and time of application on crop growth and yields and subsequent N losses have been studied for many agronomic crops and turfgrass (Owens et al., 2000; Petrovic, 1990; Toth and Fox, 1998; Upendra et al., 1999).

Very little research has been conducted to determine potential N losses in the urban landscape other than turfgrass. Erickson et al. (2001) examined both surface and leaching N losses in a simulated urban landscape (woody ornamentals, groundcovers, and trees). Fertilizer N applications of 5 $g{\bullet}m^{-2}$ (1 $lb{\bullet}1000\ ft^{-2}$) were applied in April, August, and December to a landscape with 12 ornamental species during the first year after planting (fertilizer contained 58% urea, 37.5% sulfur-coated urea, and 4.5% ammonium nitrate). The mean soil percolate NO_3-N concentration ranged from 0.2 to 15.2 $mg{\bullet}L^{-1}$ throughout the year. No N was loss via surface runoff. The soil was covered with 8 cm (3 in) of mulch in combination with a sandy textured soil which may have minimized surface water movement. They recommended lowering the FN rate, maximizing plant N uptake, and increasing soil N storage.

University extension bulletins throughout the United States provide FN rate and timing recommendations for landscape ornamentals (Appleton and Kauffman, 1999; Rose and Smith 2001; Rosen et al., 2004; Good and Weir, 2004). These recommendations are often based on early research when maximizing FN response was the primary goal with little consideration for N loss effects on water quality. Currently, it is unclear how FN landscape management practices may affect water quality.

Timing of FN application relative to the nutritional demands of the plant may affect FN losses. Several fruit crop researchers have examined plant N use patterns to improve FN management strategies. Mature kiwifruit (*Actinidia deliciosa* ‘Hayward’) utilized FN the current season when applied before or during budbreak (Legard and Smith, 1992). Other studies reported fall applied FN was stored in perennial tissues and used for the next season’s growth (Kraimer et al., 2001; Rempel et al., 2004). Several studies stated that application of

FN in the fall particularly in the northern United States is susceptible to leaching due to heavy fall and winter precipitation (Petrovic, 1990; Roy et al., 2000; Snyder et al., 1984). In contrast, Niederholzer et al., (2001) reported more than 75% of FN ultimately absorbed by fall-fertilized trees persisted in the soil throughout winter and was absorbed during the subsequent spring and summer. Working with grapevines (*Vitas* sp.), Hanson and Howell (1995) and Williams and Smith (1991) reported that N absorption was most rapid between flower and veraison. In addition, after fruit harvest to leaf fall, trunks and roots of grapevines accumulated N reserves that supported early growth during the following year (Conradie, 1991). It is unknown how time of FN application may affect herbaceous perennial performance or potential N losses

In the past decade, herbaceous perennials have increased in popularity among commercial landscapers and homeowners. In 1999, herbaceous perennials accounted for 27% of all U.S. plant sales, with $642 million wholesale value among 7,391 producers (Hamrick, 2000). Their popularity can be attributed to the vast number of species with varying growth habits and flowering times. A mixture of species is usually planted together to vary growth habit and time of flowering. Since there is little research based information on response of herbaceous perennials to FN rate and timing, current FN recommendations for herbaceous perennials are broad and vague. Some believe that herbaceous perennials do not require additional FN to perform well while most extension bulletins suggest otherwise (Armitage, 1997; Still, 1994). Recommended FN rates for herbaceous perennials in the southeastern United States range from 0 to 25 $g \cdot m^{-2}$ N (0 to 5 $lbs \cdot 1000\ ft^{-2}$) while recommendations for FN timing vary from split applications (i.e., early spring and mid-summer), once at budbreak or simply apply “in the growing season” (Brown, 1996; Evans, 2000; Kessler, 2002; Relf, 2002; Thomas, 1999). Commercial literature recommend as high as 12.2 g•m^{-2} N (2.5 lbs•1000 ft^{-2}) applied annually for established herbaceous perennials (Sinnes, 1981).

Increased use of herbaceous perennials along with little research based fertility guidelines may lead to over application of FN in fear of developing a nutrient deficient or a poor performing plant. Application of this "insurance fertilizer" may increase the risk of NO_3-N losses and greater potential of NO_3-N pollution of groundwater (Toth and Rox, 1998). This scenario could contribute to water quality issues surrounding non-point source pollution. In the 21st century fertility management without precise research-based guidelines will probably not be tolerated.

Although the underlying source of elevated N in watersheds remains unclear, one possibility includes FN runoff and leaching from residential and commercial landscapes, where FN is used routinely. The landscape industry needs to be environmentally responsible otherwise they may face tremendous public and legislative pressure. Thus, research is needed that examines how FN rate and time of application affects growth and performance of herbaceous perennials, and potential N losses.

A companion paper (Proctor et al., 2006) reports significant differences in the growth and ornamental characteristics of five herbaceous perennials in response to FN rate and timing. The objective of this research was to determine the effect of FN rate and timing on soil solution N concentrations.

Materials and Methods

The experiment was conducted at the Horticulture Field Laboratory, North Carolina State University, Raleigh, from Oct. 2000 to Oct. 2003. Prior to planting, the Cecil clay soil (clayey, kaolinitic, thermic Typic Hapludult) was amended by incorporating 2.5 cm (1 inch) of milled pine bark [<1.3 cm (<0.5 inch)] and pH, phosphorus (P), and potassium (K) were adjusted to levels recommended by the North Carolina Dept. of Agric. (NCDA) soil test report. To create individual landscapes, raised beds were constructed and individual plots 2.4 x 3.4 m (8 x 11 ft) were laid out and a plastic barrier was installed to a depth of 61 cm (24 inch) between plots to maintain treatment integrity. In addition, there was a 1.5 m (5 ft) sod (*Festuca arundinacea* 'K-31', K-31 tall fescue) buffer between each block.

The seven species used in this study were chosen to encompass a wide range of growth habits and flowering times in addition to their popularity among homeowners, landscapers, and public gardens. Most landscape perennial beds contain a variety of species ranging from early spring to fall flowering times. Examining the fertility requirements of a perennial bed instead of individual fertility requirements more resembles a typical landscape found within a home or commercial setting. The following perennials from 2.8 L (# 1) containers were planted in October 2000 in each plot: two *Coreopsis verticillata* L. 'Moonbeam' (thread leaf coreopsis), one *Echinacea purpurea* L. 'Magnus' (purple coneflower), one *Iris siberica* L. 'Caesar’s Brother' (Siberian iris), one *Panicum virgatum* L. 'Shenandoah' (switchgrass), and one *Sedum* L. 'Herbstfreude' ('Autumn Joy' sedum) and one *Salvia* x *sylvestris* L. 'East Friesland' (hybrid sage) (Fig. 1). Three rhizomes of *Canna* L. 'President' (canna lily) were planted in each plot at the same time. All plots received 5 cm (2 inch) of mulch (composted yard waste) after planting. If rainfall did not supply 2.5 cm (1 inch) of water weekly, supplemental irrigation was applied via drip emitters, (Xeri-bug, Rain Bird, Glendora, CA) at a rate of 1.9 $L \bullet h^{-1}$ (0.5 $gal \bullet h^{-1}$). Additional soil testing was performed by the NCDA for each plot in Mar. 2002 and 2003 and the pH, P, and K levels were adjusted accordingly.

The experiment was a 4 x 4 factorial in a randomized complete block design with four replications. Treatments included four rates of FN: 0, 7, 14, and 28 $g \cdot m^{-2}$ N (0, 1.5, 3.0, and 6.0 $lbs \cdot 1000\ ft^{-2}$) and four timings of FN application. Each FN rate was divided equally into two applications and applied at the following times: 1) winter (Jan. 15 and Feb.15), 2) spring (Apr. 15 and May 15), 3) summer (June 15 and July 15) or 4) fall (Sept. 15 and Oct.15). Previous turfgrass studies reported that maturity influenced N uptake given that more extensive root systems have a greater surface area to absorb plant available N (Bowman et al., 2002). Thus, FN treatments did not begin until 11 months after installation. All FN was applied as granular ammonium nitrate (NH_4NO_3) with handheld shakers beginning Sept. 15, 2001 with the last FN application applied July 15, 2003. Prior to this study, no FN has been applied to this site since 1997.

To examine the effects of FN on soil solution N concentrations, porous ceramic cup lysimeters were created and installed *in situ* in each landscape plot to sample soil solution at 38 cm (12 inch) below the soil surface. All ceramic cup lysimeters were designed and constructed as follows. The ceramic cups were a round bottom, tapered neck with 1.0 bar high flow and a maximum pore size of 2.5 µm (SoilMoisture, Santa Barbara, CA). Ceramic cups were attached to a 1.3 cm (0.5 inch) diameter schedule 80, 46 cm (18 inch) long, pvc pipe. Female iron pipe threaded end caps were placed at the top of the pvc pipe and two 0.3 cm (0.13 inch) holes were drilled to fit two nylon capillary tubes, one extraction and one pressure. The extraction tube was placed inside the lysimeter and was long enough to reach the ceramic cup and protruded 8 cm (3 inch) from the cap while the pressure tube reached 8 cm (3 inch) inside the lysimeter and 8 cm (3 inch) outside the lysimeter. The extraction tube was clamped with a clip and the pressure tube was sealed with a removable cap.

Sixty-four lysimeters (one in each plot) were installed on Dec. 19, 2001. A mud slurry using soil from the hole was poured back into the hole before insertion of the lysimeter to ensure soil contact with the ceramic cap. The top 8 cm (3 inch) of the lysimeter protruded above the soil surface to access tubes for applying a vacuum and to extract soil solution. A hand pump was used to create a vacuum of 50 kPa (7.3 psi) after insertion to promote soil contact.

Soil solution samples were collected approximately every 2 weeks from Jan. 30, 2002 to Oct. 14, 2003. The sampling dates for 2002 were Jan.30, Feb. 6, Feb. 20, Mar. 8, Mar. 20, Apr. 5, Apr. 25, May 3, May 23, June 10, July 1, July 16, July 26, Aug. 7, Sept. 5, Sept. 13, Sept. 23, Oct. 17, Nov. 3, Nov. 18, Dec. 1, and Dec. 15. The sampling dates for 2003 were Jan. 9, Jan. 23, Feb. 6, Feb. 28, Mar. 11, Mar. 31, Apr. 10, Apr. 24, May 20, May 27, June 23, July 4, July 18, Aug. 4, Aug. 19, Sept. 9, Sept 30, and Oct. 14. A vacuum [50 kPa (7.3 psi)] was applied to each lysimeter 48 h prior to each sample date. Rainfall was collected from Nov. 2002 to Nov. 2003. All samples and rainfall were kept frozen until analyzed for NO_3^- -N and NH_4^+-Nconcentrations.

Nitrate-N and NH_4-N in the soil solution and rain water were determined colormetrically with a Lachat QuikChem 8000 Automated Ion Analyzer (Lachat, 1995). Nitrate-N concentrations were analyzed using QuikChem Method 10-107-04-10A, while NH_4-N concentrations were analyzed using QuickChem Method 10-107-06-2-A (Lachat, 1995).

All data were subjected to analysis of variance procedures (ANOVA) and regression analysis, where appropriate. Treatments means were separated by Fisher's protected least significant difference (LSD), *P*= 0.05, where appropriate. To be able to compare the effects of FN timing on soil N solution concentration we needed another parameter other than chronological time. If FN timing treatments were compared based on chronological time there was an automatic significant response since the FN timing treatments created differences in soil N solution concentration with the treatments themselves. For example, FN applied on January/February was always statistically greater during those months compared to FN applied at any other time. Therefore, we assigned each lysimeter sample date x FN rate x FN timing treatment a number based on days after fertilization (DAF). This allowed us to test statistically whether FN timings were different based on number of days since FN application. The FN rate x FN timing interaction was not significant for any of the measured parameters, therefore, except for Fig. 2 FN rate is presented averaged over FN timing and FN timing is presented averaged over FN rate.

Results and Discussion

Reported soil N concentrations are for total N (NH_4-N + NO_3-N) due to the small quantity of NH_4-N found in all samples (data not presented) and will be referred to as simply N for the remainder of the paper. To provide the reader with a perspective of how soil solution N concentration responded to FN application chronologically, the soil solution N concentrations are presented from Jan. 30, 2002 to Oct. 14, 2003 after 7, 14 or 28 $g•m^{-2}$ N (1.5, 3.0 or 6.0 $lbs•1000\ ft^{-2}$) were applied in January/February, April/May, June/July, and September/October in Fig. 2. The soil N concentrations in the 0 $g•m^{-2}$ N treatment were subtracted from the 7, 14, and 28 $g•m^{-2}$ N rates.

Soil solution N concentrations remained above 10 mg•L^{-1} for 110 days (June 10, 2002), 62 days (July 16, 2002), 52 days (Sept. 5, 2002), and 192 days (April 25, 2002), when applied during January/February, April/May, June/July, 2002 and September/October in 2001 respectively, regardless of N rate. The 28 g•m^{-2} N (6.0 lbs•1000 ft^{-2}) drove N concentrations to 79 mg•L^{-1} on April 5, 135 mg•L^{-1} on July 1, and 138 mg•L^{-1} on July 26, after application was made in January/February, April/May, and June/July, respectively. Sample collection for the September/October FN applications in 2001 did not begin until 128 days after the first FN application (Sept. 15, 2001) however, soil N concentrations for all FN rates applied in September/October still exceeded 10 mg•L^{-1} until April 25. Although depth of root systems varied among species, rooting depth never reached beyond 25 cm (10 inch) for any species (Proctor, 2006). Since the lysimeters were collecting soil solution from an average depth of 38 cm (15 inch) which was below the rooting depth of the plants, N in the soil solution could be subject to leaching. Petrovic (1990) stated that this was true assuming little upward movement of water from below the root zone.

During 2002, Raleigh, NC experienced a drought from late winter to September (Fig. 3) therefore most of the water received during this time was from irrigation. While the 2.5 cm (1 inch) was adequate for plant growth, this supplemental irrigation possibly created stalled wetting fronts that contained high concentrations of nitrate at time of sampling. During dry conditions, Roy et al. (2000) reported NO_3-N remained at depths of 25 to 50 cm (10 to 20 in) in the soil profile after 15 g•m^{-2} N (3 lbs•1000 ft^{-2}) were applied in May, July, and September until a wetting front from an autumn rainfall arrived.

Much lower concentrations of soil solution N were found after FN treatments were applied in 2003 (Fig. 2). Soil N concentrations from FN rates of 7 g•m^{-2} N (1.5 lbs•1000 ft^{-2})

and 14 g•m^{-2} N (3.0 lbs•1000 ft^{-2}) applied in January/February, June/July, April/May and September/October remained below 10 mg•L^{-1} until the end of the study (Oct. 14, 2003). Nitrogen concentrations increased to 19 mg•L^{-1} on Mar. 31, 38 mg•L^{-1} on June 23, and 21 mg•L^{-1} on Sept. 30, after 28 g•m^{-2} N (6.0 lbs•1000 ft^{-2}) was applied in January/February, April/May, and June/July, respectively (Fig. 2). Lower N concentrations during 2003 could have resulted from increased N uptake as the perennials herein increased in top dry weight from 2002 to 2003 from 16% to 880%. In addition, rainfall for 2003 was above average (Fig. 3), thus nitrate, an anion, which is highly mobile and subject to leaching loss when both soil nitrate content and water movement are high (Havlin et al., 1999) may have subjected to high leaching losses. In field crops, elevated fronts of nitrate often are observed in the soil profile for several weeks after fertilization and the fronts dissipate with time as the nitrate is taken up by plant roots or leached (Wagger et al., 1993). Furthermore, when soils are saturated, conditions are favorable for denitrification and may also account for N losses (Havlin et al., 1999). The different responses recorded for 2002 and 2003 illustrate the impact that year to year variation in weather can have on soil N solution concentrations.

Atmospheric deposition of NH_4^+ is a concern throughout the Neuse River Basin in North Carolina (Aneja et al., 2000; Whitall and Paerl, 2001). Nitrogen concentrations found in rain water taken after each rain event were < 2 mg•L^{-1}. In addition N concentrations in the irrigation water samples were negligible (< 0.5 mg•L^{-1}). Therefore, both rainfall and irrigation water contributed minimal N to the soil solution.

In 2002, soil N concentrations increased linearly with increasing FN rates from 0-15 to 171-182 DAF (0-15, 31-40, 61-80, 92-101, 123-140, and 171-182 DAF presented, Fig. 4). Soil N concentrations peaked approximately 30-60 DAF whereas, soil N concentrations remained above 10 mg•L^{-1} until 171-182 DAF for 7 g•m^{-2} N (1.5 lbs•1000 ft^{-2}), 14 g•m^{-2} N (3.0 lbs•1000 ft^{-2}), and 28 g•m^{-2} N (6.0 lbs•1000 ft^{-2}). In 2003, soil N concentrations increased linearly with increasing FN rates from 36-50 to 120-128 DAF (36-50, 81-95, 98-115, and 120-128 presented, Fig. 5). The N concentrations in 2003 peaked approximately 81-95 DAF however, N concentrations remained above 10 mg•L^{-1} through 120-128 DAF. Compared to 2002, soil N concentration was much lower. Increased plant uptake of N or N leaching due to high rainfall during 2003 may have reduced soil N concentrations.

The 0 g•m^{-2} N (no FN) maintained higher than expected soil N concentrations throughout the study (Figs. 4 and 5). In field soil, N can be available from residual N, soil mineralization, and FN, if applied. No FN had been applied to this site since 1997 so we propose it is unlikely that residual N nor FN contributed to soil N solution concentration. Similarly with an average humic matter of < 1% (data not presented), N available from soil mineralization was probably low even though we did not measure it. In addition, N contributed from rainfall and irrigation water was likewise low. Therefore, it was surprising to see these elevated rates of N in the no FN treatment. Unlike field-grown perennial crops, herbaceous perennials in an urban landscape have another source of N unique to landscapes, mulch. Five cm (2.5 in) of composted yard waste was applied as mulch at planting in this study. Nitrogen in composted yard waste can range from 0.7% to 2.0% (Lloyd, 2001). Lloyd (2001) examined the effects of three mulches [composted yard waste (a mixture of wood chips, leaves, and grass clippings, C:N ratio = 20), ground wood pallets (C:N ratio = 100), and no mulch (bare soil)] on growth of river birch (*Betula nigra* 'Cully' Heritage) and rhododendron (*Rhododendron* 'Pioneer Silvery Pink'). All three mulch treatments received no FN (0 N) or 14 g•m^{-2} N (3 lbs•1000 ft^{-2}) applied in split applications (at budbreak and early October) yearly from 1998 to 2000. Compared to plants receiving no FN, FN increased growth and foliar N concentrations of river birch and rhododendron when mulched with ground wood pallets or no mulch (bare soil) compared to plants receiving no FN. However, growth and foliar N concentrations of rhododendron and river birch were similar when grown with composted yard waste with or without FN. Lloyd (2001) also reported soil N concentrations were similar in the composted yard waste treatment receiving no FN compared to the soil N concentration in the ground wood pallets and no mulch (bare soil) treatments receiving FN indicating that composted yard waste can serve as a high-quality organic fertilizer. Nitrogen measured in the soil solution under the composted yard mulch receiving no FN averaged 30 $mg \bullet L^{-1}$ N compared to 10 $mg \bullet L^{-1}$ N with no mulch (bare soil) receiving FN. In the absence of FN, N mineralization from composted yard mulch along with soil mineralization may have increased soil N concentration in the treatments receiving 0 $g \bullet m^{-2}$ FN in this study.

Data was organized to determine if N concentrations found in soil solutions were effected by the number of DAF for each FN timing x FN rate combination. Although N concentrations fluctuated in each FN timing, soil N concentrations were consistently above 10 $mg \bullet L^{-1}$ for January/February, April/May, June/July, and September/October FN timing until 231-240, 102-122, 123-140, and 281-301 DAF in 2002, respectively (Table 1). The extended period of time that soil N concentrations were greater than 10 $mg \bullet L^{-1}$ with the January/February and September/October FN applications may be a reflection of reduced N uptake during those windows of application. Likewise, the shortened time period that soil N concentrations were greater than 10 $mg \bullet L^{-1}$ for April/May and June/July FN applications may reflect increased nutrient uptake during the growing season. Many perennial plants exhibit a high rate of N uptake during active growth (Hanson and Howell, 1995). During April/May and the rest of the growing season, most herbaceous perennials are actively growing. Growth index measurements indicated the perennials herein were actively growing from May to early August (Proctor et al., 2006). Thus, N uptake after FN application in April/May and June/July would be greatest. There were few significant differences among FN timings after 231-240 DAF.

January/February FN timing is the dormant season for most perennials so it was not unexpected that N concentrations were significantly higher from 80-91 to 171-182 DAF compared to April/May and June/July in 2002 potentially due to decreased N uptake (Table 1). High soil N concentrations found in April to August after FN was applied in January/February may also be attributed to drought conditions as the irrigation wetting front may have leached the N to approximately 30 cm (15 inch) which is beyond the root zone for plant uptake until rainfall was adequate to move the nitrate below the sampling depth (Roy et al., 2000).

High N concentrations throughout 2002 indicated that applied N exceeded the N needs of the selected herbaceous perennials. However, N concentrations found in 2002 might be less representative of a stable perennial landscape since the plants were continuing to increase in size. Furthermore, drought conditions could stress plants and depress N uptake even though irrigation was applied.

During 2003, total soil N concentrations were slightly above 10 $mg.L^{-1}$ from 20 to 128 DAF or until the termination of the study (Table 2). Significance of N concentrations varied among N timings from 0-10 to 120-128 DAF. Low soil N concentrations in soil solutions were possibly due to N leaching past the root zone as a consequence of frequent rainfall events during 2003. In average years, the highest rainfall months are June through September. Nitrate is highly mobile and subject to leaching loss when both soil nitrate content and water movement are high (Havlin et al., 1999). Results herein indicate that current fertility recommendations for herbaceous perennials may lead to contamination of groundwater tables.

Plant reserves can be an important N source for perennial plants. Rempel et al. (2004) reported 24% to 37% of the N in new growth of red raspberry (*Rubus idaeus* L. ‘Meeker’) came from FN. Thus, the remaining N (63% to 76%) was derived from soil mineralization and plant reserves. Sixty percent of the N present in new growth in kiwifruit (*Actinidia deliciosa*) was from remobilization of N stored in the vines (Ledgard and Smith, 1992). Research with apples (*Malus x domestica* Borkh.‘Mutsu’) and pear (‘Comice’/’Provence’ quince BA29) have reported similar results (Sanchez et al., 1991; Toselli et al., 2000). Nitrogen mobilization may have become more important in this study as plants moved from the 1st to the 3rd growing season. The more N available from soil mineralization and N mobilization the less of a response that one might expect from FN which could lead to increased N losses. Thus, FN rates could be lowered while maintaining plant performance.

In this study, herbaceous perennial response to FN rate and time of application varied with species. Growth and ornamental characteristics of *Canna* L. ‘President’ were unaffected by FN rate and timing in 2003 (Proctor, 2006). Thus, it appears that N mobilization and N mineralization from the mulch provided adequate N. In contrast, number of flowers, visual evaluation, growth index (GI), and top dry weight of *Coreopsis verticillata* 'Moonbeam' increased linearly with increasing rate of FN (Proctor, 2006). In addition, GI was greater when FN was applied in January/February and April/May compared to June/July. Rate of FN for maximum performance of the remaining species ranged from 6.7 g·m^{-2} N (1.4 lb•1000 ft^{-2}) to 15.5 g•m^{-2} N (3.1 lb•1000 ft^{-2}). Optimal time of application for most species was either a late winter/early spring application or an early fall application. Neither growth nor ornamental performance of any of the species in this study was maximized with a summer application of FN.

The FN rate and time of application recommendation should consider both plant performance plus potential for N losses. Data herein suggests that N losses may increase with increasing rate of FN. To cover the needs of a wide variety of perennial species that usually exists in one landscape as well as minimize N concentrations in the soil solutions, we recommend a low to moderate rate of FN [5 g•m^{-2} to 15 g•m^{-2} (1 lb•1000 ft^{-2} to 3 lb•1000 ft^{-2})] be equally divided and applied in split applications in late winter/early spring and early fall. Although a split application may increase costs to landscapers, this management practice may increase the availability of FN to herbaceous perennials at critical growth stages. Thus, allowing for application of a lower FN rate while maintaining the growth and aesthetic qualities of herbaceous perennials.

Literature Cited

Appleton, B. and K. Kauffman 1999. Fertilizing landscape trees and shrubs. Virginia Coop. Ext. Serv. Publ. 430-018.

Aneja, V.P., J.P. Chauhan, and J. Walker. 2000. Characterization of atmospheric ammonia emissions from swine waste storage and treatment lagoons. Water Resources Res. Instit., Univ. North Carolina, Chapel Hill.

Armitage, A.M. 1997. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 2nd ed. Stipes Publishing. Champaign. Ill.

Bowman, D.C., C.T. Cherney, and J. T.W. Rufty. 2002. Fate and transport of nitrogen applied to six warm season turfgrasses. Crop Sci. 42:833-841.

Brown, S.P., L. Hodyss, and D. Marshall. 1996. Flowering perennials in Florida. Florida Sta. Univ. Bul. ENH-68.

Brady, N.C. and R.R. Weil. 1999. The Nature and Properties of Soils. 12th ed. Prentice Hall, Upper Saddle River, N.J.

Environmental Protection Agency. 2000. National management measures to control non-point source pollution from agriculture. [http://www.epa.gov/owow/nps/agmm/index.html] *(last accessed 04/20/04)*.

Conradie, W.J. 1991. Distribution and translocation of nitrogen absorbed during early summer by two year old grapevines grown in sand culture. Amer. J. Enol. Viticult. 42(3):145-148.

Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustine turf and alternative residential landscape. Crop Sci. 41:1889-1895.

Evans, E. 2000. Perennials: Maintaining. North Carolina State Univ. Coop. Ext. Serv. [http://www.ces.ncsu.edu/depts/hort/consumer/factsheet/perennials/text_maintaining.html] *(last accessed 01/04/05)*.

Good, G. and R. Weir. 2004. Suggested practices for planting and maintaining trees and shrubs. Cornell Coop. Ext. Publ. Bul. 24.

Hamrick, D. 2000. Dynamite in gallon pots. Grower Talks. 64(2):40-47.

Hanson, E.J.and G.S. Howell. 1995. Nitrogen accumulation and fertilizer use efficiency by grapevines in short-season growing areas. HortScience. 30:504-507.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil fertility and fertilizers: An introduction to nutrient management. Prentice Hall, Upper Saddle River, N.J.

Kessler, J.R., J.D. Williams, and B. Clendenen. 2002. Herbaceous perennials in Alabama AN-566.

Kraimer, R.A., W.C. Lindemann, and E.A. Herrera. 2001. Distribution of 15n-labeled fertilizer applied to pecan: A case study. HortScience 36:308-312.

Lachat. 1995. Quickchem 8000 continuum series automated ion analyzer. Lachat, Inc., Milwaukee, Wis.

Ledgard, S.F. and G.S. Smith. 1992. Fate of ^{15}N-labelled nitrogen fertilizer applied to kiwifruit (*Actinidia deliciosa*) vines. Plant Soil. 147:59-68.

Lloyd, J.E. 2001. Trophic cascades in ornamental landscapes mediated by soil organic matter: Effects of mulch and fertilization on microbial activity, nutrient cycling, plant carbon allocation, and insect herbivores. PhD Diss., Ohio State Univ., Columbus.

Niederholzer, F.J.A., T.M. DeJong, J.L. Saenz, T.T. Muraoka, and S.A. Weinbaum. 2001. Effectiveness of fall versus spring soil fertilization of field-grown peach trees. J. Amer. Soc. Hort. Sci. 126:644-648.

Owens, L.B., R.W. Malone, M.J. Shopitalo, W.M. Edwards, and J.V. Bonta. 2000. Lysimeter study of nitrate leaching from a corn-soybean rotation. J. Environ. Qual.29:467-474.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual.19:1-14.

Proctor, C.L. 2006. Effect of fertilizer nitrogen rate and timing on growth and performance of six herbaceous perennials and soil solution nitrogen concentration in a simulated landscape. MS Thesis, North Carolina State Univ., Raleigh

Relf, K.and E. Ball. 2002. Perennials: culture, maintenance and propagation. Virginia Coop. Ext. Bul. 426-203.

Rempel, H.G., B.C. Strik, and T.L. Righetti. 2004. Uptake, partitioning, and storage of fertilizer nitrogen in red raspberry as affected by rate and timing of application. J. Amer. Soc. Hort. Sci. 129:439-448.

Rose, M.A. and E. M. Smith. 2001. Fertilizing landscape plants. Ohio State Univ. Coop. Ext. Serv. Bul. HYG-1002-96.

Rosen, C. J., P.M. Bierman, and R.D. Eliason. 2004. Soil test interpretation and fertilizer management for lawns, turf, gardens, and landscape plants. Univ. Minnesota.Ext. Serv. Publ. BU-1731.

Roy, J.W., G.W. Parkin, and C. Wagner-Riddle. 2000. Timing of nitrate leaching from turfgrass after multiple fertilizer applications. J. Water Qual. Res. 35:735-752.

Sanchez, E.E., T.L. Righetti, D. Sugar, and P.B. Lombard. 1991. Recycling of nitrogen in field-grown 'Comice' pears. J. Hort. Sci. 66:479-486.

Sinnes, A.C. 1981. All about perennials. Chevron Chem. Co., San Francisco, Calif.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in bermudagrass turf. Agron. J. 76:964-969.

Still, S.M. 1994. Manual of Herbaceous Ornamental Plants. 4th ed. Stipes Publishing. Champaign,Ill.

Thomas, P.A. 1999. Flowering perennials for Georgia gardens. Univ. Georgia Coop. Ext. Serv. Bul. 944.

Toselli, M., J.A. Flore, C. Zavalloni, and B. Marangoni. 2000. Nitrogen partitioning in apple trees as affected by application time. HortTechnology 10:136-141.

Toth, J.D.and R.H. Fox. 98. Nitrate losses from a corn-alfalfa rotation: Lysimeter measurement of nitrate leaching. J. Environ. Qual. 27:1027-1033.

Upendra, S.M., B.P. Singh, S. Rahman, and V.R. Reddy. 1999. Soil nitrate-nitrogen under tomato following tillage, cover cropping, and nitrogen fertilization. J. Environ. Qual. 28:1834-1844.

Wagger, M.G., T.J. Sheets, and R.B. Leidy. 1993. Runoff potential and chemical transport in agricultural soils. Rep. No. 280. Water Sources Res. Inst., North Carolina State Univ., Raleigh.

Whitall, D.R.and H.W. Paerl. 2001. Spatiotemporal variability of wet atmospheric nitrogen deposition to the neuse river estuary, North Carolina. J. Environ. Qual. 30:1508-1515.

Williams, L.E. and R.J. Smith. 1991. The effect of rootstock on the partitioning of dry weight, nitrogen, and potassium, and root distribution of cabernet sauvignon grapevines. Amer. J. Enol. Viticult. 42:118-122.

Table 1. Effect of FN timing on total-N (NH_4-N + NO_3-N) concentration found in soil solution at days after fertilization (DAF) 38 cm (15 in) beneath the soil surface, 2002.

Nitrogen timing	DAF 0-15	16-30	31-40	41-60	61-80	80-91	92-101	102-122	123-140	141-155	156-170
	------------------------------------- mg•L^{-1} -------------------------------------										
January/February	23.5 b[z] (Jan 30)	16.7 b (Feb 6)	20.7 b (Feb 20)	33.4 a (Mar 8)	39.7 a (Mar 20)	38.6 a (Apr 5)	43.7 a (Apr 25)	39.1 a (May 3)	40.5 a (May 23)	17.8 a (June 10)	17.1 a (July 1)
April/May	13.7 c (Apr 25)	36.6 a (May 6)	26.6 b (May 23)	32.5 a (June 10)	43.1 a (July 1)	21.0 b (July 16)	28.5 b (July 26)	10.3 c (Aug 7)	8.2 c (Sept 5)	6.7 b (Sept 13)	9.0 b (Sept 23)
June/July	35.4 a (July 1)	13.6 b (July 16)	48.4 a (July 26)	27.7 a (Aug 7)	25.1 b (Sept 5)	16.1 b (Sept 13)	11.8 c (Sept 23)	18.1 b (Oct 17)	10.2 c (Nov 3)	6.3 b (Nov 18)	7.4 b (Dec 1)
September/October	-[y]	-	-	-	-	-	-	36.1 a (Jan 30)	26.1 b (Feb 6)	23.0 a (Feb 20)	22.4 a (Mar 8)

Table 1 cont'd

Nitrogen timing	Days after fertilization 171-182	183-210	211-230	231-240	241-260	261-280	281-300	301-311	312-330	331-345	346-365
	------------------------------------- mg•L^{-1} -------------------------------------										
January/February	13.4 b (July 16)	24.0 a[z] (July 26)	17.4 ab (Aug 7)	13.6 ab (Sept 5)	8.2 b (Sept 13)	8.2 b (Sept 23)	13.6 a (Oct 17)	8.5 b (Nov 3)	7.8 b (Nov 18)	7.0 b (Dec 1)	7.9 ab (Dec 15)
April/May	9.7 bc (Oct 17)	7.0 b (Nov 3)	6.5 c (Nov 18)	6.2 b (Dec 1)	8.2 b (Dec 15)	6.3 b (Jan 9)	12.4 a (Jan 23)	14.9 a (Jan 23)	12.9 a (Feb 28)	11.7 a (Mar 11)	9.0 a (Mar 31)
June/July	6.7 c (Dec 15)	5.6 b (Jan 9)	10.8 bc (Jan 23)	9.7 b (Jan 30)	9.7 b (Feb 6)	9.1 b (Feb 20)	9.5 a (Mar 8)	7.7 b (Mar 31)	5.5 b (Apr 10)	6.5 b (May 20)	5.4 b (May 27)
September/October	23.9 a (Mar 20)	20.5 a (Apr 5)	21.0 a (Apr 25)	20.7 a (May 3)	20.1 a (May 23)	14.6 a (June 10)	11.5 a (July 1)	6.1 b (Sept 23)	13.5 a (Nov 3)	5.8 b (Nov 18)	6.3 ab (Dec 1)

[z]Means within columns separated by Fisher's protected LSD, $P = 0.05$.

[y]Soil solution not reported since no FN treatments had been applied.

Table 2. Effect of N timing on total N (NH_4-N + NO_3-N) found in soil solution at days after fertilization (DAF) 38 cm (15 in) beneath the soil surface, 2003.

Nitrogen timing	Days after fertilization 0-10	20-35	36-50	51-64
	mg•L^{-1}			
January/February	5.9 b[z] (Jan 23)	12.7 a (Feb 6)	11.1 ab (Feb 28)	13.9 b (Mar 11)
April/May	8.7 ab (Apr 24)	10.5 ab (May 20)	18.0 a (May 27)	20.3 a (June 23)
June/July	9.9 a (June 23)	11.1 ab (July 4)	14.9 a (Jul 18)	9.6 b (Aug 4)
September/October	6.0 b (Sept 23)	5.9 b (Oct 17)	6.7 b (Nov 3)	13.1 b (Nov 18)

Table 2. cont'd

Nitrogen timing	Days after fertilization 65-80	81-95	98-115	120-128
	mg•L^{-1}			
January/February	13.2 b (Mar 31)	20.7 a (Apr 10)	14.8 ab (Apr 24)	14.0 b (May 20)
April/May	20.9 a (July 4)	17.8ab (July18)	13.2 ab (Aug 4)	10.1 b (Aug 19)
June/July	7.0 b (Aug 19)	15.0 bc (Sep 9)	16.9 a (Sep 30)	21.3 a (Oct 14)
September/October	12.8 b (Dec 1)	11.9 c (Dec 15)	7.1 b (Jan 9)	10.9 b (Jan 23)

[z]Means within columns separated by Fisher's protected LSD, P = 0.05

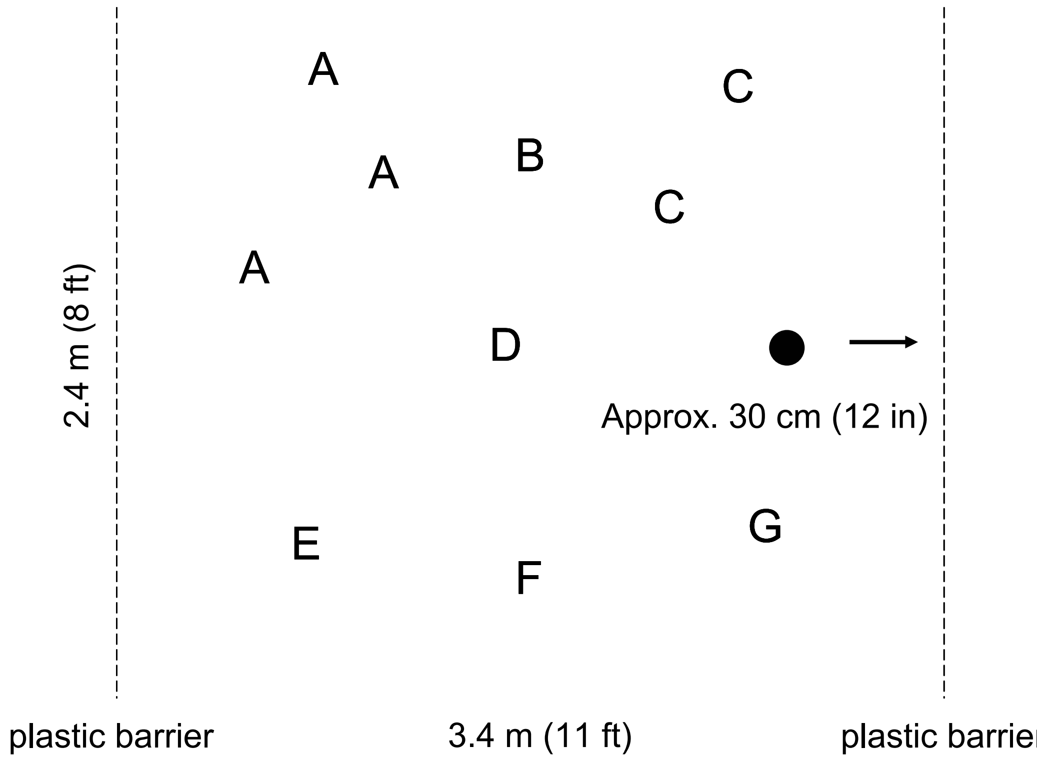

Fig.1. Placement of perennials planted in a 2.4 x 3.4 m (8 x 11 ft.) plot to simulate a landscape (A) *Canna* 'Mr. President', (B) *Panicum virgatum* 'Shenandoah', (C) *Coreopsis verticillata* 'Moonbeam', (D) *Salvia* x *sylvestris* 'East Friesland', (E) *Iris siberica* 'Caesar's Brother', (F) *Sedum* 'Herbstfreude', (G) *Echinacea purpurea* 'Magnus'. Plants were installed Oct. 2000. Lysimeters (●) were installed Dec. 19, 2001 approximately 30 cm (12 in) from plastic barrier and 38 cm (15 in) deep.

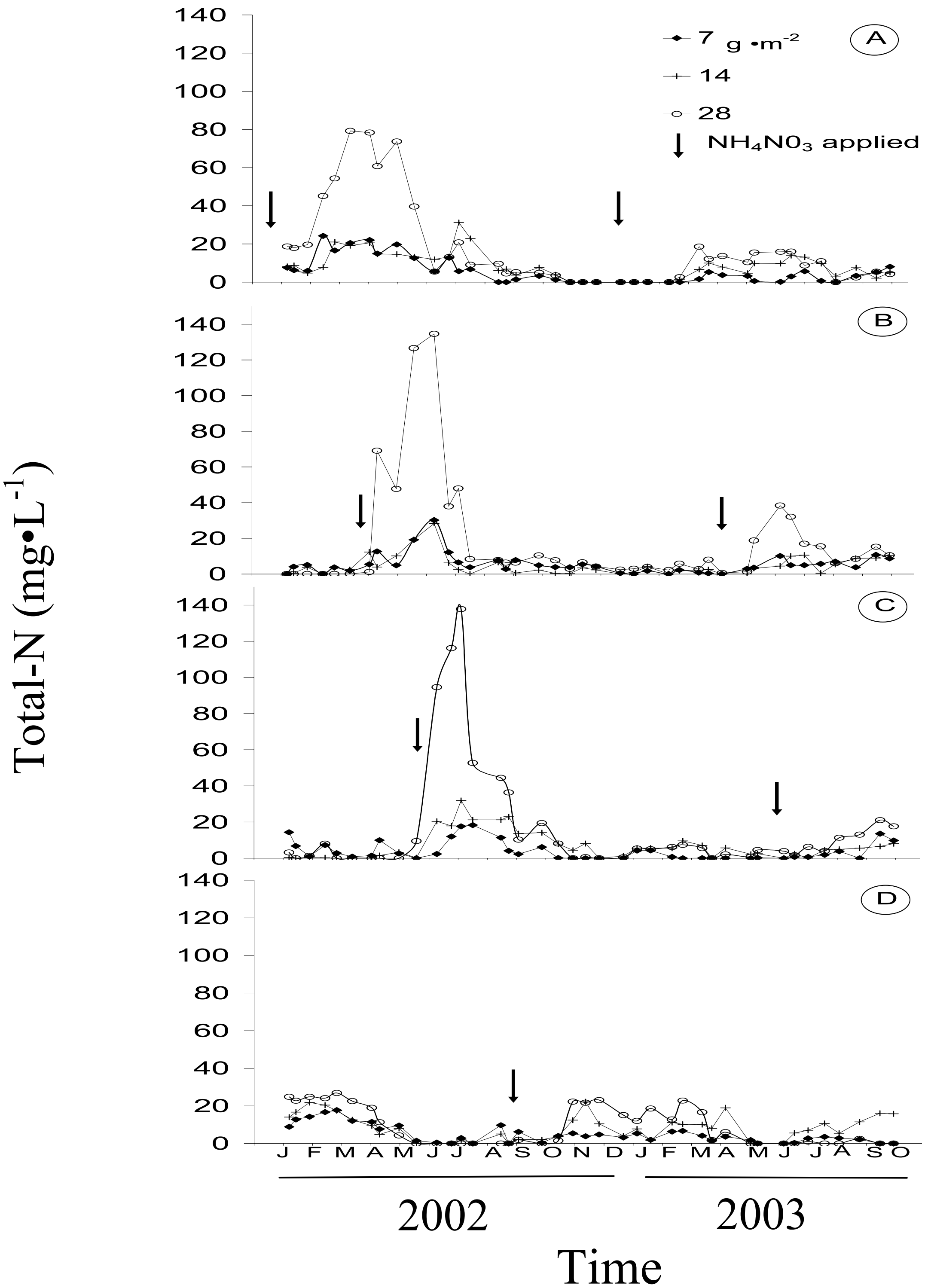

Fig. 2. Soil solution total-N (NH_4-N + NO_3-N) concentrations found 38 cm (15 inch) below the soil surface, 2002-2003 when 7, 14, and 28 g N•m^{-2} (0, 1.5, 3, and 6 lbs•1000 ft^{-2}) was applied (A) January/February (B) April/May (C) June/July or (D) September/October. The soil N concentrations in the 0 g•m^{-2} N treatment (control) were subtracted from the 7, 14, and 28 g•m^{-2} N rates. Treatments were initiated on Sept. 15, 2001 (not shown).

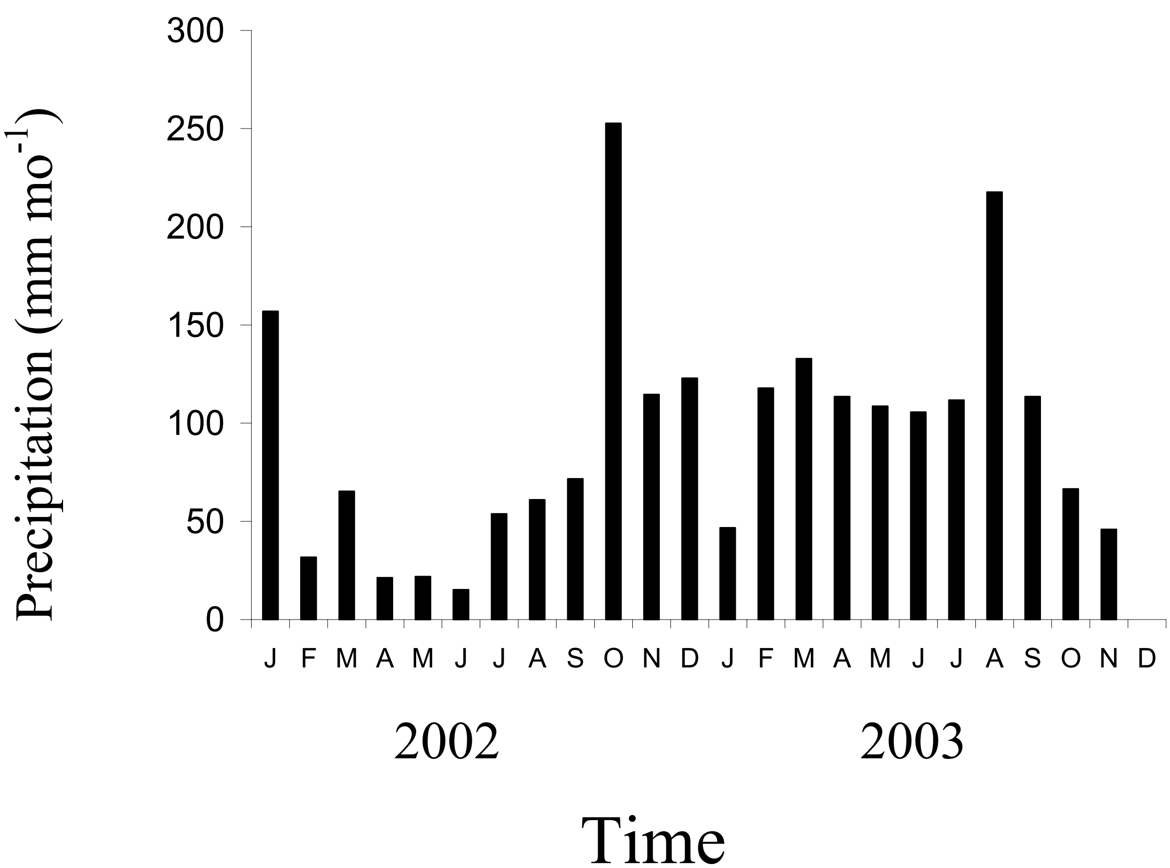

Fig. 3. Monthly precipitation (mm) recorded in 2002 and 2003.

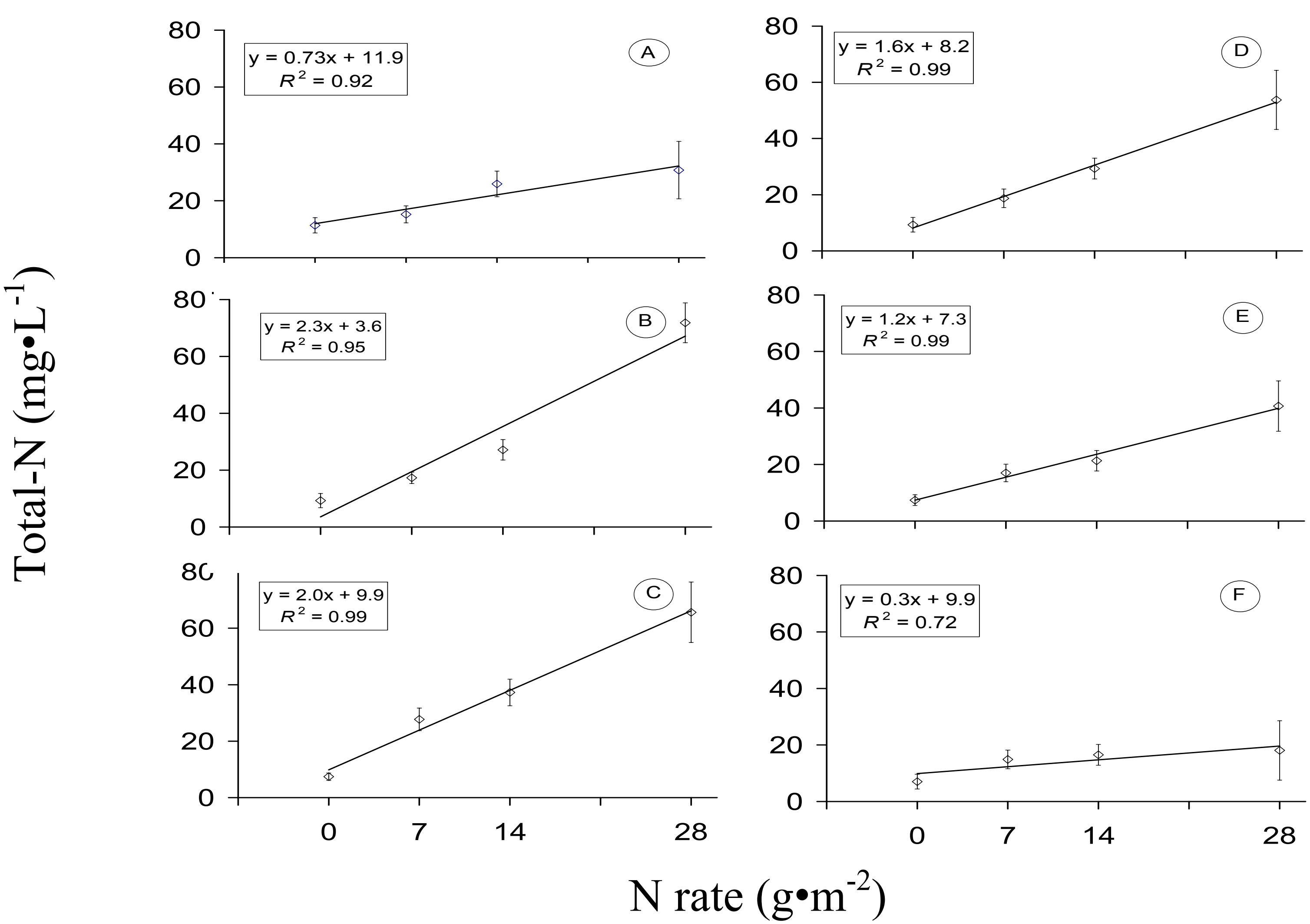

Fig.4. Effect of FN rate on soil solution total-N (NH_4-N + NO_3-N) concentration found (A) 0-15, (B) 31-40, (C) 61-80 (D) 92-101, (E) 123-140 and F) 171-182 days after fertilization 38 cm (15 inch) below the soil surface, 2002. Each symbol is based on 16 observations and vertical bars = ± S.E.

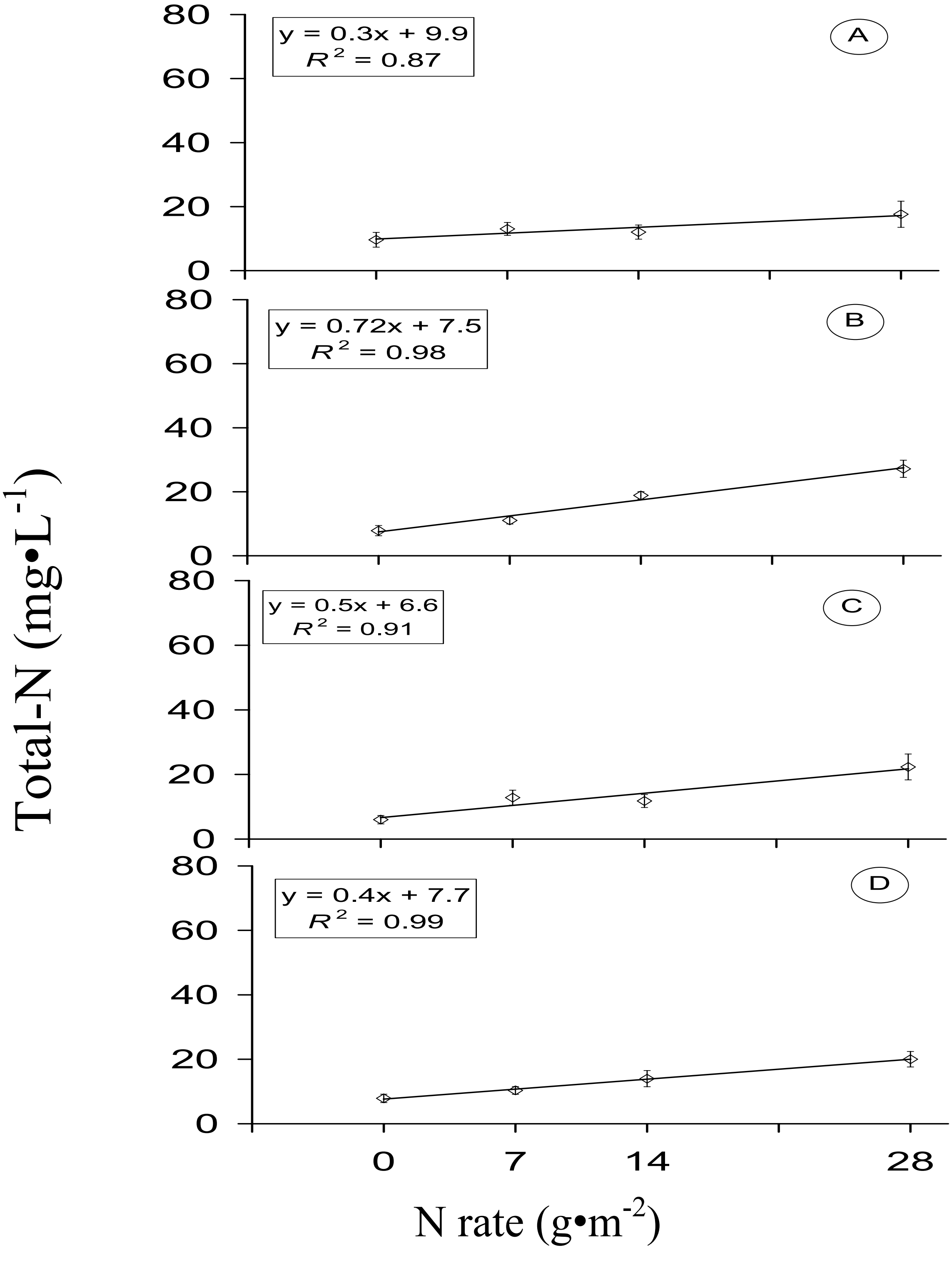

Fig. 5. Effect of FN rate on soil solution total-N (NH_4-N + NO_3-N) concentrations (A) 36-50, (B) 81-95, (C) 98-115 and (D) 120-128 days after fertilization 38 cm (15 inch) below the soil surface, 2003. Each symbol is based on 16 observations and vertical bars = ± S.E.