DISSERTATION

EFFECTS OF BOVINE URINARY NITROGEN ON THE NITROGEN CYCLE OF A SHORTGRASS PRAIRIE

Submitted by

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ABSTRACT OF DISSERTATION

EFFECTS OF BOVINE URINARY NITROGEN ON THE NITROGEN CYCLE OF A SHORTGRASS PRAIRIE

Free grazing ungulates were hypothesized to exert a significant influence on the nitrogen cycle of a grazed shortgrass prairie ecosystem. Two field studies were performed from May 1980 through March 1982 in shortgrass prairie pastures at the Central Plains Experimental Range northeast of Fort Collins, Colorado. The objective of the first study was to quantify seasonal variation in nitrogen ingested by free grazing heifers and the partitioning of the ingested nitrogen among urine, feces, and storage in animal bodies. A herd of eight yearling heifers in a 125 ha. pasture consumed 116 kg of forage nitrogen during the growing season and 91 kg of forage nitrogen during the dormant season. This was only 10% of peak standing crop of forage nitrogen. Ten percent of the nitrogen ingested during the study period was incorporated into body growth. Excreted nitrogen was partitioned between urine and feces at 54% and 46% for the growing season and 45% and 55% for the dormant season. This was a deposition rate of 1.6 kg N/ ha. for the pasture.

The objective of the second field study was to determine the fate of urinary nitrogen once it was returned

to various soils in a pasture. Simulated urine with ^{15}N labeled urea was added at the rate of 45 g/m^2 to the soil at three sites on a catena. Urea hydrolysis was rapid at all sites with little urea remaining after four days. Over a 15 month period a sandy ridgetop and a clay swale soil retained about 70% of the added nitrogen. Only 40% was recovered from a midslope soil. Elevated calcium levels in the ridgetop and high clay content in the swale soil were important in the conservation of nitrogen.

Cattle grazing was shown to be important in the N cycle by processing 10% of the standing N and depositing it in concentrated spots on the soil. Long term effects indicate that up to 50% of a community may be affected at any time.

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CHAPTER 1: INTRODUCTION

Do free grazing ungulates exert a significant influence on the nitrogen cycle of grazed shortgrass prairie ecosystems? Free grazing cattle are thought to influence the system by 1) directly removing nitrogen by ingesting forage, 2) depositing plant and microbially available nitrogen rich componds on the soil as urine, 3) depositing less readily available nitrogen compounds on the soil as feces, and 4) trampling, soil compaction and other lesser impacts. The nitrogen returned to the soil as exreta may under go chemical and biological transformation, be incorporated into plant or microbial tissue or be lost from the system as volatile gasses or through leaching of nitrate. All of these factors are affected by animal behavior and community use.

The question remains however, are the influences of free grazing cattle important in the nitrogen economy of pastures? Four basic areas must be examined to adequately address this question. They are: 1) animal behavior controling community use and redistribution within a pasture, 2) partitioning of the ingested nitrogen into growth and exreta, 3) chemical and biological transformation of the excreted nitrogen in the soil, and 4) loss of nitrogen from the system through volatilization or

leaching. This research is concerned with areas 2 and 3 above. Senft (1983) addressed #1, while Parton and Woodmansee (unpublished data) and Moiser et al. (1981) examined #4.

The general goals of my research were 1) to determine the patitioning of ingested nitrogen amoung body tissue, urine, and feces and 2) to determine the fate of the urine nitrogen once it was deposited on the soil within urine patches within pasures. The central hypothesis tested through my research was that cattle do exert a significant impact on the nitrogen cycle of pastures and this impact must be accounted for when considering the behavior of the nitrogen cycle. A significant impact for the short term could be addition or losses of nitrogen on the order of magnitude of atmospheric imputs. From the long term perspective, a significant impact could be changes in quality and quanity of forage altering animal behavior resulting in changes in community structure and nitrogen dynamics.

To accomplish the goal I established the following objectives:

Obj. 1a. Determine the amount of nitrogen ingested within a pasture,

1b. Determine the amount of nitrogen accumulated as animal protein each month, and

1c. Determine the amount of nitrogen returned to the soil-plant system through the excretion of urine and feces.

Obj. 2. Determine the fate of the urine nitrogen returned to the soil of representive patches within a pasture.

Obj. 3. Integrate this information with the animal behavior information of Senft (1983) to propose a budget for the pasture.

Ingestion and excretion of energy was measured in addition to nitrogen. This information provided an evaluation of the nutritional status of the animals during the study. It also provided information to help validate a ruminant nitrogen and energy model (Swift, 1980). The validation of the model will not be discussed in this thesis.

To adequately address the objectives, the following set of working objectives used to guide the research:

Obj. 1a. Calculate the nitrogen and energy ingested by freegrazing yearling heifers for a 7 day period each month from May through November in 1981 and for January and March 1982,

1b. Determine the animal weight gains each month and calculate the nitrogen stored in the body,

1c. Determine the actual nitrogen and energy excreted as urine and feces for a 7 day

sampling period each month from May through November 1981 and January and March 1982.

Obj. 2a. Using simulated urine , urea as the only nitrogen source, quantify the rates of transformation of urea-N in the soil,

2b. Determine the area effected by a "standard" urine spot,

2c. Propose a budget of the nitrogen deposited on the soil in the simulated urine spot,

2d. Compare the response of three sites of a catena to simulated urine.

To accomplish these objectives, I have preformed two field studies. The first study quantified intake and excretion of nitrogen and energy from free grazing heifers. The second study examined the fate of the urea-N on the soil of a catena.

CHAPTER 2: THE ANIMAL SYSTEM

INTRODUCTION

The redistribution of nutrients by free grazing ruminants can represent an important influence in the nitrogen economy of pasture ecosystems. Redistribution occurs when the animals ingest nutrients in one location and excrete them in another. The cycling of nitrogen in a pasture will be influenced by animals consumption and their mobility. Thus the N cycle of a grazed ecosystem is influenced by animal behavioral and physiological factors. These factors determine the sites of utilization by animals, rates and quantities of forage and nutrient intake, and rates and quantities of nutrient deposition in excreta. The export of nitrogen from animal products in the form of wool, meat, and milk accounts for an additional portion of the nitrogen balance.

Factors affecting sites of pasture utilization include stocking rate, resting patterns, grazing patterns, type of animal (species, breed, sex) and amount and spatial distribution of preferred plant communities. Management practices such as fencing, shelter location, water distribution, and fire also affect animal distribution within a pasture. At any one time one or more of these variables will be important in controlling animal use

patterns (Stoddart et al., 1975; Senft, 1980; Woodmansee, 1978; Hyde and Owensby, 1975).

The amount of nutrients recycled within a pasture ecosystem depends in part on the amount and quality of the forage ingested. Forage nutrients not ingested are recycled through plant residues while those consumed are recycled through animal excreta, or assimulated into body tissue. Forage utilization, a function of animal density and intake, rarely exceeds 60% for a well managed system (Henzell and Ross, 1973; Wilkinson and Lowery, 1974)). Carter and Day (1969) estimated utilization at about 53% at a stocking rate of 15 sheep per ha. and at 77% for a stocking rate of 25 sheep per ha. On annual range the estimated utilization may be as high as 80% (Jones and Woodmansee, 1980).

Control of forage intake is complex. Forage intake appears to be a function of availability, nutrient content, and digestibility of the forage, and gastrointestinal fill of the ruminant. In addition, environmental factors such as temperature and barometric pressure affect forage intake (Rittenhouse and Senft, 1982; Van Soest, 1982).

Microbial fermentation occurs in the rumen. Digestible carbohydrates are used for microbial growth and for production of volatile fatty acids (VFA's). Most of the VFA's are absorbed through the rumen wall. Some carbohydrates may pass through the rumen and then be digested and the products absorbed in the lower tract. Lignified material may pass through the digestive tract and be excreted in the feces.

Most of the nitrogen that enters the rumen as protein is hydrolyzed to amino acids and ammonia and either absorbed through the rumen wall or used for microbial growth. The digestible N that escapes fermentation in the rumen is digested and absorbed in the lower tract or incorporated into microbial biomass in the large intestines. There is little evidence of potentially digestible feed protein being excreted in the feces (Van Soest, 1982). Only 50-70% of the N in the rumen microorganisms is in the form of protein available for digestion in the lower tract. The remainding N is bound in cell wall structures and nucleic acid. Thus the largest source of N in the feces is of microbial origin; cell walls from rumen bacteria and cells from fermentation in the large intestines (Van Soest, 1982).

Nitrogen absorbed across the rumen wall or in the lower tract is used by the animal for protein synthesis or converted to urea in the liver. Urea is removed from the blood by 1) diffusion across the rumen wall to the rumen, 2) diffusion into the salivary glands and recycled via saliva, or 3) removed by the kidneys and excreted in the urine (Harper et al., 1979; Maynard et al., 1979; Van Soest, 1982).

Many of the parameters (i.e. site of utiliztion, nutrient intake, and nutrient excretion) vary with forage quality. Forage quality is a function of the time of year it is ingested. Thus to adequately study the redistribution of N by free grazing animals, parameters that must be

measured are animal behavior, N intake, and N excretion in urine and feces. A study of animal behavior was initiated by Senft (1980, 1983) and closely integrated with this study. The objective of this research was to quantify the seasonal variation in forage N and energy intake and to quantify the partitioning of ingested N and energy amoung urine, feces, and storage in cattle biomass. The specific hypotheses to be tested were:

H1. Nitrogen and energy ingested is greatest in the early summer as forage quality improves. Nitrogen and energy ingested will be reduced in the fall and winter as influenced by decreased forage quality.

H2. Nitrogen will be stored in the cattle body tissue during the summer as measured in increased body weight. During the fall and winter, the increase will be less and a function of meeting the maintainance requirements of the animals.

H3. Urinary N and energy will vary with diet quality and quanity. Fecal N and energy will also be a function of diet. Urinary and fecal N and energy will increase early in the growing season with improving dietary quality and be reduced in fall and winter with decreasing diet quality.

SITE DESCRIPTION

This study was conducted on the Central Plains Experimental Range, USDA-SEA-AR, northeast of Fort Collins, Colorado. The study was conducted on a 125 ha. pasture (N 1/2, section 21, T10N, R66W of Weld countyColorado). During the study the pasture was grazed by eight yearling heifers. Holding pens and corrals on the south half of the section were also used. A complete vegetation and soil survey of the pasture was completed the summer of 1982 (Anderson, 1983). Vegetation dynamics for the 1981 growing season were recorded by Senft (1983). This pasture was chosen because Senft (1980) had just completed an animal behavior study on the pasture and would continue research of animal movement and redistribution of N in this area (Senft, 1983).

METHODS

Each month from May through November 1981 and in January and March of 1982, four yearling heifers were catheterized and fitted with urine and fecal collection bags (Stillwell et al, 1983). Unless stated otherwise, only these four heifers were considered in the discussion. Date of each sampling trial and animal weights are given in Table 1. The animals were weighed and catheterized in the morning after going 12 hr. without water or food. Time zero was designated as the morning after the heifers were released to graze freely on the pasture. Total urine and feces were collected each morning and evening for 7 days. At the end

Table 1. Cattle weights, requirements, and calculated values for the nitrogen and metabalic energy (ME) ingested by free grazing heifers on shortgrass range.

Month	Cow weight (kg)	NRC Requirements/Calculated Intake	
		N (g/day)	ME (Mcal/day)
May 26, 1981	245	56 / 89	8.2 / 9.6
June 11, 1981	252	56 / 139	8.2 / 14.8
July 8, 1981	287	64 / 97	9.4 / 14.7
August 5, 1981	292	64 / 112	9.4 / 16.8
September 1, 1981	291	64 / 104	9.4 / 14.9
October 4, 1981	331	74 / 97	10.6 / 18.0
November 14, 1981	326	74 / 72	10.6 / 16.1
January 5, 1982	323	74 / 69	10.6 / 9.8
March 7, 1982	317	74 / 71	10.6 / 6.7

of each 12 hr. sampling period, fecal bags were changed and weighed and the urine bags drained and volume measured. The feces were then thoroughly mixed by hand and subsampled. Fecal samples were dried at 55 ^{o}C for 48 hr., ground to pass a 1mm screen, and stored for chemical analysis. The urine was stablized by adding 10 ml of 10% phenylmercuric acetate to each urine collection bag each morning of the trial. Urine samples were refrigerated at 4 ^{o}C while in the field and during transport to the laboratory.

Fecal samples were analyzed for total N by a Kjeldahl technique followed by ammonium analysis with a Technicon AAI (Bigelow et al., 1983), for energy by combustion in a bomb calorimeter, and for biological indigestible marker using a modified in vitro technique (Tilly and Terry, 1963; Van Soest, 1982). The digestion time of the in vitro technique was increased to 7 days followed by a 24 hr. pepsin post digestion. The material that remained was filtered and dried and designated as biologically indigestible, and used as a marker to estimate intake and digestibility.

Urine samples were analyzed for urea-N by a blood urea method (Stillwell, 1980), for total N as described for the feces, and for energy in a bomb calorimeter using 10 ml of freeze dried urine.

Intake was estimated from fecal, diet,and supplement marker concentration, N, and energy (Rittenhouse et al; 1970; Van Soest; 1982). The diet was estimated using esophageal fistulated heifers tethered on six different

communities each month. Weighted averages of community grazing time were used to combine samples into a pasture diet (Senft, 1983). Animals were supplemented with 430 g/day of a 32% protein supplement in January and March, the intake had to be adjusted to take this into account.

Intake was estimated from the following equation:

$$I = E / (1-D) \qquad \text{(eq 1)}$$

where I is dry matter intake (kg/day), E is the fecal dry matter (kg/day), and D is digestibility of the forage (%). Digestibility was estimated by

$$D = 1 - (Md / Me) \qquad \text{(eq 2)}$$

where Md and Me are the concentrations of marker in the diet and excreta, respectively (Van Soest, 1982; Rittenhouse et al., 1970). This assumes the actual amount of the marker ingested in the diet, MD (g/day) equals the amount of the marker excreted in the feces, ME (g/day). The supplement was weighed and individually fed to each animal to determine intake of the supplement in January and March. Thus, by knowing the amount of supplement fed, S (g/day), and the marker concentration of the supplement, Ms, the diet marker could be divided into forage and supplement marker,

$$MD = (F \times Mf) + (S \times Ms) \qquad \text{(eq 3)}$$

where F is the forage ingested and Mf is the marker concentration of the forage. As MD=ME then,

$$(F \times Mf) + (S \times Ms) = E \times Me \qquad \text{(eq 4)}$$

By manipulation of the equation, intake of the forage can be determined by,

$$F = (E \times Me - S \times Ms) / Mf \quad \text{(eq 5)}$$

or

$$F = (MD - MS) / Mf \quad \text{(eq 6)}$$

where MS is the kg of marker in the supplement each day (Rittenhouse et al., 1970).

Rates of urine and fecal excretion were estimated using a least squares analysis of cumulative excretion vs. time. Excretion rates were corrected for missing points either due to misadjustment of bags, overflow of excreta, or loss due to a passed catheter, using the least squares and polynomial fit method of Johnson et al.(1982).

RESULTS AND DISCUSSION

Dry matter intake (Table 2) varied greatly through the year. Hightest rates of dry matter intake were 118 and 120 g day^{-1} kg body weight $(BW)^{-.75}$ in September and October, respectively. These represent intake levels of 2.9% and 2.8% of body weight, well within the range of 1 to 3% reported by Van Dyne et al. (1980). Jefferies and Rice (1969) reported a range of 1.7% to 2.8% of the body weight on shortgrass range in Wyoming. Others (Holechek and Vavra, 1982; Holechek et al., 1982; Rittenhouse et al., 1970; Scales, 1972; Streeter et al., 1974) found intake to range from 1.4-3.2%. The lower rates of dry matter intake in May, June, and July as compared to September and October support Van Soest's (1982) suggestion that as digestiblity approaches 60%, bulk limitation is not important while below 60% rumen size will influence intake. The decreased intake

Table 2. Forage intake of free grazing heifers on shortgrass range (mean ± s.d.).

Month	Dry Matter Intake ($g\ day^{-1}\ BW^{-.75}$)	Intake (% of BW)	Total-N ($g\ day^{-1}\ BW^{-.75}$)	Total-N (%)	Digestibility (%)
May	73.4 ± 8.1	1.86	1.44 ± 0.16	2.0 ± 0.3	57 ± 1
June	97.1 ± 16.0	2.44	2.20 ± 0.36	2.3 ± 0.3	67 ± 1
July	93.7 ± 14.0	2.28	1.39 ± 0.21	1.5 ± 0.2	62 ± 1
August	108.8 ± 3.2	2.63	1.58 ± 0.05	1.5 ± 0.2	55 ± 1
September	117.7 ± 4.8	2.88	1.53 ± 0.06	1.3 ± 0.2	51 ± 1
October	120.3 ± 11.3	2.82	1.25 ± 0.12	1.0 ± 0.1	52 ± 1
November	102.7 ± 6.1	2.42	0.94 ± 0.06	.9 ± 0.1	49 ± 1
January	73.9 ± 3.2	1.73	0.88 ± 0.04	.9 ± 0.1	46 ± 1
March	85.3 ± 2.7	2.02	0.95 ± 0.03	.9 ± 0.1	42 ± 2

for January and March may be a function of low digestibility, supplementation, and weather. Van Soest (1982) stated that cattle showed decreased rates of intake while grazing forage with N of less than 1.2%. No increase in intake or digestibility of forage was noted by Rittenhouse et al. (1970) on winter range in Nebraska. Also January sampling occurred during cold weather which has been shown to effect grazing time and intake (Rittenhouse and Senft, 1981).

Nitrogen intake rates were greatest in June when the N concentration and digestibility of the diet were highest. The level of N intake decreased as the forage matured as seen by the decreased N concentration and degestibility of the diet. Nitrogen intake levels were adequate to meet requirements of the heifers until November when the N ingested was less than required. The deficit continued in January and March.

Energy ingested (Table 3) was greatest in September and October corresponding to the maximum rate of dry matter intake. The rate of ingestion was sufficient to meet the maintanence requirements of the heifers until the November sampling date. Despite the use of a protein and energy supplement from late November through March, energy intake was below requirements for January and March.

The nitrogen contained in the body was calculated assuming 17% protein in body weight (Van Soest, 1983). For the growing season, May to October, 2.3 kg N/animal was

Table 3. Energy budget for free grazing heifers on shortgrass range (mean ± s.d.).

Month	Ingested Energy[1]	Fecal Energy[1]	Digestable Energy[1]	Kcal DE / g DMI	Urinary Energy[1]	Metabolic Energy[1]
May	293.5 ± 32.4	123.2 ± 9.9	170.3	2.32	15.8 ± 3.2	154.5
June	388.5 ± 64.1	129.2 ± 22.3	259.3	2.67	26.1 ± 5.2	233.2
July	374.7 ± 56.0	145.8 ± 23.8	228.9	2.44	17.9 ± 2.4	211.0
Aug	450.7 ± 13.3	195.3 ± 9.9	255.4	2.35	19.2 ± 2.5	236.2
Sept	483.0 ± 19.6	243.3 ± 6.7	239.7	2.04	21.1 ± 0.4	218.6
Oct	482.1 ± 45.1	236.2 ± 22.4	245.9	2.04	11.6 ± 4.2	234.3
Nov	413.9 ± 24.6	203.9 ± 9.6	210.0	2.04	8.7 ± 2.1	201.3
Jan	292.2 ± 12.8	158.0 ± 9.5	134.2	1.82	8.3 ± 1.5	125.9
March	282.8 ± 9.2	186.1 ± 4.4	96.7	1.13	7.1 ± 0.5	89.6

[1](Kcal day^{-1} $BW^{-.75}$)

stored in body tissue. This represented 16% of the N ingested over this period. Disreguarding the August to September period which produced no gain, the amount ingested stored in body tissue increased to 21%. Thus, 79 to 84% of the N ingested was returned to the soil-plant system as urine and feces during the growing season, aggreeing closely with values of 83% estimated by Dean et al. (1975) for cattle grazing shortgrass range in the summer. There was no increase in cattle weights following October, thus no increase in N stored in the body tissue. If the entire length of the trial was considered, only 8% of the total N ingested accumulated in cattle biomass.

Urine excretion (ml day^{-1} $BW^{-.75}$) was quite variable among animals and across months (Table 4). This is due to different patterns of animal behavior as effected by water content of the vegetation, temperature, and individual animal preferences. The urinary N excreted by the heifers ranged from a high of 1.3 gN day^{-1} $BW^{-.75}$ in June to a low of 0.3 gN day^{-1} $BW^{-.75}$ in November, January, and March of 1982. The concentration of the urinary-N was more consistent, ranging from 0.90% in August to 1.48% in January. These concentrations are higher than those estimated by Doak (1952) who found a range of 0.25% to 0.83%. Urea-N in the urine showed the same trend as total N with the highest rate of excretion in June (0.8 g urea-N day^{-1} $BW^{-.75}$), and the lowest rate of excretion in March (0.1 g urea-N day^{-1} $BW^{-.75}$). The percent of the total

Table 4. Urinary Excreta from free grazing heifers on shortgrass range (mean ± s.d.).

Month	Volume (ml day^{-1} $BW^{-.75}$)	Total-N (g day^{-1} $BW^{-.75}$)	Urea-N (g day^{-1} $BW^{-.75}$)	% Urea N of total-N	Total-N (% vol)	Urea-N (% vol)
May	71 ± 16	0.9 ± 0.2	0.5 ± 0.1	63 ± 2	1.21 ± 0.19	0.76 ± 0.13
June	122 ± 20	1.3 ± 0.1	0.8 ± 0.1	67 ± 3	1.04 ± 0.08	0.69 ± 0.05
July	101 ± 40	0.9 ± 0.1	0.4 ± 0.1	48 ± 5	0.94 ± 0.28	0.45 ± 0.14
Aug	105 ± 59	0.8 ± 0.1	0.5 ± 0.1	55 ± 7	0.90 ± 0.37	0.51 ± 0.22
Sept	88 ± 22	0.8 ± 0.1	0.5 ± 0.4	58 ± 4	0.97 ± 0.18	0.56 ± 0.10
Oct	37 ± 14	0.4 ± 0.2	0.2 ± 0.1	37 ± 10	0.98 ± 0.17	0.38 ± 0.16
Nov	26 ± 9	0.3 ± 0.1	0.1 ± 0.1	38 ± 8	1.28 ± 0.15	0.49 ± 0.12
Jan	21 ± 4	0.3 ± 0.5	0.1 ± 0.1	34 ± 5	1.48 ± 0.36	0.50 ± 0.12
March	19 ± 1	0.3 ± 0.1	0.1 ± 0.1	30 ± 5	1.47 ± 0.17	0.45 ± 0.12

urinary-N in the form of urea varied with season, with 67% and 30% being the maximum and minimum for June and March, respectively. Again, this departs from Doak (1952) who measured a range of 50-74% urea-N in urine from cattle on summer range. Urinary energy follows this same pattern. The maximum energy excreted was 26.1 Kcal day^{-1} $BW^{-.75}$ in June with a minimum of 8.2 Kcal day^{-1} $BW^{-.75}$ in March (Table 3).

Total urine N and urea-N were linearly correlated (Total N = 0.19 + 1.33 (urea-N), r^2 = 96.3). This suggests there was 0.19 g N day^{-1} $BW^{-.75}$ excreted from endogenous sources such as cell sloughing of the bladder. The remaining N came from N metabolism of the animal. For every unit of metabolizable N excreted 75% was in the form of urea. Urine total and urea N were linearly correlated with N concentration of the diet (r^2= 79.5 and 84.7), N content (g) of the diet (r^2=76.3 and 75.7), and digestibility (r^2=71.7 and 67.4). This was expected as the digestibility increased and the N increased the ammonium level of the rumen would increse. Thus more N would be converted to urea in the liver and excreted in the urine (Harper et al., 1979; Maynard et al., 1979). Urinary energy was closely correlated to N (r^2=86.7) as most of the energy excreted is from N metabolism (Maynard et al., 1979; Van Soest, 1982).

Fecal excretion showed a different pattern from urinary excretion (Table 5). Excretion rate was highest in September (58.3 g day^{-1} $BW^{-.75}$) and lowest in May (31.4 g

Table 5. Fecal excreta from free grazing heifers on shortgrass range (mean ± s.d.).

Month	Dry Matter ($g\ day^{-1}\ BW^{-.75}$)	Total-N ($g\ day^{-1}\ BW^{-.75}$)	Total-N (%)
May	31.4 ± 2.9	0.63 ± 0.03	2.00 ± 0.15
June	31.8 ± 5.6	0.65 ± 0.12	2.06 ± 0.08
July	35.9 ± 6.0	0.59 ± 0.12	1.62 ± 0.10
August	48.5 ± 1.3	0.76 ± 0.01	1.57 ± 0.05
September	58.3 ± 1.4	0.79 ± 0.03	1.35 ± 0.09
October	57.5 ± 5.4	0.84 ± 0.04	1.47 ± 0.16
November	52.5 ± 2.5	0.65 ± 0.04	1.23 ± 0.03
January	38.5 ± 2.4	0.55 ± 0.05	1.43 ± 0.03
March	47.8 ± 1.1	0.74 ± 0.08	1.54 ± 0.13

day-1 BW-.75). The N concentration of the feces varied as did urinary-N, with the highest concentration of 2.06% in June and the lowest of 1.23% in January. This is within the range reported by Holechek et al. (1982) who measured a range of 1.53-3.41% for grasslands and forests in Oregon. The actual amount of N excreted was greatest in October. Fecal energy peaked in September and was lowest in May (Table 3).

The N concentration of the feces can be increased in two ways; 1) by increasing microbial populations in the rumen, or 2) by increasing the loss of fermentable matter from the rumen with increased microbial growth in the lower tract (Van Soest, 1982). High fecal N concentration in the early summer can be attributed to the increased rumen microbial biomass from highly digestible, high N forage . As digestibility decreased in late summer, energy and N in the feces increased. The increased fecal energy and low digestibility of the diet would suggest the N source was microbial growth from fermentation in the lower tract. The increased fecal N concentrations in January and March reflect supplementation of the animals (Rittenhouse et al., 1970).

A nitrogen budget for the animals was calculated using dietary and excreted N. When N ingested was greater than excreted N, the animals were in a positive N balance. When N ingested was less than excreted N, animals were in a negative N balance. By these criteria, the animals were in

Table 6. Nitrogen balance for free grazing hiefers on shortgrass range.

Month	N balance ($g\ day^{-1}\ BW^{-.75}$)
May	-0.04
June	0.30
July	-0.06
August	0.01
September	-0.09
October	0.04
November	-0.04
January	0.02
March	-0.07

a relatively even N balance each sampling period (Table 6). But this disagrees with the weight gains and calculated intake vs. NRC requirements (Table 1). Differences may be explained by sampling error of the urine, feces, and intake and stress put on the animal the week of sampling.

An energy balance for the animals was also calculated. The difference in energy ingested and excreted in the feces is digestible energy, DE. Ritthouse et al. (1971) determined that DE could readily be estimated from digestibility using the formula: Mcal DE/ kg DM = .039(DMD) - .10 , where DM is dry matter and DMD is dry matter digestibility. My data suggests Mcal DE/ kg DM = 0.05(DMD) - 0.71, suggesting that the equation of Rittenhouse et al. (1971), which was developed on sandhills range in Nebraska, could give considerably different values than actually measured for shortgrass range. DE can further be partitioned into energy lost as gasses, energy excreted in the urine, and metabolizable energy, ME. The amount lost as gasses could not be measured in this study, thus ME was estimated by subtracting urinary energy from DE. The ME ingested was higher than the requirement for maintenance for all sampling dates except November, January, and March (Table 1). The poor quality of the forage and the deficiency of N and energy would suggest the rate of supplementation was not adequate.

An N budget for the pasture was calculated using the values of intake and excretion extimated for the four

experimental heifers and the weight gains of the other four heifers (Table 7). Monthly values of intake and excretion were calculated from the average of two sampling dates.

The data shows 7810 kg of dry matter were removed from the 125 ha. pasture for the growing season, May to October, and an additional 8860 kg of dry matter ingested from Oct 4 through March 7, for a total of 16670 kg. The supplement accounted for 45 kg of this. Thus 62.5 kg/ha and 70.5 kg/ha were ingested for the growing and dormant seasons respectively, for a season total of 133 kg/ha. Peak standing crop was measured by Senft (1983) at 1220 kg/ha in June. Thus 11% of peak standing crop was utilized by the grazing heifers.

Nitrogen intake for the pasture was 116 kg N and 91 kg N for the growing and dormant seasons, respectively. An additional 2.2 kg N was added as supplement. Thus a total of 207 kg of N was ingested in the forage of the pasture, or 0.93 kg N/ha , 0.73 kg N/ha and 1.66 kg N/ha for the growing season, dormant season and total sampling period, respectively. Peak standing N was 19.8 kg/ha (Senft, 1983). The N ingested for the season represents 8% of the peak N in the vegetation standing crop.

The N accumulated into growth of the eight heifers grazing the pasture repesented 18% and 10% of the N ingested duringthe growing season and for the total sampling period respectively. Urine and fecal excretion for the pasture were 62.6 kg N and 53.1 kg N, respectively, for the growing

Table 7. Partitioning of ingested nitrogen for each sampling period from May 1981 to March 1981.

Sampling Period	Number of Days	Heifer[1] Weights (kg)	Intake[2] Dry Matter (kg)	Intake[2] N (kg)	N Stored in Tissue (kg)	Excreted N Urine-N (kg)	Excreted N Fecal-N (kg)
May 26-June 11	16	249	684	14.6	3.1	8.8	5.1
June 11-July 8	27	273	1383	26.0	7.2	15.9	9.0
July 8-Aug. 4	28	294	1608	23.6	2.0	13.5	10.7
Aug. 8-Sept. 1	27	299	1759	24.1	0.4	12.4	12.0
Sept. 1-Oct. 4	33	320	2378	27.8	8.7	12.0	16.3
Oct. 4-Nov. 15	42	339	2956	29.0	-0.7	9.4	19.8
Nov. 15-Jan. 5	51	337	2832	29.2	0.0	9.6	19.2
Jan. 5-March 7	61	340	3073	35.2	1.3	11.6	24.9

1 Average of the eight heifers each sampling period
2 Dry matter intake includes 19 kg and 26 kg of supplement for the last two sampling period, N intake includes 0.9 kg N and 1.3 kg N from the supplement for the last two sampling periods.

season and 30.6 kg N and 63.9 kg N, for the dormant season. This translated to 0.5 kg N/ha and 0.4 kg N/ha for urine and feces respectively, for the growing season and 0.2 kg N/ha and 0.5 kg N/ha in the dormant season. Thus, for the year 1.6 kg N/ha was cycled through the cattle. This included some of the 2.2 kg N feed to the herd as supplement.

As with the test animal only, the budget of ingested N was less than the N excreted or retained in body tissue. The error for the sampling period of May 25 through March 7 was only 10%. I consider this quite acceptible considering the estimates were done on free grazing animals.

SUMMARY AND CONCLUSIONS

Dry matter intake of cattle on shortgrass range varied throughout the year depending on N content and digestibility of the diet. Intake also appeared limited by bulk fill of the rumen. Higher rates of urinary-N excretion were most closely correlated with N% of the diet. Fecal N excreted (g day-1 $BW^{-.75}$) was relatively constant while the N concentration of the feces varied greatly. A possible explaination for the changes in the N concentration of the feces was that the high N in the diet early in the season produced increased rumen microbial growth while higher bypass energy levels later in the season contributed to microbial growth in the lower tract. Both these have been showing to effect fecal N levels (Van Soest, 1982).

About 10% of the ingested N was incorporated into body tissue. The N excreted was partitioned between urine and

fecal N at 54% vs. 46% for the growing season and 45% vs. 55% for the dormant season. This supports the belief that the N excreted in urine would be greater with the increased N concentration of the diet during the growing season (Van Soest, 1982).

The N and energy balance from the animal perspective showed that intake met the requirements for maintenance and growth for all months except January and March. This suggests the rate of supplementation was not adequate for animal production for the dormant months.

The growth patterns of both groups of annimals were similar, although the heifers used in the trial for urine and fecal collection had reduced gains as compared to the other four animals. This suggests stress on the animals and may exert some error of the N balance.

Nitrogen ingestion from the pasture was less than 10% of the peak N standing crop. The depostion of N as urine and feces was 1.6 kg/ha for the pasture. This does not suggest that the N was evenly detributed accross the pasture. Senft (1983) calculated from some of this data the rate of deposition. It varied from a low of 1.2 kg N/ha for an upland community to a high of 5.5 kg N/ha for a lowland community. On an even finer scale, Wilkinson and Lowery (1974) in reviewing the literature suggested the rate of application was about 450 kg N/ha in a urine spot.

Management implications of the study are that the pasture vegetation was not heavily used. Only 5% of the

peak standing crop was used during the growing season when the diet quality was the highest. There was no appreciable animal weight gain from October 4 through March 7. In a ranching situation where the goal is only to produce beef, the heifers should be removed in October to save the cost of supplements and time during the winter. Also it is possible an additional eight head of cattle could have been put on the range during the growing season to harvest more of the peak standing crop. Distribution of the cattle should be considered to ensure proper utilization of the lowlands and ridgetops.

CHAPTER 3: SOIL-PLANT SYSTEM

INTRODUCTION

Nitrogen ingested in forage and returned to the soil as excreta from grazing ungalates represents an important and sometimes critical pathway in the N cycle of grazed ecosystems (Float, 1981; Wilkinson and Lowery; 1973). Woodmansee (1978) estimated as much as 83% of ingested N may pass through the animal and be deposited on pastures in excreta. If the animal is in a negetive N balance, the amount excreted will excede that ingested.

Application rates of urinary-N to the pasture are dependent on stocking rate, animal distribution, and the level of community structure being considered (Woodmansee and Adamson, 1983). For example the rate of application may be as low as 0.73 kg N ha^{-1} $year^{-1}$ for equal distribution on a pasture, may increase to 1.3 kg ha^{-1} $year^{-1}$ for a community within the pasture, or may be a great as 450 kg N ha^{-1} for the area actually wetted by a urination (Doak, 1952; Peterson et al., 1956; Senft, 1983; Wilkinson and Lowery, 1973).

The actual area within soil/plant communities affected by excreta varies with number of excretion, volume voided per excretion, soil moisture and infiltration rate, and the chemical composition of the excreta. The area "wetted" by a

defecation or urination has been estimated at 0.09 m^2 and 0.28 m^2 respectively, for mature cattle. The area effected, measured by increased biomass and nutrient content, may be much larger. Wilkinson and Lowery (1973) suggested 1.02 m^2 , roughly 4 times the area wetted , to be a representative value for urine. The affect is not uniform but decreases from the center to the periphery of the effected area. The length of time the affect is maintained is quite variable. Joblin and Keogh (1979) and Lotero et al. (1966) noted the affect to have disappeared within ten months. However, Power (1980) and Clark (1977) suggested that once fertilizer N is in a native system the affect may be observable for five years or longer.

The nitrogenous compounds in urine include allantoin, hippuric acid, creatine/creatinine, and urea. Urea-N accounts for 50 to 80% of the urinary-N (Doak,1952; Church,1976). Urea added to the soil is quickly hydrolyzed to ammonia. Deamination of the other nitrogenous compounds also adds ammonia (Holland and During, 1977; Doak, 1952). The ammonia released quickly comes into an equilibrium with ammonium ions in the soil. The equilibrium reaction releases OH-, and thus raises the pH of the soil. Increases of 2.0-2.5 pH units for a soil of pH near 6.0 have been reported (Holland and During, 1977; Christensen et al., 1979; Overrein and Moe, 1967). The elevated pH increases the ammonia to ammonium ratio increasing the possiblity of ammonia volatilization (Woodmamsee, 1978). Any

volatilization of ammonia would decrease soil pH.

Ammonium in the soil is vulnerable to oxidation to nitrite and nitrate by nitrifying organisms, with the subsequent release of H^+ ions. The release of H^+ decreases the soil pH, often to levels lower than ambient (Stillwell and Woodmansee, 1981; Holland and During, 1977). The process of nitrification is dependent on soil temperature, moisture, the uptake of N by plants , and the presence of active nitrifying microorganisms.

The transformations of urea-N in a simulated urine spot on a shortgrass prairie site were examined by Stillwell and Woodmansee (1981) and Mosier et al. (1981). However, only one upland soil was used and the study was in a closed system of 10 cm aluminum cylinders. The study described here is a continuation of that work and had the following objectives:

1) to determine the comparative rates of N transformations of simulated urinary-N on a bottom,midslope and ridgetop site of a soil catena in the shortgrass prairie,

2) to determine the effects of urinary-N transformations on the soil pH at each site,

3) to estimate the area affected by the application of urine- the affect measured by vegetation and root biomass and N content and aided by ^{15}N labeled urea, and

4) to propose a mass balance for the N added at each site.

As it is difficult and expensive to obtain ^{15}N labeled urine, a simulated urine was used with urea as the only N source.

SITE DESCRIPTION

The study was conducted on the Central Plains Experimental Range, USDA-SEA-AR, located 56 km NE of Fort Collins, Colorado (latitude 40 48' 48'' N, longitude 104 46' 17'' W). The site was located on a semi-arid grassland in the shortgrass prairie. The study was conducted on a soil catena on a NE facing hillside of the NW 1/4 of the SW 1/4 of Sec. 26,T 10 N, R 66 W of Weld county Colorado.

This catena had three distinct soil-vegetation types (Fig. 1). Type 1 was on a soil classified as a Albinus, a fine-loamy, mixed, mesic Pachic Argiustoll, formed in medium textured alluvial sediments on a flat bottom toeslope. The vegetation was composed mainly of Blue grama (Boutoloua gracilis (H.B.K.)Lag.), Buffalo grass (Buchloe dactyloides (Nutt.)Englem), Western wheatgrass (Agropyron smithii Rydb.) and Carex spp. with a variety of forbs, cactus (Opuntia polyacanthia Haw.), and other grasses present in smaller quantities.

Soil-vegetation type 2 was the midslope position. The soil was a Vona coarse-loam, mixed, mesic Ustollic Haplargid. This soil was formed in eolian or partly wind reworked alluvial parent material. The vegetation was a blue grama, cactus, carex association with forbs and shrubs

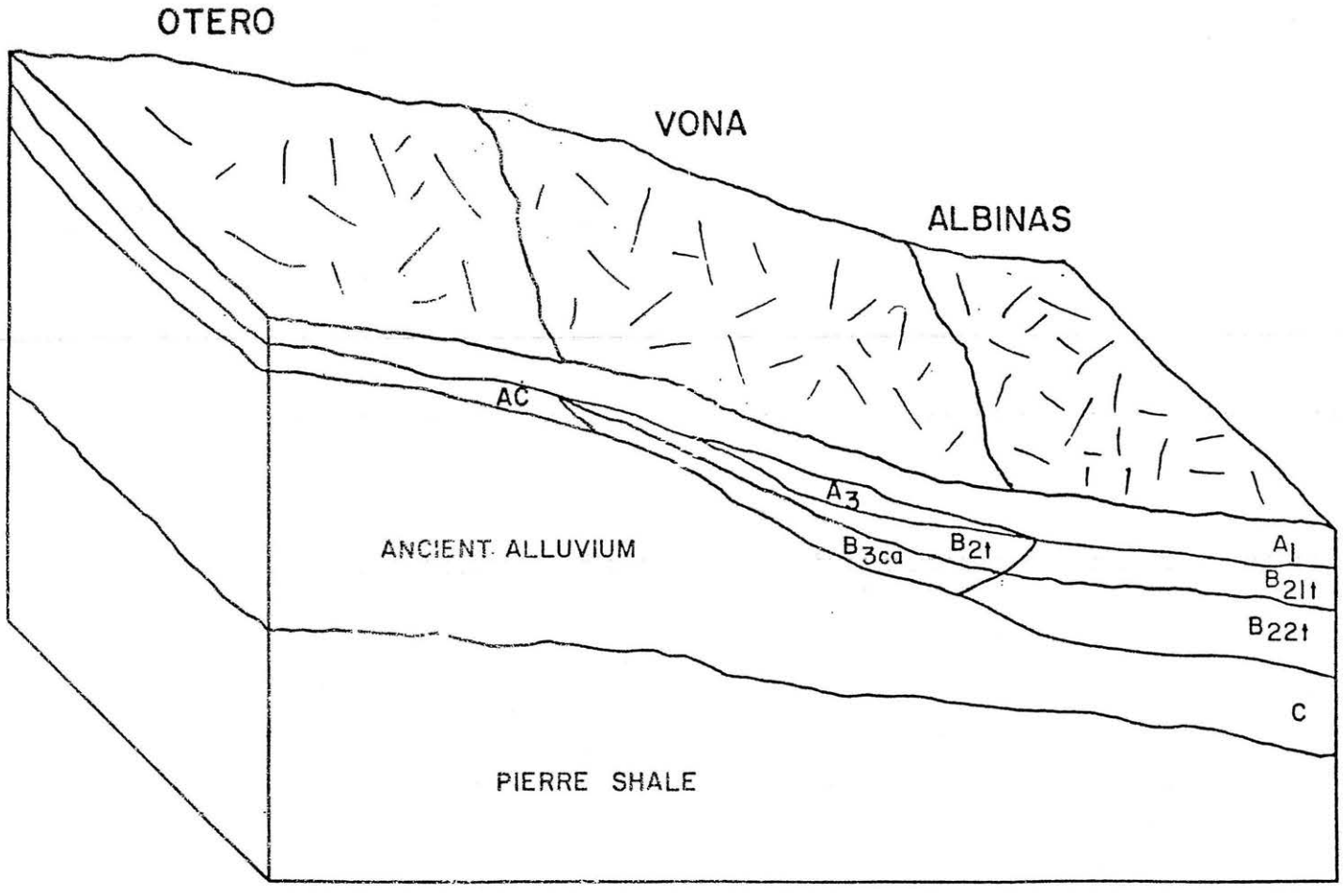


Fig. 1. Cross-section drawing of the soils that occur along the catena.

contributing to a substantial part of the early season biomass.

Type 3 was the ridgetop. The soil was classified in the Otero series, a coarse-loam, mixed, mesic Ustic Torriorthent. These are well drained soils formed in alluvial sediment. The vegetation was again dominated by blue grama and cactus with the perennial grasses needle and thread (Stipa comata Trin.+Rupn.), red three awn (Aristida longiseta Steud.), and bottle brush squirrels tail (Sitanion hystrix (Nutt.) J.G.Sm.) present in lesser amounts. Table 8 shows some further information on the three soils. For a more complete soil-vegetation description of this site see Anderson (1983).

This catena was chosen for the study for the following reasons; 1) it contained 3 soil-plant associations common to native shortgrass range, 2) it was near a weather station on the Central Plains Experimental Range maintained by the Long Term Ecological Research program and the National Atmospheric Deposition Program (NADP) and 3) it was near electrical lines needed for experimental equipment used in ammonia volatilization studies coordinated with this research. The catena was located in a pasture that was grazed at a moderate stocking rate the preceding summer. An exclosure was formed around the area in April 1980. Annual precipitation for the area averages 31 cm; ranging from 11 to 38 cm between 1932 and 1980. Typically 70% to 80% of the precipitation falls between May and September. Min-max mean

Table 8. Characteristics of the soils on a catena in the shortgrass prairie.

Soil	Depth (cm)	BD[1]	OM[2] (%)	Water Holding Capacity -0.3 bar	-15 bar	pH	CEC[3]	Depth to Lime (cm)	Ex.[4] Ca^{++}
Albinus	0-10	1.1	3.4	25	12	6.1	11.2	65	7.1
	10-20	1.1	1.4	25	12	6.3	18.4		11.4
Vona	0-10	1.4	1.2	10	5	6.4	6.9	25	4.4
	10-20	1.4	0.7	12	6	6.6	8.0		5.4
Otero	0-10	1.4	0.9	10	5	7.5	8.5	10	6.2
	10-20	1.4	0.8	12	6	7.9	13.0		9.3

1 BD = Bulk Density
2 OM = Organic Matter
3 CEC = Cation Exchange Capacity (meq/100 g)
4 Ex. Ca^{++} = Exchangable Calcium (meq/100 g)
Values from Woodmansee, Unpublished data; Schimel, 1982; and this research

temperatures for Jan. are -12.0° and 0.5° C, respectively, and for July 12° and 28° C (Woodmansee et al., 1978).

METHODS

A grid pattern of 3 rows with 4 spots per row was established on each site on the catena. The three rows were transverse to the slope of the hill. Each row would represent a replication , i.e. 3 reps. On May 22, 1980, the four spots in each of the three rows at each site were randomly assigned a treatment. The treatments were: a ^{15}N enriched simulated urine spot, an unamended control, a simulated urine spot (no ^{15}N) with an unamended control for that spot. The ^{15}N enriched spot and its control were used to evaluate a N balance and the area affected by the application of urine while the other spot and its control were used to follow the biological and chemical transformation of the urine-N.

The urine spots were made by adding 2 liters of a simulated urine (Table 9) to the soil surface in a ring 60 cm in dia.(0.28 m^2), taken from literature values of the size of a urine spot (Wilkinson and Lowery, 1973). The ring restricted the movement of the solution and defined the area of the spot. The application rate of the urea-N was 45 gN m^{-2} with 20.0% ^{15}N enrichment of the labeled spot.

URINE SPOTS- NO ^{15}N

The urine spots, designed to follow the biological and chemical transformations of the simulated urinary-N, were

Table 9. Chemical composition of the simulated urine.

Compound	Amount (g/liter)	^{15}N urine (g/liter)
Urea	13.648	10.126
^{15}N Urea (77.6 atom %)		3.604
$MgCl_2.6H_2O$	0.750	0.750
$MgSO_4.7H_2O$	0.725	0.725
$CaCl_2.2H_2O$	0.091	0.091
KCl	7.015	7.015
$KHCO_3$	6.830	6.830
NaCl	1.210	1.210

Doak, 1952; Ritman, 1961; Stillwell and Woodmansee, 1980.

sampled with a 2.5 cm soil core to 20 cm. The cores were pulled at a distance of 10 cm from the center of the spot. The soil in each core was divided into 0-2.5, 2.5-5, 5-10, and 10-20 cm depths. Subsamples of each depth were extracted with 2M-KCl/PMA (Douglas and Bremner, 1970) and the extract analyzed for N in the forms of urea, ammonium, and nitrite+nitrate. Soil water and pH were also determined for each depth. The spots were sampled at 1, 4, 7,14,28,38,56,84, and 120 days after the May 22, 1980 application. Control plots were sampled and analyzed similarly to the treated at the same time period except for day 4 and 38 when no controls were taken.

^{15}N ENRICHED URINE

The ^{15}N enriched urine spots, designed to determine the area affected by a urine spot and to calculate a balance of the added nitrogen, were sampled June 26 and Aug. 20, 1980, and Aug. 26, 1981. The vegetation was clipped by species in concentric rings from the center of the spot. Ring #1 was 60 cm in dia. and represented the area wetted by the application of the simulated urine. Rings #2 and #3 were enlarged by 15 cm in radius (30 cm increase in dia.) and ring #4 was enlarged by 30 cm radius (Fig. 2). The plant samples were dried at 55°C for one week, weighed to determine biomass, ground in a household blender, and analyzed for total-N and atom % ^{15}N. The control plots were clipped by species over the same area as the treated but not by ring and handled as the treated samples.

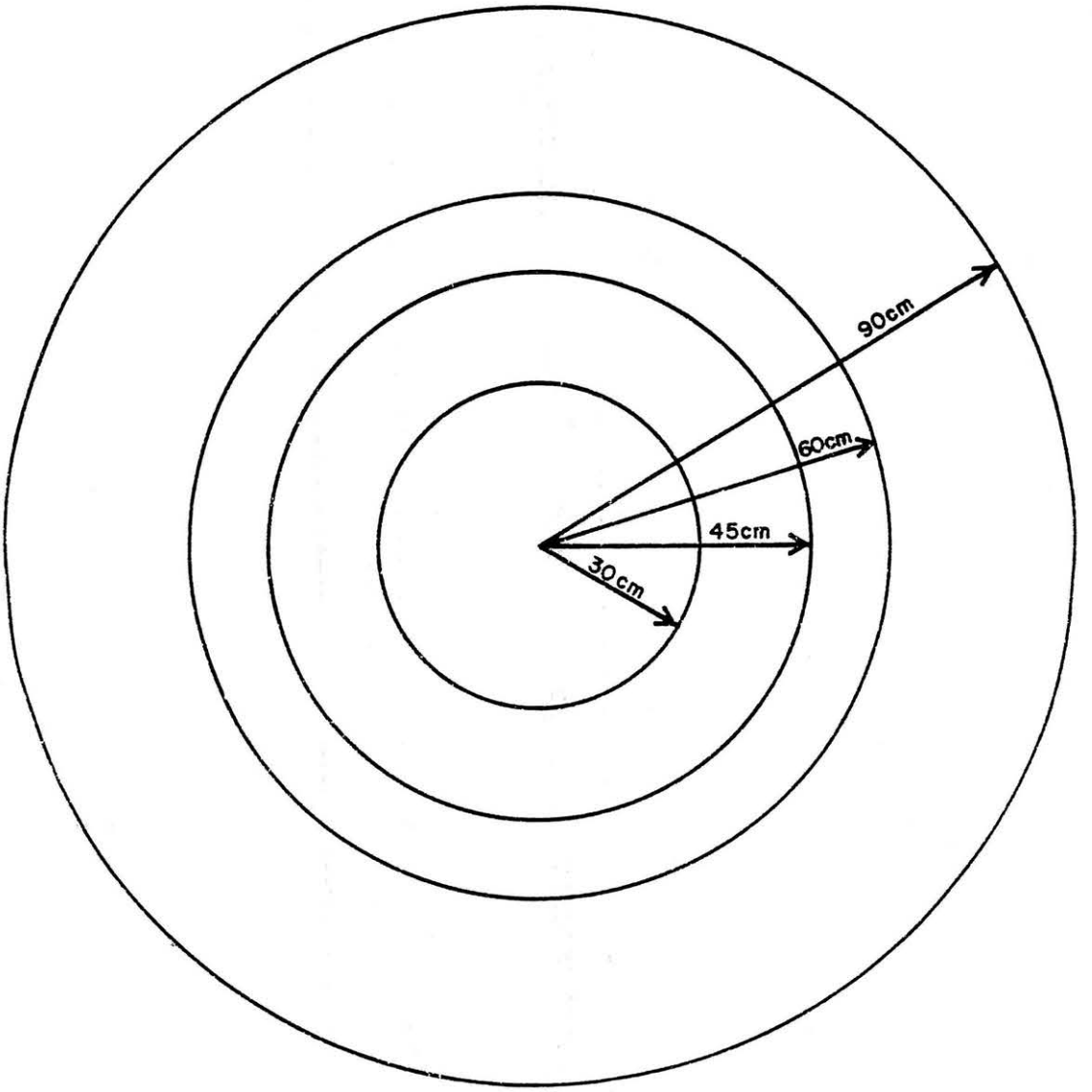


Fig. 2. Pattern of vegetation sampling around the simulated urine spot formed by the addition of ^{15}N enriched urea.

The plants were grouped as blue grama+buffalo grass (hereafter refered to as Bogr/Buda), other grasses, cactus, scarlet globemallow (Sphaeralcea coccinea (Pursh)Rydb.), Carex, and other forbs in 1980. Statistical analysis of the 1980 data required that the groupings be decreased to Bogr/Buda, other grasses, Carex, and forbs (including half-shrubs). The vegetation was clipped and chemical analysis performed on this grouping in 1981.

Soil cores of 2.5 and 10 cm dia. to a depth of 20 cm were also extracted from each ring and the controls in August of 1980 and 1981. The 2.5 cm cores were segmented into 0-10 and 10-20 cm depths and subsamples analyzed for total-N and atom % ^{15}N in the soil. The 10 cm core was used to sample root biomass and N content and atom % ^{15}N of the roots in the top 20 cm of the profile.

LABORATORY METHODS OF ANALYSIS

All soil extracts were a 1:5 (w/v) , shaken for one hour, and filtered through Whatman #1 filter paper. Urea-N was determined colorimetricly using a blood urea method (Sigma Chemical Company, 1974) as modified by Stillwell(1980). Ammonium and nitrite+nitrate were determined with a Techicon Auto Analizer I (Bigelow et al., 1983). Total inorganic N (TIN) was calculated by summing ammonium and nitrite+nitrate. The soil which was sieved through a 9 mesh screen to remove large rocks, roots, and organic debris and total N determined by the Kjeldahl method

to include nitrate (Bremner, 1965) modified to a digestion block (Nelson and Sumner, 1980) with ammonium determined with an Auto Analyzer I (Bigelow et al., 1983). Root biomass was estimated by removing the roots from the 10 cm cores mentioned above , by the flotation method (McKell et al., 1961). Roots were defined as all large organic debris in the soil which would not pass through a 60 mesh sieve. Root samples were ashed and all values reported on an ash free basis. All root and above ground vegetation samples were ground in a common household blender, with the blades and container being washed in a HCl acid bath between each sample. Control samples were ground first followed in order of ring 4, ring 3, ring 2, with ring 1 being ground last. Kjeldahl digests containing ^{15}N were diffused into 1.5N HCl using the diffusion tube method of O'Dean and Porter (1979). Subsequent atom % ^{15}N determinations were done at Los Alamos, NM by Dr. B.B. McInteer. Soil pH was determined with a glass electrode in a water saturated paste (Peech, 1965).

The amount of urea-^{15}N in a given pool was calculated by utilizing the %^{15}N excess of the N pool, the %N in the pool, and the mass of the pool (Rennie and Paul, 1971). For example, the urea-N in the vegetation was obtained as follows:

mass (yeild) = gm

nitrogen content = %N

%^{15}N excess (vegetation) =

Atom $\%^{15}N$ vegetation - Atom $\%^{15}N$ control vegetation

$\%^{15}N$ excess (urea) =

Atom $\%^{15}N$ tagged urea - Atom $\%^{15}N$ control urea

%N derived from urea (NDFU) =

$\%^{15}N$ excess vegetation / $\%^{15}N$ excess urea X 100

Total N yield = yield X %N

Total urea-^{15}N yield = Total N yield X %NDFU

Total soil N yield = Total N yield - Total urea-N yield

The atom $\%^{15}N$ in the urea was determined from a subsample of the simulated urine to be 19.47%. Atom $\%^{15}N$ in the control soil and plant tissue was measured as 0.37% $\pm$ 0.07.

Analysis of variance was used to compare the changes of each variate with time within each site and across sites. Tukey's Q test was used for mean separation (Snedecor and Cochran, 1967).

RESULTS:SITE 1 THE BOTTOM POSITION OF THE CATENA

CHEMICAL TRANSFORMATIONS

Control levels of N in the top 20 cm of the profile varied only slightly throughout the growing season (Fig. 3). Nitrate was the dominant form of inorganic N, with a summer average of 0.83 g N m^{-2}. Ammonium N averaged 0.46 g m^{-2} for the summer. Many researchers (Stillwell and Woodmansee, 1981; Clark, 1977; Mosier et al. ,1981) have found that ammonium is usually the dominant form of inorganic N in the grasslands. Evaluating their laboratory techniques , steam

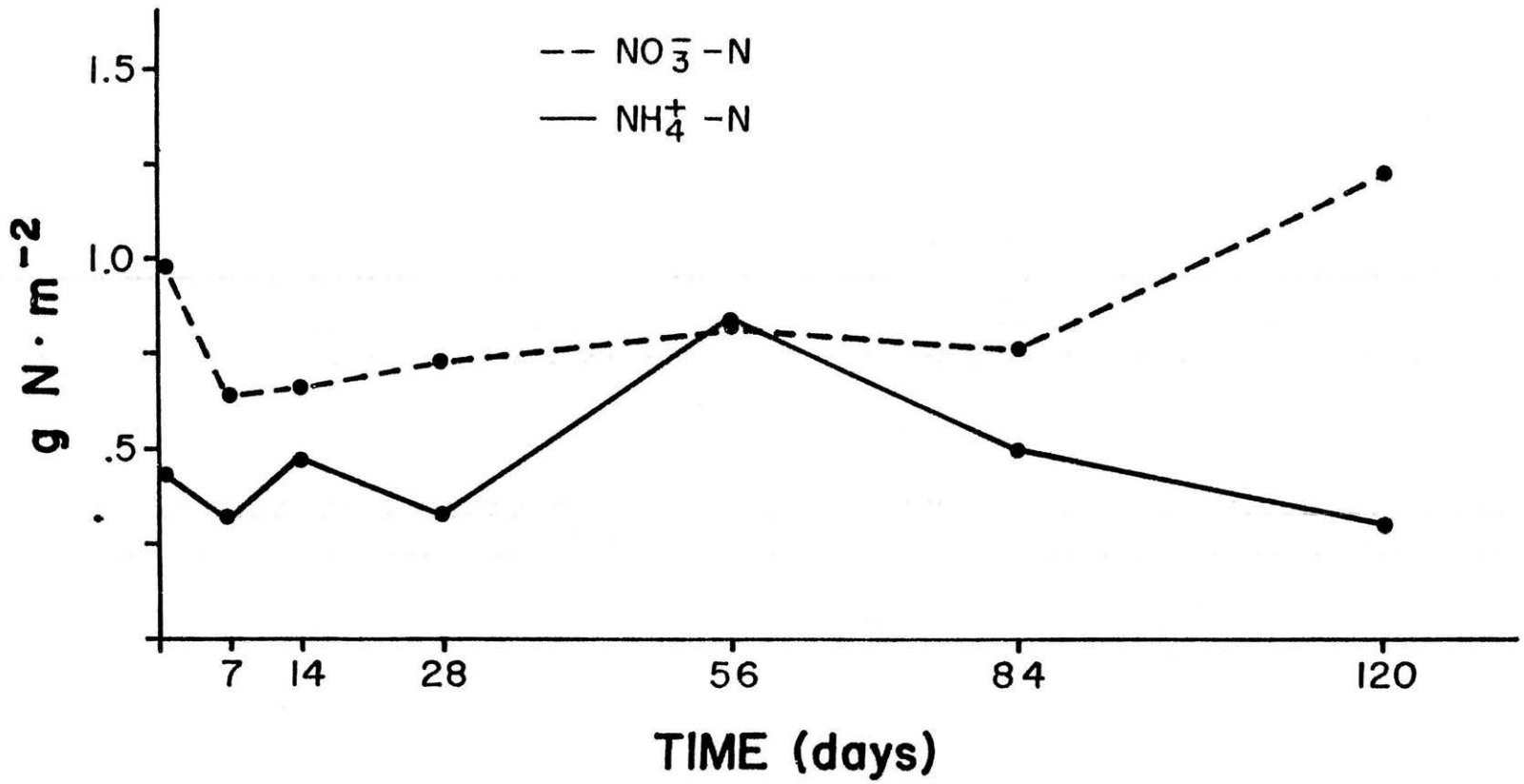


Fig. 3. Changes in the inorganic N of the control plots of Site 1, the bottom position of the catena.

distillation followed by titration, suggests that the discrepency may be in methodology. The detection limits of the colorimetric method are much lower than that of steam distillation (Bigelow et al., 1983).

Hydrolysis of the applied urea-N to ammonium was rapid on the lowland site (Fig. 4). Twenty four hours after application only 4.6g of the added 45.0 g urea-N,or 10.2%, was accounted for as urea-N in the profile. Urea was completely hydrolyzed in 4 days. This agrees with Stillwell and Woodmansee (1981) findings that only 13% remained after one day and complete hydrolysis was accomplished in 4 days.

The ammonium pool showed the greatest change in concentration at 1 day when 40.0 gN m^{-2} was present in the profile. This again agrees closely with the maximum change noted by Stillwell and Woodmansee (1981) who reported 39.9 g NH^{+}_{4}-N m^{-2} 4 days after urea application. Ammonium decreased with time until at day 56 only 2.1 g of the total N was in the form of ammonium, compared to 0.85 g of the control. After the initail decrease, the concentration changed only slightly to the end of the study. Presumably the rapid disapearance of ammonium was due to the following mechanisms: ammonia volatilization , plant or microbial immobilization, and nitrification.

Nitrification of ammonium to nitrate appeared to be slow until the plot received a 1.9 cm rain June 20, 29 days into the trial. This event and the 5.6 cm of rain that fell the first week of July permitted nitrifying microorganisms

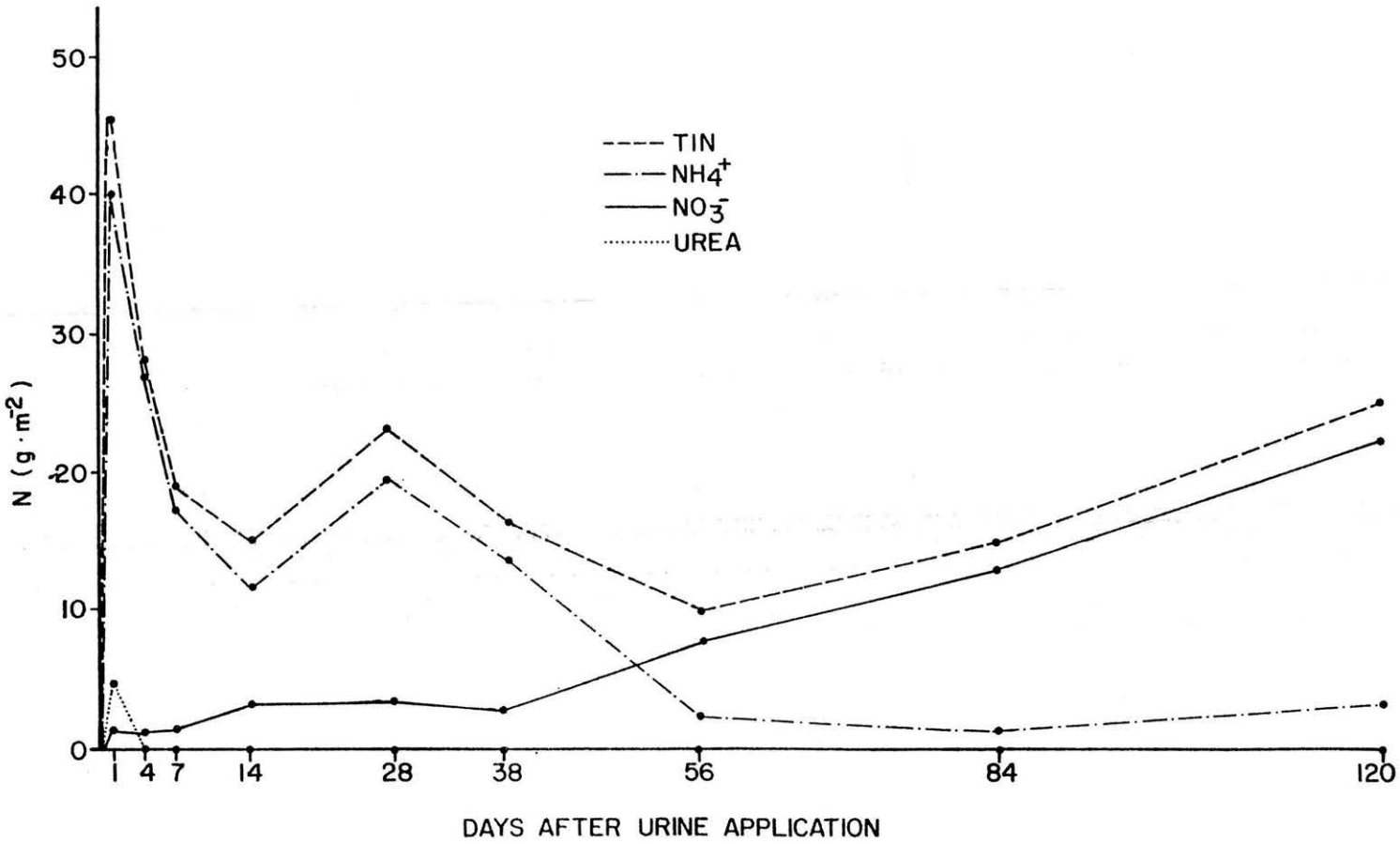


Fig. 4. Changes in the inorganic N of theurine spots formed by the simulated urine at Site 1, the bottom position of the catena.

to metabolize ammonium as is seen in an accumulation of significant levels of nitrate at day 56, 7.6 g m^{-2}. The nitrate pool continued to increase through day 120 , Sept 19, when 22.1 g N m^{-2} were present in the profile.

In the inorganic pool, nitrate accounted for 47.7% of the added 45 g urea-N plus 1.29 g indigenous N (ammonium + nitrate). Add to this the 3.1 g ammonium-N on Sept 19, and 54.4% of the added urea-N could be accounted for in the inorganic N pool at the end of the study. This leaves 45.6% or 21.1 g to be partitioned between ammonia volatilization and plant and microbial immobilization. 50% of the N added to the system by Stillwell and Woodmansee (1981) remained in the inorganic pool at the conclusion of the study.

The rapid disappearance of ammonium and slow accumulation of nitrate suggests that water may have been limiting early in the season (Fig. 5). Dry conditions combined with high soil pH and elavated ammonia levels have been shown to inhibit nitrification and be conducive to ammonia volatilization (Alexander, 1965; Anthonisen et al., 1976; Clark et al., 1960; Erh et al., 1967).

The distribution of the added N (Fig. 6) in the profile showed a significant increase in ammonium in the 0-2.5 and 2.5-5 cm depths through the first 38 days. The 5-10 cm depth also showed increased levels of ammonium for this period but only significant increases for the first week. The 10-20 depth showed no increase of ammonium. Twenty four hours after adding the simulated urine, the top three depths

Fig. 5. Soil water of the urine spots at Site 1, the bottom position of the catena. Horizontal lines represent soil water at -0.3 and -15 bars.

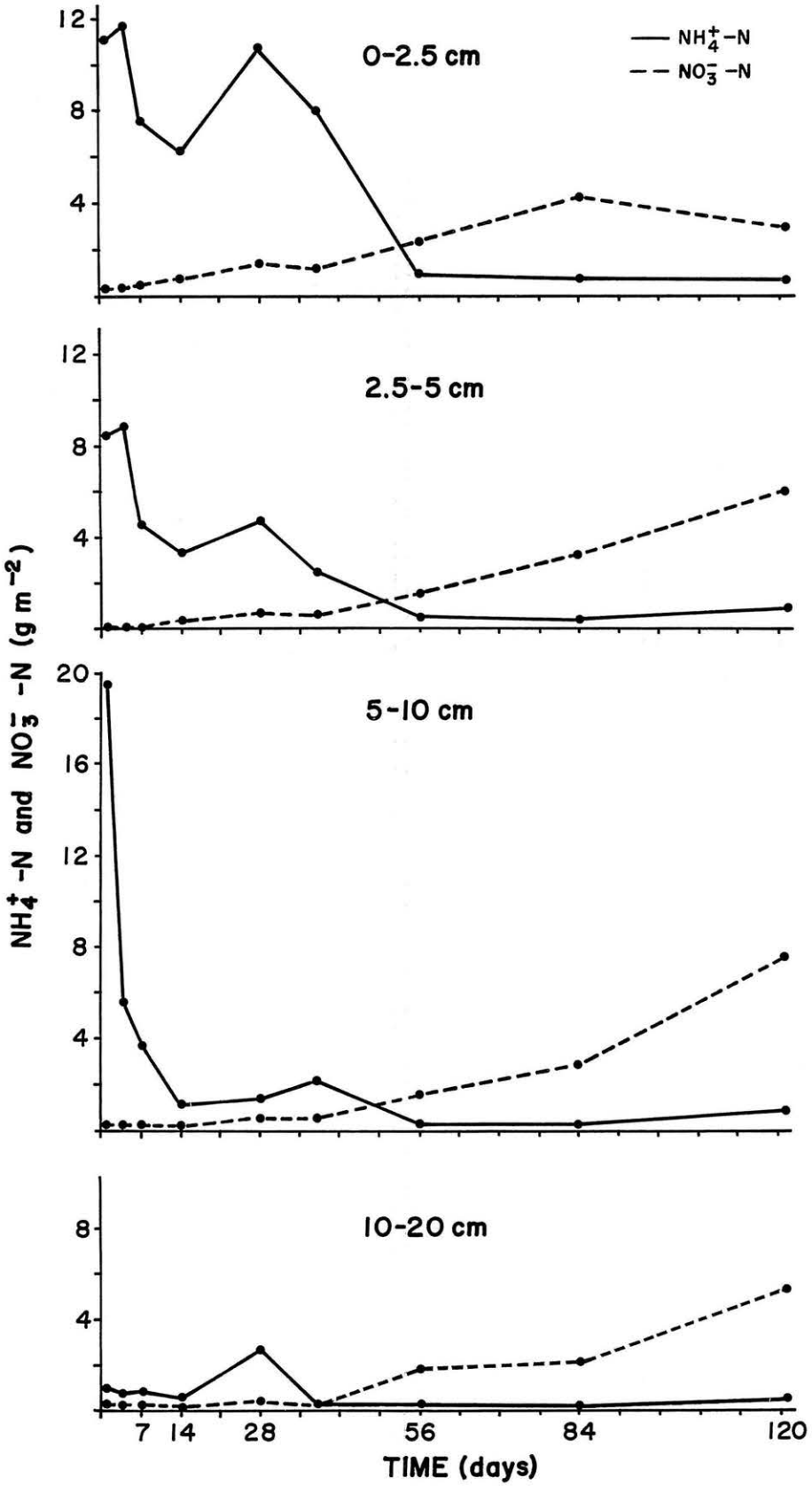
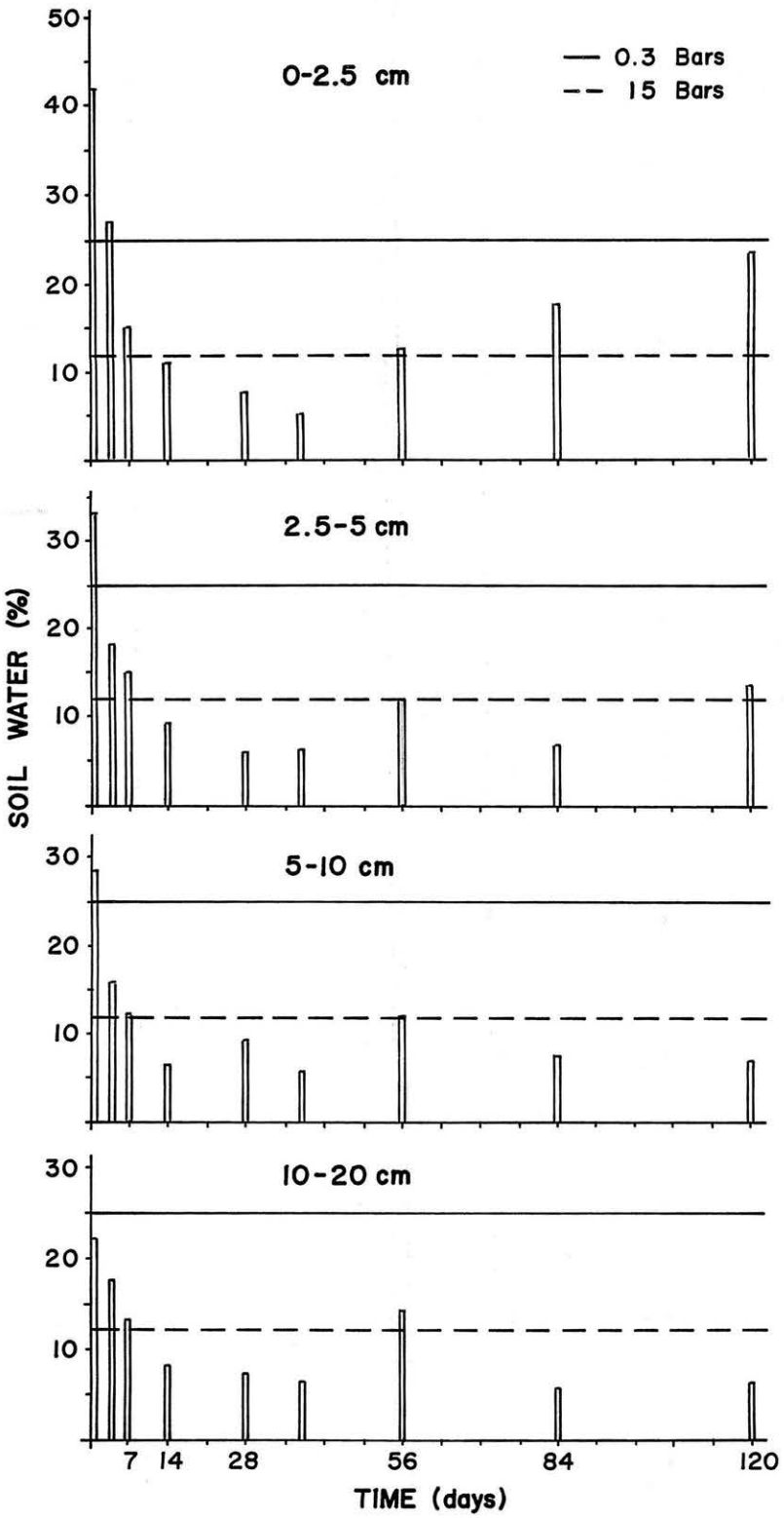

0-2.5 cm
2.5-5 cm
5-10 cm
10-20 cm
NH_4^+-N
NO_3^--N
NH_4^+-N and NO_3^--N (g m^{-2})
TIME (days)
7
14
28
56
84
120

Fig. 6. The distribution of the inorganic N for the 0-2.5, 2.5-5, 5-10, and 10-20 cm depths of the soil of the urine spots of Site 1, the bottom position of the catena.


0-2.5 cm
0.3 Bars
15 Bars
2.5-5 cm
5-10 cm
10-20 cm
SOIL WATER (%)
TIME (days)
7
14
28
56
84
120

contained 27.4, 21.2, and 48.5% of the ammonium in the profile , suggesting the solution was evenly distributed throughout the top 10 cm of the profile. By day 28, the distribution had changed to 54.6, 24.3, and 7.2% for these three depths.

The depth distribution of nitrate showed nitrate reached levels significantly above control at day 56 for all 4 depths. At this time, 30% of the NO_3-N was in the top 2.5 cm of the profile, with the lower three depths containing 21.5, 22.7, and 25.8% of the remaining nitrate. That is, 51.5% of the NO_3-N was in the top 5 cm (25% soil mass) and 48% in the bottom 15 cm. That compares to 78.9% of the ammonium in the top 5 cm at day 28. Apparently the 7.5 cm of rain over this time period allowed nitrification to progress rapidly and caused leaching of nitrate to the lower depths of the profile. At the end of the study the nitrate was distributed in the 0-2.5, 2.5-5, 5-10, and 10-20 cm depths as 12.9%, 27.5%, 35.1%, and 24.5%, respectively, even though all of the depths increased in nitrate from July 17 , day 56, to Sept. 10, day 120. The increase may be from mineralization of the N with senescence of the vegetation and dry soil conditions, which have been suggested to increase mineralization (Stanford and Smith, 1973).

The top 10 cm of the soil had a significant increase in pH with the urea-N addition (Fig 7). The top 2.5 cm increased from 5.7 to 7.8, the 2.5-5 cm depth from 6.1 to 7.7, and the 5-10 cm depth from 6.4 to 7.2 within 4 days.

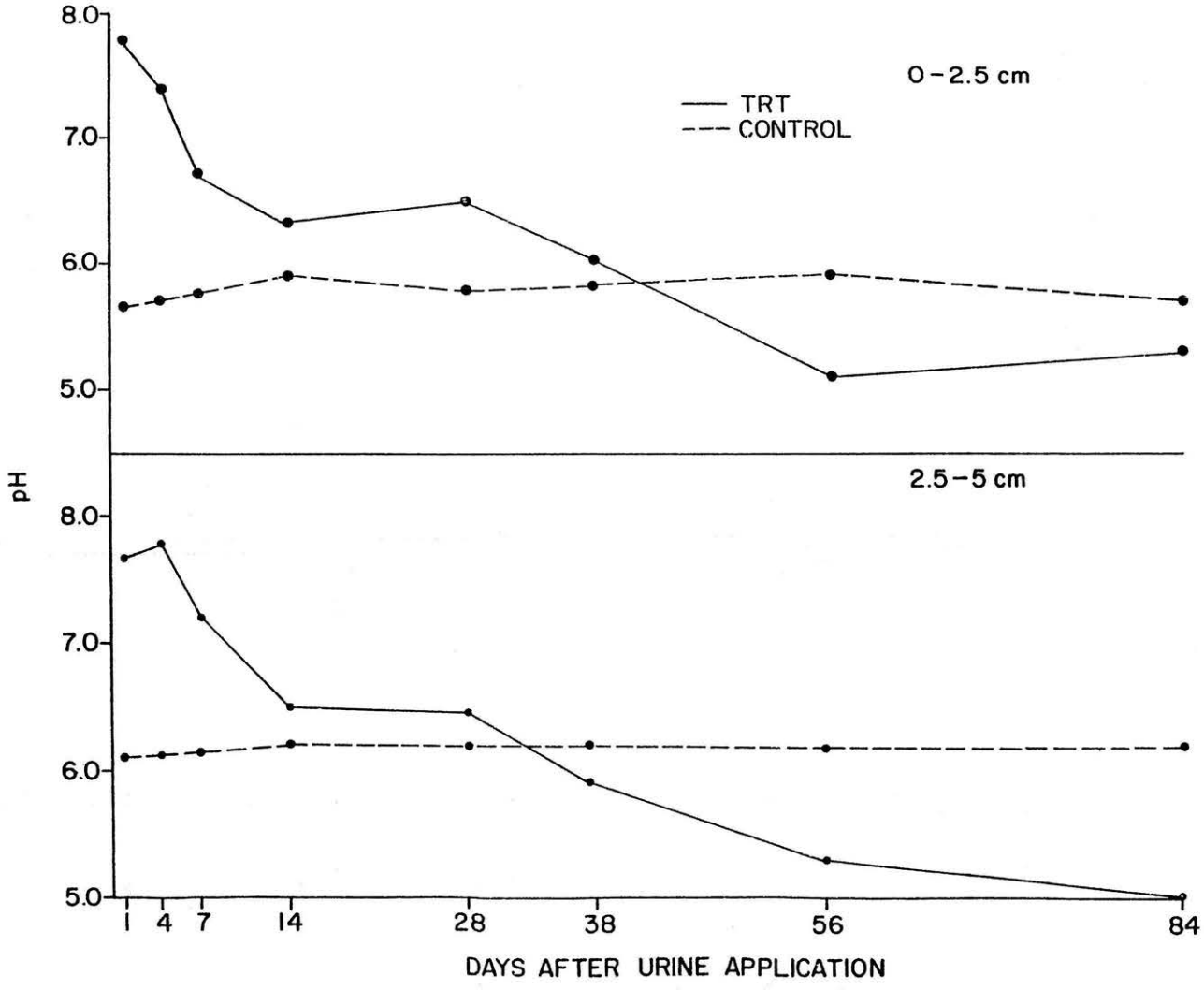


Fig. 7. Soil pH of the 0-2.5 and 2.5-5 cm depths of the soil of the urine spots of Site 1, the bottom position of the catena.

The pH increase was maintained for at least 1 week at all depths. The pH decreased to a level below the control by day 56. This reduced pH was maintained to the end of the study.

The pH changes closely followed the change in inorganic N. The increase in pH correlated with the increased ammonium resulting from urea hydrolysis, followed by a gradual decrease to control levels. The decreased pH corresponded directly with the decrease in ammonium and the increase of nitrate suggesting the nitrification reactions were responsible for the decrease (Holland and During, 1977).

SITE 1, VEGETATION

The vegetation showed a definate treatment effect (Table10). The total vegetation biomass of ring 1 was significantly greater than the control. The total biomass of ring 1 had increased by 88.5 g m^{-2} within one month of the addition of N. An increase of 115 g m^{-2} was seen by the end of the summer, for a total increase of 204 g of above ground biomass. The following year also produced an increase of biomass of 52 g m^{-2}. Ring 2 showed a slight increase but it was not significant. The late clip in August of 1980 may have damaged the vegetation thus it was unable to recover the following year. There was an increase in production for rings 1, 2, and 3 both years , but only the increase in ring 1 was statistically significant ($p=.10$). The total vegetation biomass was dominated by

Table 10. Biomass for various harvest dates of the aboveground vegetation of Site 1, the bottom position of the catena (g m^{-2}).

Vegetation	Ring	Date: June 1980	Date: Aug. 1980	Date: Aug. 1981
Total Biomass				
	1	266.5±78.5	219.0±114.9	122.0±11.5
	2	209.0±48.7	143.5± 54.3	106.7±24.1
	3	213.7±67.7	99.5± 21.5	86.0±15.9
	4	166.2±11.1	95.6± 31.5	80.9± 9.6
	Control	178.1±46.6	103.6± 22.3	70.2± 8.9
Bogr/Buda				
	1	200.9±56.8	179.4±105.9	91.6± 2.5
	2	151.0±41.1	121.0± 54.3	78.2±11.7
	3	167.7±64.0	80.7± 22.2	59.8± 9.7
	4	117.3±15.3	76.0± 30.9	52.9± 3.2
	Control	116.5±33.8	76.9± 28.5	41.3±10.1
Carex				
	1	56.2±12.3	37.6± 11.3	22.5± 9.4
	2	46.4±10.2	18.4± 5.0	23.1± 6.6
	3	34.2±16.6	14.3± 3.0	17.9± 2.0
	4	37.3± 6.2	14.0± 2.1	20.5± 4.2
	Control	42.5±11.7	19.7± 7.2	24.4± 2.5

Bogr/Buda and Carex. The inner ring had 187 g m^{-2} increase in Bogr/Buda the first year and 50 g m^{-2} increase in 1981. Carex showed an increase of 32 g m^{-2} in the 1980 growing season. The Aug. 1980 sample date for carex showed no increase in biomass in the treated plots. Forbs were only a minor part of the vegetation and showed no treatment effects. The increase of biomass in only the area wetted, ring 1, suggests the effect may be confined to a reasonably small area.

The N concentration of the biomass was the same at all dates (Table 11). However, rings 1 and 2 have a significantly higher N content than the control, 2.04%, 1.67%, and 1.46%,respectively. This increase was noted by the first harvest and continued throughout the study. The N concentration of Bogr/Buda and Carex showed this same pattern. Bogr/Buda N content increased from 1.31% of the control to 1.95% and 1.59% for rings 1 and 2. Carex N content showed the same magnitude of increase from 1.67% to 2.35% and 1.93% for the control, ring 1 and ring 2.

The aboveground biomass and N concentration data showed the treated area increased in biomass and %N , but only the %N increased in ring 2. The ^{15}N data permitted the separation of the N yield into added urea-N and soil N uptake. Most of the added N that was recovered in the vegetation was confined to rings 1 and 2, with ring 3 never accounting for more than 1% of the added N at any sample date (Table 12). The total N accounted for was 10.8% at the

Table 11. Nitrogen concentration (%) of the aboveground vegetation of Site 1, the bottom position of the catena (average of the three dates for each ring).

Ring	Total Biomass	Blue grama	Carex
1	2.04±0.18	1.95±0.20	2.35±0.21
2	1.67±0.17	1.59±0.17	1.93±0.19
3	1.49±0.18	1.42±0.15	1.68±0.21
4	1.46±0.14	1.37±0.16	1.65±0.13
Control	1.46±0.17	1.31±0.15	1.67±0.16

Table 12. Percent of the added urea-N recovered at various sampling dates for the vegetation of Site 1, the bottom position of the catena.

Vegeatation	Ring	Date		
		June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	7.3±3.6	5.5±2.7	2.2±0.2
	2	2.8±0.4	1.5±1.0	1.0±0.4
	3	0.6±0.5	0.8±0.8	<0.2
	4	<0.2	<0.2	<0.2
Bogr/Buda				
	1	5.6±2.6	4.2±2.3	1.6±0.2
	2	2.2±0.5	1.0±0.9	0.8±0.3
	3	0.2±0.2	0.6±0.7	<0.2
	4	<0.2	<0.2	<0.2
Carex				
	1	1.6±0.8	1.3±0.4	0.4±0.2
	2	0.5±0.2	0.4±0.2	<0.2
	3	0.3±0.3	<0.2	<0.2
	4	<0.2	<0.2	<0.2

June 22, 1980 sample date, 18.5% at the end of the first growing season and 21.9% at the end of the second season, Aug. 26, 1981. Again Bogr/Buda and Carex accounted for the majority of the added urea-N.

SITE 1, ROOTS

The biomass of the roots varied only slightly with ring and date with no significant effects (p=.347). The average biomass of the roots in the 20 cm core was 2535g m^{-2} $\pm$ 574 The %N of the roots was equally consistent with an average of 1.89% $\pm$0.10. The N data for the roots (Table 13) suggests that the added N remained in the roots of the wetted area, ring 1, for the first season, when 17.5% of the added N was in this pool. By the second season rings 2 and 3 had taken up 4.3% and 1.1% of the added N .

SITE 1, SOIL

The soil N varied with depth and date but not with respect to ring. In 1980, the soil contained 0.15% and 0.11% N in the 0-10 and 10-20 cm depths. The soil N was 0.17% and 0.12% N for these two depths in Aug 1981. The percent of the added N that could be found in the soil each year was 17.5% and 32.2% for year 1 and 2 (Table 14). The first season most of the added N was restricted to the top 10 cm and to the area of application. By the end of the second growing season the added N had increased in the 10-20 cm depth of the first ring, and thoughout the second ring. The overall increase of added N found in the soil could be

Table 13. Percent of the added urea-N recovered in the roots at various sampling dates for Site 1, the bottom postion of the catena.

Ring	Date	
	Aug. 1980	Aug. 1981
1	17.5±3.8	15.8±4.7
2	0.6±0.5	4.3±3.1
3	0.3±0.2	1.1±1.2
4	<0.2	<0.2
Total	18.4	21.2

Table 14. Percent of the added urea-N recovered in 1980 and 1981 for the soil of Site 1, the bottom position of the catena.

Date	Depth	Ring			
		1	2	3	4
Aug. 1980					
	0-10	13.0±11.2	0.3±0.1	<0. 2	<0.2
	10-20	4.0± 4.4	0.3±0.2	<0. 2	<0.2
Aug. 1981					
	0-10	13.7± 0.9	7.3±5.0	<0.2	<0.2
	10-20	9.2± 7.7	2.1±0.8	<0.2	<0.2

explained in three possible ways. First the heterogeneity of the system caused the variance to be so great that the difference is only sampling variability. Second, the decomposition of roots and litter and thus N turnover may have actually increased the soil N level. Finally, the increase may be from root turnover of N that was leached below 20 cm and brought to the surface in uptake during the second growing season. Certainly the increase of N in the second ring was caused by uptake and turnover from the first years growth.

SITE 1, BUDGET OF THE ADDED UREA-N

The use of ^{15}N allowed construction of a budget of the added urea-N. By Aug. 20, 1980, 18.51% of the added N could be accounted for in the vegetation, 18.4% in the root biomass, and 17.5% in the soil. Thus 54.4% of the added N was still in the system. When the site 1 was sampled the following year an additional 3.4% was removed in the vegetation for a total of 21.9% of the added urea-N removed in aboveground biomass, 21.2% was found in the roots, and 32.2% in the soil, for a grand total of 75.2% of the added urea-N accounted for. Clark(1977) found that once the N had entered a shortgrass prairie system it was reycled within the system with little loss in 5 years. If we assume 75% to be the amount held in the sysem, then 25% was lost, probably in the first month after application when conditions for volatilization , i.e. elevated ammonium levels and pH, were the greatest.

The vegetation biomass, %N, and ^{15}N data suggest the added N affected an area 45 cm in diameter, rings 1 and 2, where as the root and soil N data suggest only the first ring was affected the first year and then ring 2 the second year. As N uptake would be concentrated in aboveground vegetation during the growing season, I expected this concentration in the vegetation the first year.

RESULTS:SITE 2 THE MIDSLOPE POSITION OF THE CATENA

CHEMICAL TRANSFORMATIONS

Untreated controls showed concentrations of inorganic-N in the 20 cm profile with similar seasonal variation as with site 1 (Fig. 8). Ammonium and nitrate remained relatively constant, with a summer average of 0.48 and 1.03 gN m^{-2}, respectively.

Hydrolysis of the urea-N was rapid (Fig. 9). Within 24 hours only 2.4 g of the 45 g added urea-N (5.8%) remained in the top 20 cm. At day 4 and 7 small amounts remained. This suggests that hydrolysis of urea was as rapid as in site 1.

The ammonium-N in the top 20 cm increased to 20.9 g N m^{-2} at 24 hours when 46.4% of the added urea-N was present as ammonium. The ammonium decreased to 3.3 g N m^{-2} at day 14. There was a slight increase to 9.4 g N m^{-2} at day 28, but by day 56 the mean value had decreased to near control levels and remained there throughout the rest of the study. Nitrate had reached levels significantly greater than the

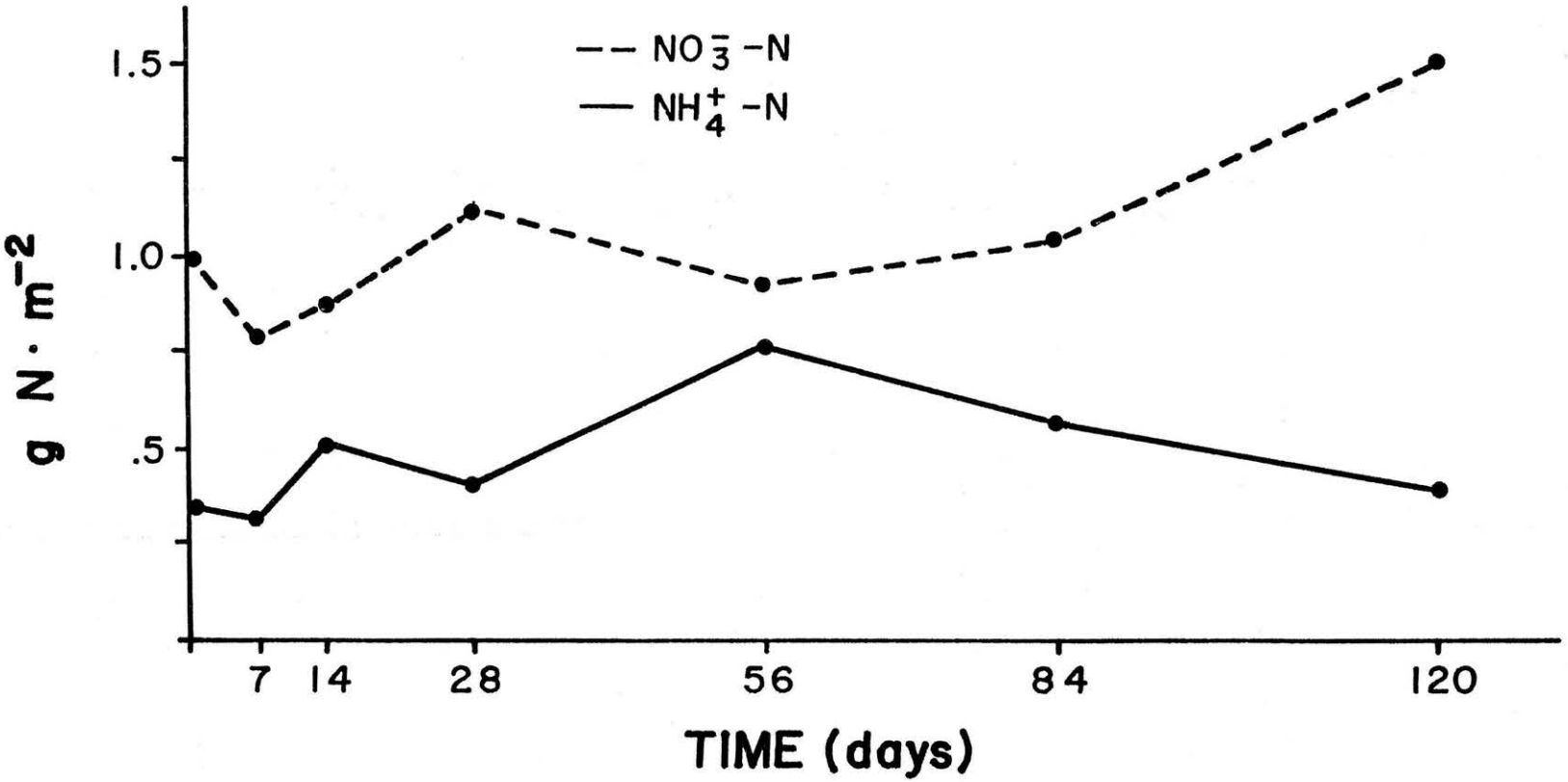


Fig. 8. Changes in the inorganic N of the control plots of Site 2, the midslope of the catena.

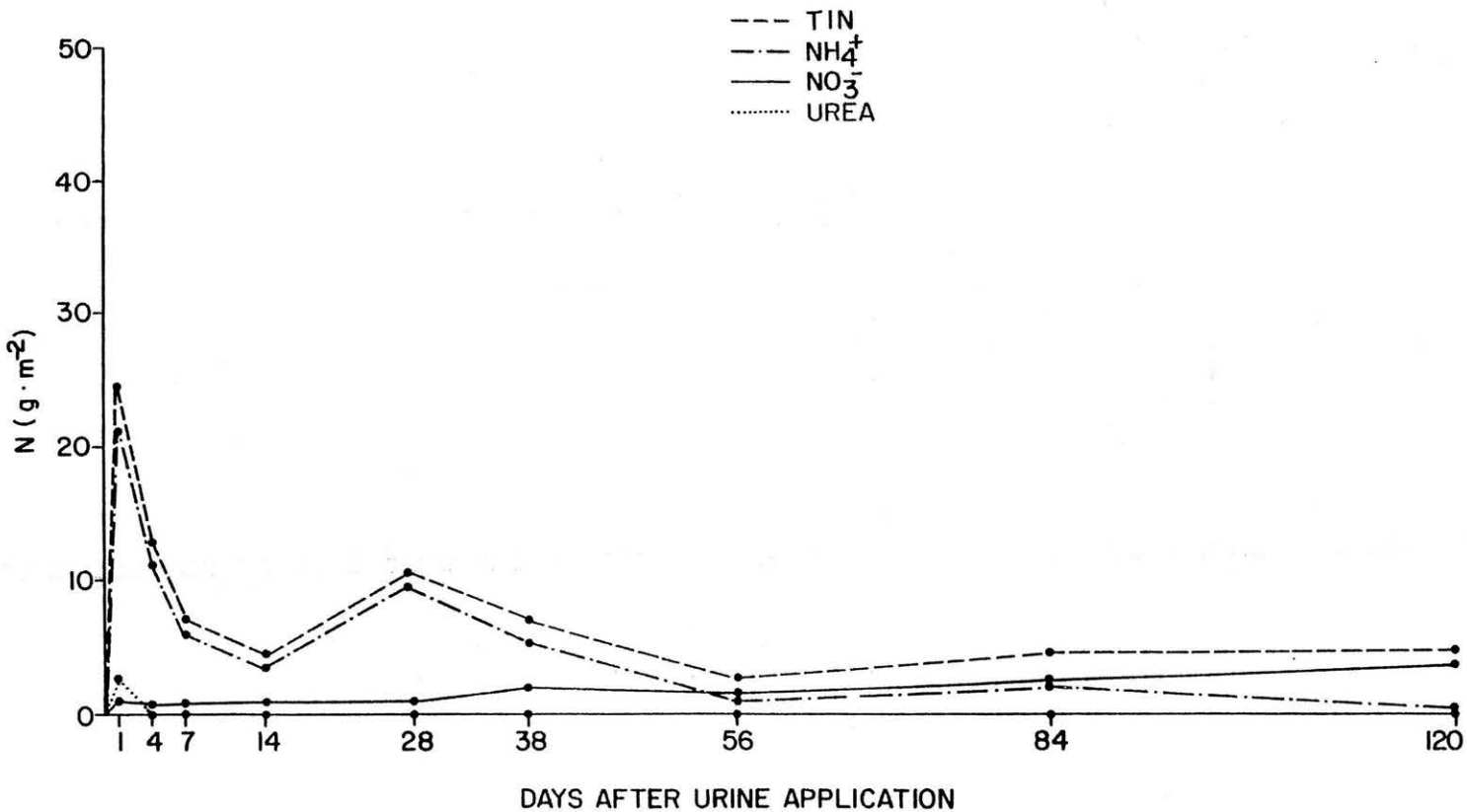


Fig. 9. Changes in the inorganic N of the urine spots formed by the simulated urine at Site 2, the midslope of the catena.

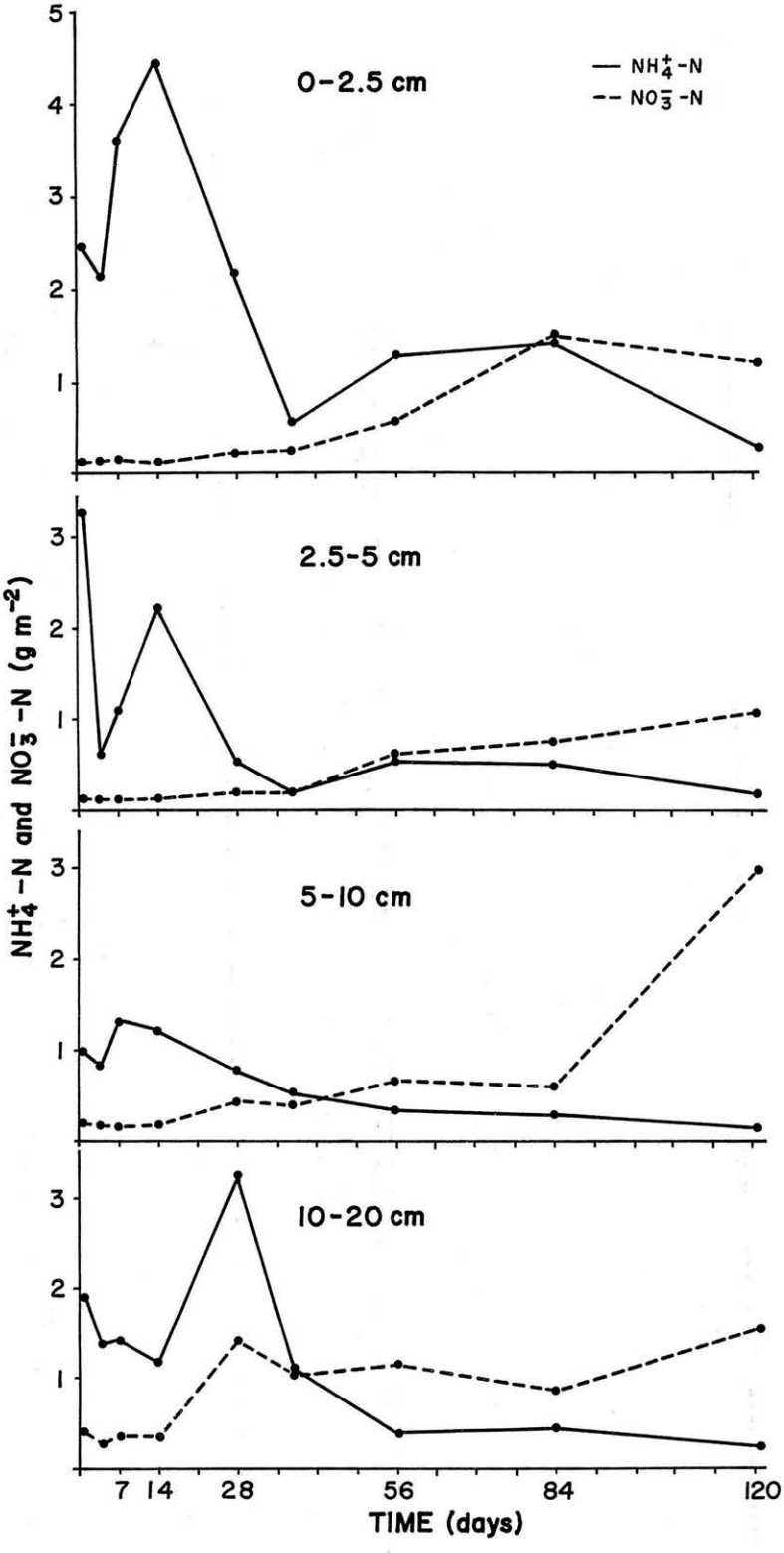
control (1.6 g N m^{-2} vs 0.9 g N m^{-2}) by day 38. Nitrate levels steadily increased until 3.7 g nitrate-N m^{-2} had accumulated at the end of the study at day 120.

Total nitrate and ammonium-N at day 1 for the control was 1.4 g N m^{-2}. The treated plots contained 21.8 g N m^{-2} at day 1, representing only 46.9% (21.8/45+1.4) of the N originally in the system - control + added urea-N. That is 53.1% or 24.6 g N m^{-2} was unaccounted for in the inorganic pool at 24 hours after application. At the end of the study, 4.3 g N m^{-2} was in this pool of the treated plots. Thus 9.2% of the original N was present mostly as nitrate. The unaccounted for N was either lost through ammonia volatilization or immobilized in plant or microbial biomass.

The depth distribution of the inorganic-N showed this same trend (Fig. 10). Ammonium-N levels increased significantly in the top 10 cm of the profile. The decrease in the ammonium levels did not correspond to an increase in nitrate, as nitrate levels did not increase for the first month of the study. Again volatilization and uptake into plant or microbial biomass may account for this observation.

Nitrate increased in the 0-5 cm depth by day 38, and increased to 10 cm by day 56. The 10-20 cm depth showed an increase of nitrate at day 120. The depth distribution of day 1 showed 5.1, 3.8, and 8.7 g N m^{-2} in the top 3 depths, suggesting the urea was evenly distributed in the top 10 cm. Some may have reached the 10-20 cm depth as 3.2 gN m^{-2} was present in this depth. The nitrate at the end of the

Fig. 10. The distribution of the inorganic N of the 0-2.5, 2.5-5, 5-10, and 10-20 cm depths of the soil of the urine spots at Site 2, the midslope of the catena.


0-2.5 cm
2.5-5 cm
5-10 cm
10-20 cm
— NH_4^+-N
-- NO_3^--N
NH_4^+-N and NO_3^--N (g m^{-2})
TIME (days)
7
14
28
56
84
120

study showed the levels of 0.6, 0.5, 1.1, and 1.5 gN m^{-2} in each of the 4 depths respectively. This distribution of N suggests there was little movement through the profile.

The pH increased slightly with the urea addition (Fig. 11). The 0-2.5 cm depth was the only depth to show an increase, with a rise in pH from an ambient level of 6.4 to 7.4, after 24 hrs. Within 2 weeks of the date of application, the pH was the same as control and remained statistically equal to the control for the rest of the study. Soil pH would be expected to increase more than the 1.0 pH unit observed with the rapid hydrolysis of urea seen here. If volatilization of ammonia occured simultaneously with urea hydrolysis, the release of H^+ would counter the pH increase caused by ammonium formation, thus one day after application the pH could have returned more to the control levels, if rapid volatilization of ammonia occurred.

SITE 2, VEGETATION

The plant biomass was quite variable on this site (Table 15) due to the heterogeneity of the community and the bloom of annual forbs in 1980. The heterogeneity masked any effect the N addition may have had on the yield of the vegetation. However, except for the first sample date, there seemed to be a general increase of vegetation in the center two rings. On Aug. 20 ,1980 the biomass of ring 1 was 64.3 g m^{-2} and ring 2 58.2 g m^{-2}, compared to 38.6 g m^{-2} of the control. This trend was also seen the following year when rings 1 and 2 contained 121.4 and 86.1 g m^{-2}

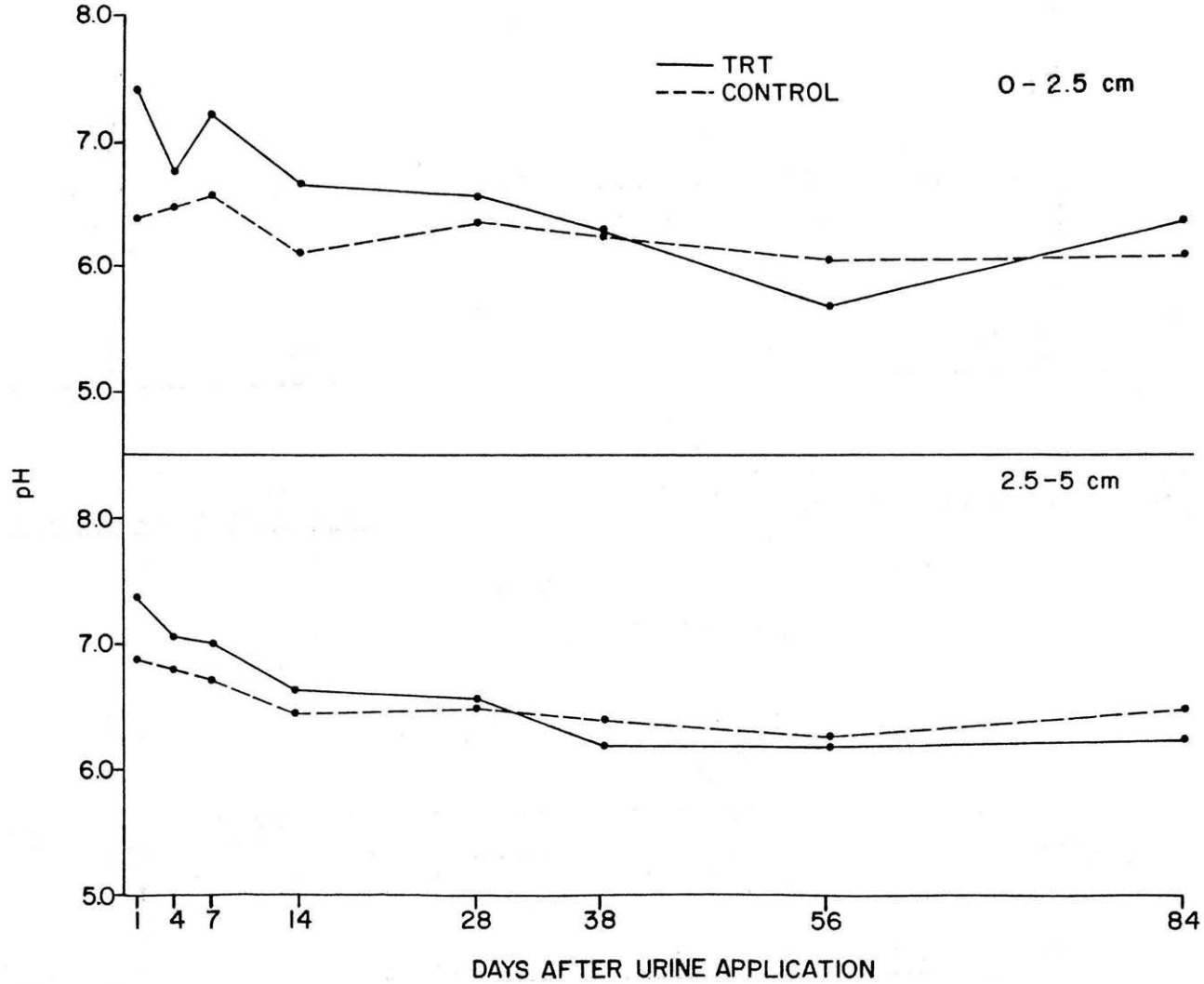


Fig. 11. Soil pH of the 0-2.5 and 2.5-5 cm depths of the soil of the soil of the urine spots at Site 2, the midslope of the catena.

Table 15. Biomass at various sampling dates for the above-ground vegetation of Site 2, the midslope position (g m^{-2}).

Vegetation	Ring	Date: June 1980	Date: Aug. 1980	Date: Aug. 1981
Total Biomass				
	1	137.1± 26.9	64.3± 8.1	121.4± 6.6
	2	159.6± 70.0	58.2± 4.3	86.1±25.1
	3	240.5±143.4	42.6± 3.2	61.4±22.2
	4	166.5± 75.5	37.6± 5.3	52.2± 8.2
	Control	229.5±171.0	38.6± 8.7	51.3± 4.5
Forbs				
	1	47.1± 11.6	1.9± 0.7	49.9± 9.4
	2	81.6± 84.4	7.6± 1.7	18.9± 7.4
	3	164.7±141.5	3.2± 0.7	10.7± 7.9
	4	91.9± 68.2	4.2± 2.3	7.2± 4.7
	Control	142.7±162.9	3.8± 2.0	5.6± 1.5
Bogr/Buda				
	1	88.5± 20.4	61.5±10.2	70.8±12.1
	2	77.0± 19.5	50.0± 6.2	66.6±20.4
	3	73.5± 5.4	38.7± 3.5	49.8±15.2
	4	69.7± 10.0	32.6± 2.8	41.0± 3.0
	Control	85.9± 11.0	34.3± 6.5	43.9± 2.3

respectively, as compared to 51.3 for the control.

The major components of the biomass for site 2 were forbs and Bogr/Buda. Forbs did not vary from treatment to treatment but did vary with time. At the first sampling date the annual forbs and particularly Colorado greenthread (Thelesperma filifolium Gray) were common across the prairie uplands and contributed much to the biomass of this site. Following this first sample period, Bogr/Buda was the dominant vegetation, showing a significant increase of biomass of 61.5 and 50.0 g m^{-2} for rings 1 and 2 respectively, vs 34.3 g m^{-2} of the control, on Aug. 20, 1980, and an increase to 70.7 and 66.2 g m^{-2} for rings 1 and 2 for August 26, 1981 vs 43.9 for the control.

The %N of the total vegetation suggests the addition of urea-N increased the N content in the vegetation to ring 3 as rings 1, 2, and 3 all had significantly higher N concentrations than the control (Table 16). This increase was consistant at all dates and appeared 1 month after additions of the urea-N. Forb and Bogr/Buda showed the same general pattern. The N concentration of the forbs increased significantly only in the center 2 rings. The Bogr/Buda showed an increase in %N in the center 3 rings. This would suggest the area effected would be at least into ring 2 and probably into ring 3 for the Bogr/Buda.

The added N that could be accounted for in the vegetation was again calculated using biomass, %N, and atom % ^{15}N. The vegetation of the first 3 rings contained 4.4%,

Table 16. Percent nitrogen at various sampling dates in the aboveground vegetation of Site 2, the midslope of the catena.

Vegetation	Ring	Date		
		June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	1.92±0.10	2.09±0.10	1.67±0.26
	2	1.74±0.21	1.90±0.19	1.70±0.14
	3	1.70±0.08	1.68±0.11	1.52±0.10
	4	1.54±0.09	1.56±0.07	1.34±0.12
	Control	1.30±0.06	1.53±0.09	1.33±0.04
Forbs				
	1	2.05±0.07	2.76±0.16	1.54±0.31
	2	1.69±0.52	2.42±0.02	1.53±0.36
	3	1.44±0.59	2.42±0.15	1.27±0.20
	4	1.44±0.47	2.26±0.21	1.14±0.21
	Control	1.05±0.47	2.11±0.31	1.11±0.32
Bogr/Buda				
	1	1.85±0.13	2.06±0.12	1.76±0.22
	2	1.53±0.05	1.80±0.26	1.75±0.14
	3	1.35±0.05	1.62±0.10	1.58±0.18
	4	1.43±0.15	1.47±0.07	1.36±0.14
	Control	1.19±0.08	1.47±0.07	1.34±0.07

2.5%, and 0.9% of the added urea-N the first year (Table 17). The second season 1.9%, 1.2%, and 0.4% more of the added N was recovered from these rings for a total of 6.3%, 3.7%, and 1.3% of the added N recovered from rings 1, 2, and 3, respectively, in the two seasons, a total of 11.3% of the added urea-N was recovered. The ^{15}N data supports the suggestion that the area affected by the treatment was into ring 3 or 60 cm from the center of the spot and roughly 4 times the area wetted. Bogr/Buda and forbs accounted for most of the added N .

SITE 2, ROOTS

As at site 1, the root data showed no increase of biomass or N concentration with either ring or date. The average biomasss was 1552 g $m^{-2} \pm$ 317 with a mean %N of 1.86% $\pm$ 0.35. The added N was found to be concentrated in the first ring at both sample dates when 10.7% and 10.7% of the added N was in the root pool of ring 1 for Aug. 20, 1980 and Aug. 26, 1981, respectively (Table 18). Rings 2 and 3 had means of 4.0% and 0.6% for 1980, and 3.0% and 0.4% for 1981. There was no statistical difference in amount of the added urea-N recovered between years with 15.2% and 14.2% recovered in 1980 and 1981, respectively.

SITE 2, SOIL N

The soil N varied with depth and date but not with ring or treatment (Table 19). The heterogeneity of the soil masked any effect the urea addition might have had on total

Table 17. Percent of the added urea-N for various sampling dates recovered in the aboveground vegetation of Site 2, the midslope of the catena.

Vegetation	Ring	Date		
		June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	2.6±0.6	1.8±0.2	1.9±0.1
	2	1.5±0.7	1.0±0.3	1.2±0.2
	3	0.9±0.6	<0.2	0.4±0.2
	4	<0.2	<0.2	<0.2
Forb				
	1	1.2±0.3	<0.2	0.8±0.1
	2	0.9±0.8	<0.2	0.3±0.1
	3	0.6±0.8	<0.2	<0.2
	4	<0.2	<0.2	<0.2
Bogr/Buda				
	1	1.4±0.4	1.7±0.3	1.1±0.2
	2	0.6±0.2	0.8±0.3	0.9±0.2
	3	0.3±0.2	<0.2	<0.2
	4	<0.2	<0.2	<0.2

Table 18. Percent of the added urea-N for various sampling dates recovered in the roots of Site 2, the midslope of the catena.

Ring	Date	
	Aug. 1980	Aug. 1981
1	10.7±1.5	10.7±0.9
2	4.0±2.9	3.0±0.6
3	0.6±0.8	0.4±0.1
4	<0.2	<0.2
Total	15.3	14.1

Table 19. Nitrogen concentration (ug N/g soil)at various sampling dates for the soil of Site 2,the midslope of the catena.

Depth	Date	
	Aug. 1980	Aug. 1981
0-10 cm	752± 98	948±111
10-20 cm	656±141	805±128

soil N. The added N was most abundant in the top 10 cm of ring 1 for each date (Table 20). Aug 20, 1980, 19.4% of the added N was in ring 1 with ring 2 accounting for 0.7%. The following Aug., ring 1 contained 10.2% of the added N with rings 2 and 3 containing 2.1% and 0.5%, respectively. The difference of 20.1 and 12.4% for the total amount recovered for 1980 and 1981 was not statistically significant ($p=0.32$).

SITE 2, BUDGET OF THE ADDED N

A budget of the added N is shown in Table 21. The first year 1980, 7.8% was removed in the biomass, 15.2% was in the roots, and 20.1% was as soil N for a total of 43.1% of the added urea-N recovered in the system. In 1981, an additional 3.6% was removed in vegetation, 14.2% was in the roots, and 12.4% was in the soil, for a total of 37.8%. Thus there was very little change in recovery between 1980 and 1981. The study of the chemical transformations suggested that only 47% of the added urea-N could be found in the inorganic N pool 24 hrs. after application. The 43% N recovery at the end of the first growing season suggests volatilization of ammonia could have been an the important pathway for loss.

In the two seasons the effect of the addition was confined to the center 3 rings or an area 4 times the area wetted.

Table 20. Percent of the added urea-N recovered at various sampling dates in the soil for Site 2, the midslope of the catena.

Date	Depth (cm)	Ring 1	Ring 2	Ring 3	Ring 4
Aug. 1980					
	0-10	15.1±13.0	0.4±0.5	<0.2	<0.2
	10-20	4.3± 3.1	0.3±0.3	<0.2	<0.2
Aug. 1981					
	0-10	6.4± 1.3	1.5±0.9	0.3±0.1	<0.2
	10-20	3.8± 1.8	0.6±0.1	0.3±0.2	<0.2

Table 21. Budget of the added urea-N for two sampling dates for Site 2, the midslope of the catena.

	Date	
	Aug. 1980	Aug. 1981
Vegetation Biomass	7.8	11.3
Roots	15.2	14.2
Soil	20.1	12.4
Total	43.1	37.9

RESULTS: SITE 3 THE RIDGETOP POSITION OF THE CATENA

CHEMICAL TRANSFORMATIONS

The inorganic N of the control plots of the ridgetop was similar to the two lower positions (Fig. 12). Nitrate was the dominant form of N throughout the season with a season average of 0.8 versus 0.5 gN m^{-2} for ammonium. As in the two lower sites, the ratio of nitrate-N to ammonium-N was approximately 2:1. The actual values were also in close agreement with the 2 lower sites.

Urea hydrolysis (Fig. 13) was not as rapid on the ridgetop as at the 2 other positions. At day 1, 9.3 g urea-N m^{-2} or 20.7% of the added urea was still present, compared to 0.88 g, 3.4 g, and 1.5 g at day 4, 7, and 14, respectively. The lower value at day 4 shows the variability of the soil and the urea transformation in the soil.

Ammonium-N increased with the urea addition to 8.6 g N m^{-2} at day 1 and 9.09 at day 14. Levels decreased to 2.4 g N m^{-2} (near ambient) by day 38. Low levels of ammonium were observed for the rest of the study. Nitrate levels were significantly greater than the control by day 28 when 2.3 gN m^{-2} was present. The nitrificaion continued throughout the remainder of the season and by day 120 6.9 gN m^{-2} was in the form of nitrate.

On day 1, the inorganic-N of the treated plots was 18.8 gN m^{-2} (8.6 ammonium + 9.3 urea +0.9 nitrate) compared to 45 g added urea-N + 1.1 g for the control or 40.7% of expected.

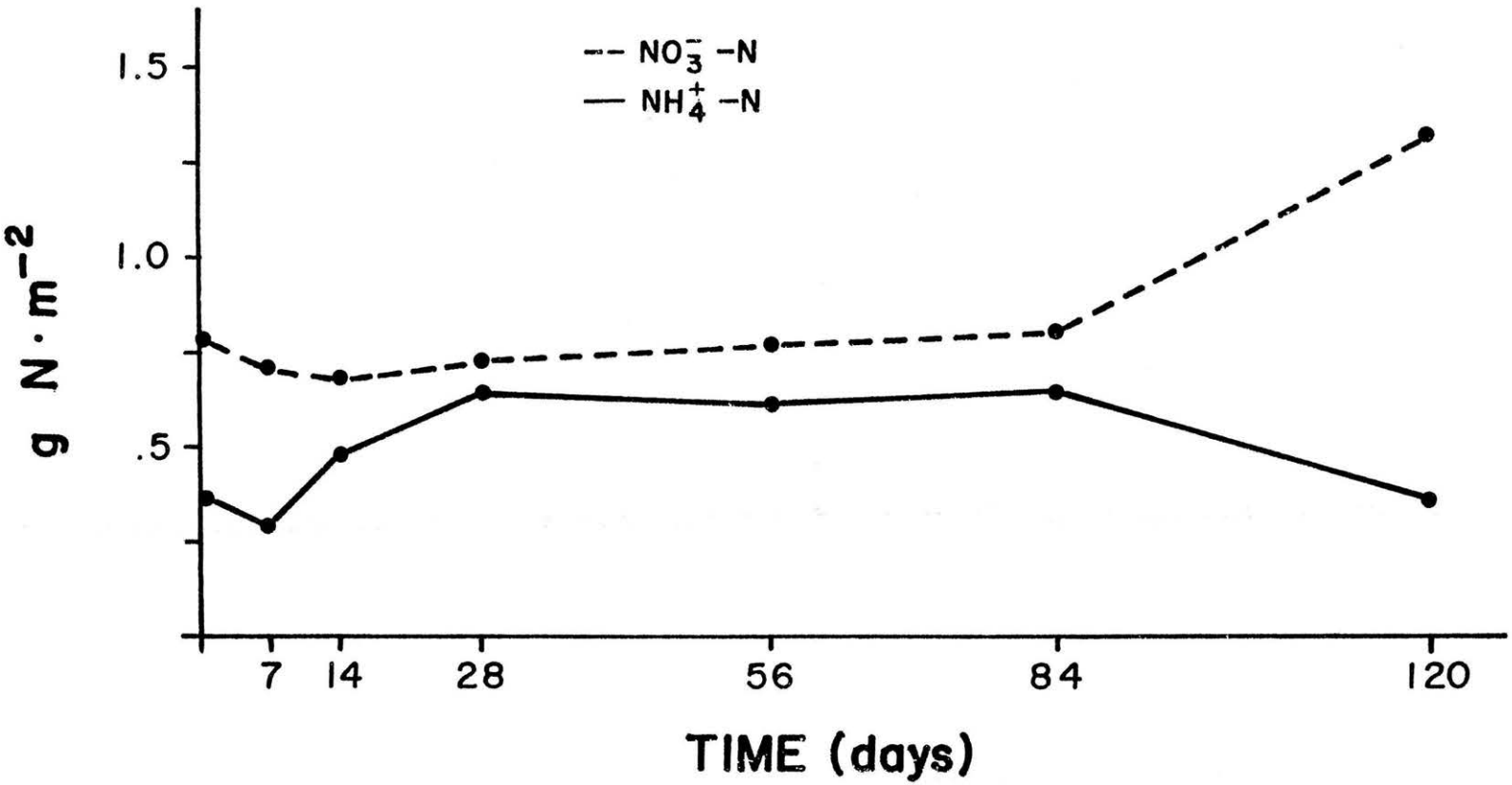


Fig. 12. Changes in the inorganic N of the control plots of Site 3, the ridgetop of the catena.

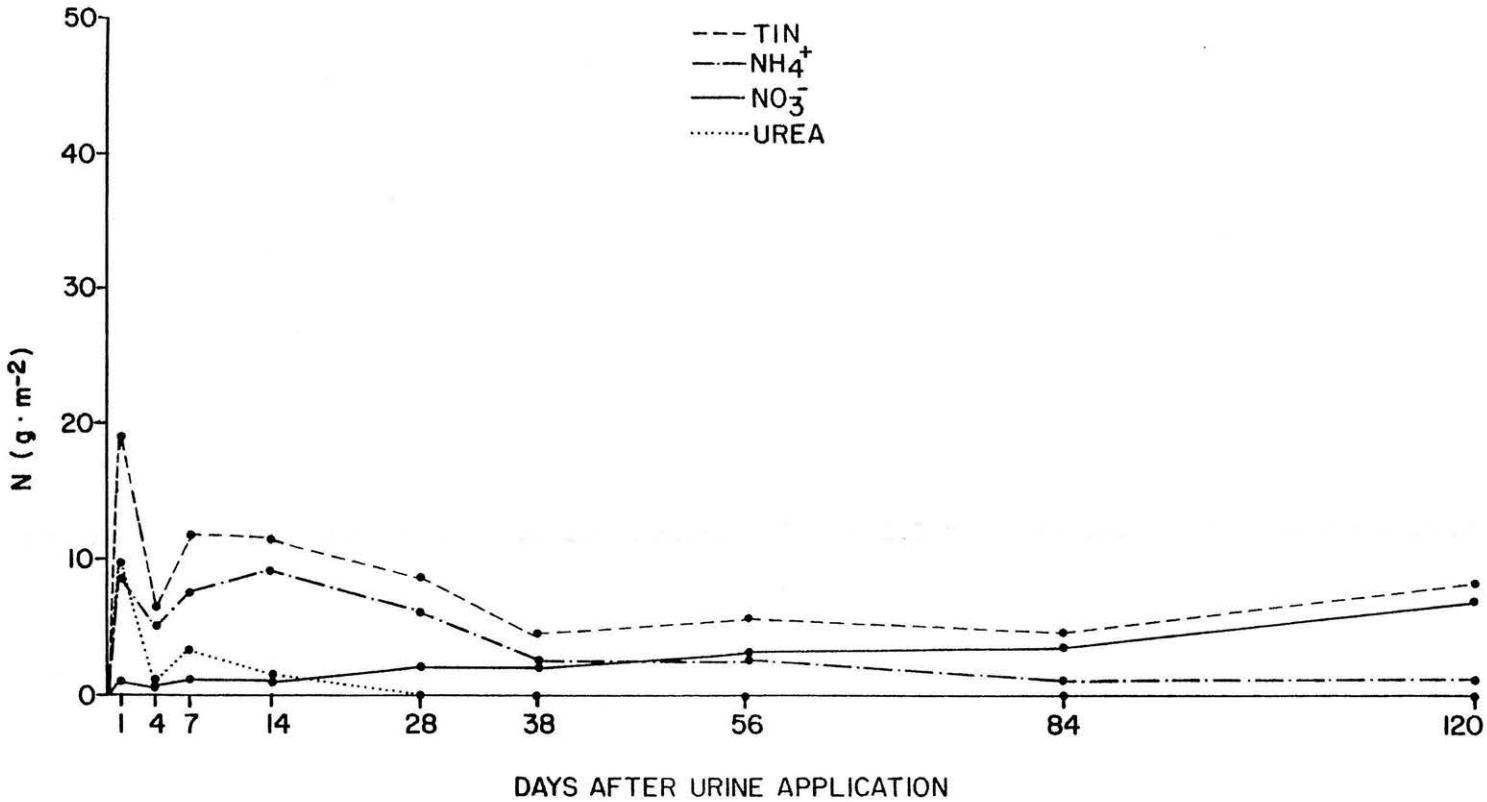


Fig. 13. Changes in the inorganic N of the urine spots formed by the simulated urine at Site 3, the ridgetop of the catena.

This decreased to 11.4 or 24.7% at day 28 and 7.8 g or 16.8% of the initial expected at the end of the trial.

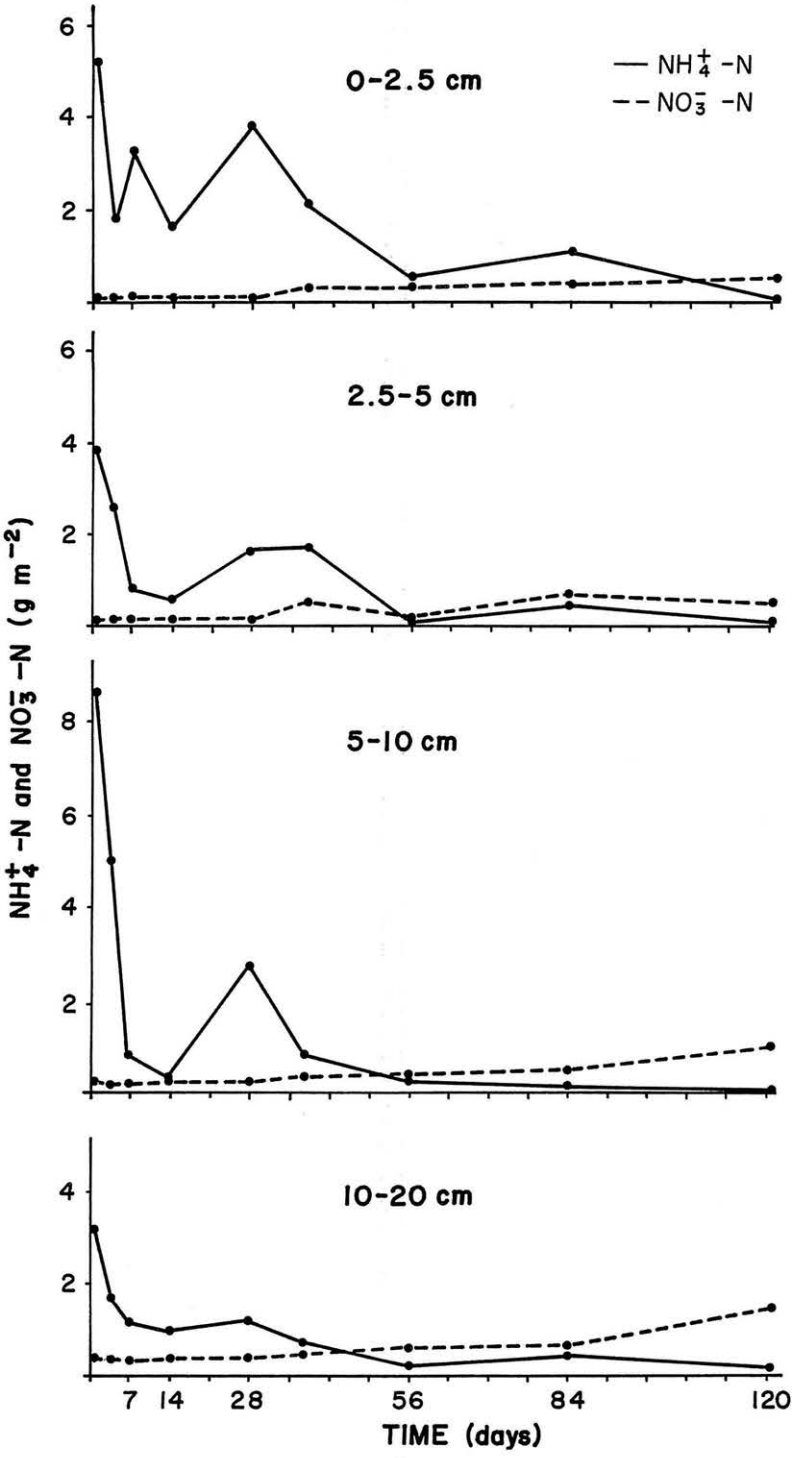
The depth distribution for ammonium and nitrate (Fig. 14) showed the urea solution may have penetrated to the 10-20 cm depth. Significant amounts of ammonium appeared in all depths in the first 2 weeks. Nitrate accumulation became apparent at day 28 in the 10-20 cm depth and by day 56 in the other depths. At the end of the study, the nitrate was evenly distributed in the top 10 cm with 1.2, 1.1, and 3.0 gN m^{-2} respectively in the top 3 depths. There was an increase in the 10-20 cm depth but this represented the initial amount of ammonium-N (1.9) being oxidized to nitrate (1.6 gN m^{-2}). Movement of N through the profile by leaching was probably not important.

The soil pH were similar to the pH changes observed in the midslope position. Soil pH at the ridgetop (Fig. 15) showed an increase from 7.0 to 8.0 in the top 2.5 cm., 24 hrs. after urea application, but returned to control levels by day 4.

SITE 3, VEGETATION

The total vegetation of the ridgetop showed a treatment effect with ring 1 statistically greater than the control (Table 22). The greatest variability was seen in the first sampling date. For the forbs there was no treatment effect but a date effect. June 22, 1980 produced 147.6$\pm$ 82.6 g m^{-2} vs. 9.7$\pm$5.8 on Aug. 20, 1980 and 14.7$\pm$5.4 g m^{-2} on Aug 26, 1981, respectively. Bogr/Buda showed no treatment or date

Fig. 14. The distribution of the inorganic N of the 0-2.5, 2.5-5, 5-10, and 10-20 cm depths of the soil of the urine spots at Site 3, the ridgetop of the catena.


0-2.5 cm
2.5-5 cm
5-10 cm
10-20 cm
— NH_4^+ -N
-- NO_3^- -N
NH_4^+-N and NO_3^--N (g m^{-2})
TIME (days)
7
14
28
56
84
120

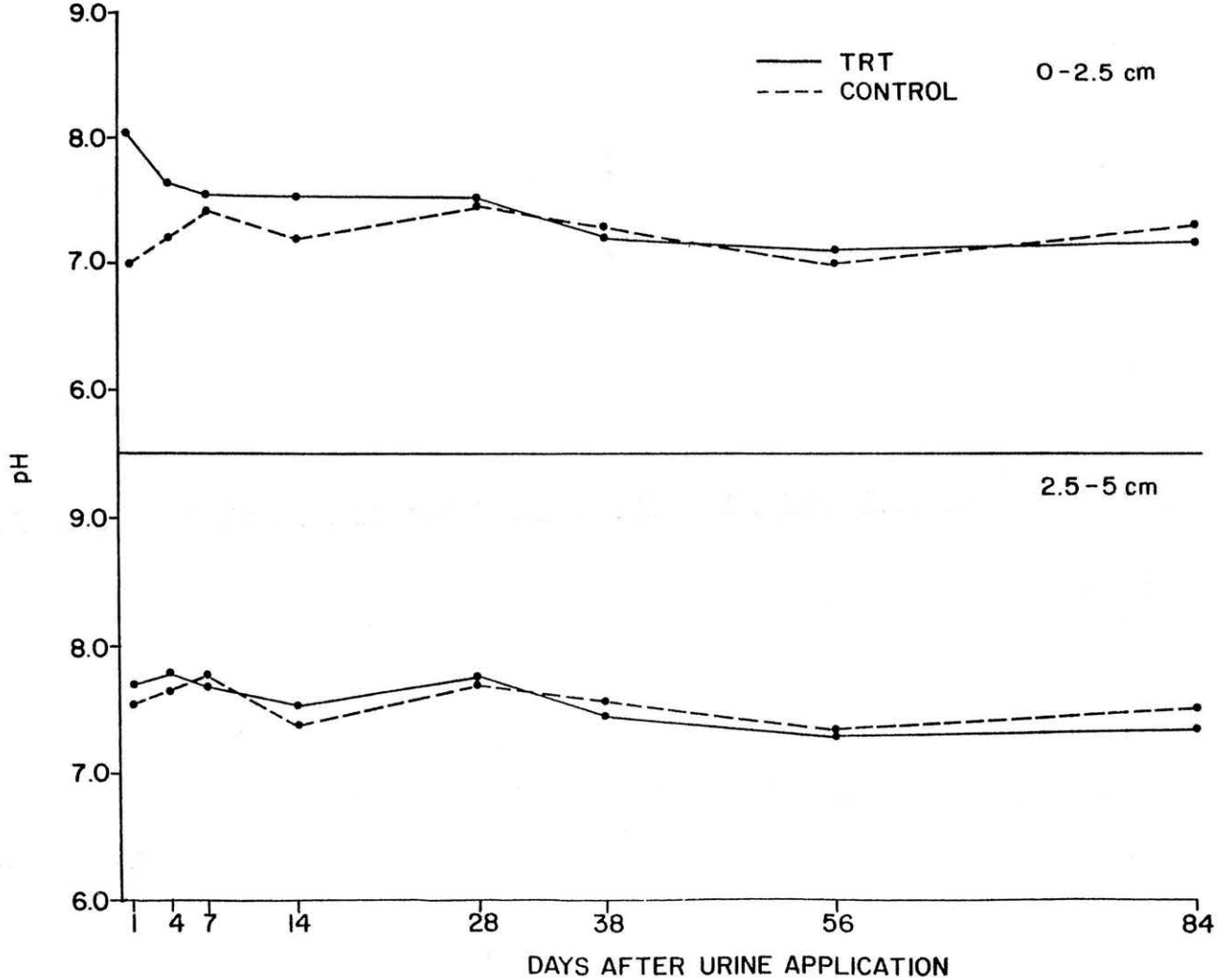


Fig. 15. Soil pH of the 0-2.5 and 2.5-5 cm depths of the soil of the urine spots at Site 3, the ridgetop of the catena.

Table 22. Biomass of the aboveground vegetation for various sampling dates for Site 3, the ridgetop of the catena.

Vegetation	Ring	Date June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	467.3±316.5	73.6±15.7	107.2±51.8
	2	240.9±194.7	57.0±12.1	75.8±30.4
	3	150.4± 57.3	37.1±25.1	60.5±15.0
	4	129.6± 73.7	47.9±10.7	58.3± 5.5
	Control	197.6± 98.2	47.6±20.0	72.8±40.0
Other Grass				
	1	60.4± 55.9	22.7±21.0	44.5±40.1
	2	31.8± 20.2	12.7±10.9	36.8±35.6
	3	27.2± 19.0	4.2± 2.4	24.9±14.0
	4	23.4± 14.4	4.6± 4.2	15.4± 1.7
	Control	24.2± 5.7	15.9± 7.5	13.5±15.0

effect. The other grasses category containing three awn, needle and thread, and bottle brush squirrels tail was important on the ridgetop. The biomass of this category increase with the urea addition.

By June 22, 1980, the %N in the vegetation had increased to 1.63% and 1.58% for rings 1 and 2 vs 1.30% for the control (Table 23). This increase was noted for both rings on Aug 20, 1980 and Aug. 26, 1981. The forbs showed this same trend with an increase from the average of 1.24% for the control to 1.93% and 1.74% for the rings 1 and 2 over the two years.

Eventhough Bogr/Buda showed no treatment effect on increased biomass, there was a treatment effect %N with ring 1 increasing to 1.72% vs the control of 1.30%. Other grasses showed no increase in concentration with an average of 1.23% $\pm$ 0.14. The Bogr/Buda appears to first increase the %N in its tissue before increasing biomass while the other grasses appear to increase growth without increases in %N.

The added N taken up into the above ground biomass in the first growing season was 7.4%, 1.7%, and 0.7% for rings 1, 2, and 3, respectively (Table 24). The second season 1.1%, 0.8%, and 0.4% were again removed from these three rings. This gives a two season total of 12.1% of the added N removed in the vegetation, which was similar to 11.3% removed at site 2. The amount in ring 1 is split amoung Bogr/Buda, other grass, and forbs, but forbs are almost

Table 23. Percent nitrogen for various sampling dates for the aboveground vegetation of Site 3, the ridgetop of the catena.

Vegetation	Ring	Date		
		June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	1.63±0.20	2.07±0.38	1.50±0.09
	2	1.58±0.25	1.66±0.25	1.38±0.15
	3	1.47±0.13	1.47±0.23	1.38±0.14
	4	1.37±0.23	1.39±0.23	1.26±0.03
	Control	1.30±0.12	1.28±0.11	1.20±0.20
Forbs				
	1	1.64±0.70	2.42±0.37	1.74±0.49
	2	1.55±0.46	2.17±0.12	1.51±0.23
	3	1.48±0.40	2.08±0.09	1.42±0.24
	4	1.40±0.33	1.75±0.19	1.39±0.12
	Control	1.09±0.28	1.40±0.49	1.21±0.24

Table 24. Percent of the added urea-N recovered for various sampling dates for the vegetation of Site 3, the ridgetop of the catena.

Vegetation	Ring	Date		
		June 1980	Aug. 1980	Aug. 1981
Total Biomass				
	1	5.8±4.8	1.6±0.1	1.1±1.0
	2	1.2±1.3	0.6±0.5	0.8±0.6
	3	0.7±0.6	<0.2	0.4±0.4
	4	<0.2	<0.2	0.3±0.3
Bogr/Buda				
	1	2.4±3.1	0.8±0.6	0.4±0.4
	2	<0.2	<0.2	<0.2
	3	<0.2	<0.2	<0.2
	4	<0.2	<0.2	<0.2
Forbs				
	1	2.6±2.3	<0.2	<0.2
	2	0.8±1.0	<0.2	<0.2
	3	0.6±0.5	<0.2	<0.2
	4	<0.2	<0.2	<0.2
Other Grass				
	1	0.8±0.8	0.5±0.4	0.5±0.6
	2	<0.2	<0.2	0.4±0.5
	3	<0.2	<0.2	<0.2
	4	<0.2	<0.2	<0.2

entirely responsible for the N in the second and third rings.

SITE 3, ROOTS

As in the previous two other sites, the biomass and %N did not show a treatment effect. The average biomass was 1548 ± 635 g m^{-2} with a %N of 1.75%±0.23. For the Aug 20, 1980 sampling, 21.8% ± 10.5 of the added N was found in the first ring with 1.9% ±0.7 and 0.4%±0.3 in rings 2 and 3. Ring 4 contributed less than 0.2%. By Aug 26, 1981, the distribution had shifted to 12.5%±1.7, 16.6 ± 10.5, 5.9±7.0 and 0.4% ±0.4 for rings 1 through 4 ,respectively. This makes a total of 24.0% recovered in 1980 and 35.4% for 1981.

SITE 3, SOIL

The concentration of the soil N for the 0-20 cm depth was 786 ±252 ug N/g soil for 1980 and 1055±149 ug N/g for 1981. The distribution of the added N varied between years (Table 25). In 1980, the N was found in ring 1 where 33.5% of the added N could be accounted for. By year 2 the N had dispersed so that small amounts were found in ring 4. A total of 13.5% of the added N was found in the soil in the 1981 sampling.

SITE 3,BUDGET OF THE ADDED UREA N

The N budget of site 3 (Table 26) shows that in 1980, 9.8%, 24.0% and 33.5% of the added N was found in the above ground vegetaion, roots and soil, respectively, for a total of 67.3%. In 1981, an additional 2.3% was removed in the

Table 25. Percent of the added urea-N recovered in the soil for two sampling dates for Site 3, the ridgetop of the catena.

Date	Depth (cm)	Ring 1	Ring 2	Ring 3	Ring 4
Aug 1980					
	0-10	20.3± 9.0	<0.2	<0.2	<0.2
	10-20	13.2±17.8	<0.2	<0.2	<0.2
Aug 1981					
	0-10	3.0± 2.7	3.9±3.3	1.4±1.3	0.6±0.9
	10-20	2.1± 0.9	1.5±0.8	0.7±0.7	0.4±0.7

Table 26. Nitrogen budget of the added urea-N for 1980 and 1981 for Site 3, the ridgetop of the catena.

	Year 1980	Year 1981
Vegetation Biomass	9.8	12.1
Roots	24.0	35.4
Soil	33.5	13.5
Total	67.3	61.0

vegetation for a total of 12.1%. Add to this the 35.4% in the roots and the 13.5% in the soil and we have a total of 61.0% recovered on the ridgetop. The distribution was different for 1980 and 1981, with the treatment effect being out into the fourth ring the second year. Overall, the N balance agrees with Clark's (1977) observation that once the N is in the system little will be lost and most will be cycled within the plant. The inorganic N data suggestd only 41% of the added N was in the inorganic pool at day one . Combined with this information, it would appear 20% of the missing N was immobilized and 40% was lost through volatilization. The total N loss was less for the top site of the catena than for the midslope, due to the slower rates of urea hydrolysis and related soil processes.

COMPARISON OF THE THREE SITES

Urea hydrolysis occurred at different rates on the three catena sites. On the bottom and midslope sites no urea-N could be detected at 4 days after application but on the ridgetop small amounts of urea was still present at 2 weeks. Urea hydrolysis on the ridgetop was retarded by the dry soil conditions (Ernst and Massey, 1960; Gould et al., 1973).

Site 1, the bottom position, behaved differently than the two upper positions, with respect to total inorganic N formed from the added urea. The inorganic N pool at day 1 contained 88%, 46% and 40% of the amount of the urea-N added at of sites 1, 2, and 3 respectively (Fig. 16). The inorganic N pool at 120 days contained 55%, 9%, and 17% of the amount added as urea-N. I hypothesize that the difference was due to soil/vegetation type and was not due to slope position. The bottom slope had close to 100% ground cover and the soil was a heavy clay (35%) with organic matter about 3% . The midslope and ridgetop soil had clay contents of the A horizon of 15% and 12% , and organic matter of 0.9% and 1.2%, respectively. The soils of these two positions are more exposed since there was only 30% ground cover (Schimel, 1983). The exposed soil, reduced organic matter, and lower clay content of the top and midslope sites would favor ammonia volitalization. This could explain the 12%, 54%, and 59% unaccounted for N at day one for sites 1, 2, and 3 respectively. By day 4 the

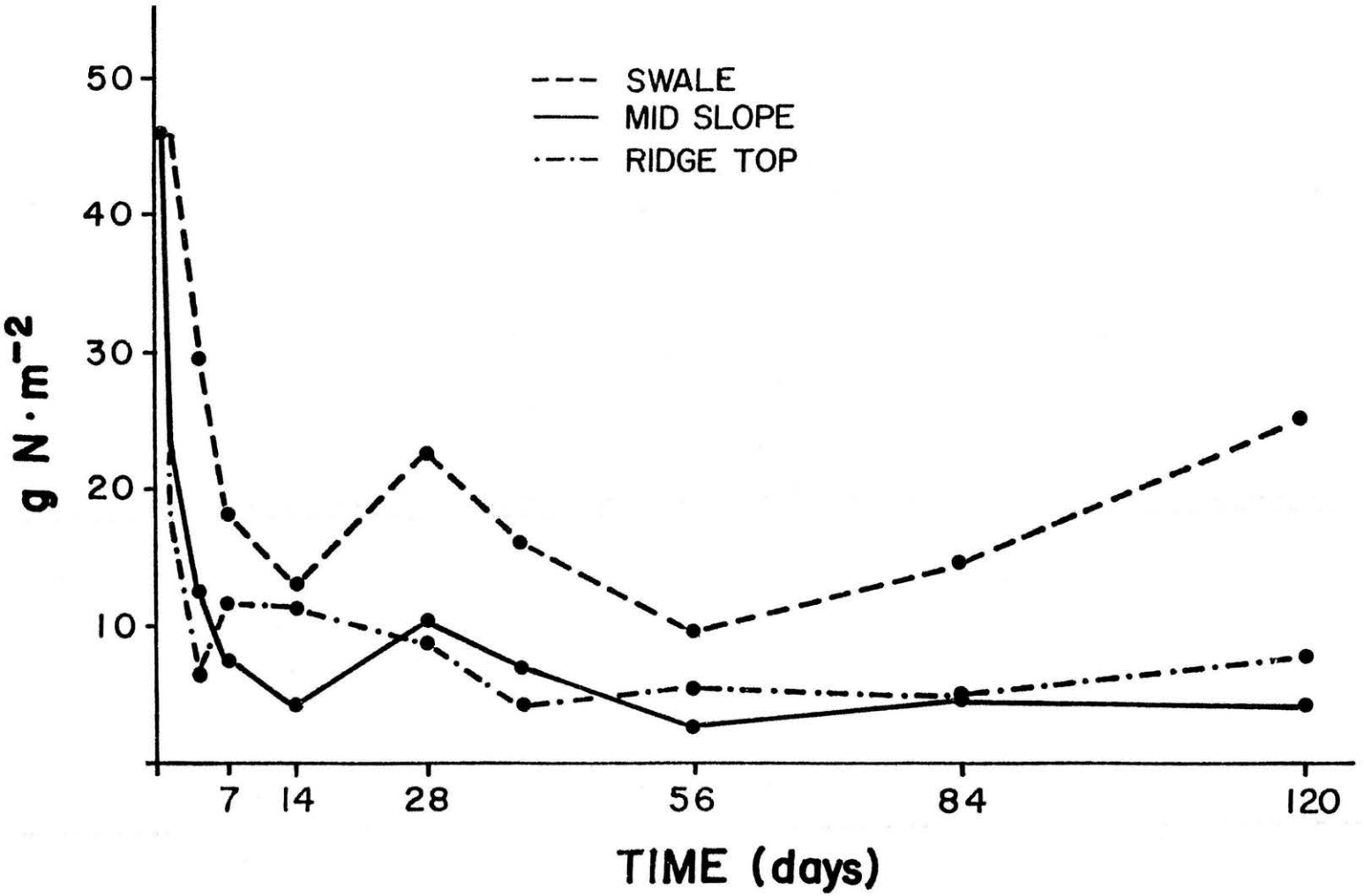


Fig. 16. Comparison of the changes of the total inorganic N in the soil of the urine spots of the three sites along the catena.

inorganic-N pool of the three sites had decreased to 31.1, 11.9, and 5.5 g N m^{-2} for sites 1, 2, and 3 respectively. Such losses could possibly be explained by volitalization of ammonia or N assimilation by plants and microorganisms.

However, the N balance from the ^{15}N data suggested that volatilization of ammonia was not the explaination of the low N recovery at day 1 for the ridgetop, site 3. The rates of recovery of the added N were statistically the same across the catena for the N in the vegetation (21.9%, 11.4%, and 12.9% for sites 1, 2, and 3, respectively) and in the soil (24.9%, 16.2%, and 24.5%). However, the ridgetop had more N taken up into the roots than the other 2 sites, 29.7% for site 3 vs. 19.9% and 14.7% for the swale and midslope. Thus overall there was no statistical difference in the dates or sites for the amount of N recovered.

The swale site appeared to keep the N in the inorganic form. The ammonium released with urea hydrolysis was initially held on the exchange sites of the soil and then immobilized into the soil organic matter. With drier conditions, the N was mineralized to be re-immobilized as soil water increased following seasonal rains. Nitrification was included in this step and nitrate accumulated.

The amount of the added urea-N recovered from the midslope was lower than on the other two sites. I suggest ammonia volatilization was most important on site 2. The

rapid rate of hydrolysis and subsequent increase of pH would be conducive to volatile ammonia loss.

Dry soil conditions were important in the conservation of the added N at site 3. The drier soil slowed the rate of urea hydrolysis. The slower rate of hydrolysis slowed the expected pH increase and minimized ammonia volatilization. Also, the roots were able to assimilate the N the first year and then recycle the N to the plant aboveground parts the next growing season.

Another factor that may have contributed to the conservation of N through reduced ammonia volatilization on sites 1 and 3 as compared to site 2, was the exchangeable soil Ca^{++}. When the urea was applied to the soil, it was hydrolyzed to ammonium carbonate $(NH_4)_2CO_3$. The ammonium carbonate forms an equilibrium with the calcium in the soil to form calcium carbonate, $CaCO_3$, which may precipitate at a pH above 7 (Fenn and Kissel,1973; Fenn et al., 1981a; Fenn and Miyamoto, 1981). The calcium removed from the exchange sites allows ammonium to be held and less available for volatile loss as ammonia. This could explain the overall similarity in the amount of N recovered on sites 1 and 3 as compared to site 2. Site 2 lost nearly twice as much N as sites 1 and 3. The exchangable calcium levels of the swale, site 1, and ridgetop, site 3, were 50% greater in the 0-10 cm and twice as large in the 10-20 cm soil depths as site 2, the midslope (Fenn et al., 1981a; Fenn et al., 1981b; Fenn and Kissel, 1973).

The soil pH measurements showed the buffering effect of calcium. The catena soils began with a pH ranging from 6.8 for the top 2.5 cm of site 1 to 7.2 for the top 2.5 cm of site 3. The pH response to the urea-N addition was similar for both theses sites, an increase to between 7.5 and 8.0. The large pH fluctuation with urea addition was only noted on site 1. The depth to lime on site 1 was 65 cm compared to 25 cm and 10 cm on sites 2 and 3. Thus the calcium buffered the pH (Fenn and Miyamoto, 1981;Fenn et al., 1981a).

The soil plant differences amoung the sites explain the conservation of N. Perhaps in a wetter year, more of the urea-N could have been lost to volatilization from the ridgetop as hydrolysis of urea would have been more rapid. The application time may also be important. In the winter, the cooler temperatures might have reduced the rates of hyrolysis, and the potential for volatile ammonia losses. The effect of urea-N on the nitrogen cycle of a shortgrass prairie depends on a variety of soil biological and chemical processes.

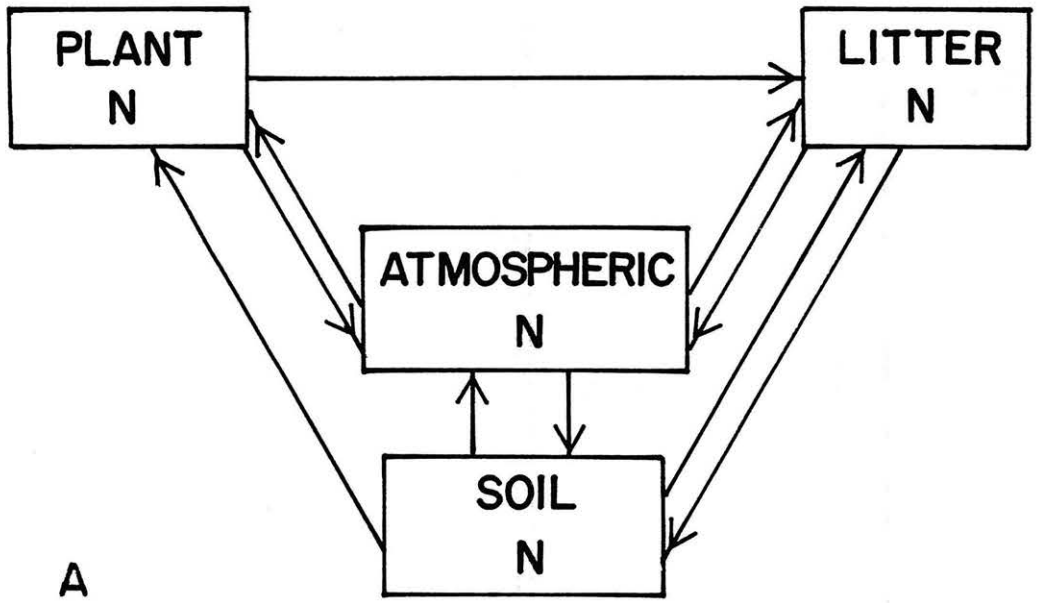
CHAPTER 4: SUMMARY, CONCLUSIONS, AND IMPLICATIONS

INTRODUCTION

The research reported here was part of a coordinated research effort designed to examine the impact of free grazing cattle on the N cycle of the shortgrass prairie. The general hypothesis of the project was that animals exert a significant influence on the N cycle by ingesting N in one community and depositing it on another as urine and feces. This redistribution was hypothesized to be important in determining community structure and stability.

In an ungrazed system a simplified N cycle within any given community can be represented as in Fig 17a. The process of converting plant N into litter N is controlled by the plant live history (i.e. growth patterns, reproduction, internal cycling of N, senescence, etc.) in response to climatic conditions of temperature, moisture, solar radiation, etc. The cycling of N between litter N and soil N is dependent on decomposition processes as controlled by substrate quality, soil N levels, and climatic conditions. Plant uptake of soil N is dependent on life history of plants, N availability in the soil, and climatic conditions. Atmospheric inputs or losses occur at all points via rain, gaseous absoption, or gaseous volatilization. There is

Fig. 17. Model of a grassland N cycle without large animal grazing (a) and influenced by large animal grazine (b).


PLANT
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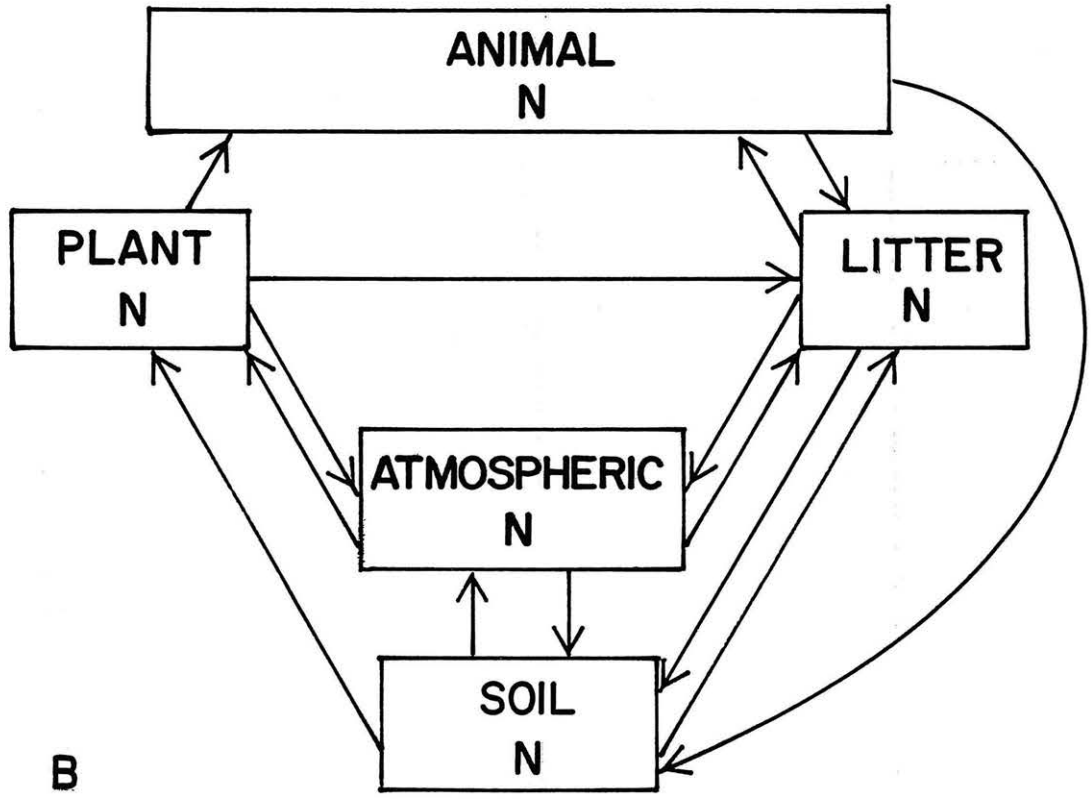
ANIMAL
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SOIL
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little exchange of N between communities within pastures except through wind and water erosion.

If grazing is imposed on this simplified community model (Fig. 17b) it becomes more complex. Grazers ingest a portion of the plant N that would be transferred to the litter N pool, and ingest a portion of the litter N. The amount ingested is dependent on forage quality, size and physiological status of the grazer, number of grazers, time spent grazing, and climatic conditions. The N consumed is metabolized and stored in body tissue for growth and reproduction or excreted in urine or feces. Urinary N and much of the fecal N is immediately available to soil processes and incorporated into the soil N pool, where it is available for plant uptake to continue the cycle. Grazers add to the litter pool by depositing recalcitrant material as feces and by trampling vegetation. The big impact of grazing is the reduction of time needed to cycle N from plant material through litter back to the soil, and the increased potential for volatile loss of ammonia from urine and fecal spots.

Grazers also complicate the cycling of N by concentrating excreted N in small patches. On ungrazed communities, litter is spread across the community in patterns approximating plant distribution. Grazers will "gather" the N and deposit it in small urine and fecal spots often covering less than 2% of a community.

Finally, grazers complicate the N cycle by the transport of N among communities. Grazers prefer different community

types for grazing, resting, and bedding. Thus N that is excreted is not only concentrated in small patches of a community but is also completely removed from a community and deposited on another.

Thus, to address the general hypothesis, four areas of study were essential: 1) partitioning of ingested plant N among animal growth and wastes (urine and feces), 2) transformations and budgets of the excreted N on the soil, 3) losses of N from the pasture system, and 4) animal grazing and social behavior affecting the redistribution of N . Within this context, the goals of this research were to determine the partitioning of the ingested N and to determine the fate of the urine N once it was deposited on the soil.

SUMMARY

Nitrogen intake of four experimential heifers averaged 2.2 kg N day^{-1} $BW^{-0.75}$ for June and decreased to 0.9 kg N day^{-1} $BW^{-0.75}$ in November. The herd of eight heifers ate 116 kg N for the growing season of May 25 to October 4, and ate 91 kg N for the dormant season of October 4 to March 7. Thus 207 kg N was ingested by the herd for the study period, representing 8% of the peak standing N.

The nitrogen incorporated into the growth of the herd was 18% of the N ingested during the growing season. Over the entire periodof study, 10% of the N ingested was incorporated into animal growth or less than 1% of the peak

standing crop. Urine N excretion rates were highest in June (1.3 g N day^{-1}) and decreased to 0.3 g N day^{-1} for the dormant season. Thus, a total of 62.6 kg N was excreted by the herd during the growing season and 30.6 kg N for the dormant season. Fecal N excretion rate was highest in October (0.8 g N day^{-1}). The lowest rate of fecal N excretion was in January when the digestibility and dry matter intake were low. The N excreted was partitioned as 54% urine N and 46% fecal N for the growing season and 32% urine N and 68% fecal N for the dormant season.

Senft (1983) used some of this data and developed a model predicting the rate of removal of N and of deposition of excreted N on the lowlands, hillslopes, and ridgetops of the pasture. The area of the 125 ha. pasture represented by each position was 10.5 ha (8.4%) for the ridgetop, 71.0 ha. (56.8%) for the hillslopes, and 27.1 ha (21.7%) for the lowlands. The remainder of the pasture was partitioned into the fencelines (14.0 ha;11.2%) and the area around water (2.4 ha; 1.9%). Using this model we calculated for the growing season that 2.2 kg N ha^{-1} was ingested from the lowlands, 1.0 kg N ha^{-1} on the hillslopes, and 1.4 kg N ha^{-1} on the ridgetops. During the dormant season animals ingested 0.2, 0.3, and 0.7 kg N ha^{-1} for the lowlands, hillslopes, and ridgetops, respectively. Senft defined the growing season as April through October and the dormant season as November through March. Thus the slope positions lost 2.4, 1.3, and 2.1 kg N ha^{-1} for the lowlands,

hillslopes, and ridgetops, respectively, on an annual basis. An additional 1.9 kg N ha^{-1} was removed from the fence.

Excretion of N was also predicted from this model. On an annual basis, 2.1 kg N ha^{-1} was deposited as urine and feces on the lowlands, 1.0 kg N ha^{-1} on the hillslopes, and 1.2 kg N ha^{-1} on the ridgetops. Thus, each catena position lost some N; 0.3 kg N ha^{-1} from the lowlands, 0.3 kg N ha^{-1} from the hillslopes, and 0.9 kg N ha^{-1} from the ridgetops. Not all of this N was lost from the pasture. Some N was stored into body tissue of the grazing heifers. Most of the deficit of ingested N was redistributed to the fence lines and watering areas.

Assuming the processes and controls were similar for the pasture soils as for the catena soils (Chapter 3), most of the N that was deposited on the swales and ridgetops was conserved while most deposited on the sandy hillslopes was lost. Assuming the same rate of loss of the added N, the loss rate was of 0.5 kgN ha^{-1} for the lowlands, 0.6 kg N ha^{-1} for the hillslopes, and 0.4 kg N ha^{-1} for the ridgetops. The hillslopes had less urine N deposition on an area basis than the ridgetops but the greater loss potential gave equal amount of N loss on an annual basis.

The combination of loss of N from excreta and the loss by redistribution accounted for 0.8 kg N ha^{-1}, 0.9 kg N ha^{-1}, and 1.3 kg N ha^{-1} for the lowlands, hillslopes, and ridgetops, respectively. This amount was small compared to Denmead et al. (1974) who estimated daily rates of loss from a pasture grazed by sheep at 0.26 kg N ha^{-1} for a 20 day

period. However, the daily rate of input, 1.0 kg N ha^{-1}, was much greater than reported here. The rate of loss 26% was similar to the loss rate of the lowlands.

CONCLUSIONS AND IMPLICATIONS

Free grazing heifers on shortgrass range did not greatly alter the N economy of the pasture. The combined rates of deposition and redistribution to fence lines and watering areas were less than 10% of atmospheric inputs (Woodmansee et al., 1978). However, grazing by heifers did effect the cycling of N through the system. The cattle processed 10% of the standing N through their bodies and returned it to the system as readily available N in urine or in feces. At the local area of the spot, available N increased to levels 10 to 20 times greater than the annual rates of mineralization reported for a shortgrass catena (Schimel, 1982). One urine event would decrease or remove N as a limiting factor and increase plant production.

The processing of N by cattle had significant effects at the community level. Grazing increased the rate of turnover of 10% of the N. This reduced litter buildup and the formation of recalcitrant organic matter in a system where N could be tied up in litter for 1-5 years (Clark, 1977).

The decrease in N accumulated in litter could be advantageous to plants. It would increase available N by increasing the cycling pool of N by 5 to 10% of the mineral

N annually available to the community. However, the N is not evenly distributed across the community. Only 2% of the heavily used communities were covered with excreta each year. The upland communities had less than 1% covered. How could this N then be important to the communities? First the area affected was 2-4 times the area covered. Second, the effect of excreta may be long term. Black and Wright (1979) did a study in blue grama/carex communities in Sidney, MT. They had one broadcast application of ammonium nitrate at rates of 112, 336, or 1,008 kg N ha^{-1}. I am only concerned with the lower two rates as they approximate rates of deposition (330 kg N ha^{-1}) calculated by Senft(1983). Through the first 8 years, the vegetation showed increased rates of uptake of 58 kg N ha^{-1} and 125 kg N ha^{-1} for the two levels of fertilization. They concluded the effect was caused by the N immobilized into N poor roots and subsequent release at rates approaching 0.5 Kg N ha^{-1} for the 112 kg N ha^{-1} addition and 2.6 kg N ha^{-1} for the 336 kg N ha^{-1} addition above the control levels for a period up to 13 years. The effect of the one time fertilization as measured by increased uptake could be seen several years after increased production ceased.

Following this line of reasoning, we can assume a deposition rate of 330 kg N ha^{-1} for 2% of a community. The area effect is roughly 3 times the area wetted changing the deposition rate to 110 kg N ha^{-1} for 6% of the community. But the effect may last may years. Black and Wright (1979) suggest at least 8 years. Thus at any given year, up to 48%

of a given community could be effected. This would assume no overlap in urine spots or fecal pats. The effect would not be the same for each year. Initially the effect would be seen in increased production and N concentration, later the effect would only be seen in increased uptake. The increased uptake of 0.5 kg N ha^{-1} and 2.6 kg N ha^{-1} at the two fertilization rates represent 4% to 22% of the annual plant uptake and were measured 8 years after the N addition.

On communities that are not as heavily used, only 0.5% of the area may be covered with excreta each year. Thus the area affected at any one time would be only 12% of the community. But these are also the upland communities where grazing pressure was least (Senft, 1983).

This limited addition of N may be important in community structure and stability. Lauenroth and Dodd (1979) found decreases in density and diversity of legumes with a 50 kg N ha^{-1} fertilization. Kirchner (1977) reported shortgrass range fertilization to significantly decrease species diversity and evenness.

Addition complication enter the picture when transport of N amoung communities was considered. Senft(1983) predicted 32% of the N ingested in the pasture would be redistributed to communities other than the point of ingestion. The general pattern of redistribution was from the lowlands to the ridgetops or from communities of highest N pool to communities of lower pools where N would be more

limiting. Thus the redistribution would further help decrease N limitiation.

Thus, in a grazed system such as this pasture in the shortgrass prairie where the actual amount of N in the system changes little with grazing, the increased rate of cycling of N processed through the cattle could increase the N available for plants in the pasture , effecting community development, diversity, and stability.

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