NITROGEN CYCLING ASSOCIATED WITH

VEGETATION TYPE CONVERSION

IN THE CROSS TIMBERS

By

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PREFACE

This thesis is formatted for submission as two manuscripts to separate scientific journals. Chapter I will be submitted to the Journal of Range Management and Chapter II will be submitted to the Agronomy Journal. Many thanks need to be extended for assistance in completion of this project.

I extend appreciation to the Department of Agronomy at Oklahoma State University for the use of facilities and equipment. I wish to thank my co-advisers, Dr. Dave Engle and Dr. Earl Allen. Both have provided every opportunity possible for learning and project completion. Dr. Earl Allen provided financial support, encouragement, and knowledge to keep me going in the early stages of this endeavor. Dr. Dave Engle has been unwavering in his enthusiastic support over the years it has taken for completion and has also provided financial support. Both have given much time and energy for which I am grateful. Dr. Jim Stritzke, my other committee member, has also been an encouragement and supplied many good ideas for development and culmination of my M.S. research project.

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Chapter I

NITROGEN AND BIOMASS DYNAMICS WITHIN ECOSYSTEM COMPARTMENTS FOLLOWING BRUSH CONTROL IN A POST OAK-BLACKJACK FOREST

ABSTRACT

Converting marginal hardwood forests to grass can increase economic output from livestock grazing, but nitrogen management during conversion needs to be evaluated to minimize possible adverse effects on the environment. This study was conducted to determine temporal changes in quantities of N and biomass within ecosystem compartments during conversion to grass from a mature post oak (Quercus stellata Wangenh.)-blackjack oak (Quercus marilandica Muenchh.) forest. The 4 treatments evaluated included; 1) no brush kill with no grass overseeding, 2) brush kill with no grass overseeding, 3) brush kill with cool-season grass overseeding, and 4) brush kill with warm-season grass overseeding. The herbaceous layer in the no-grass overseeding treatment, which was revegetated by secondary autogenic succession, consisted of mostly annual forbs. The cool-season, overseeded grass was 'K-31' tall fescue (Festuca arundinacea Schreb.), and the warm-season overseeded grass was 'Plains' Old World bluestem [Bothriochloa ischaemum var. ischaemum (L.) Keng.]. Brush kill was accomplished with tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea), which was applied in March and May 1993. Monitoring took place in 4 plots (15 X 25m) per treatment during a 21-month period (June 1993 to February 1995) at 6 predetermined sampling dates. Total N was measured within 8 compartments: soil (0 to 60 cm), roots (0 to 60 cm), litter, herbaceous plants, woody plants with a diameter at breast height (dbh) of < 2.5 cm, and leaves, branches, and boles from trees with a dbh > 2.5 cm. Treatments were compared with orthogonal contrasts. Stored N in tall fescue was 6 to 7 times greater than in Old World bluestem or native vegetation by June 1994 and was still 2 times greater in October 1994 and February 1995. However, tall fescue and Old World bluestem biomass were not different in October 1994 or

February 1995, but both were greater than native vegetation. Total N in the soil for all treatments averaged 5100 kg ha^{-1} and fluctuations were not detectable among treatments. Total N changes in other compartments were not observable or were minimal.

INTRODUCTION

Oklahoma, Texas, and Kansas contain more than 11 million acres of the cross timbers vegetation type (SCS 1981). Much of that land has little economic value other than recreational use. Livestock production is marginal since lack of proper management in the past has reduced thousands of acres to cull hardwoods (Byrd et al. 1984). Herbicide treatments can improve use and production from this land (Elwell 1950, Elwell 1968, Elwell et al. 1970, Scifres et al. 1981, McCollum et al. 1987, Scifres et al. 1987, Smith et al. 1987, Smith 1988, Engle et al. 1991, Stritzke et al. 1991), but these severe disturbances may also have negative environmental consequences.

The fate of nitrogen within the ecosystem after conversion is an environmental concern that has been studied in a variety of forests and shrublands (Likens et al. 1970, Hibbert et al. 1974, Knight et al. 1983, Lloyd-Reilley et al. 1984). When disturbances such as clear-cutting and herbicide treatment occur in forests, large amounts of organic matter can be mineralized resulting in an abundance of available nitrogen (Vitousek 1981). Significant nitrogen losses through leaching and runoff are the norm when plant uptake is temporarily reduced well below the available source of nutrients (Vitousek and Melillo 1979). Negative environmental consequences of nitrogen loss may be a decline in site fertility and productivity.

At the Cross Timbers Experimental Range near Stillwater, Okla., Stritzke et al. (1991) determined the response of overstory woody species and Engle et al. (1991) determined the response of understory herbaceous vegetation during secondary autogenic succession after application of herbicides and fire. In the closed overstory of these mature post oak-blackjack forests, herbaceous plants were sparse and understory herbage production did not peak until 2 years after herbicide treatment (Engle et al. 1991). A lag time resulted between expected N release and available vegetation for N uptake. Herbage production peaked at 4800 kg ha^{-1}, but by ten years post treatment, total herbaceous production had dropped to as much as half of the maximum (Unpublished data, Engle et al.). Similar herbage production response has been noticed in other studies (Davis 1967, Klimo and Kulhavý 1994). We hypothesize that loss of N from the ecosystem was partially responsible for the reduced level of production, although no research has been done to date on the fate of nitrogen in the cross timbers following brush control. If indeed N is lost after brush control, it is possible that capturing the mineralized N in herbaceous material will result in a more sustainable forage production system. With this in mind, the objective of this study was to determine effects of brush kill and grass establishment by overseeding on the temporal variation in N storage within ecosystem compartments of the cross timbers.

MATERIALS AND METHODS

Study Area

This study was conducted on the Oklahoma State University Research Range, located approximately 11 km southwest of Stillwater, Okla. The vegetation of the area is dominated by post oak (Quercus stellata Wangenh.) and blackjack oak (Quercus marilandica Muenchh.). The site is an upland forest on a sandy savannah range site. We established study plots on nearly level topography of Stephenville sandy loam soils (fine-loamy, siliceous, thermic Ultic Haplustalfs) (SCS 1981). Soils in the series have an average depth of 60 cm, are well drained, and are moderately permeable. Annual precipitation in the area averages 830 mm, falling mostly from April to October. Mean annual temperature is 15.5 °C, with the mean in January of 2.3 °C, and the mean in July of 27.6 °C (Myers 1982).

Treatments and Design

Sixteen plots, (15 x 25 m), with 4 replications of 4 treatments were arranged in a completely randomized design in March 1993. The 4 treatments evaluated included; 1) no brush kill with no grass overseeding, 2) brush kill with no grass overseeding, 3) brush kill with cool-season grass overseeding, and 4) brush kill with warm-season grass overseeding. The no grass overseeding treatment, which was revegetated by secondary autogenic succession, consisted of mostly annual forbs. The cool-season, overseeded grass was 'K-31' tall fescue (Festuca arundinacea Schreb.), and the warm-season grass was 'Plains' Old World bluestem [Bothriochloa ischaemum var. ischaemum (L.) Keng.]. Brush kill was achieved with tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N'*-dimethylurea), which was applied to 8 of the plots in March 1993 and to 4 of the plots in May 1993, at a rate of 2.2 kg a.i. ha^{-1}. The tebuthiuron effect on overstory oaks resulted in excellent control with results similar to those reported by Stritzke et al. (1991). Leaf litter in the 12 herbicide-treated plots was burned on 30 September 1993, 8 plots were immediately overseeded (4 with tall fescue at 15 kg PLS ha^{-1} and 4 with Old World bluestem at 6 kg PLS ha^{-1}) and 4 were left unseeded. The remaining 4 served as controls and were not treated with herbicide, burned, or overseeded. Tall fescue established 100% ground cover by April 1994 and Old World bluestem established 100% ground cover by August 1994.

Field Sampling

Plots were divided into 6 sections to match 6 sampling dates over a 21-month period (June 1993 through February 1995), to avoid disturbance before sample collection, with all compartments randomly sampled in a different section at each date. Sampling dates corresponded to either expected pulses of plant N uptake or mineralized N in the soil. We sampled in June 1993 to measure base N levels before tebuthiuron treatment was effective. November 1993 sampling coincided with expected maximum accumulation of mineralized N in biomass. We sampled in January 1994 to correspond with maximum accumulation of mineralized N in the soil, because mineralization by this time is minimal, and because tall fescue would not be actively growing and Old World bluestem would not yet have germinated. The June 1994 sampling represented reduced N uptake and near maximum accumulation of mineralized N by tall fescue, corresponding to time of seed production and reduced growth in tall fescue. The October 1994 sampling, after the first killing frost, represented maximum accumulation of mineralized N by Old World bluestem. Finally, sampling in February 1995, we expected maximum mineralized N in the soil before uptake by tall fescue and Old World bluestem began in the second growing season. Biomass and N concentrations were determined in samples from 5 compartments: soil, roots, litter, herbaceous plants, and woody plants with a diameter at breast height (dbh) of < 2.5 cm. We collected samples for N concentrations in 3 additional compartments: leaves, branches, and boles from trees with a dbh > 2.5 cm. Biomass in components of trees with a dbh > 2.5 cm was estimated from values of Johnson and Risser (1974).

Soils were sampled and composited from 5 random locations per plot on each date during the experiment. Samples were taken with a 2.5-cm diameter corer at 4 depth increments (0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm). Root biomass was sampled in 3 root cores per plot by driving a 6.5 cm diameter corer into the ground and extracting cores in the same depth increments as soil. Litter samples were collected to mineral soil within three, 0.25-m^2 circular quadrats per plot. Herbaceous material and woody (< 2.5 cm dbh) material were sampled within three, 1.0-m^2 circular quadrats per plot. Twenty tree leaves per plot were collected randomly on those dates when leaves were live and present in the canopy. Ten branches (< 1.25 cm in diameter) per plot were randomly collected, excluding current years growth that would have been higher in N in untreated plots compared to herbicide treated plots. Two bole samples per plot were randomly collected with a 5.15-mm increment borer.

Laboratory Procedures

Soil samples were dried at 90 °C in a forced air drying oven and ground in a hammer mill to pass a 2.0-mm mesh screen. Biomass samples were dried at 65 °C. Litter, herbaceous, and woody samples were weighed, composited, and quartered before grinding. Roots were separated from root core samples by washing the composited samples with water through 20-mesh and 32-mesh screens simultaneously to recover root fragments. All biomass samples were ground in Wiley and Udy mills consecutively to pass 1.0-mm and 0.25-mm mesh screens, respectively. Both soil and biomass samples were analyzed in the LECO model FP 428 by dry combustion for total N as described in Page et al. (1982). Total compartment N was calculated as the product of the compartment N concentration and mass. Total N value for the ecosystem in each treatment over time was calculated as the sum of all N in all compartments. Nitrogen values were converted to kg ha^{-1} and soil sample concentrations of N were adjusted for bulk density by multiplying an average dry weight of 60 core samples per 15-cm soil depth increment taken from the study area in February 1995. We present total soil N for the beginning June 1993 sampling date and the ending February 1995 sampling date because analyses were done on these samples first and no treatment differences were detected. Additional analysis of 320 soil samples for total N was deemed unnecessary.

Statistical Analysis

Statistical analysis was performed with a split plot arrangement of treatments in a one way analysis of variance. Treatments were main units and dates were subunits. Differences between treatments were detected with orthogonal contrasts: no brush kill vs. brush kill, brush kill with overseeding vs. brush kill with no overseeding, and brush kill with cool-season grass overseeding vs. brush kill with warm-season grass overseeding. A two tailed *t*-test was used to compare means in all compartments and contrasts except for the herbaceous compartment. We expected an increase in total N in the herbaceous material in June 1994, so a one tailed *t*-test was used to compare treatment means for this date. However, we had no basis for anticipating whether tall fescue or Old World bluestem would have accumulated greater total N in October 1994 or February 1995, so we used a two tailed *t*-test to contrast the overseeding treatments at those dates.

RESULTS AND DISCUSSION

Below-ground Nitrogen and Biomass

Soil total N (0 to 60 cm) in June 1993 was about 5000 kg ha^{-1} (Table 1). Johnson and Risser (1974) reported 9591 kg ha^{-1} of total soil N to an average soil depth of 300 cm in a similar post oak-blackjack area. Our values appear high but are likely more accurate for the 0- to 60-cm soil layer than those of Johnson and Risser because we measured total N in 4 succeeding soil layers. Johnson and Risser estimated total N for lower soil depths based on total N in the 0- to 15- and 30- to 45-cm soil layers only. Soil organic matter and total N decrease with soil depth and would be difficult to estimate at 300 cm from samples at 30 cm. Sears et al. (1986) reported soil total N values ranging from 1346 to 2153 kg ha^{-1} (0 to 60 cm), which are half those we reported. The primary soil in the sand shinnery oak (Quercus havardii Rydb.) community of West Texas is a fine sand 40 to 70 cm deep, and less organic matter and total N would be expected in the sandy, more arid soils of West Texas.

No differences were detected in total N in soil among treatments at the June 1993 or February 1995 sampling (Table 1), which leads us to conclude that either the 21-month sampling period was too brief for changes in soil total N to occur in response to woody material decomposition, or that total N was not affected by brush kill. However, soil NO_3-N in all the brush kill plots compared to the untreated plots rose from < 3 kg ha^{-1} to > 60 kg ha^{-1} (Gay et al 1995), but at maximum levels represented only about 1.0% of the total N in the soil.

Root biomass differed ($P \leq 0.10$) between tall fescue overseeding and Old World bluestem overseeding in June and October of 1994 in the 0- to 15-cm soil layer (Table 2). The smaller root quantity in plots overseeded with Old World bluestem could help explain the lack of NO_3-N uptake in that treatment (Gay et al. 1995). Total N stored in root biomass was also lower in the Old World bluestem plots. Our estimate of 18,000 kg ha^{-1} in root (<2.5 cm) biomass to a depth of 60 cm and 115 kg N ha^{-1} in roots in June 1993 averaged over all treatments approximates the 30,000 kg ha^{-1} root biomass (0 to 60 cm) and 169 kg N ha^{-1} for a similar area reported by Johnson and Risser (1974).

Above-ground Nitrogen and Biomass

Total N within the litter compartment was reduced after brush kill by June 1994 (Table 3), but burning in late September 1993 apparently had no influence on litter biomass or total N because no difference was detected in the control vs. brush kill contrast in November 1993. Lab analysis of leaf litter collected before burning suggested an average of 8900 kg biomass ha^{-1} and 177 kg N ha^{-1} could have been lost in burning the brush kill plots assuming all of the N was volatilized from the leaf litter consumed by fire. Van Lear and Kapeluck (1989) estimated losses of N ranging from 130 to 170 kg ha^{-1} in a burned mixed pine hardwood forest. Burning was done on 30 September 1994 and post-burn litter was not collected until November 1994. The lack of detectable differences could have occurred because leaf fall had not completely occurred in

September and leaf fall after that date disguised any treatment effects. We may have also overestimated the amount of leaf litter that was actually consumed by fire. Differences in total N in litter in June 1994 were still observed in October 1994 and February 1995 in the brush kill plots, which were burned, compared to the no brush kill plots. By February 1995, the tall fescue overseeding plots had less litter biomass and less total litter N than plots overseeded with Old World bluestem. The difference may have been produced from a more mesic micro-climate created at the soil surface, which is more conducive to litter decomposition. Ground cover establishment dates for tall fescue and Old World bluestem would substantiate this observation.

Herbaceous biomass increased after brush kill both with and without overseeding (Table 4). Both the tall fescue and Old World bluestem overseeding treatments produced > 3000 kg ha^{-1} above-ground biomass the first growing season compared to 1800 kg ha^{-1} in the brush kill with no overseeding. However, there was a difference in total N stored in tall fescue and total N stored in Old World bluestem. Whereas untreated plots contained almost no N in herbaceous biomass, plots with tall fescue overseeding sequestered over 60 kg N ha^{-1} in above-ground biomass by October 1994. The maximum total N sequestered in plots overseeded with Old World bluestem was 34 kg N ha^{-1}. Unseeded brush-kill plots, which revegetated through secondary autogenic succession, stored about half the N in above-ground biomass as the tall fescue-overseeded plots and about the same as Old World bluestem-overseeded plots. Lower concentrations of N in Old World bluestem suggest that it is a more efficient user of N, a characteristic of plants with the C_4-photosynthetic pathway (Waller and Lewis 1979). This does not explain, however, why Old World bluestem did not produce more biomass than tall fescue if the N present was more efficiently utilized by Old World bluestem. One likely explanation is that during Old World bluestem seedling establishment in May and June of 1994, precipitation was half of the long term mean for the area (118 mm vs. 225 mm). Soil water within the seedling root zone was limiting plant growth and N uptake. When rainfall amounts returned to normal, there was insufficient time in the growing season for substantial growth of Old World bluestem.

Small (< 2.5 cm dbh) woody plants were a minor biomass component (Table 5) and had little influence on ecosystem total N after brush kill. Biomass and total N in the brush kill treatments were less than in control treatments, but total N was < 0.1% of the N in the entire system and less than 0.4% of the N in above-ground and below-ground biomass.

We have observed that branches of large trees (>2.5 cm dbh) do not begin to fall until 2 years post-herbicide treatment, and tree boles remain standing for 3 to 5 years after treatment. Decomposition is slow because the biomass is suspended and remains relatively dry. Indeed, neither N concentrations in branches or boles changed over the 21-month period (Table 6). Total N stored in these compartments, obtained by using Johnson and Risser (1974) tree biomass data, did not change either. Biomass reported by Johnson and Risser (1974) was 109,500 kg ha^{-1} for tree boles, 64,563 kg ha^{-1} for branches, and 4759 kg ha^{-1} for leaves. While biomass of boles and branches did not change over the 21-month period, leaf biomass was reduced the second growing season after herbicide treatment. No leaf production resulted in 110 kg N ha^{-1} that was not taken up by tree roots.

CONCLUSIONS

Brush kill and overseeding had little influence on total N stored within the ecosystem for 21 months after treatment. Although soil NO_3-N increased following brush kill (Gay et al. 1995), total N within the soil remained unchanged. Except for the 0- to 15-cm soil layer, total N in roots did not change. Brush kill followed by overseeding with tall fescue resulted in an increase in total N in herbaceous above-ground biomass and root biomass in the 0- to 15-cm soil layer and a decrease in total N in the litter.

A range of values from beginning and ending sampling dates in this post oak-blackjack forest indicate that of the total N stored within the ecosystem, 77 to 88% is stored in the soil, 1.5 to 2.7% in small (<2.5 cm) roots, 1.3 to 5.7% in litter, 0 to 0.7% in herbaceous material, and 8 to 15% in all woody biomass. Total ecosystem N ranges from 5500 to 6600 kg ha^{-1}, of which 770 to 940 kg ha^{-1} is stored in above-ground biomass excluding forest floor N. This estimate is near equivalent to the 902 kg ha^{-1} reported by Johnson and Risser (1974). Others, summarized by Khanna and Ulrich (1991), have reported much lower values of 139 kg N ha^{-1} in an oak-hickory (Quercus-Carya) forest in Missouri and 470 kg N ha^{-1} in an oak-hickory forest in Tennessee, with a near equivalent value of 995 kg N ha^{-1} in an oak-hickory forest in North Carolina. These results indicate the post oak-blackjack forest of the cross timbers is a nitrogen-rich ecosystem, in a productive temperate climate, with the potential for redistribution of N to enhance utilization from these marginal forests.

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Table 1. Total N[1] in soil by treatment[2] and depth in a post oak-blackjack oak community in the cross timbers of north central Oklahoma.

	June 1993				February 1995			
Depth (cm)	Control	No seed	Fescue	Owb	Control	No seed	Fescue	Owb
	$kg\ ha^{-1}$							
0 to 15	1920	1980	1710	1810	1860	1810	1710	1400
15 to 30	590	990	870	700	930	1010	1060	850
30 to 45	930	1220	1230	1170	1310	1390	1350	1220
45 to 60	1000	1090	990	870	1350	1400	1380	1160
0 to 60	4430	5280	4800	4540	5450	5610	5510	4620

[1] No differences $P > 0.05$.

[2] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

Table 2. Total N and biomass in roots (<2.5 cm diameter) by date and treatment in a post oak-blackjack oak community in the cross timbers of north central Oklahoma after herbicide application.

Soil depth and treatment[1]	Jun 1993 Total N	Jun 1993 Biomass	Nov 1993 Total N	Nov 1993 Biomass	Jan 1994 Total N	Jan 1994 Biomass	Jun 1994 Total N	Jun 1994 Biomass	Oct 1994 Total N	Oct 1994 Biomass	Feb 1995 Total N	Feb 1995 Biomass
(0 to 15 cm)						kg ha^{-1}						
Control	31	4000	55	6110	37	3890	22	3260	44	7060	22	2450
Brush kill:												
No seed	42	5480	34	3960	31	4470	27	3970	32	4320	24	2600
Seed:												
Fescue	50	6530	26	3030	34	4410	39	4790	42	5020	46	4370
Owb	31	4470	40	4763	28	3460	22	2890	24	2810	25	3270
Contrasts[2]:												
Control vs brush kill	----	----	----	----	----	----	----	----	----	----	----	----
No seed vs seed	----	----	----	----	----	----	----	----	----	----	----	----
Fescue vs owb	----	----	----	----	----	----	†	†	*	†	†	----
(15 to 60 cm)[3]												
Control	49	9400	85	13,680	89	14,550	64	12,860	71	13,270	97	17,630
Brush kill:												
No seed	67	10,670	109	15,970	77	12,070	59	8960	47	7800	53	8690
Seed:												
Fescue	118	18,470	66	10,740	83	13,790	80	13,930	71	10,840	63	11,000
Owb	74	13,540	102	15,010	71	11,200	47	7520	59	9680	73	12,890

[1] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

[2] †, *, Significant at the 0.10, and 0.05 probability levels, respectively. Dashed line represents no difference in contrast.

[3] No significant treatments F-test for the lower depth increments. These data represent a sum of the lower 3, 15-cm depth increments.

Table 3. Total N and biomass in litter by date and treatment in a post oak-blackjack oak community in the cross timbers of north central Oklahoma after herbicide application.

Treatment[1]	Jun 1993 Total N	Jun 1993 Biomass	Nov 1993 Total N	Nov 1993 Biomass	Jan 1994 Total N	Jan 1994 Biomass	Jun 1994 Total N	Jun 1994 Biomass	Oct 1994 Total N	Oct 1994 Biomass	Feb 1995 Total N	Feb 1995 Biomass
	------	------	------	------	------	------kg ha^{-1}------	------	------	------	------	------	------
Control	292	23,500	111	15,900	221	18,000	335	24,900	253	18,100	230	19,600
Brush kill:												
No seed	371	27,400	137	14,700	223	16,500	266	18,900	150	10,200	155	13,400
Seed:												
Fescue	336	24,700	78	17,300	219	15,600	162	12,100	122	8170	82	5810
Owb	337	25,800	154	14,800	278	20,100	229	15,700	150	10,900	171	14,300
Contrasts[2]:												
Control vs brush kill	----	----	----	----	----	----	*	**	**	*	*	**
No seed vs seed	----	----	----	----	----	----	----	†	----	----	----	----
Fescue vs owb	----	----	----	----	----	----	----	----	----	----	†	†

[1] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

[2] †, *, **, significant at the 0.10, 0.05, and 0.01 probability levels respectively. Dashed line represents no significant difference in contrast.

Table 4. Total N and biomass in above-ground herbaceous plant material by date and treatment in a post oak-blackjack oak community in the cross timbers of north central Oklahoma after herbicide application

Treatment[1]	Jun 1993 Total N	Jun 1993 Biomass	Nov 1993 Total N	Nov 1993 Biomass	Jan 1994 Total N	Jan 1994 Biomass	Jun 1994 Total N	Jun 1994 Biomass	Oct 1994 Total N	Oct 1994 Biomass	Feb 1995 Total N	Feb 1995 Biomass
	kg ha^{-1}											
Control	0.1	10	0.1	10	0.2	20	0.4	30	0.2	20	0.0	0
Brush kill:												
No seed	0.1	10	0.0	0	0.0	0	7.4	240	26.5	1790	7.7	640
Seed:												
Fescue	0.0	0	0.0	0	0.0	0	40.6	1760	66.3	3480	41.8	2600
Owb	0.1	10	0.0	0	0.0	0	6.3	210	34.3	3100	21.9	2380
Contrasts[2]:												
Control vs brush kill	----	----	----	----	----	----	***	***	***	***	***	***
No seed vs seed	----	----	----	----	----	----	----	----	*	----	**	*
Fescue vs owb	----	----	----	----	----	----	***	*	*	----	----	----

[1] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

[2] *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels respectively. Dashed line represents no significant difference in contrast.

Table 5. Total N and biomass in small (<2.5 cm dbh) woody plants by date and treatment in a post oak-blackjack oak community in the cross timbers of north central Oklahoma after herbicide application.

Treatment[1]	Jun 1993 Total N	Jun 1993 Biomass	Nov 1993 Total N	Nov 1993 Biomass	Jan 1994 Total N	Jan 1994 Biomass	Jun 1994 Total N	Jun 1994 Biomass	Oct 1994 Total N	Oct 1994 Biomass	Feb 1995 Total N	Feb 1995 Biomass
	kg ha^{-1}											
Control	4.0	348	0.3	26	0.7	79	4.4	424	2.4	304	3.0	420
Brush kill:												
No seed	2.4	218	0.4	57	0.7	74	1.3	65	0.4	66	0.3	46
Seed:												
Fescue	1.9	95	0.4	32	0.4	45	0.4	27	0.5	44	0.3	26
Owb	0.8	45	0.9	94	0.0	2	0.2	10	0.0	2	0.0	3
Contrasts[2]:												
Control vs brush kill	----	----	----	----	----	----	***	**	**	**	***	*
No seed vs seed	----	----	----	----	----	----	----	----	----	----	----	----
Fescue vs owb	----	----	----	----	----	----	----	----	----	----	----	----

[1] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

[2] *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels respectively. Dashed line represents no significant difference in contrast.

Table 6. N concentration[1] by compartment and date for each treatment (n=4) in a post oak-blackjack oak community in the cross timbers of north central Oklahoma after herbicide application.

Compartment and treatment[2]	Sampling Date					
	Jun 93	Nov 93	Jan 94	Jun 94	Oct 94	Feb 95
	% N					
Leaves						
Control	1.94	----[3]	----	2.14	1.45	----
No seed	2.32	----	----	----	----	----
Fescue	2.35	----	----	----	----	----
Owb	2.60	----	----	----	----	----
Branches						
Control	0.65	----	0.73	0.42	0.51	0.51
No seed	0.68	----	0.69	0.48	0.55	0.53
Fescue	0.68	----	0.74	0.51	0.59	0.49
Owb	0.74	----	0.76	0.53	0.49	0.58
Boles						
Control	0.25	0.26	0.24	0.18	0.19	0.18
No seed	0.24	0.24	0.24	0.19	0.18	0.21
Fescue	0.26	0.23	0.23	0.17	0.18	0.19
Owb	0.26	0.22	0.24	0.19	0.17	0.18

[1] No differences $P > 0.05$.
[2] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.
[3] Dashed line represents no sample collected.

Chapter II

NITRATE DYNAMICS IN SOIL AND LEACHATE FOLLOWING BRUSH CONTROL IN A POST OAK-BLACKJACK FOREST

ABSTRACT

Converting marginal hardwood forests to grass can increase economic output from livestock grazing. However, nitrogen dynamics during conversion need to be evaluated to determine if conversion will result in excessive quantities of NO_3-N released with potential adverse effects on the environment. This study was conducted to determine the amount of NO_3-N present during conversion to grass from a mature post oak (Quercus stellata Wangenh.)-blackjack oak (Quercus marilandica Muenchh.) forest, and to identify optimum time periods for sequestering available mineralized nitrogen in grass biomass after herbicide treatment. The four treatments evaluated included; 1) no brush kill with no grass overseeding, 2) brush kill with no grass overseeding, 3) brush kill with cool-season grass overseeding, and 4) brush kill with warm-season grass overseeding. Overseeded grasses were 'K-31' tall fescue (Festuca arundinacea Schreb.) (cool-season) and 'Plains' Old World bluestem [Bothriochloa ischaemum var. ischaemum (L.) Keng.] (warm-season). Soil NO_3-N to a depth of 60 cm and NO_3-N concentrations in soil leachate at 60 cm were measured in four plots (15 X 25m) per treatment during a 22-month period (June 1993 to March 1995). Soil NO_3-N increased from < 5 kg ha^{-1} initially to > 50 kg ha^{-1} when brush was killed with tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea). Soil NO_3-N levels in tall fescue overseeded plots returned to near pretreatment conditions by the end of the first rapid growth phase of tall fescue in June 1994. Soil NO_3-N in Old World bluestem overseeded and unseeded brush-kill plots remained high throughout the experiment. Leachate NO_3-N concentrations rose from 0 to over 70 mg L^{-1}, with leachate NO_3-N in the tall fescue treated plots returning to near 0 mg L^{-1}. The risk of NO_3-N

leaching after brush control can best be reduced by overseeding tall fescue, a cool-season perennial grass.

INTRODUCTION

Oklahoma, Texas, and Kansas contain more than 11 million acres of the cross timbers vegetation type (SCS 1981). Much of that land has little economic value other than recreational use. Livestock production is marginal since lack of proper management in the past has reduced thousands of acres to cull hardwoods (Byrd et al. 1984). Herbicide treatments can improve use and production from this land (Elwell 1950, Elwell 1968, Elwell et al. 1970, Scifres et al. 1981, McCollum et al. 1987, Scifres et al. 1987, Smith et al. 1987, Smith 1988, Engle et al. 1991, Stritzke et al. 1991), but these severe disturbances may also have some negative environmental consequences.

The fate of nitrogen within the ecosystem after conversion is an environmental concern that has been studied in a variety of forests and shrublands (Likens et al. 1970, Hibbert et al. 1974, Knight et al. 1983, Lloyd-Reilley et al. 1984). When disturbances such as clear-cutting and herbicide treatment occur in forest lands, large amounts of organic matter can be mineralized resulting in an abundance of available nitrogen (Vitousek 1981). Significant nitrogen losses through leaching and runoff are the norm when plant uptake is temporarily reduced well below the available source of nutrients (Vitousek and Melillo 1979). Possible negative environmental consequences of nitrogen loss through leaching or runoff are a decline in site fertility or increased nitrates in ground water.

At the Cross Timbers Experimental Range near Stillwater, OK, Stritzke et al. (1991) determined the response of overstory woody species and Engle et al. (1991) determined the response of understory herbaceous vegetation during secondary autogenic succession after application of herbicides and fire. In the closed overstory of these mature post oak-blackjack forests, herbaceous plants were sparse and understory herbage production did not peak until two years after herbicide treatment (Engle et al. 1991). A lag time resulted between expected N release and available vegetation for N uptake. Herbage production peaked at 4800 kg ha^{-1}, but by ten years post treatment, total herbaceous production had dropped to as much as half of the maximum (Unpublished data, Engle et al.). Similar herbage production has been noticed in other studies (Davis 1967, Klimo and Kulhavý 1994). Although other responses following brush control occur such as a short term increase in available soil water and a gradual recurrence of woody plant species, we hypothesize that loss of N from the ecosystem was partially responsible for the reduced level of production. No research has been done to date on the fate of nitrogen in the cross timbers following brush control. If indeed N is lost after brush control, it is possible that capturing the mineralized N in herbaceous material will result in a more sustainable forage production system. With this in mind, the objective of this study was to determine effects of brush kill and grass establishment by overseeding on NO_3-N dynamics in the cross timbers.

MATERIALS AND METHODS

This study was conducted on the Oklahoma State University Research Range, located approximately 11 km southwest of Stillwater, OK. The vegetation of the area is dominated by post oak (Quercus stellata Wangenh.) and blackjack oak (Quercus marilandica Muenchh.). The site is an upland forest on a sandy savannah range site. We established study plots on nearly level topography of Stephenville sandy loam soils (fine-loamy, siliceous, thermic Ultic Haplustalfs) (SCS 1981). Soils in the series have an average depth of 60 cm, are well drained, and are moderately permeable. Annual precipitation in the area averages 830 mm, falling mostly from April to October. Mean annual temperature is 15.5 °C, with the mean in January of 2.3 °C, and the mean in July of 27.6 °C (Myers 1982).

Sixteen plots, (15 x 25 m), with four replications of four treatments were arranged in a completely randomized design in March 1993. The four treatments evaluated included; 1) no brush kill with no grass overseeding, 2) brush kill with no grass overseeding, 3) brush kill with cool-season grass overseeding, and 4) brush kill with warm-season grass overseeding. Overseeded grasses were 'K-31' tall fescue (Festuca arundinacea Schreb.) (cool-season) and

'Plains' Old World bluestem [Bothriochloa ischaemum var. ischaemum (L.) Keng.] (warm-season). The no grass overseeding treatment, which revegetated by secondary autogenic succession, consisted of mostly annual forbs. Brush kill was achieved by application of tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea), which was applied to eight of the plots in March 1993 and to four of the plots in May 1993, at a rate of 2.2 kg a.i. ha^{-1}. The tebuthiuron effect on overstory oaks resulted in excellent control with results similar to those reported by Stritzke et al. (1991). Leaf litter in the 12 herbicide treated plots was burned on 30 September 1993, eight plots were immediately overseeded (four with tall fescue at 15 kg PLS ha^{-1} and four with Old World bluestem at 6 kg PLS ha^{-1}) and four were left unseeded. The remaining four served as controls and were not treated with herbicide, burned, or overseeded. Tall fescue established 100% ground cover by April 1994 and Old World bluestem established 100% ground cover by August 1994.

Soils were sampled and composited from five random locations per plot. Samples were taken with a 2.5-cm diameter corer at four depth increments (0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm) during a 21-month period on six dates (June 1993 through February 1995). Sampling dates corresponded to either expected pulses of plant N uptake or mineralized N in the soil. We sampled in June 1993 to measure NO_3-N available in the soil before tebuthiuron treatment was effective. November 1993 sampling coincided with expected maximum accumulation of mineralized N in biomass. We sampled in January 1994 to correspond with maximum accumulation of mineralized N in the soil, because mineralization by this time is minimal and because tall fescue would not be actively growing and Old World bluestem would not yet have germinated. The June 1994 sampling represented reduced N uptake and near maximum accumulation of mineralized N by tall fescue, corresponding to time of seed production and reduced growth in tall fescue. The October 1994 sampling, after the first killing frost, represented maximum accumulation of mineralized N by Old World bluestem. Finally, sampling in February 1995, we expected maximum mineralized N in the soil before uptake by tall fescue and Old World bluestem began in the second growing season. After collection, soil samples were transported to the laboratory and dried at 90 °C in a forced air oven, then ground to pass a 2-mm mesh screen before analysis.

Leachate samples were collected over a 22-month period (June 1993 through March 1995) monthly or when leachate in lysimeters was available. One suction lysimeter was installed in each plot at a depth of 60 cm. It consisted of a 4.8-cm diameter PVC pipe with a porous ceramic cup attached to the end. An 8-cm diameter hole was augured for inserting the lysimeter and soil was replaced around the installed lysimeter by horizon except for two 2.5-cm layers of bentonite clay, one above the ceramic cup and one near the surface to prevent water from moving down the side of the tube. The day of collection, vacuum was applied equally to all lysimeters at 70 centibars (Hansen and Harris 1975). Twenty four hours later, samples were collected and immediately transported to the laboratory for analysis.

Both soil and leachate samples were analyzed on the LACHAT model QuickChem IV flow injection autoanalyzer, which uses the colorimetric cadmium reduction of NO_3-N to NO_2-N method (Page et al. 1982). Soil NO_3-N was extracted with 2 *M* KCl and concentrations were converted to kg ha^{-1} by multiplying an average dry weight of 60 core samples per 15-cm soil depth increment taken from the study area in February 1995. Leachate NO_3-N results are actual concentrations in mg L^{-1}.

Statistical analysis was performed with a split plot arrangement of treatments in a one way analysis of variance. Treatments were main units and dates were subunits for soil data. Leachate data, which were unbalanced, were analyzed in a one way analysis of variance for each sampling date. Differences between treatments were detected with orthogonal contrasts: no brush kill vs. brush kill, brush kill with overseeding vs. brush kill with no overseeding, and brush kill with cool-season grass overseeding vs. brush kill with warm-season grass overseeding. A one tailed *t*-test was used to compare means in the no brush kill vs brush kill and brush kill with overseeding vs brush kill with no overseeding contrasts because we expected an increase in NO_3-N as biomass decomposition began. We had no basis for anticipating whether tall fescue or Old World bluestem would better assimilate available NO_3-N, so we used a two tailed *t*-test to contrast the overseeding treatments.

RESULTS

Soil profile NO_3-N (0 to 60 cm) did not differ among treatments in June 1993, because tebuthiuron effects were not yet exhibited fully (Table 1). By the next sampling, November 1993, soil NO_3-N was greater in brush kill plots than in untreated plots. Soil NO_3-N in the 0- to 15- cm soil layer changed most, increasing from 1 to 25 kg ha^{-1} in the treated-unseeded plots. Soil NO_3-N in the untreated plots remained low throughout the experiment. Of the remaining soil layers, the smallest increase in soil NO_3-N was 0 to 4 kg ha^{-1} (Fig. 1). Biomass growth in the spring of 1994 likely explains the soil NO_3-N decrease that occurred in all the brush kill plots in June 1994 (Gay et al. 1995). Except for the Old World bluestem treatment, the amount of NO_3-N utilization corresponded to the amount of herbaceous vegetation present within each brush kill treatment. As biomass increased, soil NO_3-N decreased proportionally. Although Old World bluestem overseeding produced as much vegetation as the tall fescue overseeding by October of 1994 (Gay et al. 1995), Old World bluestem did not harvest the available NO_3-N. In contrast, tall fescue harvested most of the available NO_3-N by June 1994 and by October 1994, residual soil NO_3-N in the tall fescue plots was near that of the untreated plots.

Concentrations of NO_3-N in the leachate taken from a 60-cm depth were negligible and not different among all treatments in June 1993, but concentrations increased after June 1993 in the brush kill treatments (Fig. 2). No comparison to the untreated plots was possible between July 1993 and March 1994 because of water demand by the forest vegetation, but in March 1994, NO_3-N concentrations were higher in the brush kill plots which produced 50 mg L^{-1}, compared to 0 mg L^{-1} in the untreated plots. Beginning in June 1994, treatment comparisons (Table 2) indicated that seeding treatments reduced leachate NO_3-N concentrations and tall fescue overseeding reduced concentrations more than Old World bluestem. Leachate in lysimeters was limited among all treatments from July through October 1994, so no comparisons were possible through this time period. However, leachate samples taken from the no-overseeding and Old World bluestem overseeded plots had elevated concentrations of NO_3-N (Fig. 2). Leachate was again more common in lysimeters by December 1994 through March 1995, a period in which NO_3-N levels remained low in both the tall fescue plots and untreated plots. Lechate NO_3-N concentrations in the no-overseeding and Old World bluestem overseeded plots remained high throughout the study.

DISCUSSION

The potential for loss of NO_3-N is well documented in many different forest and shrub communities. Likens et al. (1970) reported NO_3-N export in stream water 46 times greater in a herbicide treated forest compared to a control (no herbicide application). This converted into a loss of 97 kg NO_3-N ha^{-1} the first year after herbicide treatment and 142 kg NO_3-N ha^{-1} the second year. Sollins et al. (1981) reported a 12-fold increase in NO_3-N concentrations in leachate from suction lysimeters located in an herbicide-killed douglas fir forest in Oregon. Our 60-fold increase in leachate NO_3-N concentrations is even greater than these increases. NO_3-N in soil samples collected from brush kill plots during the same time period increased 10- to 12-fold. Sears et al. (1986) reported an increase in soil total N six years after herbicide treatment of a sand shinnery oak community in West Texas which suggests that the N stored in the sand shinnery oak biomass is transferred to the soil and none is lost. Little opportunity exists for loss of N through leaching because average annual precipitation is 400 mm in the West Texas study area. The cross timbers has double the precipitation of West Texas and NO_3-N likely moved through the soil profile to lower depths as indicated in Fig. 1. The lysimeter data strongly indicate that considerable NO_3-N leaching is possible after brush kill in the cross timbers when no grass vegetation is present to utilize the released N.

We expected to reduce the risk of NO_3-N loss by overseeding because of the work by Martinez and Guiraud (1990) who overseeded with ryegrass between a cropping rotation and reduced NO_3-N concentrations in collection lysimeters from 40 mg L^{-1} to 0.25 mg L^{-1} by the end of the ryegrass growth period. By overseeding tall fescue after herbicide treatment in our experiment, NO_3-N concentrations in leachate from suction lysimeters were reduced from 60 mg L^{-1} to near 0 mg L^{-1} by the end of the tall fescue rapid growth period. Little information can be found on soil NO_3-N quantities in disturbed, natural ecosystems to compare to our study. Our results, however, indicate that overseeding reduces soil NO_3-N. Tall fescue overseeding reduced soil NO_3-N from over 50 kg ha^{-1} to 2 kg ha^{-1}. Without overseeding, soil NO_3-N remained greater than 40 kg ha^{-1} two years after herbicide application. Other work at the OSU Research Range found that residual soil NO_3-N in herbicide-treated, unseeded plots was near 0 kg ha^{-1} by the beginning of the third year after application (Unpublished data, Gay et al.). NO_3-N loss from the ecosystem by leaching was likely because herbaceous biomass there was not sufficient to harvest the available NO_3-N.

Harvesting of NO_3-N by overseeding was dependent on grass species. Both the leachate and soil data indicate that the Old World bluestem overseeding treatment did not utilize the released NO_3-N. Explanation for the differences in NO_3-N utilization is speculative. Both species produced similar biomass although accumulated N in tall fescue was double that of Old World bluestem (Gay et al. 1995). This would indicate a better nitrogen use efficiency in Old World bluestem as defined by Brown (1978), i.e. the ability to produce more biomass per unit of N. Since mineralized NO_3-N release was equivalent in both tall fescue plots and Old World bluestem plots, another limiting factor for NO_3-N utilization by Old World bluestem must have been present. Water availability during seedling establishment and growth may have limited the ability of Old World bluestem to grow and utilize NO_3-N sufficiently. During the establishment of Old World bluestem in May and June 1994, precipitation was 118 mm compared to an average of 225 mm for that period (Myers 1982). July was a hot dry month and the monthly average precipitation occurred, but came late in the month. Tall fescue, however was able to establish and produce roots during a period of high water availability. Root biomass was greater ($P \leq 0.10$) in the tall fescue plots (Gay et al. 1995) in June and October 1994 since seedling emergence occurred earlier than Old World bluestem. The growth pattern of tall fescue better matches both the water availability and early release of mineralized N after brush kill treatments even though, better utilization of NO_3-N by Old World bluestem might have occurred if precipitation had been normal.

Future research is needed to develop an overseeding regime that captures the mineralized N even earlier after herbicide treatment than tall fescue. One possibility is single tree injection of herbicide in September, with litter burn and overseeding done at litter fall in

October. Since little root decomposition would occur with cooler soil temperatures during the winter, grass could become established the same time as NO_3-N release in the spring. Research may also be needed to determine why Old World bluestem was unable to harvest the available NO_3-N so that other warm-season native grass species might be successfully reintroduced.

SUMMARY AND CONCLUSIONS

Herbicide treatment results in the potential for loss of N from the cross timbers ecosystem through NO_3-N leaching. Increases in $N0_3$-N occur soon after herbicide treatment as a result of decomposition of fine root biomass and the lack of vegetation present in the understory to utilize the released NO_3-N. Although our methods could not account for the fate of all $N0_3$-N, the amount of $N0_3$-N that has the potential of leaching can be significantly reduced by overseeding a cool-season forage grass. Tall fescue, a cool-season perennial grass, greatly reduced the potential loss of $N0_3$-N after growth occurred. Old World bluestem, a warm-season perennial grass, was unable to do the same even though the total biomass produced was equivalent to that of fescue. Conversion of a lower canopy cover forest with a grass understory may not have the same potential for loss since existing vegetation could be ready to assimilate any released N.

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Table 1. Soil profile NO_3-N (0 to 60 cm) in a post oak-blackjack forest after herbicide application.

Treatment	Jun-93	Nov-93	Jan-94	Jun-94	Oct-94	Feb-95
	kg ha^{-1}					
Control†	3	4	6	3	4	2
Brush kill:						
No seed	4	58	62	40	56	44
Seed:						
Fescue	3	39	51	10	6	2
Owb	4	48	58	35	59	38
Contrasts :						
Control vs brush kill	NS	***	***	***	***	***
No seed vs seed	NS	NS	NS	NS	*	***
Fescue vs owb	NS	NS	NS	NS	***	***

*, *** Significant at the 0.05, and 0.001 probability levels, respectively.

† Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

Table 2. Treatment contrasts[†] for leachate collected by suction lysimeters in a post oak-blackjack forest after herbicide application.

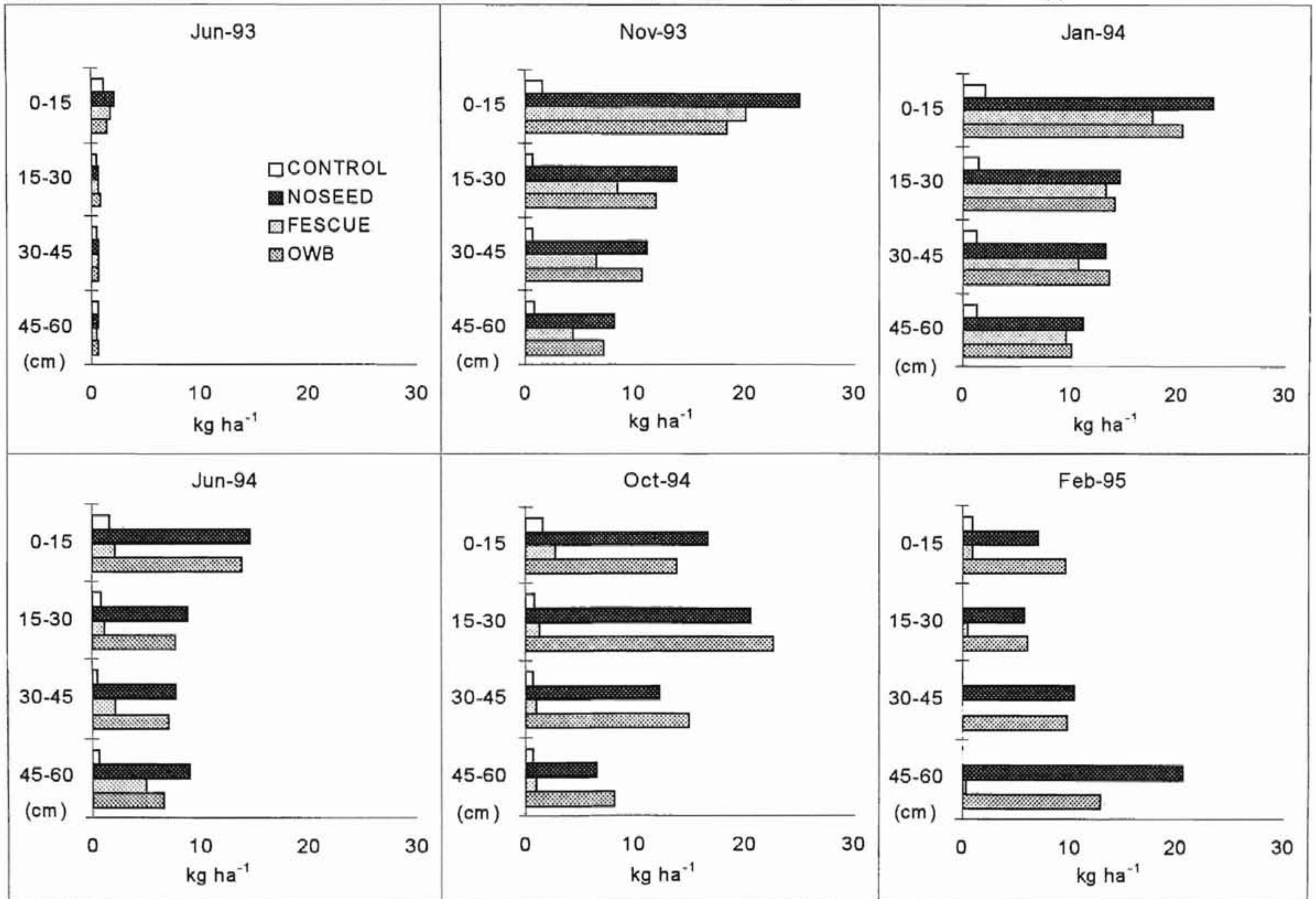
	6/11/93	7/17/93	3/16/94	4/27/94	5/10/94	5/31/94	6/15/94	11/29/94	1/27/95	3/22/95
Contrasts[‡]:										
Control vs brush kill	NS	NS	***	***	***	***	***	***	***	***
No seed vs seed	NS	NS	NS	NS	NS	**	**	*	*	**
Fescue vs owb	NS	NS	NS	NS	NS	**	***	**	**	*

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

[†] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

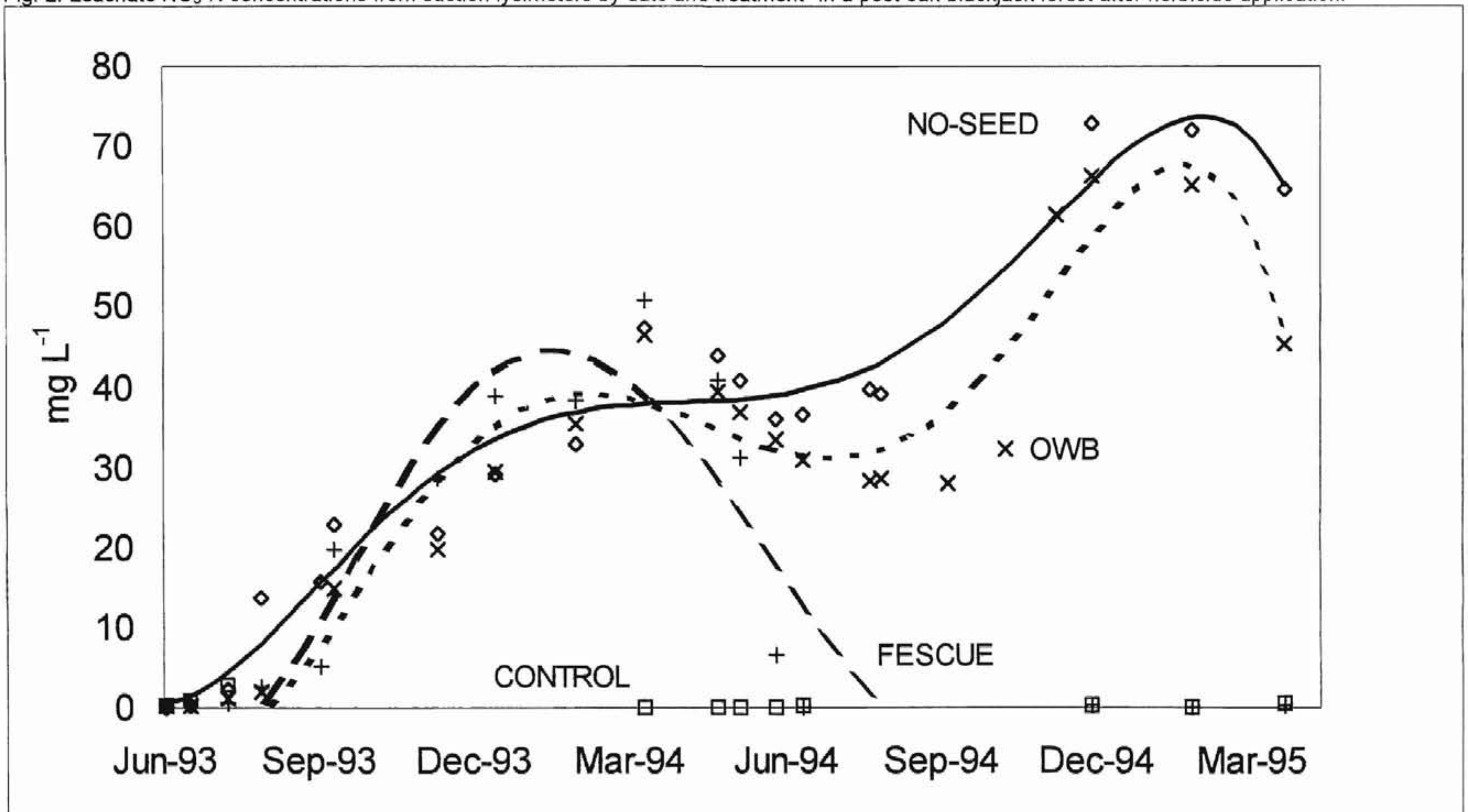
[‡] Contrasts were only possible on dates with leachate present in lysimeters.

Fig. 1. Soil NO_3-N by treatment[†] and depth as a function of time in a post oak-blackjack forest after herbicide application.



[†] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

Fig. 2. Leachate NO_3-N concentrations from suction lysimeters by date and treatment[†] in a post oak-blackjack forest after herbicide application.



[†] Treatments are: control = no brush kill with no overseeding, no seed = brush kill with no overseeding, fescue = brush kill with tall fescue overseeding, owb = brush kill with old world bluestem overseeding.

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Education: Attended Oklahoma Baptist University, Seminole Junior College, and University of Wyoming. Graduated from Oklahoma State University, Stillwater, Oklahoma in May 1985 with a Bachelor of Science degree in Agriculture majoring in Animal Science. Completed the requirements for the Master of Science degree with a major in Range Science at Oklahoma State University in July 1995.

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