Nitrogen Allocation of Three Turfgrass Species and Turf-type Buffalograss Management

by

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GRADUATE COLLEGE
UNIVERSITY OF NEBRASKA

NITROGEN ALLOCATION OF THREE TURFGRASS SPECIES

AND TURF-TYPE BUFFALOGRASS MANAGEMENT

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University of Nebraska, 2000

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Environmental concerns about reducing the amount of chemicals and water applied to turfgrass have resulted in interest in using buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] as a turfgrass. Buffalograss has commonly been cited as having minimal response to nitrogen applications but nitrogen use in the species has not been thoroughly investigated. Research was conducted to compare nitrogen allocation among Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), and buffalograss and to determine nitrogen rate and mowing height effects on buffalograss.

Double-labeled ammonium nitrate with 5% ^{15}N enrichment was applied at 24 and 49 kg N ha^{-1} to Kentucky bluegrass and tall fescue and at 49 and 98 kg N ha^{-1} to buffalograss to determine nitrogen allocation in verdure, thatch, roots, and soil. For the buffalograss cultivars, the soil accounted for the largest percent of nitrogen recovered from fertilizer and for Kentucky bluegrass and tall fescue the thatch layer and soil accounted for the largest percent of nitrogen recovered from fertilizer. The average total nitrogen recovery in Kentucky bluegrass and tall fescue at the 24 and 49 kg N ha^{-1} rates was 95 and 73%, respectively. The

average total nitrogen recovery in the buffalograss cultivars at the 49 and 98 kg N ha^{-1} rates was 51 and 31%, respectively. Low nitrogen recovery in buffalograss indicated potentially significant volatilization and denitrification losses.

Nitrogen was applied at 0, 24, 49, 98, and 195 kg N ha^{-1} and mowing heights of 2.5, 5.0, and 7.5 cm were imposed on four buffalograss cultivars at sites in Nebraska, Kansas, and Utah to determine nitrogen rate and mowing height effects. Significant nitrogen rate x year interactions revealed that the 98 kg N ha^{-1} rate sustained quality, while lower nitrogen rates did not. For NE 91-118 turfgrass quality was best at the 2.5 and 5.0 cm mowing height, 378 performed well at all mowing heights and 'Cody' and 'Texoka' were best at the 5.0 and 7.5 cm mowing height.

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CHAPTER 1

Nitrogen Allocation of Three Turfgrass Species

ABSTRACT

Environmental concerns about nitrogen applied to turfgrass have stimulated research to quantify the amounts of nitrogen taken up by the plant and lost from the system. This research was conducted to determine nitrogen allocation among the verdure, thatch, soil, and roots of Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), and two buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] experimental selections, NE 86-120 and NE 91-118. To facilitate identification of fertilizer nitrogen, double-labeled ammonium nitrate with 5% ^{15}N enrichment was applied at 24 and 49 kg N ha^{-1} to Kentucky bluegrass and tall fescue and at 49 and 98 kg N ha^{-1} to the buffalograss selections. The research was conducted at the John Seaton Anderson Turfgrass and Ornamental Research Facility located near Mead, Nebraska on a Tomek silty clay loam soil (fine montmorillonitic, mesic Typic Arguidoll).

For the buffalograss selections, the soil accounted for the largest percent of nitrogen recovered from fertilizer with an average of 35%. In buffalograss, the percent of nitrogen recovered from fertilizer in the soil at the 49 and 98 kg N ha^{-1} rates were 45 and 25%, respectively. The thatch layer and soil accounted for the largest percent of nitrogen recovered from fertilizer in Kentucky bluegrass and tall fescue. The average percent of nitrogen recovered from fertilizer in the thatch and soil was 37 and 42%, respectively. For buffalograss roots and verdure, and

for Kentucky bluegrass and tall fescue verdure, the amount of applied nitrogen recovered at the higher nitrogen rate was greater initially, but over time declined more rapidly than the amount of applied nitrogen recovered at the lower nitrogen rate. Total nitrogen recovery in Kentucky bluegrass and tall fescue at the 24 and 49 kg N ha^{-1} rates were 95 and 73% of applied nitrogen, respectively. Total nitrogen recovery in the buffalograss selections at the 49 and 98 kg N ha^{-1} rates were 51 and 31% of applied nitrogen, respectively. The nitrogen rates applied to the buffalograss selections were either in excess of the amount of nitrogen required by buffalograss or the irrigation practices imposed contributed to significant denitrification losses.

LITERATURE REVIEW

Nitrogen Fate in Turfgrass

Application of nitrogen fertilizer to turfgrass is one of the most common turfgrass management practices. Recently, environmental concerns over the fate of nitrogen fertilizer applications have stimulated research to quantify nitrogen fate in turfgrass systems.

Research efforts have focused on maximizing the efficiency of nitrogen applications by quantifying the amount of applied nitrogen used by the turfgrass and the amount lost from the system. Research on fate of applied nitrogen has focused on traditional, widely used turfgrasses like Kentucky bluegrass (*Poa pratensis* L.) and to a lesser extent on creeping bentgrass (*Agrostis palustris* Huds.), perennial ryegrass (*Lolium perenne* L.), and bermudagrass (*Cynodon dactylon* L.) (Petrovic, 1990). Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] has gained attention as a reduced maintenance turfgrass due to exceptional drought resistance, heat tolerance, and reduced nitrogen requirements. Buffalograss is cited in numerous sources as having minimal response to nitrogen applications but to date no research has investigated the fate of nitrogen applied to buffalograss (Harivandi and Wu, 1995; Pozarnsky, 1983; Riordan, 1991; Wenger,1943).

The fate of nitrogen applied to turfgrass is dependent upon several factors. Nitrogen release rate, nitrogen source, nitrogen rate, species, cultivar, clipping management, soil texture, and irrigation management all have the potential to influence the fate of nitrogen applications (Petrovic, 1990). The five major components of the nitrogen cycle critical to determining nitrogen fate in turfgrass are plant uptake, atmospheric loss, soil storage, leaching, and surface runoff.

Nitrogen uptake by turfgrass has primarily focused on nitrogen recovered in clippings and above ground vegetation. Bristow et al. (1987) applied ^{15}N-labeled ammonium nitrate to perennial ryegrass and recovered, over four harvests, a total of 55% of applied nitrogen. Bowman et al. (1989) recovered 75% of applied nitrogen in Kentucky bluegrass at 5 d after treatment. Miltner et al. (1996) recovered 35% of applied nitrogen in Kentucky bluegrass clippings over a 2 yr period. Starr and DeRoo (1981) recovered 35 and 20% of applied nitrogen in clippings after a May and September nitrogen application, respectively. Wesely et al. (1988) investigated nitrogen recovery in Kentucky bluegrass as nitrogen rate increased from 8 to 32 kg N ha^{-1}. There were no differences in percent of applied nitrogen recovered at nitrogen rates greater than 8 kg N ha^{-1} (Wesely et al., 1988). Barraclough et al. (1985) applied ammonium nitrate at high rates to perennial ryegrass and found that as nitrogen rate increased from 250 to 900 kg N ha^{-1}, the percent of applied nitrogen recovered decreased from 99 to 50%.

Atmospheric nitrogen losses from denitrification and ammonia volatilization vary widely due to different soil conditions and management practices. The amount of irrigation or precipitation following a nitrogen application and the presence or absence of a thatch layer influence volatility losses. The thatch layer has significant urease activity which is necessary to convert urea to NH_3 (Bowman et al., 1987). Therefore, the presence or absence of a thatch layer influences volatility losses. Nelson et al. (1980) found volatilization losses of 39% of applied nitrogen from Kentucky bluegrass cores with a 5 cm thatch layer and only 5% of applied nitrogen from cores with no thatch layer. Irrigation or precipitation following nitrogen applications affect the position of nitrogen in the turfgrass and thereby influence volatilization. If the nitrogen remains in the shoot and thatch regions, volatilization potential is greater than if the nitrogen is moved into the soil. Bowman et al. (1987) reported that 36% of applied nitrogen was volatilized when no irrigation followed the nitrogen application. Irrigation applications of 1 and 4 cm within 5 min of the nitrogen application reduced volatility losses to 8 and 1%, respectively. Sheard and Beauchamp (1985) found volatility losses reduced from 15 to 7% when a 1.2 cm rainfall occurred within 72 h of the urea application. Wesely et al. (1987) measured volatilization losses of 35 and 31% from foliar applied urea at 17 and 34 kg N ha^{-1}, respectively. The mechanism whereby foliar applied urea is volatilized was elucidated by Torello et al. (1983). High levels of urease activity in the thatch layer can cause rapid hydrolysis of applied urea thereby increasing the pH of the water film on the thatch and turfgrass tissue and promoting volatilization.

There have been few attempts to quantify denitrification losses from turfgrass. Mancino et al. (1988) measured denitrification losses from Kentucky bluegrass of less than 1% of applied nitrogen at gravimetric soil moisture content of 75%. Under saturated soil conditions and temperatures 30° C or greater, 45 to

93% of applied nitrogen was lost via denitrification for a silt loam and silt soil, respectively.

Leaching losses from turfgrass are variable and primarily dependent on rate and formulation of fertilizer applied, soil texture, and irrigation or precipitation. There has been extensive research on leaching losses from golf course putting greens that has shown nitrogen losses ranging from 1 to 56% of applied nitrogen (Brown et al., 1977; Brown et al., 1982; Sheard et al, 1985; Snyder et al., 1981; Snyder et al., 1984). Leaching losses from lawns have been shown to be negligible by several researchers (Starr and DeRoo, 1981; Morton et al., 1988; Miltner et al., 1996).

Research on nitrogen runoff losses from turfgrass is limited but several researchers have found that runoff losses occur only under specific circumstances. In most cases inorganic nitrogen concentrations found in adjacent surface water were below the 10 mg L^{-1} drinking water standard (Brown et al., 1977; Morton et al., 1988).

Research on nitrogen fate in turfgrass often focuses on only one aspect of the nitrogen cycle such as leaching losses or plant uptake. Few attempts have been made to determine a mass nitrogen balance in turfgrass. Starr and DeRoo (1981) investigated the effects of returning turfgrass clippings on nitrogen allocation among clippings, thatch, leachate, and soil components by applying ^{15}N-labeled ammonium sulfate at 180 kg N ha^{-1} to a mixture of Kentucky bluegrass and red fescue (*Festuca rubra* L.). When clippings were returned to the plots, 76% of applied nitrogen was recovered. When clippings were removed, 64% of applied nitrogen was recovered. The research was conducted on a sandy loam soil and little nitrate nitrogen was leached from the soil profile. The authors attributed the unaccounted nitrogen losses to denitrification and volatilization.

Joo et al. (1991) investigated the fate of ^{15}N-labeled urea applications with and without a urease inhibitor. Nitrogen was applied at 49 kg N ha^{-1} to a blend of Kentucky bluegrass consisting of 'Parade', 'Adelphi', 'Glade', and 'Rugby'. A total of 29% of applied nitrogen was recovered with the majority of nitrogen recovered in the clippings and the 0 - 7.5 cm soil depth. The results indicate that from 55 to 71% of urea nitrogen was lost from the soil profile. Although leachate was not collected, the authors speculated that heavy precipitation shortly after the nitrogen applications could have resulted in considerable leaching of urea-nitrogen from the soil profile.

Miltner et al. (1996) investigated the effects of spring and fall nitrogen application schedules on nitrogen fate in a blend of 'Adelphi', 'Nassau' and 'Nugget' Kentucky bluegrass. On two dates in the first year of the research, ^{15}N-labeled urea was applied at 39.2 kg N ha^{-1}. Mass nitrogen balance was determined for clippings, verdure, thatch, soil, and leachate components. For the spring application schedule, total labeled fertilizer nitrogen recovery ranged from 25.1 to 36.1 kg N ha^{-1}, which is equivalent to recovery of 64 to 92% of applied nitrogen. For the fall application schedule, 30.0 to 43.1 kg N ha^{-1} or 77 to 109% of labeled fertilizer nitrogen was recovered. For the spring schedule, 31% of labeled fertilizer nitrogen was recovered in the thatch layer at 18 d after treatment

(DAT) but this value declined to 20% after 2 yr. Labeled fertilizer nitrogen recovered from the soil was 8% at 18 DAT and increased to 20% after 2 yr. The authors concluded that the increase in labeled fertilizer nitrogen recovery in the soil was most likely due to mineralization of fertilizer nitrogen in the thatch layer and subsequent downward movement into the soil. For the fall treatments, 62% of labeled fertilizer nitrogen was recovered from the thatch at 18 DAT but by the following June only 35% was recovered. Labeled fertilizer nitrogen recovered in the soil increased from 12 to 25% over 2 yr. The soil was a fine sandy loam and leaching was determined to be negligible and not different from zero for both nitrogen application schedules.

Bowman et al. (1989) applied ^{15}N-labeled ammonium sulfate at 50 kg N ha^{-1} to Kentucky bluegrass and recovered 75% of applied nitrogen in the shoots and less than 3% of applied nitrogen in the roots at 5 DAT. Barraclough et al. (1985) applied ^{15}N-labeled ammonium nitrate at 250, 500, and 900 kg N ha^{-1} to perennial ryegrass and recovered 99, 76, and 50% of applied nitrogen, respectively. Bristow et al. (1987) applied ^{15}N-labeled ammonium nitrate at 60 kg N ha^{-1} to perennial ryegrass and recovered 48% of applied nitrogen in the herbage harvested 28 and 51 DAT. At 2 DAT, 37% of labeled nitrogen was recovered in the soil microbial biomass. This value fluctuated widely over the next 14 d indicating rapid cycling of labeled nitrogen between the microbial and mineral nitrogen soil fractions.

Power and Legg (1984) applied ^{15}N-labeled ammonium nitrate to crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] and accounted for approximately 70 to 95% of applied nitrogen in tops, roots, and soil. The results indicate that from 12 to 52% of applied nitrogen was recovered in top-growth the season of application. After the first growing season, 15% of applied nitrogen was recovered in roots but within 3 yr only 5% of applied nitrogen was present in roots. The results indicate that approximately two-thirds of fertilizer nitrogen immobilized in grass roots during the year of fertilizer application is mobilized and recycled over the next several years.

Clark (1977) found that fertilizer nitrogen was quickly immobilized by plant and microbial uptake during the first growing season in a shortgrass prairie. Blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] roots and crowns contained approximately 9 and 20% of applied nitrogen, respectively. Recovery of fertilizer nitrogen in native mixed prairies generally has been on the order of 25 to 50% (Black and Wight, 1979; Power, 1981). Power (1981) found that when 270 or 540 kg N ha^{-1} was applied to a native mixed prairie, 30% was permanently immobilized by absorption into root material, 35% was removed in top growth, and 35% was either immobilized permanently in soil organic matter or lost by gaseous means.

Nitrogen Isotopes

The desire to improve the quantitative assessment of nitrogen uptake efficiency or to quantify nitrogen losses in the plant-soil system has resulted in increased use of heavy isotopes of nitrogen (Bremner and Hauck, 1982). The use of stable nitrogen isotopes has been facilitated by the reduced costs of the fertilizer and improved instrumentation for conducting nitrogen isotope-ratio analysis.

Stable nitrogen isotopes are used primarily because there are no radioactive nuclides of nitrogen suitable for conducting research on nitrogen transformations in the plant-soil system. The half-lives of the radioactive nuclides of nitrogen are too short, on the order of magnitude of seconds and minutes, to facilitate their use in nitrogen efficiency or nitrogen fate research (Jansson, 1971). Stable isotopes are natural components of the elements they represent. The most commonly used stable isotope of nitrogen is ^{15}N, which comprises a small percentage of all nitrogen found in the atmosphere, soil, and biological organisms. The natural abundance of ^{15}N in nitrogen is approximately 0.366 atom % ^{15}N. Fertilizers are available with different degrees of ^{15}N enrichment. The degree of fertilizer enrichment with the heavy isotope is described as the atom percent excess over the natural abundance of the element in question. For ^{15}N, the degree of enrichment would be expressed as the atom percent excess over 0.366, or the enrichment = atom % $^{15}N - 0.366\%$.

Using stable ^{15}N isotopes in research has several advantages. The use of ^{15}N isotopes provides a method to easily identify the fate of applied nitrogen. Applied nitrogen can be followed in the plant-soil system as it enters, is transported within, or leaves the system (Hauck and Bremner, 1976). The main advantage of using ^{15}N stable isotopes is that there are no health hazards to the researcher, no risk of radiation damage to the biological material, and no time limits on the duration of the research (Jansson, 1971). Another advantage in using ^{15}N stable isotopes is the accuracy with which the ^{15}N can be detected in samples. The ^{15}N isotope ratio analysis is conducted using either a mass spectrometer or an optical emission spectrometer. Optical emission spectrometers are cheaper than mass spectrometers but are 10 to 100 times less precise (Bremner and Hauck, 1982). Mass spectrometers can detect a change in ^{15}N abundance ratio of 0.2% and produce results with an error less than 0.2% on samples with any isotopic composition down to natural abundance (Jansson, 1971). To illustrate the accuracy of mass spectrometers, a nitrogen source with 10 atom % excess ^{15}N could be diluted 10,000 times and the presence of the labeled ^{15}N would still be detected by the mass spectrometer (Jansson, 1971).

One of the objectives for using ^{15}N in research involving the plant-soil system is to be able to distinguish between applied nitrogen and soil derived nitrogen. By adding a nitrogen fertilizer labeled with ^{15}N, the researcher can determine the amounts of ^{15}N entering a particular nitrogen pool in the soil and determine the amount of ^{15}N uptake by the plant. Norman and Werkman (1943) conducted the first research using ^{15}N to investigate nitrogen transformations in the plant-soil system. Their research studied the uptake of nitrogen by soybeans. Since this early work, the use of ^{15}N in nitrogen transformation research has increased dramatically.

The percentage of ^{15}N in natural substances is not constant due to isotope effects during biological or chemical transformations in the soil. Bremner and Hauck (1982) described isotope effects as, "the effect of nuclear characteristics other than atomic number on the nonnuclear chemical and physical properties of isotopes that lead to variations in the expression of these properties." In short, isotope effects may lead to differences in the natural abundance of ^{15}N in the soil. Changes in isotope composition have been observed in nitrification and denitrification reactions. Isotope effects result in only small changes in isotope distribution over a long period of time. Therefore, isotope effects are not a great concern in short term or single growing season research investigations into nitrogen transformations in soil. Due to the variation in natural ^{15}N abundance, researchers should test soils before applying isotope treatments and the ^{15}N abundance value from the soil should be used instead of the standard value of 0.366% for all calculations.

As the use of ^{15}N in nitrogen uptake research increased, some trends became evident (Jansson and Persson,1982). The difference method of determining nitrogen uptake by calculating the difference in nitrogen uptake between an unfertilized control and a fertilized treatment seldom gave the same result as the direct method of determining the amount of ^{15}N uptake by the plant. In many investigations the difference method using unlabeled nitrogen fertilizer often resulted in higher recoveries of nitrogen in the plant than the direct method. There are two general lines of thought concerning the observed differences. The first idea is that nitrogen applications stimulate mineralization of soil nitrogen. An increase in plant nitrogen uptake following nitrogen applications is commonly called a priming effect. Bingeman et al. (1953) were the first to introduce the terminology of "priming effect". They used the term "priming effect" to describe the increased decomposition of resident soil organic matter due to the addition of fresh organic matter. The alternative explanation for an increase in nitrogen uptake following nitrogen applications was put forth by Jansson (1971) who suggested that priming effects were due to microbial activity and the result of mineralization and immobilization turnover of nitrogen. Essentially, the lower nitrogen recovery observed with the direct method was due to pool substitution of labeled nitrogen for unlabeled nitrogen. Jenkinson et al. (1985) confirmed that priming effects were caused by pool substitution reactions of labeled nitrogen for unlabeled nitrogen.

Mineralization and immobilization turnover of the labeled nitrogen source results in lower calculated fertilizer nitrogen recovery by the direct method than by the difference method. Due to mineralization and immobilization turnover of the labeled nitrogen fertilizer, nitrogen recovery calculated by the isotope method is termed apparent nitrogen recovery.

Due to the expense of acquiring ^{15}N-labeled fertilizers and intense sampling required to characterize mass nitrogen balance in a turfgrass and soil profile, most nitrogen fate research has focused on one grass species or nitrogen rate. The objectives of the research were to determine the quantity and turn-over rate of soil nitrogen and ^{15}N-labeled ammonium nitrate fertilizer in verdure, thatch, roots, and soil of Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.) and buffalograss [*Buchloe dactyloides* (Nutt.) Engelm].

MATERIALS AND METHODS

Field experiments were conducted at the John Seaton Anderson Turfgrass and Ornamental Research Facility located near Mead, Nebraska to determine nitrogen allocation in buffalograss, Kentucky bluegrass, and tall fescue. Established turfgrass plots of two experimental selections of buffalograss, NE 91-118 and NE 86-120, a blend of Kentucky bluegrass (cv. 'Merit', 'Baron', 'Touchdown', 'Adelphi') and a blend of tall fescue (cv. 'Arid', 'Mustang', 'Olympic') were used. The Kentucky bluegrass and tall fescue plots were established in 1990 and the buffalograss plots were established in 1995. The soil type was a Tomek silty clay loam (fine montmorillonitic, mesic Typic Argiudoll, 2.66% organic matter, and pH of 6.83).

The total amount of nitrogen applied each year to a 9 m^2 plot was 0, 97.6, and 195.3 kg N ha^{-1}. Kentucky bluegrass and tall fescue nitrogen amounts were split among four equal applications. In 1997, 24.4 and 48.8 kg N ha^{-1} were applied on 1 May, 16 June, 10 Sept., and 7 Nov. The application dates in 1998 were 29 April, 1 June, and 2 Sept. Because of completion of the study in 1998, no nitrogen was applied in Nov. Nitrogen amounts applied to buffalograss were split among two equal applications. In 1997, 48.8 and 97.6 kg N ha^{-1} were applied on 16 June and 29 July. In 1998, the application dates were 1 June and 15 July. On the 16 June nitrogen application in 1997, double-labeled ammonium nitrate with 5% ^{15}N enrichment was applied in 650 mL of water at 24.4 and 48.8 kg N ha^{-1} to Kentucky bluegrass and tall fescue and at 48.8 and 97.6 kg N ha^{-1} to the buffalograss selections. Hereafter the nitrogen rates will be referred to as 24, 49, and 98 kg N ha^{-1}. All other nitrogen applications in 1997 and 1998 were with a non-labeled commercial ammonium nitrate fertilizer (34N-0P-0K). Immediately following nitrogen applications, plots were irrigated with 1.3 cm water.

Plots were mowed weekly at 5 cm and clippings returned. Irrigation was applied according to individual species requirement. For Kentucky bluegrass and tall fescue, 80% of evapotranspiration was returned every 3 d and for the buffalograss selections 60% of evapotranspiration was returned weekly. Dithiopyr preemergence herbicide [S,S-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbothioate] was applied in April of 1997 and 1998. Heritage fungicide [Methyl (E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate)] was applied 17 July 1998 to all plots to suppress Rhizoctonia blight (*Rhizoctonia solani* Kuhn) pressure. Clopyralid [3,6-dichloro-2-pyridinecarboxylic acid] + triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid was applied to the Kentucky bluegrass and tall fescue plots 13 Aug. 1998 to reduce weed interference. Fenoxaprop-ethyl [(±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid] was applied to the Kentucky bluegrass plots on 13 Aug. 1998 to reduce weed interference from large crabgrass [*Digitaria sanguinalis* (L.) Scop.].

Plots were sampled prior to each fertilizer application to determine total nitrogen and percent ^{15}N enrichment in plant and soil components. In addition, the buffalograss selections were sampled in late Aug. in both 1997 and 1998. The Kentucky bluegrass and tall fescue plots were sampled on the following dates in 1997: 28 April (early spring), 30 May (late spring), 4 Sept. (early fall), and 6 Nov. (late fall). Sampling dates in 1998 were 27 April (early spring), 26 May (late spring), 27 Aug. (early fall), and 29 Oct. (late fall). The first sampling after application of the 5% atom enriched ^{15}N ammonium nitrate application was the 4 Sept. 1997 sampling that corresponded to 80 d after treatment (DAT). Subsequent sampling dates represent 143, 315, 344, 438, and 501 DAT.

The buffalograss selections were sampled on 2 June (late spring), 24 July (summer), and 7 Sept. (early fall) in 1997. In 1998 the sampling dates were 28 May (late spring), 10 July (summer), and 28 Aug. (early fall). Hereafter, all sampling dates will be referred to according to the seasonal designation. The first sampling after application of the 5% atom enriched ^{15}N ammonium nitrate application was the 24 July sampling in 1997 which corresponded to 38 DAT. Subsequent sampling dates represent 83, 346, 390, and 439 DAT.

Six soil cores, 5 cm diameter, were extracted to a depth of 64 cm. The soil cores were partitioned into four depths: 0-8, 8-16, 16-32, and 32-64 cm. After partitioning the cores by depth, the six samples were composited, mixed thoroughly, and analyzed for total nitrogen, ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and ^{15}N enrichment. NH_4-N and NO_3-N of soil samples were determined via 2N KCL extraction using a Lachat QuikChem autoanalyzer (Lachat Instruments, Milwaukee, WI.). Roots were washed from a 250 g soil sample, dried at 60°C and weighed. Thatch samples were taken from the Kentucky bluegrass and tall fescue plots; buffalograss lacked a well defined thatch layer, so it was not sampled. Verdure samples were collected on all plots. Plant and soil samples were ball milled into a fine powder prior to analysis. Total nitrogen and ^{15}N enrichment of verdure, thatch, roots, and soil samples were determined using a Carlo-Erbo model NA 1500 N-C-S analyzer interfaced to a Tracermass mass spectrometer (Europa Scientific USA, Cincinnati, OH).

The calculations used to determine mass of nitrogen and percent of nitrogen recovered were from Kessavalou (1994). The soil bulk densities used for calculations are presented in Table 1.1. Because of similarities in the soil bulk densities of NE 86-120 and NE 91-118, the same bulk density values were used for both selections. The background values of atom % ^{15}N used for the soil and plant components were as follows: soil 0.374%, verdure of NE 86-120 and Kentucky bluegrass 0.377% and of NE 91-118 and tall fescue 0.374 and 0.378%, respectively, the roots of the buffalograss selections 0.383% and of Kentucky bluegrass and tall fescue 0.377%, the thatch layer of Kentucky bluegrass and tall fescue 0.372%. The calculations used were as follows.

1. Percent nitrogen derived from fertilizer (%NDFF)

$$\%NDFF = \frac{(A - B)}{(C - B)}$$

A = Atom % ^{15}N of the plant or soil sample

B = Atom % ^{15}N of unfertilized plant or soil sample (background atom % ^{15}N)

C = Atom % ^{15}N of the nitrogen fertilizer

2. Nitrogen derived from fertilizer (NDFF, kg N ha^{-1})

$$NDFF = \%NDFF * TN$$

%NDFF = Percent nitrogen derived from fertilizer

TN = Total nitrogen in the plant or soil, kg N ha^{-1}

3. Percent nitrogen recovered from fertilizer (%NRFF)

$$\%NRFF = \frac{(NDFF,\ kg\ N\ ha^{-1})}{(Total\ fertilizer\ nitrogen\ applied,\ kg\ N\ ha^{-1})}$$

The experimental design for the individual turfgrass species and selections was a completely randomized design. The treatment design was a factorial with grass species or cultivar and nitrogen rate as treatment factors. Because of differences in the amount of ^{15}N labeled ammonium nitrate applied to the buffalograss selections compared to Kentucky bluegrass and tall fescue, and the differences in the sampling schedule, the buffalograss selections were analyzed separately from Kentucky bluegrass and tall fescue. Treatment differences were tested using Proc Mixed statistical analysis (SAS Institute Inc., 1997). Each component of the turfgrass and soil profile was analyzed using repeated measures analysis with an independent errors covariance structure. Means were separated using Fisher's LSD procedure.

Table 1.1 Soil bulk densities of Kentucky bluegrass, tall fescue, and the buffalograss selections.

Depth	Kentucky bluegrass	Tall fescue	Buffalograss selections
cm		$g\ cm^{-3}$	
0-8	1.39	1.35	1.33
8-16	1.45	1.47	1.48
16-32	1.54	1.55	1.55
32-64	1.69	1.65	1.65

RESULTS AND DISCUSSION

Nitrogen Recovery in Soils of Buffalograss

There was a significant selection x N rate x sampling date interaction for the quantity of soil nitrogen derived from fertilizer for buffalograss (Table 1.2). However, the interaction revealed no biologically important trends (Figure 1.1). The selection x N rate x sampling date interaction is not likely an important selection or treatment effect, but may be the by-product of sample variability. Miltner et al. (1996) also noted similar fluctuations in ^{15}N fertilizer recovery from soil, and concluded these fluctuations were caused by sample variability and mixing procedures.

The largest amount of soil nitrogen derived from fertilizer in buffalograss was 38.2 kg N ha^{-1} (39 %NRFF) for NE 86-120 at the 98 kg N ha^{-1} rate, late spring 1998 (Table 1.3). At the same sampling date, NE 91-118 at the 49 kg N ha^{-1} rate accounted for 33.4 kg N ha^{-1} of soil nitrogen derived from fertilizer (68 %NRFF). With respect to the %NRFF, the 49 kg N ha^{-1} rate usually had a higher percent of fertilizer nitrogen recovered in the soil than the 98 kg N ha^{-1} rate (Table 1.3).

There were significant differences in NH_4-N concentration among soil depths for the buffalograss selections throughout 1997 and 1998 (Table 1.4). For the summer and early fall 1997 sampling dates, the highest NH_4-N concentration was in the 0-8 cm soil depth. At the late spring 1998 sampling date, NH_4-N concentration was highest at 0-8, 8-16, and 32-64 cm soil depths. The early fall 1998 sampling date had the highest NH_4-N concentration in the

Table 1.2 Repeated measures analysis of variance table for nitrogen derived from fertilizer (NDFF) and percent nitrogen recovered from fertilizer (%NRFF) in all components of NE 86-120 and NE 91-118 in 1997 and 1998.

		NDFF				%NRFF
Source	df	Soil	Roots	Verdure	Total	Total
		Pr > F				
Rep	2					
Selection	1	NS	*	*	NS	NS
N rate	1	NS	**	**	NS	**
S X N	1	NS	NS	NS	NS	NS
W.P. Error	6					
Time	4	NS	**	**	NS	NS
S X T	4	NS	**	**	NS	NS
N X T	4	NS	**	**	NS	NS
S X N X T	4	*	NS	NS	*	NS
S.P. Error	32					

*,**, and NS indicate significance at P=0.05, 0.01, and not significant at P=0.05, respectively

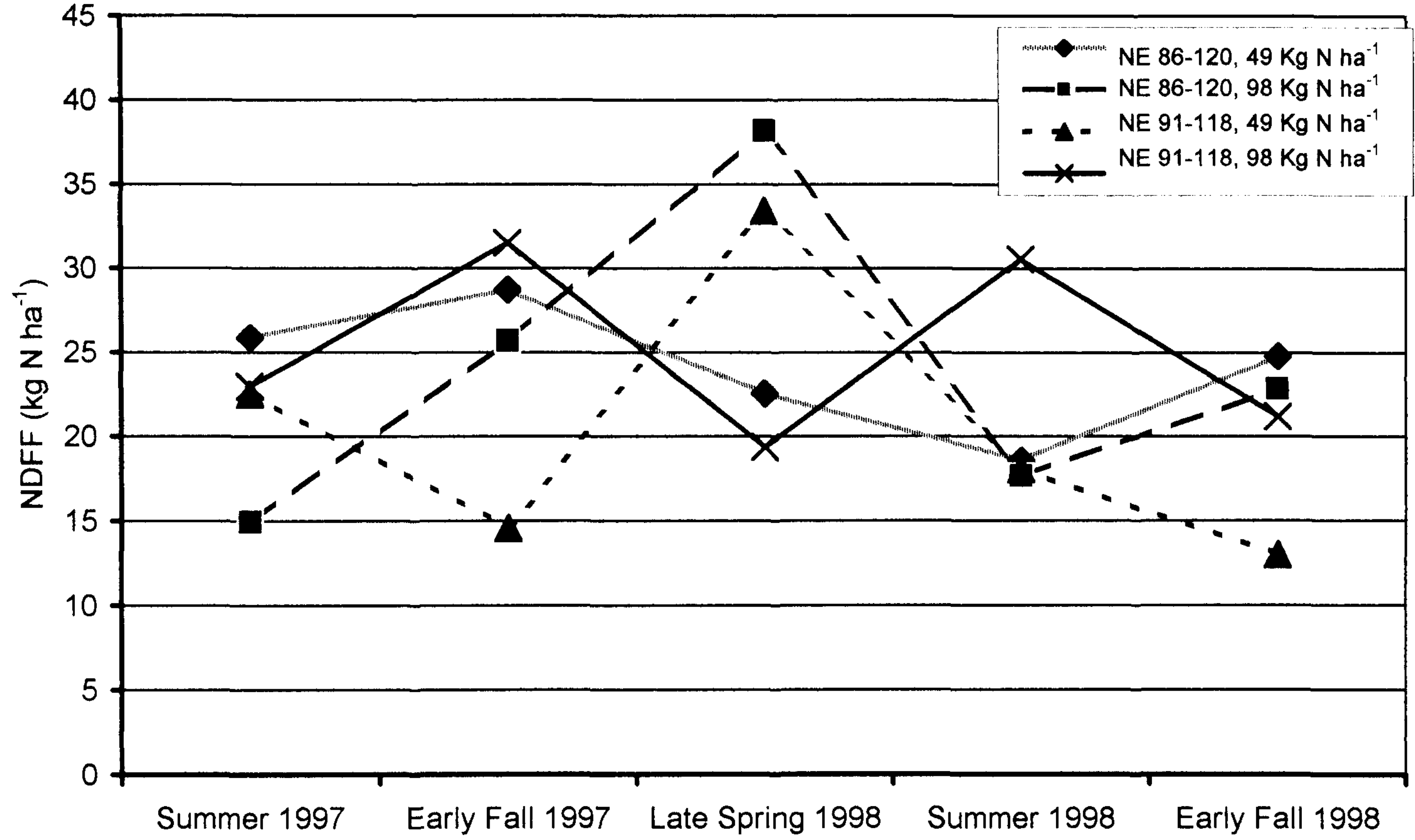

Figure 1.1. Soil nitrogen derived from fertilizer (NDFF) for the selection x N rate x sampling date interaction in buffalograss.

Table 1.3 Nitrogen derived from fertilizer (NDFF) and percent nitrogen recovered from fertilizer (%NRFF) in NE 86-120 and NE 91-118 at all sampling dates in 1997 and 1998.

Selection	N rate	Date	Verdure	Soil	Roots	Total
	— kg N ha^{-1} —		kg N ha^{-1} (%)			
NE 86-120	49	Summer 97	2.6 (5.3)	25.9 (52.9)	1.1 (2.2)	29.6 (60.4)
		Early fall 97	2.5 (5.1)	28.7 (58.6)	1.4 (2.9)	32.6 (66.5)
		Late spring 98	2.1 (4.3)	22.5 (45.9)	0.6 (1.2)	25.2 (51.4)
		Summer 98	0.8 (1.6)	18.5 (37.8)	0.5 (1.0)	19.8 (40.4)
		Early fall 98	1.5 (3.1)	24.8 (50.6)	0.6 (1.2)	26.9 (54.9)
	98	Summer 97	5.5 (5.6)	14.9 (15.2)	2.2 (2.2)	22.6* (23.1)
		Early fall 97	5.4 (5.5)	25.7 (26.2)	2.8 (2.9)	33.9 (34.6)
		Late spring 98	4.1 (4.2)	38.2 (39.0)	0.8 (0.8)	43.1 (44.0)
		Summer 98	1.8 (1.8)	17.7 (18.1)	1.1 (1.1)	20.6 (21.0)
		Early fall 98	2.0 (2.0)	22.8 (23.3)	1.1 (1.1)	25.9 (26.4)
NE 91-118	49	Summer 97	1.9 (3.9)	22.5 (45.9)	1.8 (3.7)	26.2 (53.5)
		Early fall 97	1.8 (3.7)	14.6 (29.8)	1.7 (3.5)	18.1 (36.9)
		Late spring 98	1.4 (2.9)	33.4 (68.2)	1.2 (2.4)	36.0 (73.5)
		Summer 98	1.1 (2.2)	18.1 (36.9)	0.9 (1.8)	20.1 (41.0)
		Early fall 98	0.7 (1.4)	13.0 (26.5)	0.6 (1.2)	14.3 (29.2)
	98	Summer 97	5.4 (5.5)	23.0 (23.5)	5.4 (5.5)	33.8 (34.5)
		Early fall 97	3.6 (3.7)	31.5 (32.1)	4.7 (4.8)	39.8 (40.6)
		Late spring 98	3.1 (3.2)	19.3 (19.7)	2.4 (2.4)	24.8 (25.3)
		Summer 98	2.0 (2.0)	30.5 (31.1)	1.9 (1.9)	34.4 (35.1)
		Early fall 98	1.4 (1.4)	21.2 (21.6)	1.7 (1.7)	24.3 (24.8)

* Total apparent ^{15}N recovery values are not equal to the sum of the apparent ^{15}N recovery values for the components due to differences in the statistical calculations performed on missing data points

Table 1.4 Ammonium-nitrogen concentration in buffalograss selections at soil depths.

Depth	Summer 1997	Early fall 1997	Late spring 1998	Summer 1998	Early fall 1998
cm	mg NH_4-N kg^{-1} soil				
0-8	13.0 a[†]	10.3 a	14.6 a	16.4	12.4 b
8-16	12.5 a	8.5 b	13.9 a	16.3	14.2 a
16-32	9.5 b	6.0 c	11.6 b	15.4	10.8 c
32-64	8.9 b	6.0 c	13.0 ab	15.7	14.0 a
LSD	1.5	1.0	1.7	NS	1.2

[†] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05)

Table 1.5 Ammonium-nitrogen concentration in buffalograss at soil depths for the selection X depth interaction at the late spring 1997 sampling date.

Depth	NE 86-120	NE 91-118
cm	mg NH_4-N kg^{-1} soil	
0-8	7.7 a[†]	8.9 a
8-16	7.1 a	7.8 b
16-32	5.2 b	5.3 c
32-64	6.9 a	6.0 c
LSD	1.0	1.0

[†] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05)

8-16 and 32-64 cm soil depths. A selection x soil depth interaction for NH_4-N concentration occurred at the late spring 1997 sampling date and indicated that NH_4-N concentration in NE 86-120 was highest at the 0-8, 8-16, and 32-64 cm depths while for NE 91-118 NH_4-N concentration was highest at the 0-8 cm depth (Table 1.5). Although the NH_4-N concentration at the soil depths varied among the sampling dates, generally NH_4-N concentration was highest in the 0-8 and 8-16 cm soil depths.

Nitrate-nitrogen concentrations in buffalograss soils do not indicate any leaching losses (Table 1.6). There was a significant selection x depth interaction for NO_3-N concentration at the late spring and summer 1997 sampling dates (Table 1.7). Experimental selection NE 91-118 had the highest NO_3-N concentration at the 0-8 and 16-32 cm depths at the late spring 1997 sampling date. For the other sampling dates in 1997 and 1998 there were no increases in NO_3-N concentration as soil depth increased. Starr and DeRoo (1981) applied ammonium nitrate at an annual rate of 195 kg N ha^{-1} to a mixture of Kentucky bluegrass and red fescue on a Merrimac sandy loam soil and had little NO_3-N leached from the turf. There was one occurrence of the ^{15}N labeled fertilizer appearing in the water sampled from ground water wells and this level was at or near NO_3-N background levels previously tested for the groundwater. Miltner et al. (1996) found minimal leaching losses from applications of urea to Kentucky bluegrass turf on a Marlette fine sandy loam soil. Nitrate-nitrogen concentrations in groundwater were generally less than 1 mg NO_3-N L^{-1} for both spring and fall

Table 1.6 Nitrate-nitrogen concentration in buffalograss selections at soil depths.

	Sampling Date			
Depth	Early Fall 97	Late Spring 98	Summer 98	Early Fall 98
cm	mg NO_3-N kg^{-1} soil			
0-8	2.1 a[†]	2.0 a	2.0 a	2.2 a
8-16	1.1 b	1.1 b	1.2 b	1.4 b
16-32	1.0 b	0.8 c	1.2 b	1.1 c
32-64	1.0 b	0.8 c	0.7 c	1.0 c
LSD	0.2	0.2	0.4	0.1

[†] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Table 1.7 Nitrate-nitrogen concentration in buffalograss at soils depths for the selection x soil depth interaction.

	Sampling Date			
	Late Spring 97		Summer 97	
Depth	NE 86-120	NE 91-118	NE 86-120	NE 91-118
cm	mg NO_3-N kg^{-1} soil			
0-8	1.6 a[†]	1.7 ab	2.0 a	1.6 a
8-16	1.0 b	1.6 b	1.1 b	1.1 b
16-32	0.9 b	2.1 a	1.0 b	1.0 b
32-64	1.1 b	1.6 b	1.0 b	1.2 b
LSD	0.4	0.4	0.2	0.2

[†] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

applied nitrogen treatments. Both of these studies indicated that when proper turf management practices were followed, leaching of applied fertilizer nitrogen was of minimal concern.

Nitrogen Recovery in Buffalograss Roots

There was a significant N rate x sampling date interaction for the quantity of nitrogen in roots derived from fertilizer in buffalograss (Table 1.2). The N rate x sampling date interaction showed that the decrease over time in the amount of nitrogen in roots derived from fertilizer was different between the nitrogen rates (Table 1.8). For the summer and early fall 1997 sampling dates, the 49 and 98 kg N ha^{-1} rates recovered on average 1.55 and 3.75 kg N ha^{-1}, respectively. By the late spring 1998 sampling date, the amount of nitrogen in roots derived from fertilizer for the 49 and 98 kg N ha^{-1} rates had declined to 0.9 and 1.6 kg N ha^{-1}, respectively. The decline in the amount of nitrogen in roots derived from fertilizer from the early fall 1997 to the late spring 1998 sampling date represents a 1.3 and 2.2% decrease for the 49 and 98 kg N ha^{-1} rates. The decrease in the amount of nitrogen in roots derived from fertilizer was almost double for the 98 kg N ha^{-1} rate when compared to the 49 kg N ha^{-1} rate. From late spring until early fall 1998 there was a slight decrease in the amount of nitrogen in roots derived from fertilizer for both nitrogen rates.

Table 1.8 Nitrogen derived from fertilizer and percent nitrogen recovered from fertilizer (%NRFF) in buffalograss roots at the 49 and 98 kg N ha^{-1} rates in 1997 and 1998.

N rate	Sampling Date†				
	Sum 97	Efall 97	Lspr 98	Summ 98	Efall 98
kg N ha^{-1}	kg N ha^{-1} (%)				
49	1.5 b‡ (3.1)	1.6 b (3.3)	0.9 (1.8)	0.7 (1.4)	0.6 (1.2)
98	3.7 a (3.8)	3.8 a (3.9)	1.6 (1.6)	1.5 (1.5)	1.4 (1.4)
LSD	0.9	0.8	NS	NS	NS

† The sampling dates are: Sum 97 = summer 1997, Efall 97 = early fall 1997, Lspr 98 = late spring 1998, Summ 98 = summer 1998, Efall 98 = early fall 1998

‡ Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

The 98 kg N ha^{-1} rate had a greater amount of nitrogen in roots derived from fertilizer than the 49 kg N ha^{-1} rate in 1997 but there were no differences in the amount of nitrogen in roots derived from fertilizer between the N rates in 1998 (Table 1.8). In 1997 the 98 kg N ha^{-1} rate had greater %NRFF than the 49 kg N ha^{-1} rate but by 1998 there was little difference in %NRFF between the N rates. There was a rapid decrease in the amount of nitrogen in roots derived from fertilizer for the 98 kg N ha^{-1} rate between the early fall 1997 and late spring 1998 sampling dates. Regression analysis revealed a significant linear effect for the N rate x sampling date interaction. The slopes of the lines for recovery of nitrogen derived from fertilizer for the two nitrogen rates were not equivalent over the sampling dates (Figure 1.2). The 98 kg N ha^{-1} rate had a greater negative slope, than the 49 kg N ha^{-1} rate indicating a more rapid decline in the amount of nitrogen in roots derived from fertilizer over time. The rapid decline from early fall 1997 to late spring 1998 could be attributed to sloughing of roots during the winter and subsequent mineralization of the nitrogen to the soil. Another possibility is that the nitrogen stored in roots in 1997 was mobilized for top-growth in early 1998. However, the amount of nitrogen derived from fertilizer in buffalograss verdure does not support this claim. Power and Legg (1984) applied ^{15}N-labeled ammonium nitrate to crested wheatgrass and found that after the first growing season, 15% of applied nitrogen was recovered in roots but within 3 yr only 5% of the applied nitrogen was present in the roots. They concluded that approximately two-thirds of fertilizer nitrogen is immobilized in grass roots during the year of fertilizer application and is subsequently mobilized

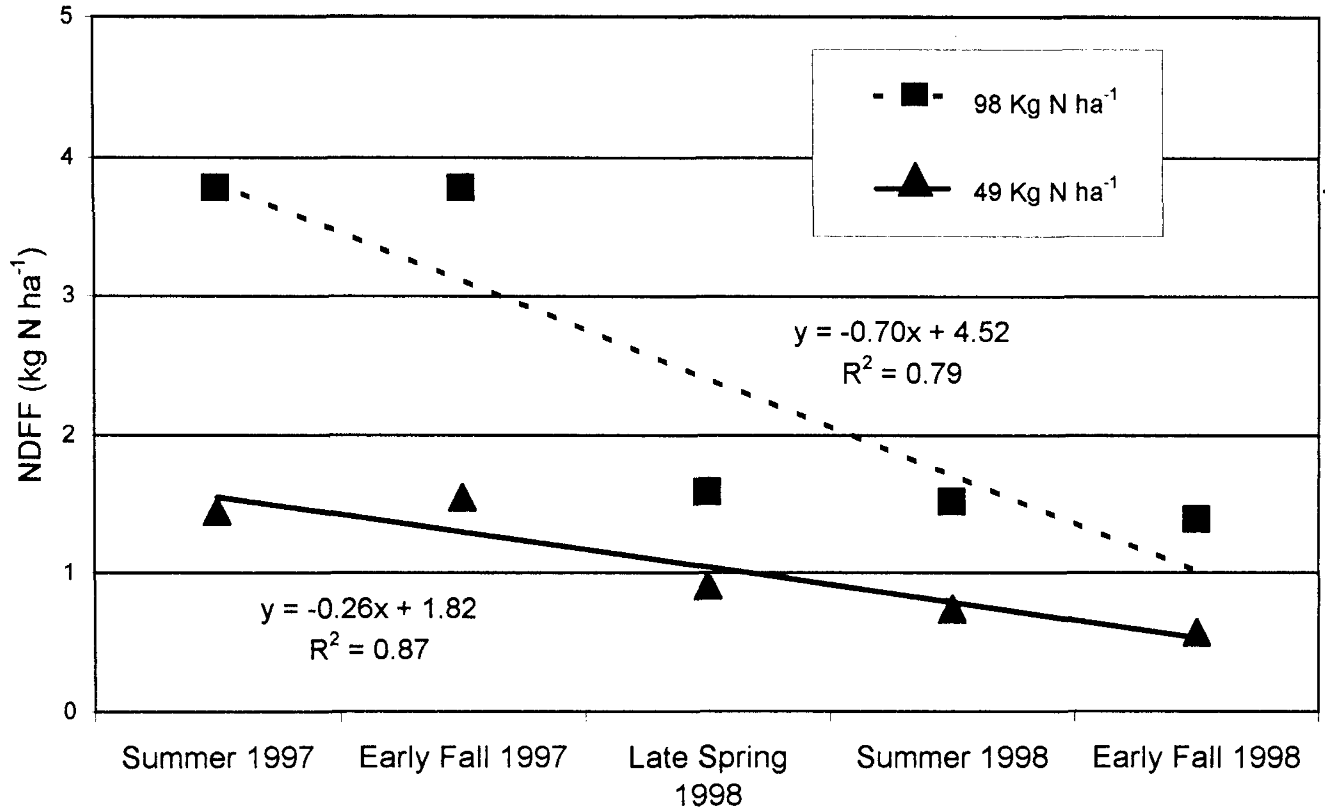

Figure 1.2. Nitrogen derived from fertilizer (NDFF) in buffalograss roots for the N rate X sampling date interaction and regression of NDFF on sampling date for each nitrogen rate.

and recycled during the following years.

There was a significant selection x sampling date interaction for the quantity of nitrogen in buffalograss roots derived from fertilizer (Table 1.2). The interaction revealed that the recovery of nitrogen derived from fertilizer over time was different between NE 86-120 and NE 91-118 (Figure 1.3). Regression analysis confirmed that the slopes of the lines for nitrogen derived from fertilizer in NE 86-120 and NE 91-118 were not equivalent. NE 91-118 had a greater negative slope than NE 86-120. The analysis indicated that although NE 91-118 had a higher initial amount of nitrogen in roots derived from fertilizer, it either mobilized the nitrogen to top-growth or lost it via root turnover at a faster rate than NE 86-120. NE 91-118 had greater amounts of nitrogen in roots derived from fertilizer than NE 86-120 for all sampling dates except summer and early fall 1998 (Table 1.9).

Analysis of root dry weights revealed a significant buffalograss selection effect at the summer 1997 sampling (Table 1.10). The root dry weights for NE 86-120 and NE 91-118 were 8405 and 9937 kg roots ha^{-1}. Throughout the other sampling dates in 1997 and 1998 there were no significant differences for root dry weights between either buffalograss selections or nitrogen rates. Mean root dry weights for all sampling dates are presented in appendix tables A29 – A34.

Overall, roots contributed only a small fraction to the total amount of nitrogen derived from fertilizer in the buffalograss selections (Table 1.3). The

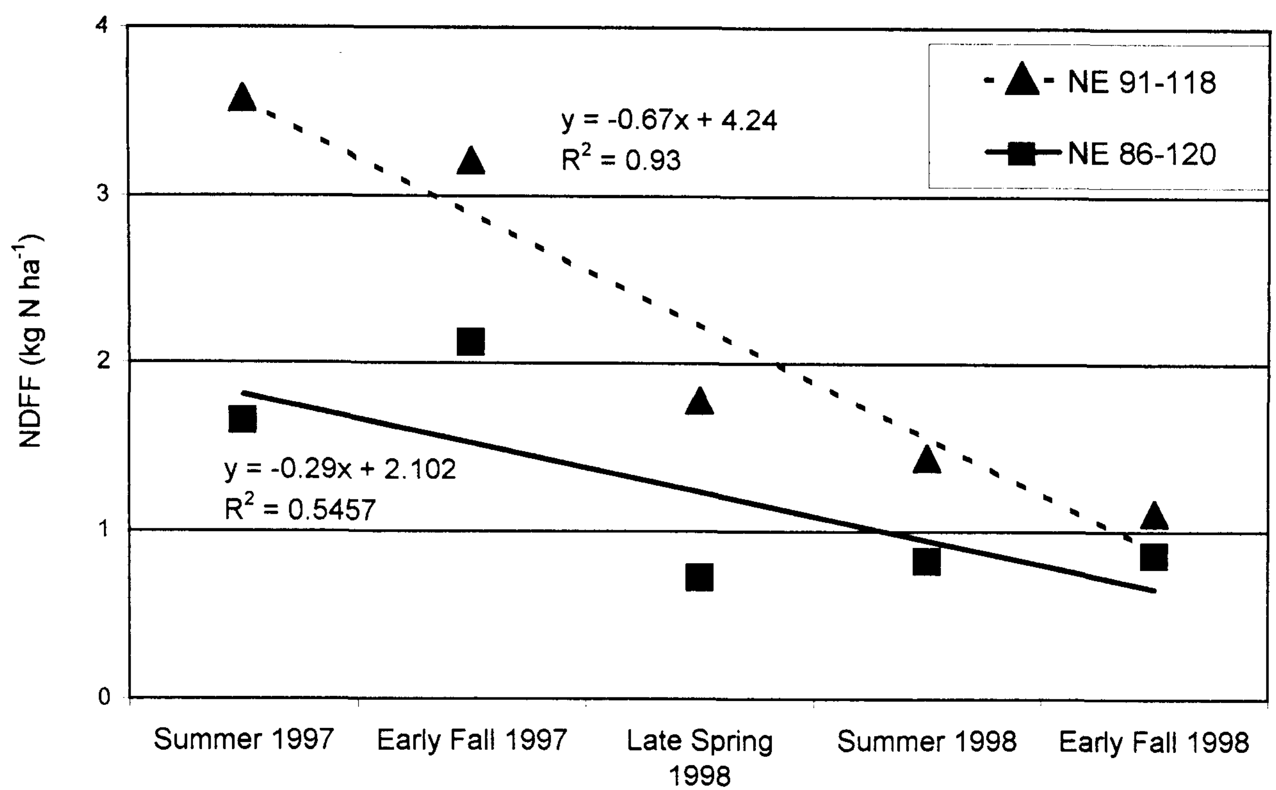

Figure 1.3. Nitrogen derived from fertilizer (NDFF) in buffalograss roots for the selection X sampling date interaction and regression of NDFF on sampling date for each buffalograss selection.

Table 1.9 Nitrogen derived from fertilizer and percent nitrogen recovered from fertilizer in roots of NE 86-120 and NE 91-118 at all sampling dates in 1997 and 1998.

	Sampling Date[†]				
Selection	Sum 97	Efall 97	Lspr 98	Summ 98	Efall 98
			kg N ha^{-1}		
NE 91-118	3.6 a[‡]	3.2 a	1.8 a	1.4	1.1
NE 86-120	1.7 b	2.1 b	0.7 b	0.8	0.9
LSD	0.9	0.8	0.8	NS	NS

[†] The sampling dates are: Sum 97 = summer 1997, Efall 97 = early fall 1997, Lspr 98 = late spring 1998, Summ 98 = summer 1998, Efall 98 = early fall 1998

[‡] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Table 1.10 Analysis of variance table for total buffalograss root dry weights in 1997 and 1998.

		Sampling Date				
Source	df	Summer 1997	Early fall 1997	Late spring 1998	Summer 1998	Early fall 1998
				Pr > F		
Rep.	2					
Selection	1	*	NS	NS	NS	NS
N rate	2	NS	NS	NS	NS	NS
S X N	1	NS	NS	NS	NS	NS
Error	12					

*,**, and NS indicate significance at P=0.05, 0.01, and not significant at P=0.05, respectively.

calculations used rely on the mass of the particular component, in this case roots, to determine the amount of nitrogen derived from fertilizer. This is not an indication that roots are not a significant source of nitrogen storage in the plant but rather an artifact of the calculations used to determine nitrogen recovery. When compared to the mass of soil per hectare, the mass of roots is rather small and the small mass value results in a low amount of nitrogen derived from fertilizer.

Nitrogen Recovery in Buffalograss Verdure

There was a significant N rate x sampling date interaction for the amount of nitrogen in verdure derived from fertilizer (Table 1.2). The 98 kg N ha^{-1} rate had a larger amount of nitrogen derived from fertilizer in verdure than the 49 kg N ha^{-1} rate at all sampling dates except early fall 1998 (Table 1.11). However, the %NRFF was very similar between the two N rates indicating that the 49 kg N ha^{-1} rate is a more efficient application rate with respect to the %NRFF in verdure.

There was a significant linear effect for the N rate x sampling date interaction (Figure 1.4). The 98 kg N ha^{-1} rate had a steeper slope, indicative of a more rapid decline in the amount of nitrogen derived from fertilizer over time, than the 49 kg N ha^{-1} rate (Figure 1.4). This result is similar to the decline in the amount of nitrogen in roots derived from fertilizer at the two nitrogen rates. In both verdure and roots, the 98 kg N ha^{-1} rate had higher initial amounts

Table 1.11 Nitrogen derived from fertilizer and percent nitrogen recovered from fertilizer in buffalograss verdure at the 49 and 98 kg N ha^{-1} rates at all sampling dates in 1997 and 1998.

	Sampling Date[†]				
N rate	Sum 97	Efall 97	Lspr 98	Summ 98	Efall 98
— kg N ha^{-1} —			kg N ha^{-1} (%)		
49	2.3 b[‡] (4.7)	2.2 b (4.5)	1.8 b (3.7)	0.9 b (1.8)	1.1 (2.2)
98	5.5 a (5.6)	4.5 a (4.6)	3.6 a (3.7)	1.9 a (1.9)	1.7 (1.7)
LSD	0.7	0.7	0.7	0.7	NS

[†] The sampling dates are: Sum 97 = summer 1997, Efall 97 = early fall 1997, Lspr 98 = late spring 1998, Summ 98 = summer 1998, Efall 98 = early fall 1998

[‡] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

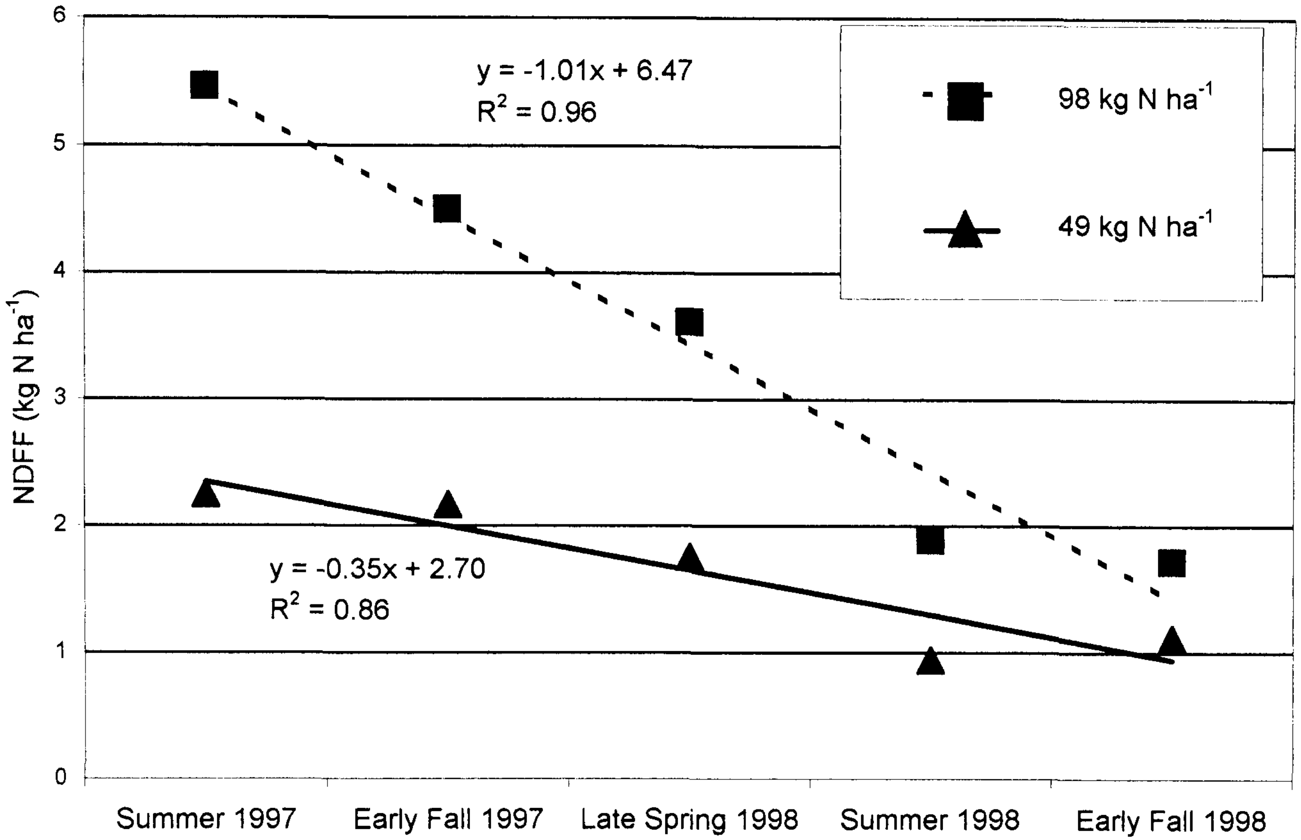

Figure 1.4. Nitrogen derived from fertilizer (NDFF) in buffalograss verdure for the N rate X sampling date interaction and regression of NDFF on sampling date for each nitrogen rate.

of nitrogen derived from fertilizer but over time the amount of nitrogen derived from fertilizer declined more rapidly at the 98 than the 49 kg N ha^{-1} rate. The results suggest that although plant uptake of applied nitrogen is initially greater at the 98 kg N ha^{-1}, over time the amount of nitrogen derived from fertilizer in the plant is equivalent between the two nitrogen rates.

There was a significant selection x sampling date interaction for the amount of nitrogen derived from fertilizer in verdure. NE 86-120 had greater amounts of nitrogen derived from fertilizer than NE 91-118 at the early fall 1997, late spring 1998, and early fall 1998 sampling dates (Figure 1.5 and Table 1.12). Regression analysis determined that the slopes of the lines for the amount of nitrogen derived from fertilizer in the selections were not significantly different. These results confirm that although NE 86-120 had higher amounts of nitrogen derived from fertilizer at several sampling dates, there was no difference between the selections with respect to the decline in the amount of nitrogen derived from fertilizer over time.

Total Nitrogen Recovery in Buffalograss

There was a significant selection x N rate x sampling date interaction for the total amount of nitrogen derived from fertilizer in buffalograss (Table 1.2). As with the selection x N rate x sampling date interaction observed in soil, the interaction appears to have no real biological significance (Figure 1.6). Since the buffalograss soils contributed the greatest amount to the total amount of

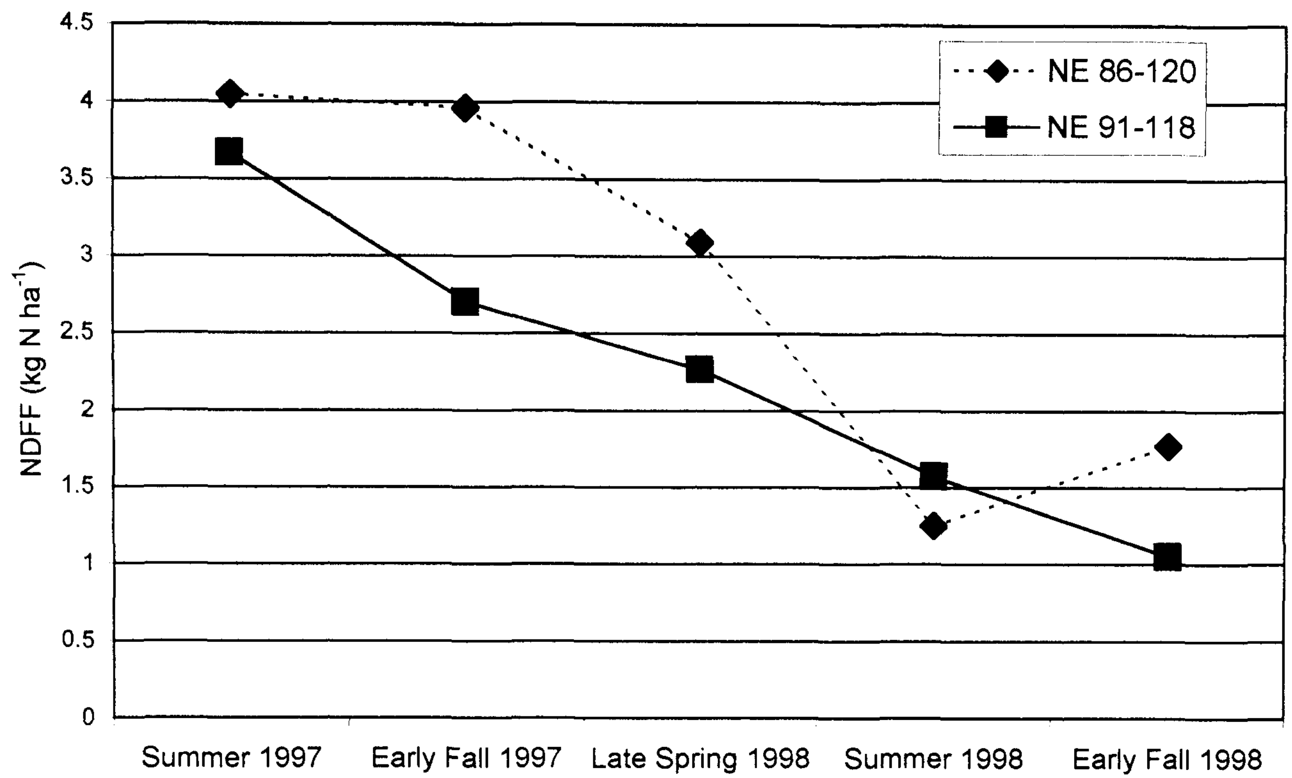

Figure 1.5. Nitrogen derived from fertilizer (NDFF) in verdure for the buffalograss selection X sampling date interaction.

Table 1.12 Nitrogen derived from fertilizer in verdure of NE 86-120 and NE 91-118 at all sampling dates in 1997 and 1998.

	Sampling Date[†]				
Selection	Sum 97	Efall 97	Lspr 98	Summ 98	Efall 98
	kg N ha^{-1}				
NE 91-118	3.7	2.7 b[‡]	2.3 b	1.6	1.0 b
NE 86-120	4.1	4.0 a	3.1 a	1.3	1.8 a
LSD	NS	0.7	0.7	NS	0.7

[†] The sampling dates are: Sum 97 = summer 1997, Efall 97 = early fall 1997, Lspr 98 = late spring 1998, Summ 98 = summer 1998, Efall 98 = early fall 1998

[‡] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

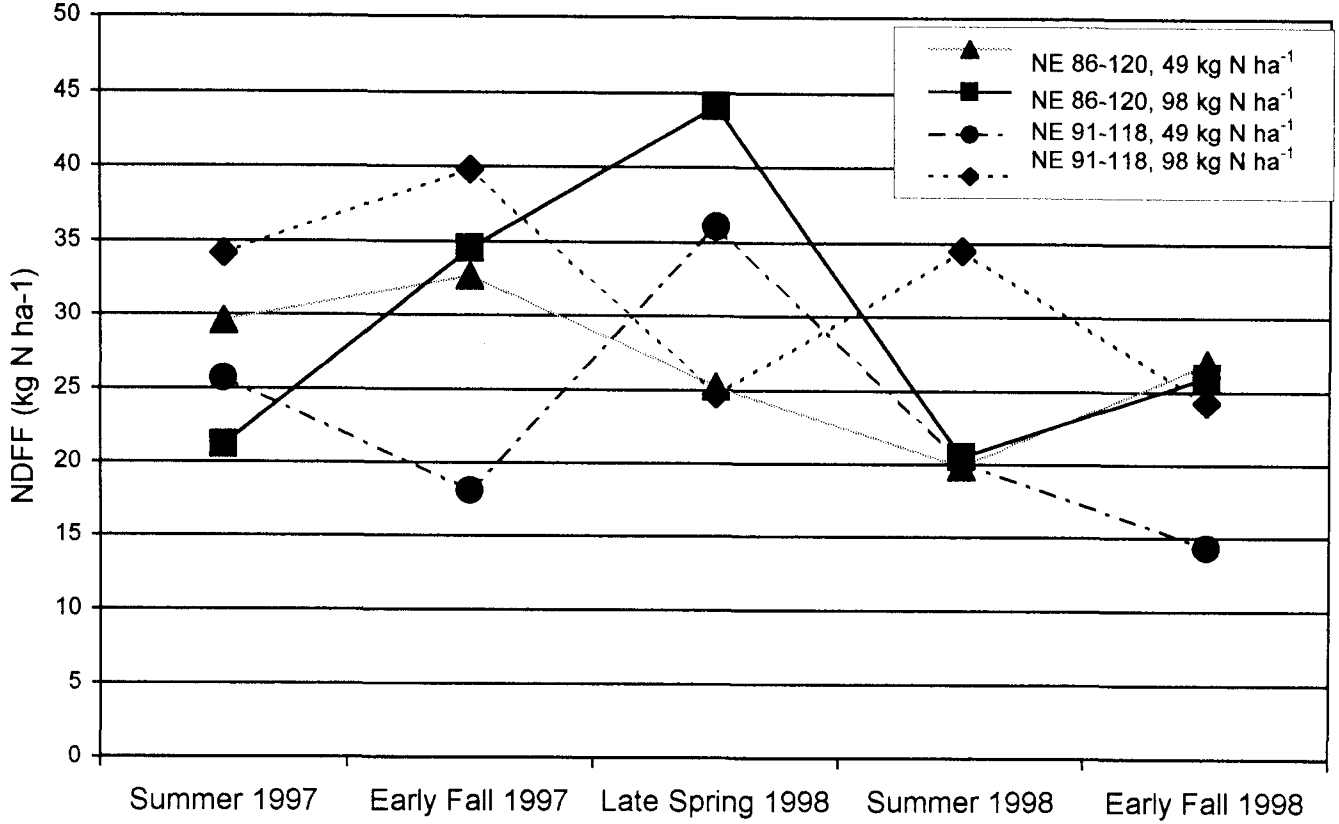

Figure 1.6. Total nitrogen derived from fertilizer (NDFF) for the selection X N rate X sampling date interaction in buffalograss.

nitrogen derived from fertilizer, it is likely that the three-way interaction is a result of the nitrogen recovery in the soil and not the result of an important interaction in the total amount of nitrogen derived from fertilizer.

Soil accounted for the greatest amount of nitrogen derived from fertilizer among the turfgrass and soil components. Buffalograss verdure and roots accounted for smaller amounts of nitrogen derived from fertilizer. Although there were no significant differences in the total amount of nitrogen derived from fertilizer between buffalograss selections or N rates, there was a significant N rate effect for the %NRFF (Table 1.2). The 49 kg N ha^{-1} rate recovered approximately 51% of the applied nitrogen while the 98 kg N ha^{-1} rate recovered only 31% of the applied nitrogen.

Overall, the total %NRFF in the buffalograss selections was low. The highest %NRFF was 74% for NE 91-118 at 49 kg N ha^{-1} for the late spring 1998 sampling. The lowest %NRFF was 21% for NE 86-120 at the 98 kg N ha^{-1} rate for the summer 1998 sampling date. Nitrogen losses could be attributed to either leaching, volatilization, or denitrification. There was no evidence of NO_3-N concentration increasing with soil depth throughout the sampling dates. The results suggest that if leaching losses were significant, they must have occurred between the ^{15}N application and the first sampling date which was 38 DAT.

Volatilization could have accounted for a portion of the nitrogen lost. Wesely et al. (1987) found volatilization losses of 31% when urea was foliarly applied at 34 kg N ha^{-1} to Kentucky bluegrass. Torello et al. (1983) speculated that urease activity could promote volatilization for foliar applied nitrogen.

Although buffalograss did not have a distinct thatch layer, the potential for volatility losses from the shoot tissue exists.

Denitrification losses may have been responsible for considerable loss of nitrogen. Mancino et al. (1988) recorded denitrification losses of 45% of applied nitrogen from a saturated silt loam soil at 30° C. Anaerobic microsites favorable for denitrification are created when increasing soil moisture decreases the rate of oxygen diffusion through the soil (Sexstone et al., 1985). Smith and Tiedje (1979) reported that most denitrification losses occurred during brief periods beginning a few hours after an irrigation or rainfall. Rolston et al. (1982) and Ryden and Lund (1980) found denitrification losses to be greatest immediately following irrigation. The irrigation practices imposed on the buffalograss selections may have facilitated denitrification by creating temporary anaerobic microsites. Sixty percent of potential evapotranspiration was returned weekly to buffalograss. This schedule resulted in relatively large amounts of water being applied every 5 to 6 d. Applying 2.5 to 5.1 cm of water over a 1 - 2 d period on a silty clay loam soil may have created, at least temporarily, saturated soil conditions which would be conducive to denitrification. Sexstone et al. (1985) observed that 48 to 60 h were required after wetting of clay loam soil before denitrification losses returned to the prewet levels. The highest nitrogen loss was 1.9 kg N ha^{-1} d^{-1} following a 4 cm rain (Sexstone et al., 1985). If anaerobic microsites were created by the irrigation practices imposed on the buffalograss the potential denitrification losses over a 2 to 3 d period may have been considerable.

Soil water content was not measured at each sampling date but soil moisture measurements from another project conducted on the same plots provide an indication of the potential for denitrification losses. Soil moisture was measured and percent water filled pore space (%WFPS) was calculated from soil cores taken on 23 July 1998. For Kentucky bluegrass and tall fescue the %WFPS was 46 and 73%, respectively. For NE 91-118 and NE 86-120 the %WFPS was 66 and 48%, respectively. The soil cores were taken 1 d after a 2.5 cm rainfall event. Denitrification processes begin at approximately 60% WFPS and increase dramatically above 80% WFPS (Parkin et al., 1996). The calculated %WFPS would not suggest significant denitrification but since the samples were taken 24 h after the rainfall event it is possible to conclude that %WFPS was initially greater and would have supported denitrification losses. The irrigation practices imposed on the buffalograss often resulted in 2.5 cm of irrigation being applied in 1 d. According to the %WFPS values calculated on 23 July 1998, the potential did exist for conditions conducive to denitrification. It can not be concluded with certainty, but it appears that denitrification was the primary means of nitrogen loss from the buffalograss selections.

The higher %NRFF at the 49 kg N ha^{-1} rate suggests that either nitrogen losses were increased by the 98 kg N ha^{-1} rate or that buffalograss simply does not require and therefore will not take up the excessive nitrogen applied. It is difficult to assess which of the hypothesis is correct because nitrogen losses from volatilization, denitrification, and leaching were not measured directly. Future research investigating lower nitrogen rates and directly measuring nitrogen losses could clarify the nitrogen use requirement of buffalograss.

Nitrogen Recovery in Kentucky Bluegrass and Tall Fescue Soils

There was a significant species X sampling date interaction for the amount of soil nitrogen derived from fertilizer in Kentucky bluegrass and tall fescue (Table 1.13). Across sampling dates, the amount of soil nitrogen derived from fertilizer in Kentucky bluegrass varied from 11.7 to 13.5 kg N ha^{-1} (Figure 1.7). In contrast, the amount of soil nitrogen derived from fertilizer in tall fescue ranged from 11.8 kg N ha^{-1} at the early spring 1998 sampling date to 22.8 kg N ha^{-1} at the early fall 1997 sampling date. For tall fescue, the amount of soil nitrogen derived from fertilizer was high at the early fall 1997 sampling date, decreased through the early spring 1998 sampling date and then increased to the late fall 1998 sampling date. Although there was greater variability in the amount of soil nitrogen derived from fertilizer in tall fescue, only at the early fall 1997 sampling date was the amount of soil nitrogen derived from fertilizer significantly different between the species (Table 1.14).

The Kentucky bluegrass and tall fescue thatch layers averaged 1.6 and 1.2 cm thick, respectively. The thicker thatch layer in Kentucky bluegrass may be responsible for sequestering the majority of applied nitrogen and reducing the amount entering the soil. The thinner thatch layer of tall fescue would facilitate a more rapid movement of applied fertilizer nitrogen into the soil and ultimately result in larger amounts of nitrogen derived from fertilizer in the soil. In tall fescue the high amount of soil nitrogen derived from fertilizer at the early fall 1997 sampling date and then a decline through early spring 1998 could be

Table 1.13 Repeated measures analysis of variance table for nitrogen derived from fertilizer (NDFF) and percent nitrogen recovered from fertilizer (%NRFF) in all components of Kentucky bluegrass and tall fescue in 1997 and 1998.

Source	df	NDFF					%NRFF
		Soil	Roots	Verdure	Thatch	Total	Total
		Pr > F					
Rep	2						
Species	1	*	NS	**	**	NS	*
N rate	1	**	NS	**	**	**	**
S X N	1	NS	NS	**	NS	NS	NS
W.P. Error	6						
Time	4	NS	**	**	**	NS	**
S X T	4	*	**	**	**	**	*
N X T	4	NS	NS	**	NS	NS	*
S X N X T	4	NS	NS	**	NS	NS	NS
S.P. Error	32						

*,**, and NS indicate significance at P=0.05, 0.01, and not significant at P=0.05, respectively

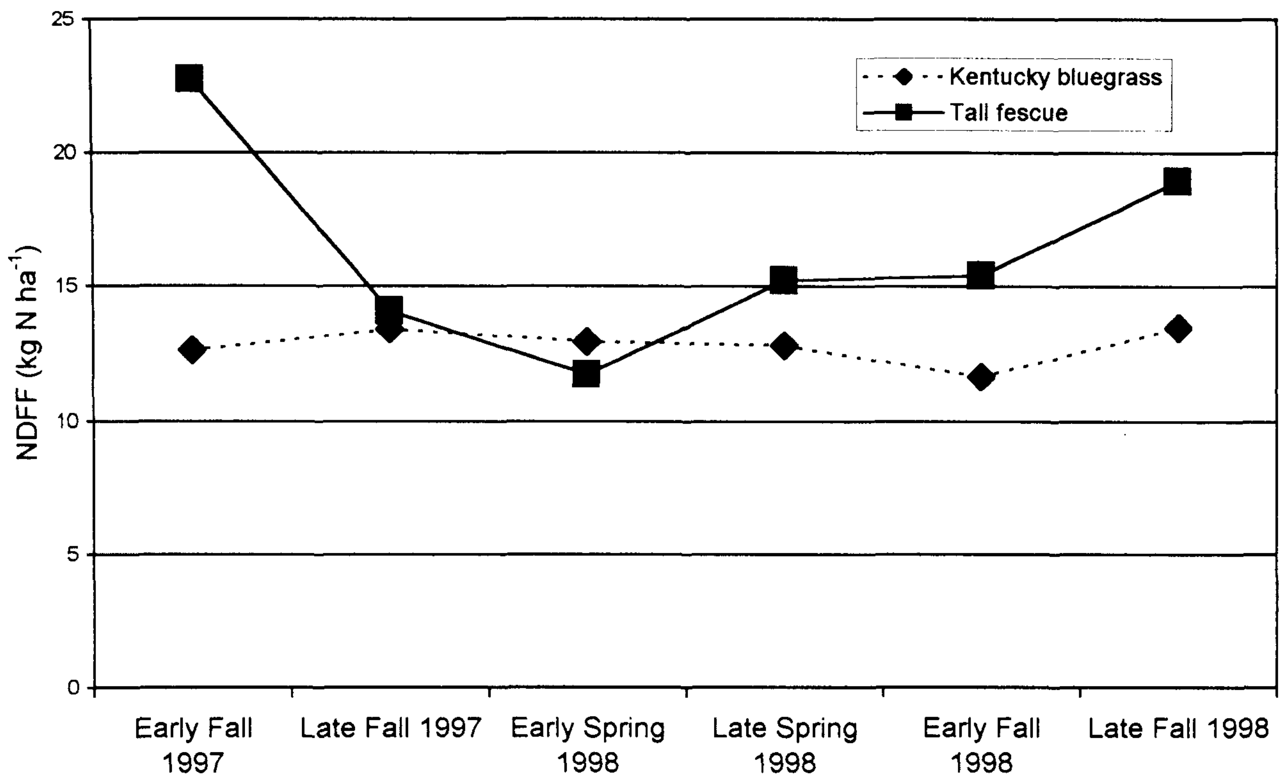

Figure 1.7. Soil Nitrogen derived from fertilizer (NDFF) for the species X sampling date interaction in Kentucky bluegrass and tall fescue.

Table 1.14 Soil nitrogen derived from fertilizer for the species x sampling date interaction in Kentucky bluegrass and tall fescue at all sampling dates in 1997 and 1998.

	Sampling Date†					
Species	Efall 97	Lfall 97	Espr 98	Lspr 98	Efall 98	Lfall 98
			$kg\ N\ ha^{-1}$			
K. bluegrass	12.6 b‡	13.4	13.0	12.8	11.7	13.5
Tall fescue	22.8 a	14.1	11.8	15.2	15.4	18.9
LSD	5.4	NS	NS	NS	NS	NS

† The sampling dates are: Efall 97 = early fall 1997, Lfall 97 = late fall 1997, Espr 98 = early spring 1998, Lspr 98 = late spring 1998, Efall 98 = early fall 1998, Lfall 98 = late fall 1998.

‡ Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

caused by plant uptake, immobilization reactions, or leaching losses.

There were significant soil depth main effects for NH_4-N concentration at all sampling dates except at the early fall and late fall 1998 sampling dates (Table 1.15). For all sampling dates NH_4-N concentration was greatest at the 0-8 cm depth.

Analysis of NO_3-N concentration by soil depth does not support the hypothesis that leaching was a significant source of nitrogen loss. There were significant depth main effects for NO_3-N concentration at all sampling dates and significant species x depth interactions at the early fall 1997, early spring 1998, and late fall 1998 sampling dates. For the sampling dates when there was only a depth main effect, soil NO_3-N concentration was highest at the 0-8 cm depth (Table 1.16). Only at one time, the early spring 1998 sampling date, was there an increase in NO_3-N concentration as soil depth increased (Table 1.17). For tall fescue, the 16-32 and 32-64 cm depths had the highest NO_3-N concentration at the early spring 1998 sampling date (Table 1.17). This effect could be caused by spring precipitation and snow-melt facilitating the movement of NO_3-N through the soil profile. Since the effect was only seen for tall fescue at one sampling date and the magnitude of the difference between the 0-8 cm and the 32-64 cm depth was only 0.2 mg NO_3-N kg^{-1} soil, it does not appear to be indicative of large leaching losses of applied nitrogen.

Table 1.15 Ammonium-nitrogen concentration in Kentucky bluegrass and tall fescue soils.

	Sampling Date							
Depth	Early Spring 97	Late Spring 97	Early Fall 97	Late Fall 97	Early Spring 98	Late Spring 98	Early Fall 98	Late Fall 98
— cm —	mg NH_4^{+}-N kg^{-1} soil							
0-8	9.4 a[†]	10.4 a	9.2 a	9.5 a	11.0 a	15.4 a	13.7	11.1
8-16	7.2 b	7.5 b	7.4 b	6.6 b	9.2 b	12.7 b	13.1	9.6
16-32	6.4 b	6.6 b	6.7 b	6.9 b	9.6 b	10.8 b	12.0	9.5
32-64	6.3 c	6.6 b	7.2 b	6.5 b	9.2 b	11.3 b	13.1	11.4
LSD	0.8	1.1	0.8	1.1	1.0	2.2	NS	NS

[†] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Table 1.16 Nitrate-nitrogen concentration in Kentucky bluegrass and tall fescue soil depths.

	Sampling Date[†]				
Depth	Espr 97	Lspr 97	Lfall 97	Lspr 98	Efall 98
cm	mg NO_3-N kg^{-1} soil				
0-8	1.7 a[‡]	1.4 a	1.2 a	1.0 a	2.1 a
8-16	1.1 b	0.9 b	0.9 b	0.8 b	1.5 b
16-32	1.2 b	0.9 b	1.0 b	0.8 b	1.5 b
32-64	1.1 b	0.9 b	0.9 b	0.8 b	1.7 b
LSD	0.2	0.1	0.1	0.1	0.4

[†] The sampling dates are: Espr 97 = early spring 1997, Lspr 97 = late spring 1997, Lfall 97 = late fall 1997, Lspr 98 = late spring 1998, Efall 98 = early fall 1998.

[‡] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Table 1.17 Nitrate-nitrogen concentration for the species x soil depth interaction.

	Sampling Date					
	Early Fall 97		Early Spring 98		Late Fall 98	
Depth	K. blue[†]	Tall fescue	K. blue	Tall fescue	K. blue	Tall fescue
cm	mg NO_3-N kg^{-1} soil					
0-8	1.1	1.7 a[‡]	0.8	0.7 bc	1.4	1.4
8-16	0.9	1.1 b	0.8	0.6 c	1.3	1.2
16-32	0.9	1.1 b	0.9	0.8 ab	1.5	1.2
32-64	1.0	1.0 b	0.8	0.9 a	1.4	1.2
LSD	NS	0.2	NS	0.1	NS	NS

[†] Kentucky bluegrass

[‡] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

The increase in the amount of soil nitrogen derived from fertilizer in tall fescue from early spring 1998 through late fall 1998 may be the result of mineralization of soil nitrogen or from root turnover. The magnitude of the increase, 11.8 to 18.9 kg N ha^{-1}, suggests that root turnover is not the source of the increase in the amount of soil nitrogen derived from fertilizer. Roots had relatively low amounts of nitrogen derived from fertilizer in comparison to soils and therefore, would most likely not be the source of the increase. Mineralization of soil nitrogen is more likely the cause of the increase in the amount of soil nitrogen derived from fertilizer in tall fescue. However, it is unclear as to why a similar increase in the amount of soil nitrogen derived from fertilizer was not observed in the Kentucky bluegrass soils. The thicker thatch layer may be responsible for sequestering more of the applied nitrogen and thus reducing the amount of nitrogen entering the soil and potentially undergoing mineralization processes.

There was a significant N rate main effect with the 24 and 49 kg N ha^{-1} rates recovering, on average across sampling dates, 12.0 and 17.2 kg N ha^{-1}, respectively. However, with respect to the %NRFF, the 24 kg N ha^{-1} rate had a higher percent recovery than the 49 kg N ha^{-1} rate, 50 to 35%, respectively.

Nitrogen Recovery in Kentucky Bluegrass and Tall Fescue Roots

There was a significant species x sampling date interaction for the amount of nitrogen in roots derived from fertilizer for Kentucky bluegrass and tall fescue (Table 1.13). For both species, the amount of nitrogen in roots derived from fertilizer increased from early fall to late fall 1997 (Figure 1.8). The amount of nitrogen in roots derived from fertilizer in tall fescue decreased after late fall 1997 but increased in Kentucky bluegrass through the early spring 1998 sampling date. Kentucky bluegrass roots had a maximum recovery of 1.3 kg N ha^{-1} at the early spring 1998 sampling date. After the early spring 1998 sampling date, the amount of nitrogen derived from fertilizer in Kentucky bluegrass roots declined rapidly. The amount of nitrogen in roots derived from fertilizer was significantly different between species at the early spring 1998 sampling date (Table 1.18). The large amount of nitrogen derived from fertilizer in Kentucky bluegrass roots at the early spring 1998 sampling could be attributed to greater root mass. Analysis of root dry weights revealed a significant species effect for the early spring 1998 sampling date (Table 1.19). Kentucky bluegrass and tall fescue had 7676 and 4754 kg roots ha^{-1}, respectively at the early spring 1998 sampling date. The large difference in root mass between Kentucky bluegrass and tall fescue was the primary reason that Kentucky bluegrass had a higher amount of nitrogen derived from fertilizer than tall fescue at the early spring 1998 sampling date. Mean root dry weights for all sampling dates are presented in appendix tables A35 – A42.

The amount of nitrogen in roots derived from fertilizer was very small, less than 1.4 kg N ha^{-1}. As discussed previously for buffalograss roots, the mass of roots when compared to the mass of soil and thatch on a per hectare basis

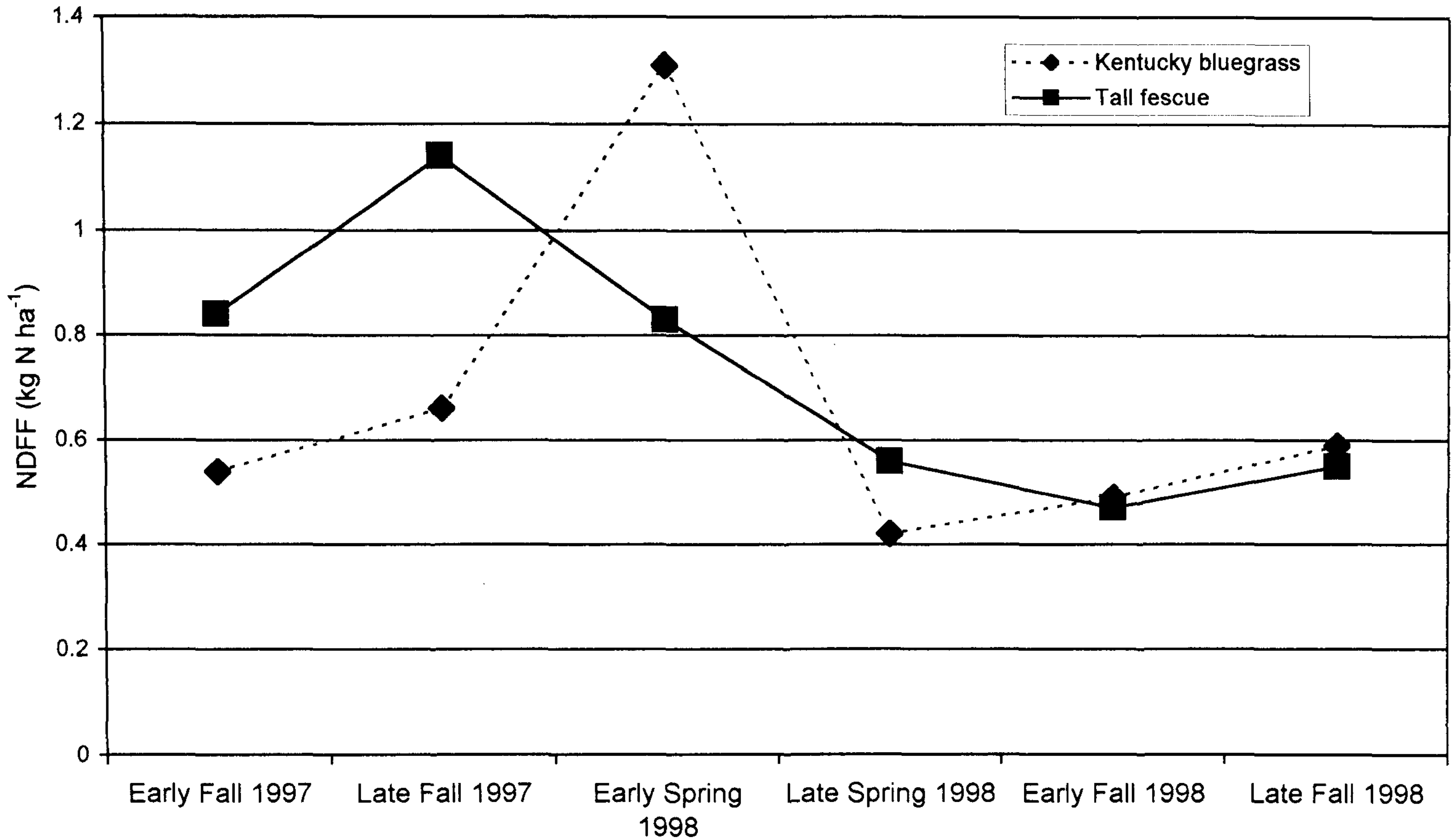

Figure 1.8. Nitrogen derived from fertilizer (NDFF) in roots for the species X sampling date interaction in Kentucky bluegrass and tall fescue.

Table 1.18 Nitrogen derived from fertilizer in roots of Kentucky bluegrass and tall fescue for all sampling dates in 1997 and 1998.

Species	Sampling Date[†]					
	Efall 97	Lfall 97	Espr 98	Lspr 98	Efall 98	Lfall 98
			kg N ha^{-1}			
K. blue.[‡]	0.5	0.7	1.3 a[§]	0.4	0.5	0.6
Tall fescue	0.8	1.1	0.8 b	0.6	0.5	0.6
LSD	NS	NS	0.4	NS	NS	NS

[†] *The sampling dates are: Efall 97 = early fall 1997, Lfall 97 = late fall 1997, Espr 98 = early* spring 1998, Lspr 98 = late spring 1998, Efall 98 = early fall 1998, Lfall 98 = late fall 1998.

[‡] Kentucky bluegrass

[§] Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Table 1.19 Analysis of variance table for Kentucky bluegrass and tall fescue root dry weights in 1997 and 1998.

Source	df	Sampling Date						
		Late spring 1997	Early fall 1997	Late fall 1997	Early spring 1998	Late spring 1998	Early fall 1998	Late fall 1998
		Pr > F						
Rep.	2							
Species	1	NS	NS	NS	*	NS	NS	NS
N rate	1	NS	NS	NS	NS	NS	NS	NS
S X N	1	NS	NS	NS	NS	NS	NS	NS
W.P. Error	6							
Depth	3	**	**	**	**	**	**	**
S X D	3	**	NS	NS	**	NS	**	NS
N X D	3	NS	NS	NS	NS	NS	NS	NS
S X N X D	3	NS	NS	NS	NS	NS	NS	NS
S.P. Error	24							

*,**, and NS indicate significance at P=0.05, 0.01, and not significant at P=0.05, respectively.

is very small and influences the calculation to determine nitrogen derived from fertilizer. Therefore, even if the atom % ^{15}N enrichment in root samples is high, the amount of nitrogen derived from fertilizer on a per hectare basis will be low due to the small relative proportion of root mass.

Nitrogen Recovery in Kentucky Bluegrass and Tall Fescue Thatch

There was a significant species x sampling date interaction for the amount of nitrogen derived from fertilizer in the thatch layer of Kentucky bluegrass and tall fescue (Table 1.13). Although the interaction was significant, it is difficult to draw any relevant conclusions from this interaction with respect to species or time effects (Figure 1.9). The great variability in the amount of nitrogen derived from fertilizer over time makes it difficult to explain the trends observed for the species x sampling date interaction. The trend was similar between species for the first three sampling dates. The amount of nitrogen derived from fertilizer was low at the early fall 1997 sampling date, increased through late fall 1997, and then decreased again at the early spring 1998 sampling date. These results could be explained by mineralization and immobilization turnover reactions in the thatch layer. From early to late fall 1997, mineralization reactions in the thatch layer could be responsible for the increase in the amount of nitrogen derived from fertilizer. The decrease from late fall 1997 to early spring 1998 could be due to several factors. Plant uptake, immobilization reactions in the thatch layer or downward movement of nitrogen through the thatch layer from winter precipitation and snow melt could cause the lower amounts of nitrogen

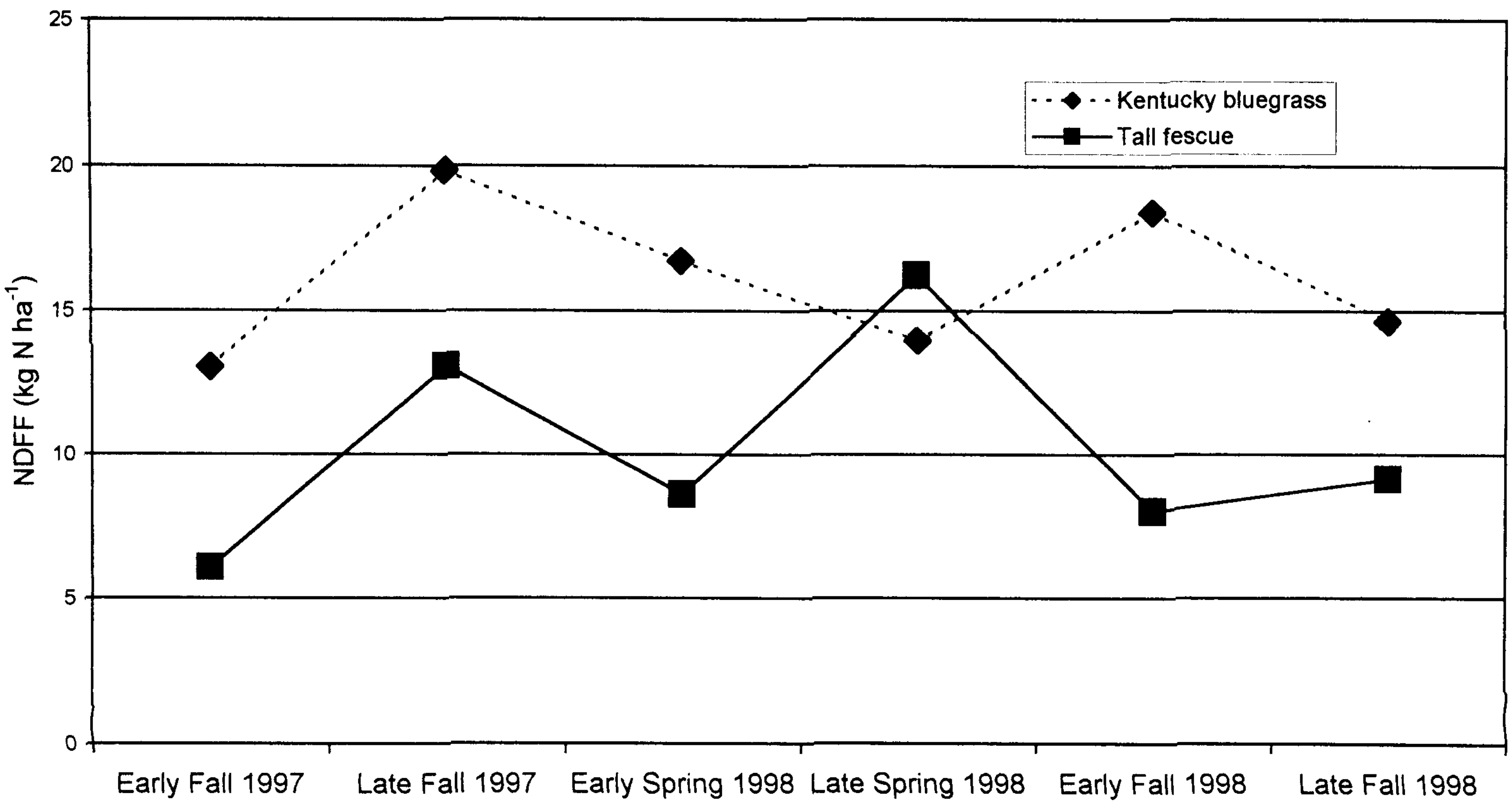

Figure 1.9. Nitrogen derived from fertilizer (NDFF) in the thatch layer for the species X sampling date *interaction in Kentucky bluegrass and tall fescue.*

derived from fertilizer. The amount of nitrogen derived from fertilizer in the soil and verdure do not support the hypothesis that the nitrogen was either moving from the thatch layer to the soil or being taken up by the plant.

The variability in the amount of nitrogen derived from fertilizer over time may be due to the heterogeneous nature of the thatch samples and not time effects. The thatch samples were analyzed as a mixture of vegetative material and soil. Inspection of % total nitrogen values of thatch samples revealed that when compared to % total nitrogen values of verdure and soil, the thatch samples varied in their composition of vegetative and soil material (Appendix tables A1-A8). A thatch sample with a high proportion of vegetative material, high % total N, resulted in larger amounts of nitrogen derived from fertilizer than a sample composed mainly of soil. Although thatch sample composition may be responsible for some of the variability observed in the species x sampling date interaction, the species effect on the amount of nitrogen derived from fertilizer in the thatch layer should not be ignored.

The Kentucky bluegrass thatch layer had a larger amount of nitrogen derived from fertilizer than the tall fescue thatch layer at all sampling dates except the late spring 1998 sampling date (Table 1.20). The thicker thatch layer of Kentucky bluegrass was probably the determining factor for the greater amounts of nitrogen derived from fertilizer.

Table 1.20 Nitrogen derived from fertilizer in the thatch layer of Kentucky bluegrass and tall fescue for all sampling dates in 1997 and 1998.

Species	Sampling Date†					
	Efall 97	Lfall 97	Espr 98	Lspr 98	Efall 98	Lfall 98
	kg N ha^{-1}					
K. blue.‡	13.1 a§	19.8 a	16.7 a	14.0	18.4 a	14.6 a
Tall fescue	6.1 b	13.1 b	8.6 b	16.2	8.0 b	9.1 b
LSD	3.5	3.5	3.5	NS	3.5	3.5

† *The sampling dates are:* Efall 97 = early fall 1997, Lfall 97 = late fall 1997, Espr 98 = early spring 1998, Lspr 98 = late spring 1998, Efall 98 = early fall 1998, Lfall 98 = late fall 1998.

‡ Kentucky bluegrass

§ Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

Nitrogen rate main effects reveal that, over time, the 49 kg N ha^{-1} rate recovered more nitrogen from fertilizer than the 24 kg N ha^{-1} rate, 16.6 to 9.7 kg N ha^{-1}, respectively. For the %NRFF, the 24 and 49 kg N ha^{-1} rates recovered 40 and 34%, respectively. The %NRFF in the thatch layer was similar to the values found by Miltner et al. (1996). For spring and fall applied nitrogen treatments, 31 and 62% of applied nitrogen was recovered in the thatch layer of a Kentucky bluegrass turf at 18 d after fertilizer treatment (Miltner et al., 1996). For the spring and fall treatments, the %NRFF declined to 13 and 17% after 2 yr, respectively. Starr and DeRoo (1981) recovered 19 and 27% of applied nitrogen in the thatch layer of a Kentucky bluegrass and red fescue turf when clippings were removed and returned, respectively. As Starr and DeRoo commented (1981), the large amounts of nitrogen sequestered in the thatch layer implicate it as an environment favorable for an active microbial population. The dead and decaying organic matter and the moist conditions in the thatch layer provide both a suitable substrate and environment for microorganisms. Applied nitrogen remaining in the thatch layer is available for use by microorganisms and thus potentially unavailable for immediate plant uptake. These results stress the importance of thatch management with respect to the utilization of applied nitrogen by turfgrass. A large thatch layer has the potential to immobilize large amounts of nitrogen, thereby rendering nitrogen unavailable for plant uptake.

Nitrogen Recovery in Kentucky Bluegrass and Tall Fescue Verdure

There was a significant species x N rate x sampling date interaction for the amount of nitrogen derived from fertilizer in verdure (Figure 1.10). The three-way interaction was explained by conducting regression analysis which revealed a significant linear effect for both the N rate x sampling date and species x sampling date interactions.

For the N rate x sampling date interaction, the amount of nitrogen derived from fertilizer declined at a faster rate for the 49 kg N ha^{-1} rate than for the 24 kg N ha^{-1} rate (Figure 1.11). The 49 kg N ha^{-1} rate had larger amounts of nitrogen in verdure derived from fertilizer than the 24 kg N ha^{-1} rate at all sampling dates except early fall and late fall 1998. However the magnitude of the difference was less than 1 kg N ha^{-1} (Table 1.21). With respect to the %NRFF, the 24 kg N ha^{-1} rate had greater %NRFF than the 49 kg N ha^{-1} rate.

Regression analysis revealed that the slopes for the amount of nitrogen in verdure derived from fertilizer were different for Kentucky bluegrass and tall fescue (Figure 1.12). The difference in slopes was small and overall it appears that the decrease in the amount of nitrogen in verdure derived from fertilizer was similar between the species. Kentucky bluegrass recovered greater amounts of nitrogen derived from fertilizer than tall fescue at the early fall 1997, late fall 1997, and late fall 1998 sampling dates indicating that Kentucky bluegrass allocated more nitrogen to top-growth than tall fescue (Table 1.22).

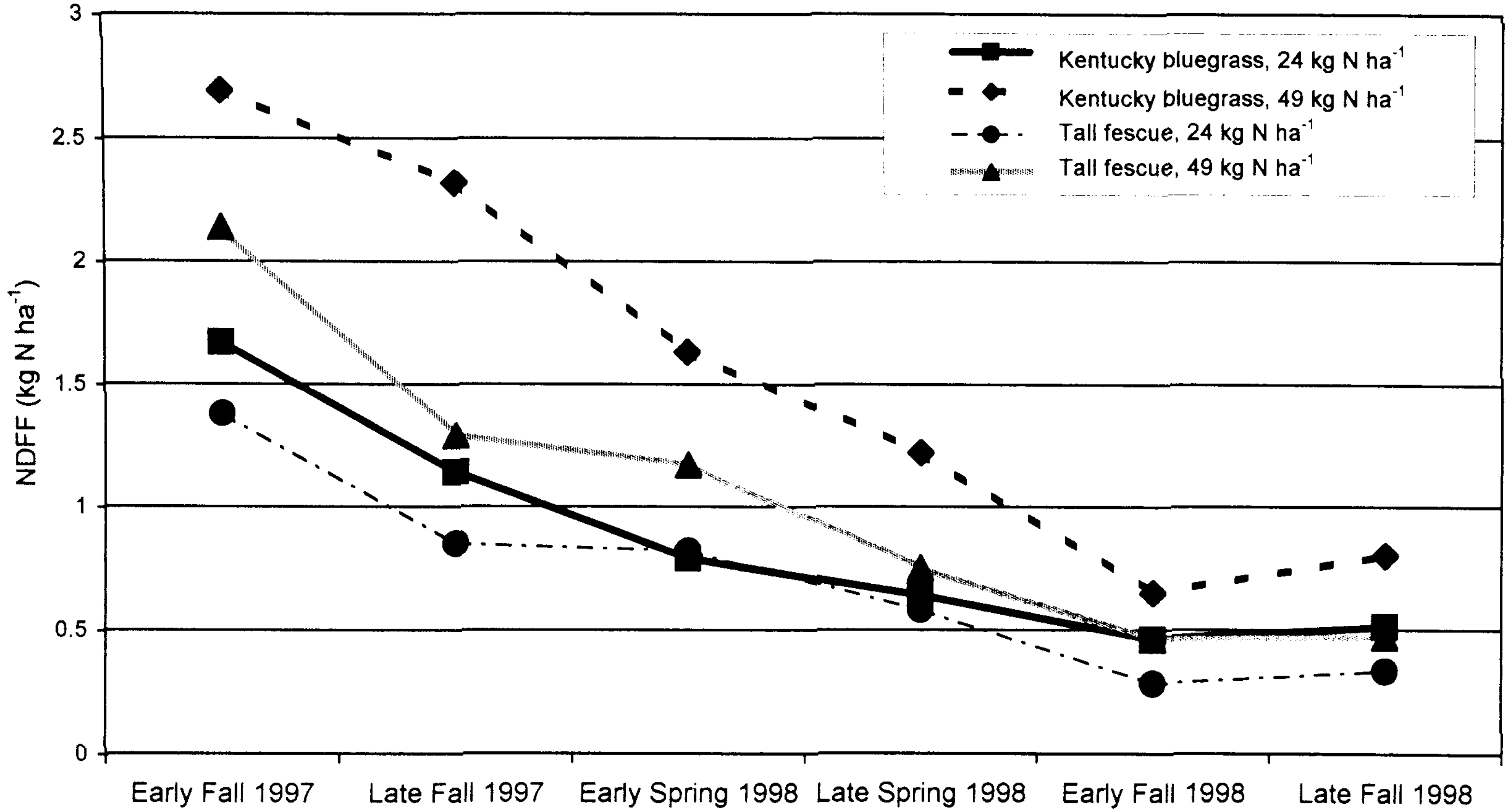

Figure 1.10. Nitrogen derived from fertilizer (NDFF) in verdure for the species X N rate X sampling date interaction in Kentucky bluegrass and tall fescue.

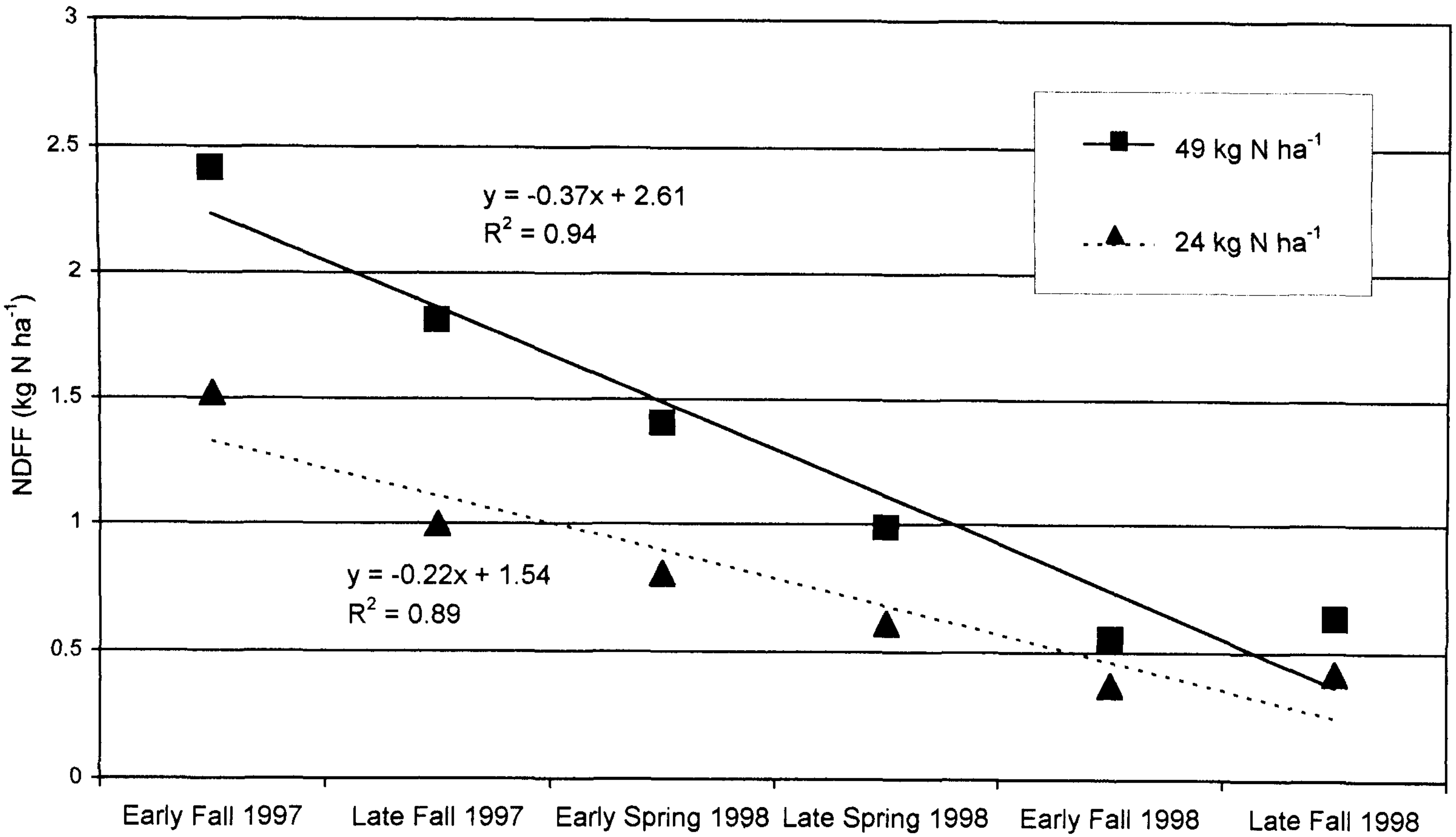

Figure 1.11. Nitrogen derived from fertilizer (NDFF) in verdure for the N rate X sampling date interaction and regression of N rate on sampling date for NDFF in Kentucky bluegrass and tall fescue.

Table 1.21 Nitrogen derived from fertilizer and percent nitrogen recovered from fertilizer (%) in the verdure of Kentucky bluegrass and tall fescue for all sampling dates in 1997 and 1998.

	Sampling date†					
N rate	Efall 97	Lfall 97	Espr 98	Lspr 98	Efall 98	Lfall 98
— kg N ha^{-1} —	kg N ha^{-1} (%)					
24	1.5 b‡ (6.3)	1.0 b (4.2)	0.8 b (3.3)	0.6 b (2.5)	0.4 (1.7)	0.4 (1.7)
49	2.4 a (4.9)	1.8 a (3.7)	1.4 a (2.9)	1.0 a (2.0)	0.6 (1.2)	0.6 (1.2)
LSD	0.2	0.2	0.2	0.2	NS	NS

† The sampling dates are: Efall 97 = early fall 1997, Lfall 97 = late fall 1997, Espr 98 = early spring 1998, Lspr 98 = late spring 1998, Efall 98 = early fall 1998, Lfall 98 = late fall 1998.

‡ Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

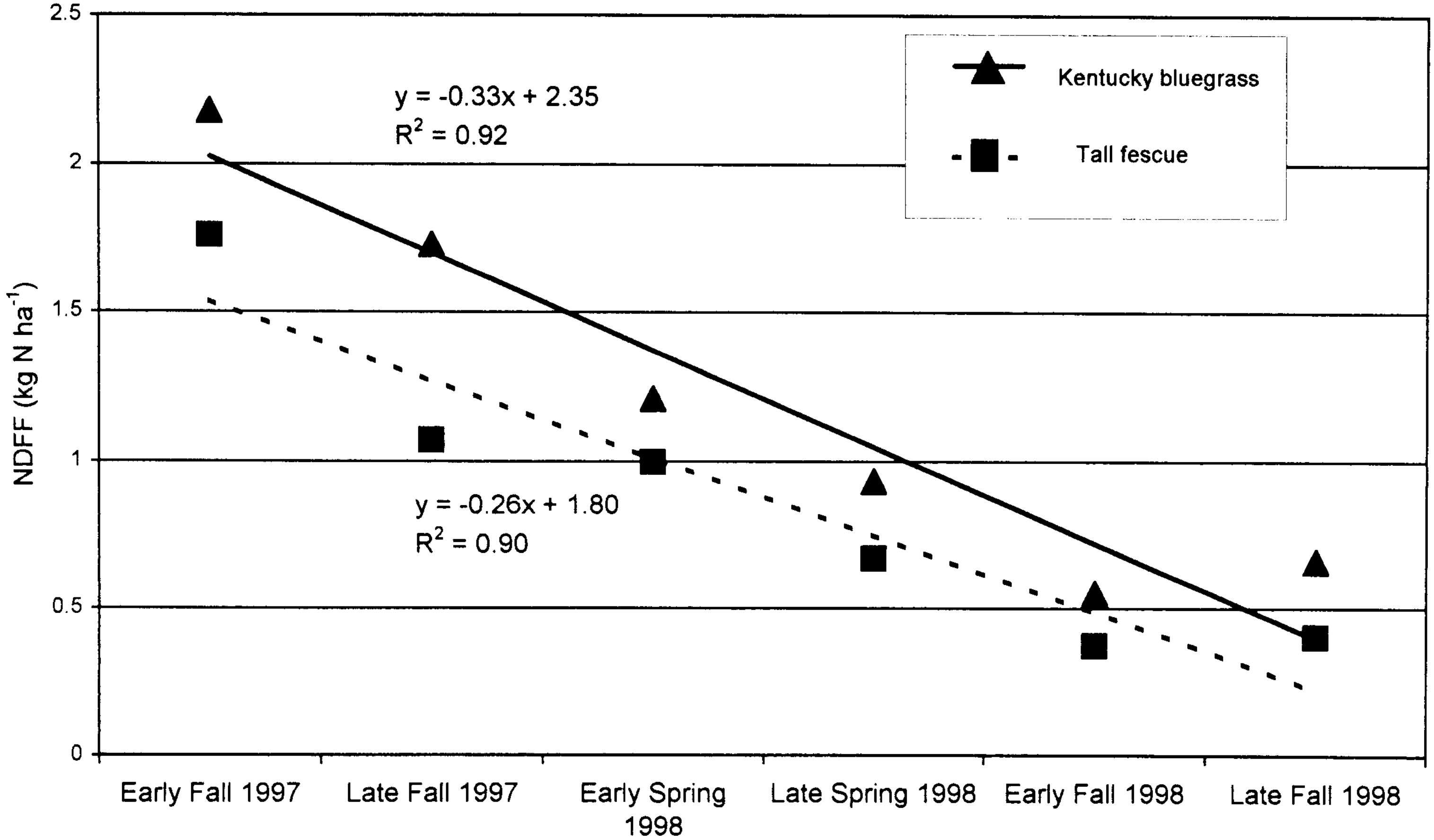

Figure 1.12. Nitrogen derived from fertilizer (NDFF) in verdure for the species X sampling date interaction in Kentucky bluegrass and tall fescue.

Table 1.22 Nitrogen derived from fertilizer in the verdure of Kentucky bluegrass and tall fescue for all sampling dates in 1997 and 1998.

	Sampling Date†					
Species	Efall 97	Lfall 97	Espr 98	Lspr 98	Efall 98	Lfall 98
	kg N ha^{-1}					
K. blue.‡	2.2 a§	1.7 a	1.2	0.9	0.6	0.7 a
Tall fescue	1.8 b	1.1 b	1.0	0.7	0.4	0.4 b
LSD	0.2	0.2	NS	NS	NS	0.2

† The sampling dates are: Efall 97 = early fall 1997, Lfall 97 = late fall 1997, Espr 98 = early spring 1998, Lspr 98 = late spring 1998, Efall 98 = early fall 1998, Lfall 98 = late fall 1998.

‡ Kentucky bluegrass

§ Means in a column followed by the same letter are not significantly different according to LSD (P=0.05).

A significant species x N rate interaction revealed differences in the amount of nitrogen derived from fertilizer between N rates and species. The difference in the amount of nitrogen in verdure derived from fertilizer between N rates was greater for Kentucky bluegrass than for tall fescue . The amount of nitrogen derived from fertilizer in Kentucky bluegrass was 0.9 and 1.6 kg N ha^{-1} at the 24 and 49 kg N ha^{-1} rates, respectively. This was a difference of 0.7 kg N ha^{-1}. The amount of nitrogen derived from fertilizer in tall fescue was 0.7 and 1.1 kg N ha^{-1} at the 24 and 49 kg N ha^{-1} rates, respectively, for a difference of only 0.4 kg N ha^{-1}. The difference in the amount of nitrogen derived from fertilizer between N rates for Kentucky bluegrass was almost twice the difference in tall fescue. The interaction indicates that Kentucky bluegrass responds to higher nitrogen application rates by allocating the nitrogen to top growth. In tall fescue the additional nitrogen available at the high N rate may be used for root growth or may remain in the soil or thatch layer.

Total Nitrogen Recovery in Kentucky Bluegrass and Tall Fescue

There was a significant species x sampling date interaction for the total amount of nitrogen derived from fertilizer in Kentucky bluegrass and tall fescue (Table 1.13). The thatch and soil components had the largest amount of nitrogen derived from fertilizer and therefore, the strongest influence on the species x sampling date interaction (Table 1.23). The species x sampling date interaction for the total amount of nitrogen derived from fertilizer reflects the species x sampling date interactions in the soil and thatch layer (Figures 1.7 and 1.9). Kentucky bluegrass had relatively little variability in the total amount of nitrogen derived from fertilizer across sampling dates with a peak at the late fall 1997 sampling date (Figure 1.13). The peak at the late fall 1997 sampling date was due to the large amount of nitrogen derived from fertilizer in the thatch layer of Kentucky bluegrass. Similar to the species x sampling date interactions observed in tall fescue soils and thatch, there was greater variability in the total amount of nitrogen derived from fertilizer across sampling dates for tall fescue. Due to the strong influence of the soil and thatch components on the total amount of nitrogen derived from fertilizer, the species x sampling date interaction provides little insight into differences in the total amount of nitrogen derived from fertilizer in both turfgrass species.

A significant N rate main effect showed that the 24 and 49 kg N ha^{-1} rates recovered 23.1 and 35.7 kg N ha^{-1}, respectively. The %NRFF was 96 and 73% for the 24 and 49 kg N ha^{-1} rates, respectively. This result was similar to the

Table 1.23 Nitrogen derived from fertilizer (NDFF) and percent nitrogen recovered from fertilizer (%NRFF) of Kentucky bluegrass and tall fescue in 1997 and 1998.

Species	N rate	Date	Verdure	Thatch	Soil	Roots	Total
	— kg N ha^{-1} —		kg N ha^{-1} (%)				
Kentucky bluegrass	24	Early fall 97	1.7 (7.1)	9.5 (39.6)	14.1 (58.8)	0.6 (2.5)	25.9 (107.9)
		Late fall 97	1.1 (4.6)	15.4 (64.2)	10.2 (42.5)	0.6 (2.5)	27.3 (113.8)
		Early spring 98	0.8 (3.3)	12.5 (52.1)	9.0 (37.5)	1.0 (4.2)	23.3 (97.1)
		Late spring 98	0.6 (2.5)	9.4 (39.2)	10.7 (44.6)	0.4 (1.7)	21.1 (87.9)
		Early fall 98	0.5 (2.1)	15.0 (62.5)	11.7 (48.8)	0.5 (2.1)	27.7 (115.4)
		Late fall 98	0.5 (2.1)	12.0 (50.0)	9.6 (40.0)	0.4 (1.7)	22.5 (93.8)
	49	Early fall 97	2.7 (5.5)	16.6 (33.9)	11.2 (22.9)	0.5 (1.0)	31.0 (63.3)
		Late fall 97	2.3 (4.7)	24.3 (49.6)	16.7 (34.1)	0.7 (1.4)	44.0 (89.8)
		Early spring 98	1.6 (3.3)	21.0 (42.9)	16.9 (34.5)	1.6 (3.3)	38.7† (79.0)
		Late spring 98	1.2 (2.4)	18.6 (38.0)	15.0 (30.6)	0.4 (0.8)	35.2 (71.8)
		Early fall 98	0.7 (1.4)	21.8 (44.5)	11.6 (23.7)	0.5 (1.0)	34.6 (70.6)
		Late fall 98	0.8 (1.6)	17.3 (35.3)	17.4 (35.5)	0.8 (1.6)	36.3 (74.1)
Tall fescue	24	Early fall 97	1.4 (5.8)	4.0 (16.7)	18.2 (74.8)	0.7 (2.9)	24.3 (101.3)
		Late fall 97	0.9 (3.8)	10.1 (42.1)	10.4 (43.3)	0.9 (3.8)	22.3 (92.9)
		Early spring 98	0.8 (3.3)	6.3 (26.3)	10.7 (44.6)	0.7 (2.9)	18.5 (77.1)
		Late spring 98	0.6 (2.5)	10.7 (44.6)	13.5 (56.3)	0.6 (2.5)	25.4 (105.8)
		Early fall 98	0.3 (1.3)	6.0 (25.0)	9.4 (39.2)	0.4 (1.7)	16.1 (67.1)
		Late fall 98	0.3 (1.3)	5.9 (24.6)	16.4 (68.3)	0.4 (1.7)	23.0 (95.8)
	49	Early fall 97	2.1 (4.3)	8.2 (16.7)	27.4 (55.9)	1.0 (2.0)	38.7 (79.0)
		Late fall 97	1.3 (2.7)	16.0 (32.7)	17.9 (36.5)	1.4 (2.9)	36.6 (74.7)
		Early spring 98	1.2 (2.4)	10.9 (22.2)	12.8 (26.1)	1.0 (2.0)	25.9 (52.9)
		Late spring 98	0.8 (1.6)	21.7 (44.3)	16.9 (34.5)	0.5 (1.0)	39.9 (81.8)
		Early fall 98	0.5 (1.0)	10.1 (20.6)	21.4 (43.7)	0.6 (1.2)	32.6 (66.5)
		Late fall 98	0.5 (1.0)	12.4 (25.3)	21.5 (43.9)	0.7 (1.4)	35.1 (71.6)

† Total apparent ^{15}N recovery values are not equal to the sum of the apparent ^{15}N recovery values for the components due to differences in the statistical calculations performed on missing data points

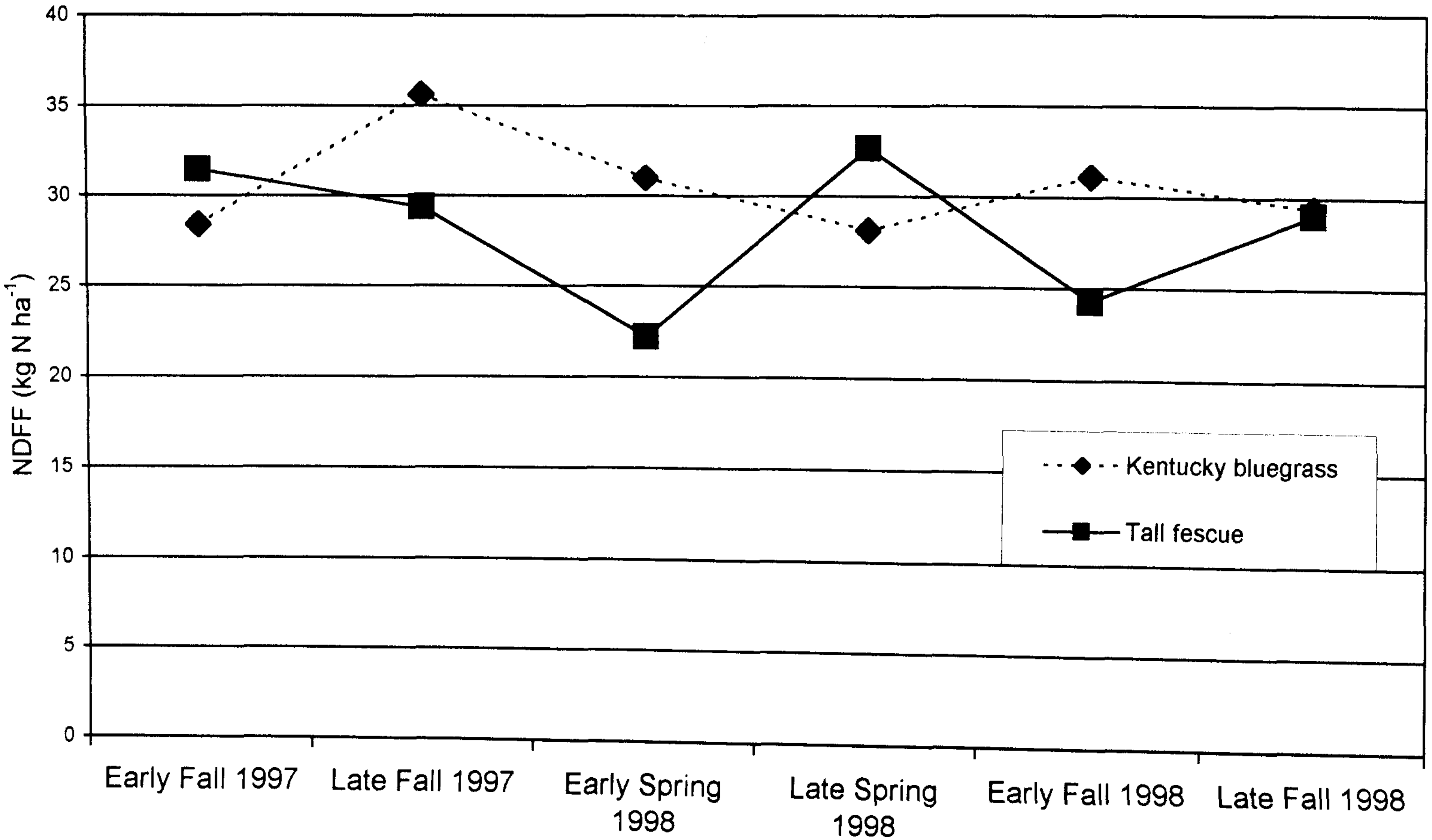

Figure 1.13. Total nitrogen derived from fertilizer (NDFF) for the species X sampling date interaction in Kentucky bluegrass and tall fescue.

N rate effect in the buffalograss selections where the lower N rate had a higher %NRFF.

The verdure and root components had low amounts of nitrogen derived from fertilizer in comparison to the thatch layer and soil. The primary difference in the total amount of nitrogen derived from fertilizer between species was the amount of nitrogen recovered in the thatch and soil. As discussed previously, the thicker thatch layer in Kentucky bluegrass resulted in the amount of nitrogen derived from fertilizer being equal to or greater than the amount recovered in the soil. In contrast a thinner thatch layer in tall fescue led to greater amounts of soil nitrogen derived from fertilizer at almost all sampling dates. These results stress the importance of thatch management in a fertility program. A thick thatch layer can sequester large amounts of applied nitrogen, thereby rendering it unavailable to plant uptake.

CONCLUSIONS

Statistical comparisons were not made between Kentucky bluegrass and tall fescue and the buffalograss selections because of differences in the amounts of ^{15}N labeled fertilizer applied and sampling dates. Nevertheless, it is worthwhile to speculate on the differences in the amounts of nitrogen derived from fertilizer among the turfgrass species.

For buffalograss roots and verdure and for Kentucky bluegrass and tall fescue verdure the higher nitrogen rate had greater initial recovery of nitrogen derived from fertilizer. However, the higher nitrogen rate had a more rapid decline overtime in the amount of nitrogen derived from fertilizer. These results reveal that although plant uptake of nitrogen at higher nitrogen rates is initially greater, after a period of time the amount of nitrogen recovered by the plant is equivalent between the two nitrogen rates. This does not imply that the total amount of nitrogen recovered by the plant is equivalent at high and low nitrogen rates but rather that after the initial uptake of applied nitrogen, the amount of nitrogen taken up by the plant at later dates is equivalent. If the higher nitrogen rate resulted in greater amounts of soil nitrogen derived from fertilizer, the potential would exist for the applied nitrogen to be available for plant uptake over time. In the buffalograss selections, the average %NRFF in soil at the 49 and 98 kg N ha^{-1} rates were 45 and 25%, respectively. In Kentucky bluegrass and tall fescue, the average %NRFF in soil at the 24 and 49 kg N ha^{-1} rates were 49 and 35 %NRFF, respectively. The higher nitrogen rate did not result in greater amounts of fertilizer nitrogen in the soil.

The presence of the thatch layer in Kentucky bluegrass and tall fescue was one of the major differences in the total amount of nitrogen recovered between Kentucky bluegrass and tall fescue and the buffalograss selections. In Kentucky bluegrass and tall fescue the thatch layer sequestered large amounts of nitrogen derived from fertilizer. The average %NRFF in the thatch layer of Kentucky bluegrass and tall fescue for all sampling dates was 37%. Buffalograss did not have a well defined thatch layer and it is unclear whether the nitrogen that would normally be sequestered in the thatch layer was lost or moved into the soil profile. At the 49 kg N ha^{-1} rate, the soil of the buffalograss selections accounted for 45% of the applied nitrogen and the soil of Kentucky bluegrass and tall fescue accounted for 35% of the applied nitrogen. In comparison to Kentucky bluegrass and tall fescue, the absence of a thatch layer in buffalograss resulted in a moderate increase of 10 %NRFF in soil.

The average total %NRFF over all sampling dates at the 49 kg N ha^{-1} rate for Kentucky bluegrass and tall fescue together was 73% and for the buffalograss selections together was 51%. For the buffalograss selections the average total %NRFF over all sampling dates at the 98 kg N ha^{-1} rate was only 31%. Clearly the %NRFF in the buffalograss selections was less than that recovered in Kentucky bluegrass and tall fescue. The lower nitrogen recovery in the buffalograss selections could be attributed to greater nitrogen losses from denitrification. As previously discussed, the irrigation practices imposed on the buffalograss selections may have temporarily resulted in saturated soil conditions conducive to denitrification losses. Kentucky bluegrass and tall fescue were irrigated every three days and received smaller amounts of water during each irrigation than buffalograss. These irrigation practices may have resulted in lower rates of denitrification from Kentucky bluegrass and tall fescue and therefore greater recovery of applied nitrogen.

The average total %NRFF for all sampling dates of Kentucky bluegrass and tall fescue at the 24 and 49 kg N ha^{-1} rates were 95 and 73%, respectively. For the buffalograss selections, the average total %NRFF for all sampling dates at the 49 and 98 kg N ha^{-1} rates were 51 and 31%, respectively. In Kentucky bluegrass and tall fescue nitrogen recovery was high and even at the 49 kg N ha^{-1} rate the majority of the nitrogen applied was recovered. In contrast, in the buffalograss selections approximately 50% of the applied nitrogen was recovered at the 49 kg N ha^{-1} rate. At the 49 kg N ha^{-1} rate, 22% less of the applied nitrogen was recovered in buffalograss in comparison to Kentucky bluegrass and tall fescue. As discussed previously, the irrigation practices imposed on the buffalograss may have resulted in increased nitrogen losses from denitrification. It is also possible that due to the lack of a thatch layer in buffalograss which would sequester nitrogen and slow nitrogen movement into the soil, nitrogen may have leached from the soil profile before soil sampling was conducted.

These results suggest that the nitrogen rates applied to buffalograss were either excessive or the irrigation practices imposed actually increased nitrogen loss. Future research to determine nitrogen allocation in buffalograss should investigate lower nitrogen rates and consider modifying the irrigation practices in order to reduce the potential for denitrification losses.

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