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An Examination of the Inorganic Nitrogen Status of a Soil of the Alaskan Coastal Tundra Plain

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AN EXAMINATION OF THE INORGANIC NITROGEN STATUS OF A SOIL OF THE ALASKAN COASTAL TUNDRA PLAIN

by

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Norton R. Munn

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STATUS OF A SOIL OF THE ALASKAN

COASTAL TUNDRA PLAIN

by

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This experiment was designed to measure in situ concentrations of NH_4^+-N and NO_3^--N in a soil of the arctic coastal tundra plain, to determine if nitrification was taking place in this soil and to determine if the vascular plants growing in this soil could assimilate NH_4^+-N.

The extractable NH_4^+-N concentration was approximately 40 µg/g in the O_1 horizon and 10 µg/g in the O_2 horizon. The NO_3^--N concentration was approximately 5 µg/g in the O_1 horizon and 4 µg/g in the O_2 horizon.

The presence of NO_3^--N in this soil indicates that nitrification is taking place but perfusion experiments indicate that it is not bacterial nitrification. Fungi may be responsible for nitrification in this soil.

Carex aquatilis, a common plant in the study area, was found to readily assimilate NH_4^+-N as well as NO_3^--N.

(58 pages)

INTRODUCTION

Nitrogen is one of the most prevalent and important elements in living tissue.. It is a constituent of proteins, nucleic acids, hormones, and many other metabolites. An actively growing plant needs a continuous supply of available nitrogen.

In light of the above, any comprehensive analysis of an ecosystem would logically be concerned with the movement of nitrogen through that system. Recent work at the Barrow intensive site of the U. S. International Biological Program-Tundra Biome project has suggested some interesting questions in terms of nitrogen movement in cold, wet tundra soil. A synoptic study of the nutrient status of a Pergelic Cryofibrist of the Barrow tundra conducted by Gersper and Arkley (1970) indicated an almost total lack of nitrate nitrogen in the soil solution over the entire summer season.

These data are preliminary but they may indicate an absence of nitrification or the presence of very rapid denitrification. In any event, these questions bear directly on the forms of inorganic nitrogen which are available for plant uptake. They will have to be answered if nitrogen transfers are to be evaluated for the Barrow ecosystem.

This experiment was designed to measure the NH_4^+-N and NO_3^--N concentrations in a soil of the coastal tundra plain, to determine if nitrification was taking place in this soil, and to determine if the vascular plants growing in this soil had the capability of assimilating NH_4^+-N.

REVIEW OF THE LITERATURE

Recent work by Gersper and Arkley (1970) indicates the absence of nitrate nitrogen in a soil of the Barrow tundra. These findings raise a series of questions about the nitrogen status of the soil and about the plants growing in the soil.

Soil

The soil investigated in this study is that which occurs in the polygon "pans" or the level, central area of the low-center polygons of the tundra near Barrow, Alaska (Figure 1). The microrelief and the soil morphology have been discussed by Brown, Dingman, and Lewellen (1968); Brown (1969); and Douglas and Tedrow (1960). Gersper and Arkley (1970) have conducted an extensive study of the physical and chemical properties of this soil. Tabulations of some of these data appear in Appendix I. Gersper and Arkley have tentatively classified this soil as a Pergelic Cryofibrist (Gersper and Arkley, 1971, Personal Communication). The term "Pergelic" refers to the presence of permafrost. This phenomenon has been extensively described in the literature and Brown, Dingman, and Lewellen (1968) and Brown (1969) discuss its importance in terms of hydrology and soil development.

The data in Appendix I reveal that this soil is cold, wet, and quite acidic. This would seem to be a harsh environment for bacteria since most species are thought to function best at temperatures of 25-35 C and pH's around neutrality (Alexander, 1961). However, Anderson, Boswell, and Harrison (1971) found that certain strains of bacteria

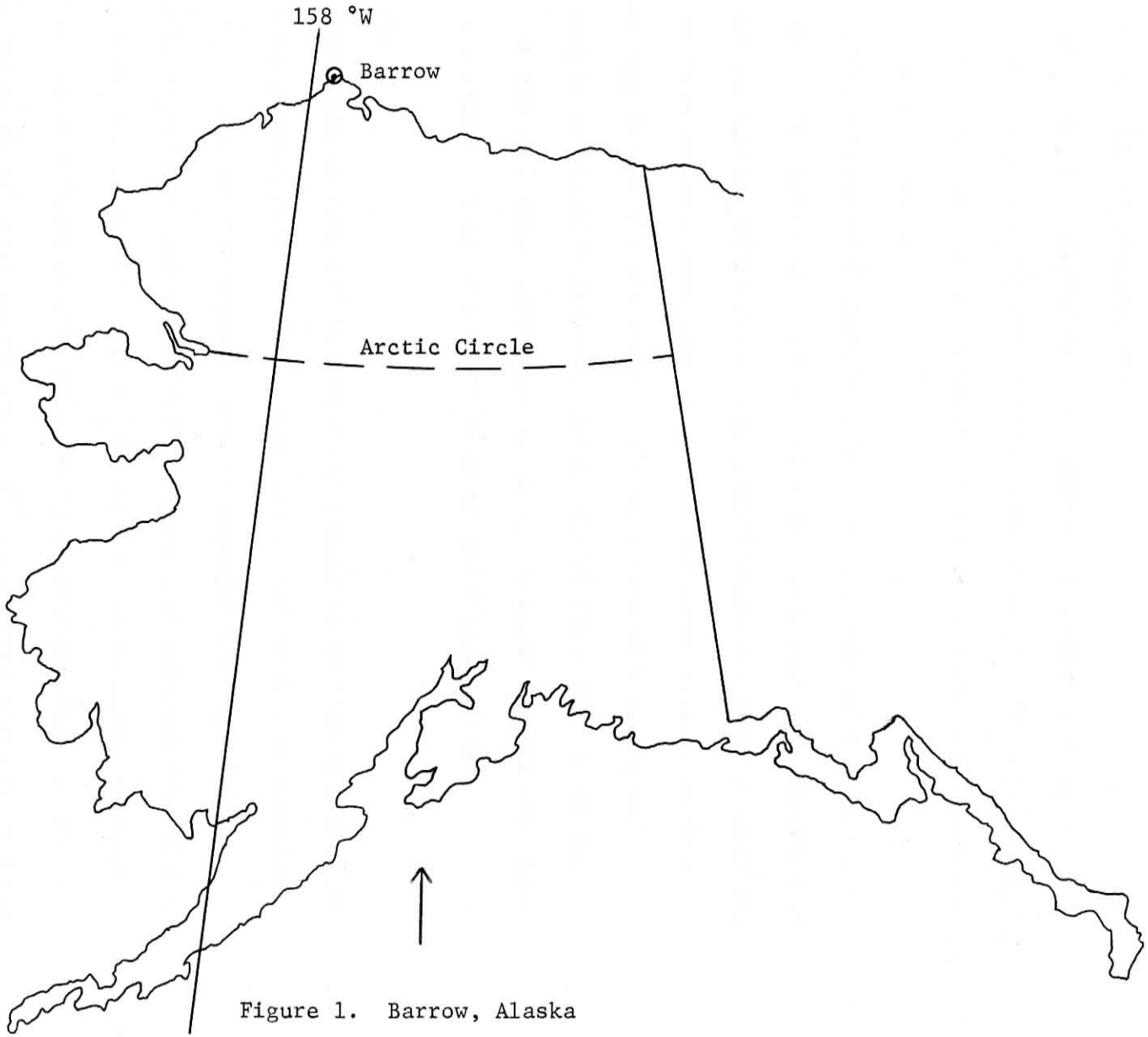

Figure 1. Barrow, Alaska

from some cold, acid soils had evolved with a capability of nitrifying under these conditions. Mahendrappa, Smith, and Christainsen (1966) arrived at similar conclusions.

In addition, Campbell and Lees (1967) state that under acid conditions nitrification can be carried on by fungi. It is possible, then, that neither the cold temperature nor the low pH is sufficient to prohibit nitrification.

Other factors which must be considered are soil moisture and soil aeration. The soil under investigation is exceedingly wet (Appendix I). Parker and Larsen (1962) found that nitrification was severly inhibited by moisture contents near saturation. As the water content reaches these high levels the air space in the soil (and with it the soil oxygen) is drastically reduced. Benoit (1970) found this to be the case in the soil under investigation here. He found O_2 concentrations to be low-10 to 15 percent at 15 cm depth and 0 below 20 cm.

Plants

Nitrogen is required in continuous supply in an available form by actively growing plants. Plants can take up and assimilate ammonium, nitrate, and even some organic forms of nitrogen (Devlin, 1966). DeWitt, Dijksloorn, and Noggle (1963) report that although some plants absorb NH_4^+-N more readily than NO_3^--N they seem to do better in terms of dry matter production with NO_3^--N as their nitrogen source. In addition to this, large quantities of NH_4^+-N have been shown to be toxic to many plants (Hewitt, 1952).

Despite these considerations some plants, such as rice, do quite well with ammonium as the exclusive nitrogen source under anaerobic

conditions (Patrick and Sturgis, 1955). This could become an important consideration for the Barrow tundra which is frequently waterlogged.

The most common vascular plants at experimental site number 2 are *Carex aquatilis* Wahl., *Eriophorum angustifolium* Roth, and *Dupntia fischeri* R. Br. (Tieszen and Dennis, 1970).

METHODS OF PROCEDURE

Inorganic Nitrogen

Three plots were selected at the IBP experimental site number 2 at Barrow, Alaska. The plots were numbered 250, 251, and 252 according to the IBP system. Uniformity within and among plots was the primary selection criterion. This applied to both the soil and the plant community. In addition to these considerations, an effort was made to select plots which were similar to those being studied in the Tundra Biome's intensive effort at Barrow. The plots finally selected were polygons and the sampling area was confined to the level, sunken "polygon pan" in the center (Figure 2) of each polygon. Final plot dimensions were approximately 4 m x 5 m.

Each plot was dissected on a half-meter grid system and the main axes numbered so that each point on the grid had two coordinates. A table of random numbers was then used to select the sampling points. However, this was not rigidly adhered to since some areas of the plot had suffered damage due to tracked vehicles (Figure 3). These areas were avoided.

On June 27, 1971 plots 251 and 252 received nitrogen fertilizer applications. Plot 250 was left untreated and was used as a control. Plot 251 received 100 kg/ha of fertilizer grade $Ca(NO_3)_2$. This was equivalent to 15.5 kg/ha of NO_3^--N. Plot 252 received 100 kg/ha of fertilizer grade urea. If hydrolysis was complete this was equivalent to 45 kg/ha of NH_4^+-N.

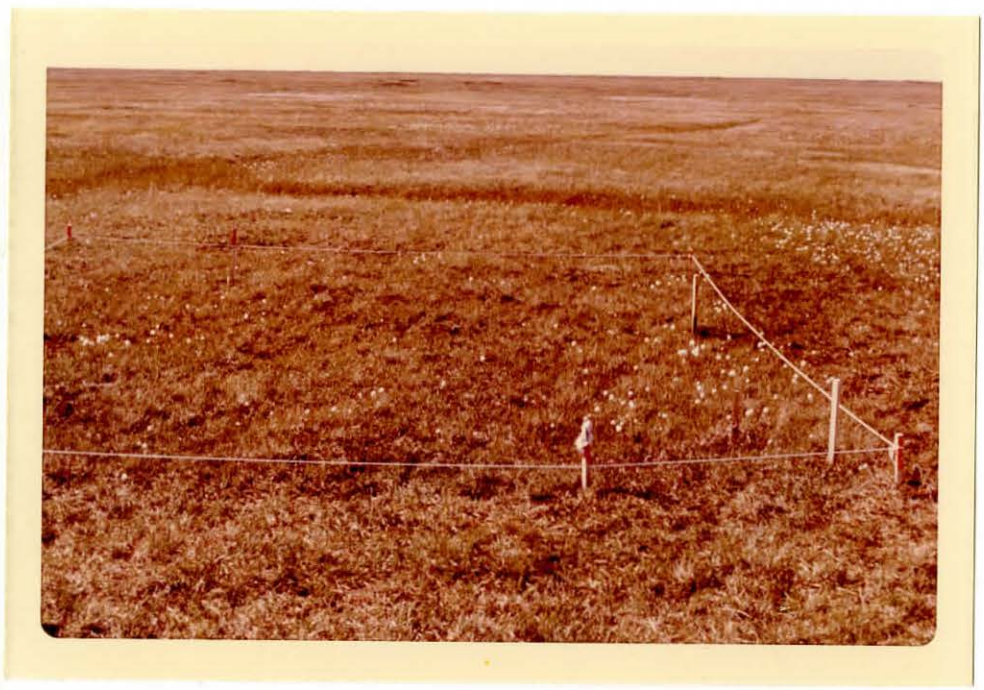

Figure 2. Sample plots in polygons of arctic tundra.

Figure 3. Damage to tundra resulting from tracked vehicles.

Assuming that on both plots the fertilizer was distributed evenly, that it remained in the 0_1 horizon until after the first sampling, and that the average bulk density of the 0_1 horizon was 0.25 g/cc (Appendix I) then the theoretical maximum concentrations of both species of N can be calculated for the first sampling day. These values are approximately 200 µg/g NO_3^--N in plot 251 and 600 µg/g NH_4^+-N in plot 252. In both cases allowance has been made for native levels of N as measured in the control plot.

Sampling began on the day following fertilizer application and continued at ten day intervals over the summer. At each sample point a 35 cm ring was pinned to the ground with small nails and all of the vascular plant material within the ring was clipped off at the moss surface. The actual surface of the 0_1 horizon was extremely difficult to delineate since the moss layer grows in intimate association with the partially decomposed organic matter which forms the 0_1 horizon. For this reason, the top of the moss layer was arbitrarily designated as the "ground" surface.

Following the clipping, a soil core 15 cm in diameter and down to the frost line was taken at each sampling point. Each core was then separated by horizon (Figure 4 and 5). Horizons were distinguished in the field on the basis of color and texture (Table 1). Each horizon slice was measured and packaged in plastic bags and frozen within one to two hours of sampling. At the end of the season, the frozen samples were shipped to Logan, Utah for subsequent analysis. Because of the fact the the majority of plant roots occur in the first two horizons (Dennis and Johnson, 1970) shipping and analytical resources were

Figure 4. Procedure for extracting soil cores.

Figure 5. Separating the soil horizons in a sample core.

Table 1. Field texture and color designations for the soil found in Tundra Biome plots 250, 251, and 252 at Barrow, Alaska

Approximate Depth (cm)[a]	Horizon	Texture	Color (wet)
0- 5	O_1	peat	5YR 2/2
5-10	O_2	peat	5YR 3/2
10-18	II C_g	silt loam with some slight gleying	10YR 3/2
18-23	III C	peat (buried)	10YR 2/2

[a]Depths varied somewhat from sample to sample

concentrated on these two horizons. Complete profiles were analyzed for only three sampling days; June 28, July 18, and August 24.

At the time of sampling, soil temperature was determined at 5 cm depths using thermistor probes inserted into the ground via the sampling hole. The probes were Yellow Springs models #418 and the meter was a Yellow Springs model #42. In addition, a slice was taken from the side of the hole down to the frost line. This sample was separated by horizon also. Each slice was placed immediately into a tared moisture can for determination of the oxidation-reduction potential, Eh, and the percent moisture by weight, ω. Each hole was then plugged with a core taken from an adjoing polygon not being used for experimental work.

Eh was measured with a Photovolt portable pH meter using a platinum electrode. Field Eh readings were corrected for temperature and to pH 6.0 by the following equation which was developed by Dr. Harvey E. Doner

of the University of California at Berkeley (1972, Personal Communication):

$$R_c = R_o - 244.0 + 0.81\ (T_c^\circ - 25) + 60\ (pH - 6.0)$$

where R_c = corrected oxidation-reduction potential in millivolts

R_o = field oxidation-reduction potential measurement in millivolts

T_c° = soil temperature in degrees centigrade

Because of difficulties with the electrode these data are not considered to be very accurate. These Eh values may, however, be useful in a qualitative way.

Each sample (core slice) was analyzed for NH_4^+-N and NO_3^--N plus NO_2^--N by the steam distillation technique described by Bremner (1965). A major variation in the extraction technique was necessary for this soil, however. Bremner's (1965) extraction procedure involves adding 100 ml of 2N KCl solution to 10 g of air dry soil. However, the soil used in this experiment was very difficult to re-wet after drying. To overcome this problem, each sample was extracted without drying. Calculations were made (from the ω values) to determine how much wet soil would contain 10 g of oven dry soil. This amount was weighed out on a Mettler P 1200 balance. Water was added to bring the total weight to 110 g or 100 ml water plus 10 g of dry soil.

In order to avoid water loss, each sample was cut up and weighed while frozen. The sample plus water was then mixed thoroughly in a

Waring laboratory blender. The pH of this solution was then measured. Following this, approximately 15 g granular KCl was added to each sample to obtain the prescribed 2N KCl concentration and the samples were shaken for one hour.

The one exception to this procedure occurred in the surface horizon. These horizons were so high in organic matter that 100 ml of water was not enough to provide sufficient extract. Therefore 150 ml of water and 22.5 g of KCl were added to these horizons. The colloidal matter in these samples caused problems in filtration. Bremner (1965) prescribes the use of Whatman number 42 filter paper. This paper was unsatisfactory as it clogged almost immediately. Whatman GF/A paper, which is designed for thick, viscous solutions, performed quite well and was used for the extractions in this study.

Perfusion

In order to obtain an estimate of the nitrifying potential of this soil, samples of the surface horizon of the control plot were perfused with ammonium sulfate according to the procedure described by Lees and Quastel (1946) and Collins and Sims (1956). These samples represented each sampling day so the time effect over the growing season was examined also. Analysis of NH_4^+-N was by the Nesslerization method (Allen, 1957). Nitrate was determined by the 4-methylumbelliferone method (Skujins, 1964), and nitrite by the sulfanilic acid method (Snell and Snell, 1949). The pH of the perfusate was measured on the first and last sampling days.

N^{15}

Late in the growing season a small amount of N^{15} labelled nitrogen compounds became available. In order to obtain a first estimate of uptake

rates 10 µg each of $N^{15}O_3^-$-N and $N^{15}H_4^+$-N were injected into isolated soil cores with living vegetation still growing in them.

Each core was taken with a plastic cylinder which was 4 cm in diameter and about 15 cm in length. The cylinders were pushed into the soil until the top end was flush with the moss surface. The soil-filled cylinders were removed, the bottoms were capped and they were placed back into the holes. Each soil core was then in the same environment as the undisturbed area except that input and output of soil solution were limited.

Five injections of 2 µg each were made with a long-needled syringe at a depth of 7 cm in each core. This was intended to coincide with the depth of maximum root concentration. Twenty-four hours after injection, the cores were removed from the ground and taken to the lab where the plant material was removed. Plant material was separated according to the following scheme:

live vascular plant material above the ground surface

live vascular plant material below the ground surface (by horizon)

moss layer

dead vascular plant material above the ground surface

dead vascular plant material below the ground surface (by horizon)

The samples were then dried and sent to Fairbanks for mass spectrometry analysis (a Tundra Biome service).

RESULTS AND DISCUSSION

Soil Environment

The *in situ* soil temperatures, moisture contents (ω's), oxidation-reduction potentials (Eh values), and pH values are summarized in Tables 2, 3, and 4. The values for temperature and pH are similar to those reported by Gersper and Arkley (Appendix I). The addition of urea seems to have raised the pH slightly on the first sampling day but not thereafter. The moisture contents reported here are slightly higher than those of Gersper and Arkley.

The oxidation-reduction potentials reported here indicate the presence of reducing conditions throughout the period of measurement, especially in the lower horizons.

In summary, this soil is cold, wet and acid. It is also poorly aerated and has low oxidation-reduction potentials.

Table 2. Average soil temperatures by depth for Tundra Biome plots 250, 251, and 252

Depth	Sampling Date						
	6/28/71	7/8/71	7/18/71	7/28/71	8/5/71	8/14/71	8/24/71
(cm)							
0	8.8	11.4	12.2	9.9	2.7	8.1	4.3
5	4.4	5.0	6.1	7.2	2.0	3.8	2.6
10	2.5	2.3	3.7	5.2	1.8	1.7	2.4
15	0.7	1.4	2.3				1.3
20		0.5	1.5				1.2
25			0.4				1.2

Table 3. Average soil moisture contents (ω) and oxidation-reduction potentials (Eh) by horizon for Tundra Biome plots 250, 251, and 252

Horizon	Sampling Date						
	6/28/71	7/8/71	7/18/71	7/28/71	8/5/71	8/14/71	8/24/71
(A) Percent Moisture by Weight							
O_1	726	550	631	697	698	678	669
O_2	355	320	349	329	378	409	434
IIC_G	97		80				81
IIIO			92				106
(B) Oxidation-reduction Potential (mv)							
O_1			17.08	- 16.07	- 44.25	- 3.23	- 11.26
O_2			-155.10	-202.73	-214.11	-191.22	-176.33
IIC_G			-173.91				-185.15
IIIO			-137.82				-179.18

Table 4. Average pH values by plot and horizon for Tundra Biome plots 250,251, and 252

Horizon	pH Sampling Date						
	6/28/71	7/8/71	7/18/71	7/28/71	8/5/71	8/14/71	8/24/71
Plot 250-Control							
O_1	5.34	5.30	5.33	5.08	5.13	5.35	5.08
O_2	5.31	5.38	5.32	5.07	5.48	5.21	5.32
IIC_G	5.42		5.46				5.65
IIIO			5.43				

Table 4. Continued

Horizon	pH						
	Sampling Date						
	6/28/71	7/8/71	7/18/71	7/28/71	8/5/71	8/14/71	8/24/71
	Plot 251-$Ca(NO_3)_2$						
O_1	5.31	5.40	5.06	5.25	5.20	5.52	5.25
O_2	5.26	5.45	5.16	5.22	5.08	5.36	5.01
IIC_G	5.38		5.36				5.35
IIIO			5.26				5.65
	Plot 252-Urea						
O_1	5.80	5.15	5.28	5.38	5.06	5.16	5.18
O_2	5.50	5.15	5.10	5.37	5.18	5.18	5.32
IIC_G	5.46		5.48				5.38
IIIO			5.28				5.58

Inorganic nitrogen

The raw data from this phase of the experiment are tabulated in Appendix III. The average values of NH_4^+-N and NO_3^--N by plot and horizon for each sampling day are illustrated in Figures 6, 7, and 8.

Analyses of variance were run by plot on the O_1 and O_2 horizons for NH_4^+-N and NO_3^--N concentrations to determine if there were significant trends in these concentrations with time. These analyses are tabulated in Appendix IV. The results of these analyses are summarized in Table 5.

In those cases where there was not a significant trend with time over the growing season, the observations for a given horizon were treated as a simple population and sample means, $\bar{x}$'s, and standard errors for those

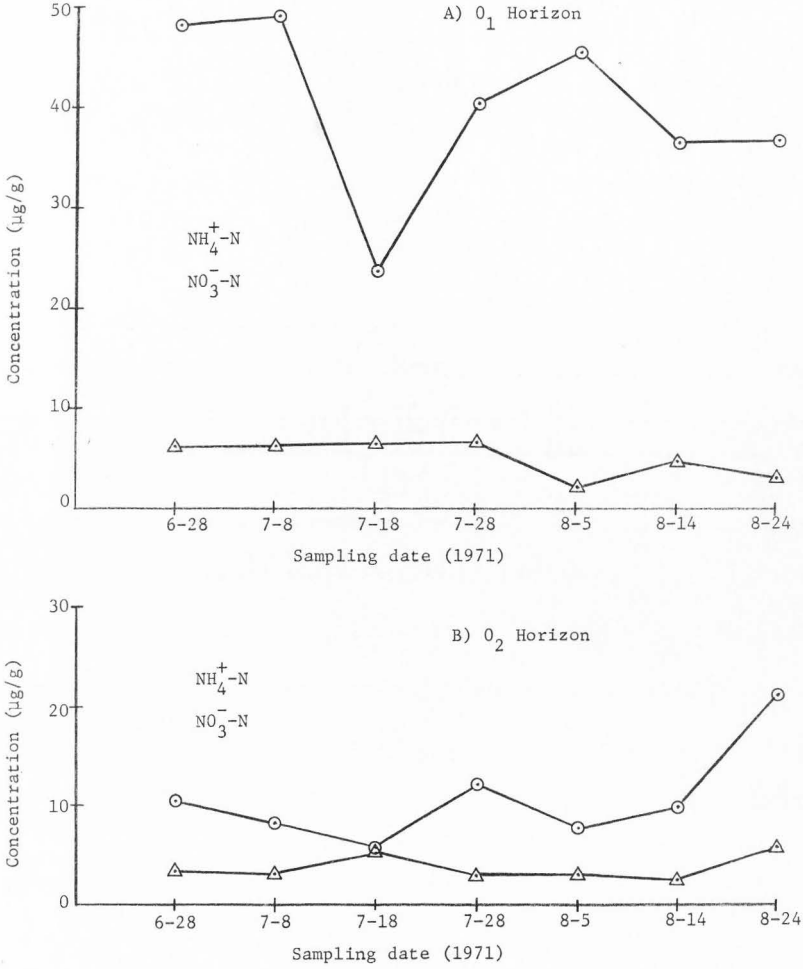

Figure 6. NH_4^+-N and NO_3^--N concentrations over time for plot 250.

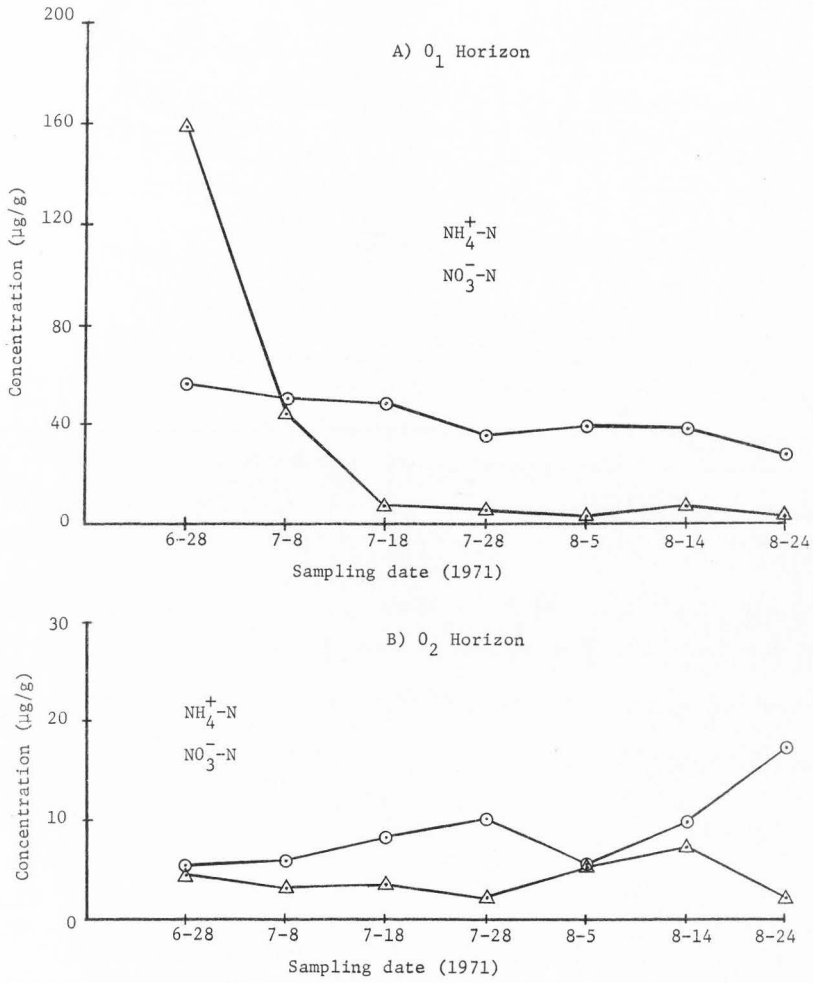

Figure 7. NH_4^+-N and NO_3^--N concentrations over time for plot 251.

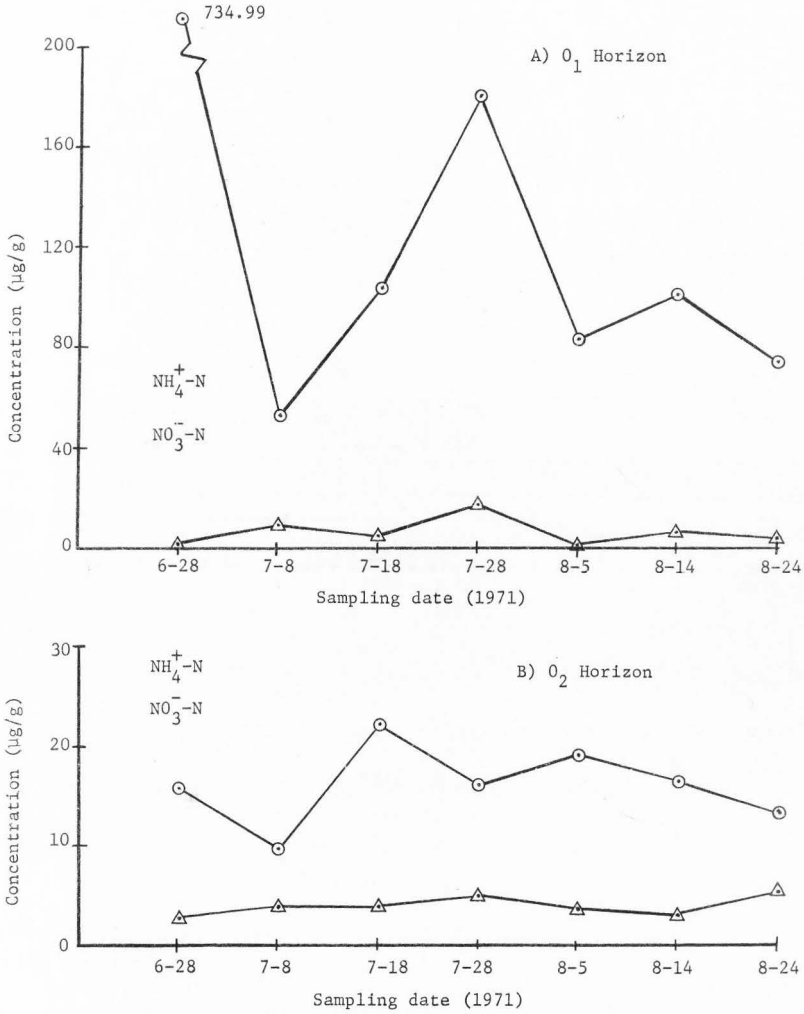

Figure 8. NH_4^+-N and NO_3^--N concentrations over time for plot 252.

Table 5. Summary of the results of analyses of variance to test time effect on the NH_4^+-N and NO_3^--N concentrations in the O_1 and O_2 horizons of the control, $Ca(NO_3)_2$ and urea plots

Plot	Form of N	Horizon	Time Mean Square	Error Mean Square	F
Control	NH_4^+	O_1	316.6945	345.0450	0.92
		O_2	105.3767	27.0541	3.90
	NO_3^-	O_1	11.7157	14.2729	0.82
		O_2	6.3931	8.3950	0.76
$Ca(NO_3)_2$	NH_4^+	O_1	374.1421	209.3110	1.79
		O_2	70.4206	31.1056	2.26
	NO_3^-	O_1	13278.3008	1112.4871	11.94*
		O_2	13.4526	5.9193	2.2727
Urea	NH_4^+	O_1	236743.0607	202762.5366	1.17
		O_2	63.8407	125.8041	0.51
	NO_3^-	O_1	132.7640	83.0977	1.60
		O_2	3.4723	13.5189	0.26

*significant at .05 $F_{(6,6)} = 4.28$

means, $S\bar{x}$'s, were calculated. These results, along with confidence intervals are summarized by plot in Table 6.

The control plot had an average NH_4^+-N concentration of 40.15 µg/g of oven dry soil in the O_1 horizon. This is a comparatively high level when contrasted to mineral soils from temperate regions. The NH_4^+-N concentration in the O_2 horizon dropped sharply to 10.75 µg/g. There were no statistically significant trends in NH_4^+-N concentrations in

Table 6. The mean $\bar{x}$, standard error of the mean, $S\bar{x}$, and the 95 percent confidence interval, CI.95, by horizon for the NH_4^+-N and NO_3^--N concentrations in the control $Ca(NO_3)_2$, and urea plots

Plot	Form of N	Horizon	$\bar{x}$ (µg/g)	$S\bar{x}$ (µg/g)	CI.95 (µg/g)
Control	NH_4^+	O_1	40.15	2.50	35.02 to 45.28
		O_2	10.75	1.10	8.45 to 13.01
	NO_3^-	O_1	5.23	0.67	3.86 to 6.60
		O_2	3.79	0.44	2.89 to 4.69
$Ca(NO_3)_2$	NH_4^+	O_1	42.26	2.49	37.15 to 47.37
		O_2	8.83	0.92	6.94 to 10.72
	NO_3^-	O_1	-----	----	----- -----
		O_2	4.02	0.47	3.06 to 4.98
Urea	NH_4^+	O_1	190.70	64.39	58.57 to 322.83
		O_2	16.11	1.33	13.38 to 18.84
	NO_3^-	O_1	6.62	1.48	3.58 to 9.66
		O_2	3.94	0.48	2.96 to 4.92

either horizon over the growing season. These results are illustrated in Figure 6 and summarized in Tables 5 and 6.

Unlike the data reported by Gersper and Arkley (1970), these data are estimates of those concentrations of inorganic nitrogen on the soil exchange complex as well as those in the soil solution. This would account for the NH_4^+-N levels being so much higher than those reported by Gersper and Arkley (1970).

The NO_3^--N plus NO_2^--N (hereafter referred to simply as NO_3^--N concentration) of the untreated plot was measurable although very low. The mean concentration of NO_3^--N in the O_1 horizon was 5.23 µg/g and in the O_2 horizon it was 3.79 µg/g. Again there were no statistically significant trends with time (Figure 6 and Tables 5 and 6). These findings differ with those of previous workers who found no NO_3^--N.

The NH_4^+-N and NO_3^--N concentrations generally decreased with depth with the exception of the IIIO horizon. This was a buried peat horizon and it showed an increase in NH_4^+-N concentration in all plots on July 18 (Table 7). On August 24, the frost line was beginning to rise and this increase in NH_4^+-N was not detected. The significance, if any, of this relationship is obscure at this time.

Plot 251 received 15.5 kg/ha NO_3^--N as $Ca(NO_3)_2$. Assuming even fertilizer distribution this would provide a theoretical maximum concentration of approximately 200 µg/g NO_3^--N in the O_1 horizon. The average concentration on the first sampling day was near 160 µg/g NO_3^--N and was thus within this theoretical limit (Figure 7).

The mean NH_4^+-N concentration in the O_1 horizon was 42.26 µg/g. Statistically, this was in the same population as the O_1 horizon in the control plot (Table 6). There was no significant trend with time (Table 5). The mean NH_4^+-N concentration in the O_2 horizon was 8.83 µg/g, again statistically in the same population as the control plot (Table 6). There was no significant trend with time (Table 5).

The NO_3^--N concentration of the O_1 horizon presented an entirely different picture, however. The initial concentration on the day following fertilizer application was nearly 160 µg/g and it dropped off rapidly

Table 7. Average concentrations of NH_4^+-N and NO_3^--N by horizon for three sampling days on the control, $Ca(NO_3)_2$ and urea plots

Plot	Form of N	Horizon	N Concentration in µg/g		
			6/28/71	7/18/71	8/24/1971
Control	NH_4^+	O_1	48.38	23.59	36.90
		O_2	10.40	5.62	21.37
		IIC_g	5.03	6.25	25.20
		IIIO		11.50	
	NO_3^-	O_1	6.08	6.34	3.25
		O_2	3.50	5.32	5.85
		IIC_g	3.55	3.35	2.80
		IIIO		2.40	
$Ca(NO_3)_2$	NH_4^+	O_1	56.25	48.23	28.28
		O_2	5.45	8.10	17.35
		IIC_g	9.90	8.70	9.90
		IIIO		22.68	7.10
	NO_3^-	O_1	159.08	7.28	3.19
		O_2	4.55	3.60	2.10
		IIC_g	1.20	2.00	2.40
		IIIO		2.78	2.40
Urea	NH_4^+	O_1	734.99	104.38	75.26
		O_2	15.72	22.20	13.42
		IIC_g	22.50	23.70	7.30
		IIIO		40.40	5.45
	NO_3^-	O_1	0.73	4.68	5.18
		O_2	2.82	3.80	5.40
		IIC_g	3.40	2.40	1.40
		IIIO		1.90	3.05

until it was approximately the same as that of the control plot (Figure 7). This trend was statistically significant (Table 5).

An interesting point here is the fact that the increased NO_3^--N concentration does not show up in the O_2 horizon nor in the lower horizons (Figure 7 and Tables 6 and 7). If the NO_3^--N loss in the O_1 horizon were due to leaching alone, one would expect to detect an increase in NO_3^--N concentration in the lower horizons and especially near the frost line.

Of further interest here is the hypothesis of Jerry Brown (1970, Personal Communication) that subsurface water flow is hindered by the presence of the frost line beneath and the ice wedges on the sides of the polygons. If the NO_3^--N was retained in this polygon "basin" for any length of time and was not immediately lost to leaching, then it was lost via some other mechanism. Considering the low oxidation-reduction potentials (Table 2) and Benoit's (1970) low O_2 measurements for this soil (especially the lower horizons), denitrification seems a likely possibility.

Plot 252 received 45 kg/ha NH_4^+-N as urea, assuming complete hydrolysis. This would produce a theoretical maximum concentration of 600 µg/g of NH_4^+-N in the O_1 horizon if the fertilizer were spread evenly. This maximum was grossly exceeded on the first sampling day (Figure 8). In addition, subsample measurements were widely disparate (Appendix III); the seasonal trend in NH_4^+-N concentration was erratic (Figure 8) and the standard error of the mean was very large (Table 6). These facts all seem to indicate an uneven distribution of fertilizer. This

may have been the case on both the $Ca(NO_3)_2$ and the urea plots but since NH_4^+-N is less mobile in the soil than NO_3^--N an uneven distribution would have remained uneven for a longer time in the case of the former.

There were no statistically significant trends in NH_4^+-N concentration in either the 0_1 or the 0_2 horizon (Table 5). However, the large error involved may have masked such a trend.

The mean NH_4^+-N concentration for the 0_1 horizon was 190.70 µg/g and was significantly different from the other plots. The 0_2 horizon had a mean value of 16.11 µg/g and was different from the 0_2 horizon of the control plot and the $CaNO_3$ plot (Table 6). The depth profile seems to indicate an increase in NH_4^+-N for all horizons over the control plot and the $CaNO_3$ plot. The NH_4^+-N seems to have been redistributed somewhat throughout the profile but a large amount remained in the 0_1 horizon (Table 7 and Figure 8).

The NO_3^--N level in the 0_1 and 0_2 horizons of the urea plot were not significantly different from those of the control plot. The NO_3^--N concentration in the 0_1 horizon was 6.62 µg/g and in the 0_2 horizon it was 3.94 µg/g (Table 6). The added NH_4^+-N did not give rise to a detectable increase in nitrification. This is not surprising in the light of the high levels of extractable NH_4^+-N present in the undisturbed system (as estimated by the control plot). The presence of such large amounts of unconverted extractable NH_4^+-N in the control plot is evidence that nitrification is proceeding only slowly.

One additional point which should be mentioned concerning the experimental procedure used in this study is the breakdown of the source

of error. The analyses of variance (Table 5 and Appendix IV) show a consistently large experimental error. Calculations of relative efficiency will show that an increase in the number of samples taken relative to the number of subsamples would reduce the experimental error. As an example, the relative efficiency ratio for having four samples and no subsamples as opposed to the scheme used for this report is 0.55 for NH_4^+-N measurements in the 0_1 horizon of the control plot (a relative efficiency ratio of less than 1.0 indicates that the new sampling scheme will yield more information than the old). A scheme of increased samples and decreased subsamples produces a favorable ratio for all plots and horizons in this report. Subsampling could be dispensed with in favor of taking more samples in the field. This could be facilitated by using a smaller diameter coring device which would allow the use of a finer grid system. In this way more samples could be taken from a polygon without exhausting the area.

Plant uptake of nitrogen

If nitrate levels are low in the tundra coastal plain ecosystem then perhaps the plants in that system are taking up some other form of nitrogen. As previously stated, some plants which live in wet, low 0_2 environments take up NH_4^+-N.

This phase of the experiment was tried only once. In addition to this, the dilution of labelled NO_3^--N and NH_4^+-N was only approximate. In light of these considerations the results of this experiment should be viewed as being qualitative.

The data shown in Table 8 indicate that uptake of both NH_4^+-N and NO_3^--N can be clearly detected after a 24-hour period. Ammonium appeared to be rapidly assimilated into both the live below ground plant parts and the live above ground plant parts as well as into the moss.

The results for NO_3^--N indicated similar uptake rates to NH_4^+-N by the live above ground plant parts while having lower rates for the below ground live plant parts than for NH_4^+-N. Any quantitative comparison of uptake rates at this stage is dangerous in that the $N^{15}O_3^-$-N may have been denitrified and thus lost to the plants before uptake could take place. One interesting point here is that no detectable $N^{15}O_3^-$-N reached the moss layer.

Soil perfusion

The results of the soil perfusion experiment are partially summarized in Appendix V. The conversion of NH_4^+-N to NO_3^--N was negligible for all samples. The NO_3^--N concentrations in the perfusate were so low that color development with the 4-methylumbelliferone method was inconsistent. Reproduceable standard curves could not be developed for these low concentrations.

There was, then, no significant nitrification. Also, the time of sampling during the growing season made no difference in the nitrifying capability of this soil. The NO_2^--N concentration does seem to be greater for the samples taken later in the summer but these measurements are so varied that the trend is not clear.

These results are especially interesting since the perfusion technique involves the bubbling of air through the soil, thus aerating

Table 8. Uptake of $N^{15}H_4^+$-N and $N^{15}O_3^-$-N by moss and *Carex aquatilis* in a 24-hour period

	At % Excess	N Content (%)	Dry Weights (g)	µg N Taken Up/ g Dry Weights
Live above ground NO_3	0.017	2.91	0.198	5.47
Moss layer NO_3	0	1.89	1.085	0
Live below ground O_1 horizon NO_3	0.017	1.72	0.449	3.23
Dead below ground O_1 horizon NO_3	0.012	1.97	2.106	2.62
Live below ground O_2 horizon NO_3	0.076	1.72	0.430	14.5
Dead below ground O_2 horizon NO_3	0.017	1.97	2.216	3.70
Live above ground NH_3	0.012	2.91	0.115	6.98
Moss layer NH_3	0.012	2.23	0.866	5.35
Live below ground O_1 horizon NH_3	0.066	1.59	0.728	20.98
Dead below ground O_1 horizon NH_3	0.012	1.90	1.439	4.56
Live below ground O_2 horizon NH_3	0.289	1.59	0.312	91.9
Dead below ground O_2 horizon NH_3	0.032	1.90	1.522	12.16

Assumed dilutions: $N^{15}H_4^+$-N 50% $N^{15}O_3^-$-N 10%

it quite well. Also, the temperature was around 23 C throughout the experiment and the ammonium sulfate raised the pH of the perfusate solution to a level more conducive to bacterial activity (Table 9).

Table 9. pH of the perfusate at the beginning and end of the perfusion experiment on soil samples from the O_1 horizon of the control plot

Field Sampling Date	pH of Perfusate	
	6/ 8/72	6/20/72
6/28/71	6.20	6.09
7/ 8/71	5.92	5.68
7/ 8/71	6.10	6.30
7/18/71	6.02	6.10
7/18/71	5.82	5.68
7/28/71	5.90	5.80
7/28/71	5.86	6.30
8/ 5/71	6.08	5.98
8/ 5/71	5.84	5.80
8/14/71	5.91	6.29
8/14/71	5.80	6.09
8/24/71	5.97	6.02
8/24/71	5.99	6.04

These considerations indicate a very low or nonexistant indigenous population of nitrifying bacteria. If this is true, than the NO_3^--N which was measured may have been produced by fungi.

Campbell and Lees (1967) reported that some fungi were capable of nitrifying in acid soils. Hora and Iyengar (1960) reported similar findings and they identify two species of fungi (members of the genera *Aspergillus* and *Penicillium*) which have this capability. They also mentioned that fungi do not appear to nitrify well in an ammonium sulfate culture. This could possibly account in part for the negligible NO_3^--N perfusion results. If the nitrifying fungi were present they may not have functioned well in the ammonium sulfate.

Speculations and Recommendations

The results presented in this study suggest some possibilities for future investigation. The following discussion outlines some of these possiblities.

The disparity between this report and that of Gersper and Arkley (1970) as regards NO_3^--N does not necessarily mean that one version or the other is incorrect. The data reported by Gersper and Arkley were NO_3^--N concentrations in the soil solution. The data reported here are measurements of solution plus extractable NO_3^--N. These two quantities are usually thought to be the same because NO_3^--N is an anion and the net residual charge on soil particles is usually negative (cation exchange capacity).

Coleman and Thomas (1967) report the existence of anion adsorption in some soils. They attribute it to Al and Fe^{+3} oxides and soil organic matter and state that sulfate, Cl^- and NO_3^- ions have been shown to be adsorbed in this phenomenon. The soil investigated here may have this capacity. If so, this will have important ramifications in soil data interpretation.

The apparent absence of bacterial nitrifiers raises questions as to why adapted strains are not present. Perhaps the total soil environment is too harsh. Perhaps just one facet of the environment such as O_2 concentration or pH is the critical factor. In order to examine these possibilities, further perfusion experiments with varying temperatures and pH's might be profitable. Injections of *Nitrosomonas* and *Nitrobacter* from cold, acid soils (such as those cultures used by Anderson, Boswell, and Harrison, (1971) might also yield some answers.

If the NO_3^--N concentrations reported here are correct, then the possibility of fungal conversion of NH_4^+-N to NO_3^--N assumes real importance. This possiblity should be investigated.

Since the uptake of nitrogen by vascular plants will play an important role in an attempt to quantify nitrogen transfer rates in the tundra ecosystem, this question should be studied thoroughly. One possible method of study would involve labelled N compounds. It should be pointed out, however, that dilution of the labelled compounds by native forms of N in the soil will have to be evaluated carefully if results are to be considered quantitative.

SUMMARY AND CONCLUSIONS

As part of the Tundra Biome ecosystem analysis project, this study was designed to examine the inorganic nitrogen status of a soil of the tundra coastal plain. Of particular interest were the inorganic nitrogen transfers taking place in the soil and at the soil-plant interface. Specifically, this experiment was designed to measure the NH_4^+-N and NO_3^--N concentrations in the soil, to determine if nitrification was taking place in this soil, and to determine if the vascular plants of the wet tundra coastal plain had the capability of assimilating NH_4^+-N.

The *in situ* level of extractable NH_4^+-N was approximately 40 µg/g in the O_1 horizon and 10 µg/g in the O_2 horizon. NO_3^--N was present in this system, though in low amounts. The extractable NO_3^--N concentration was approximately 5 µg/g in the O_1 horizon and 4 µg/g in the O_2 horizon.

The presence of even small amounts of NO_3^--N indicates that nitrification is taking place in this system. However, perfusion results indicate either a very low or nonexistant indigenous population of nitrifying bacteria. The reasons for this are speculation at this point but the soil environment is a harsh one for nitrifying bacteria. This soil is cold, very wet, acid, and poorly aerated. It is possible that a low level of nitrification is being conducted by fungi instead of bacteria. Such activity has been previously reported and should be investigated for the arctic coastal plain.

If NO_3^--N were the sole source of plant nitrogen in the tundra system one might expect nitrogen to be limiting to plant growth. Preliminary qualitative results from an N^{15} uptake experiment indicate, however, that vascular plants in the tundra system will readily take up NH_4^+-N, an abundant source of nitrogen, as well as NO_3^--N. A quantitative examination of nitrogen uptake rates would be very valuable for the future workers in this area.

Future workers in this area may find the following suggestions useful. It is recommended that analysis be completed as soon as possible after sampling. This will require a great deal of advance preparation but the shipping, storing, and handling of frozen samples are costly, tedious, and fraught with risks of error.

Secondly, it is likely that experimental error can be reduced significantly by taking more samples and fewer subsamples. This could be facilitated by using a smaller diameter coring device.

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APPENDICES

Appendix I

Unpublished Data by Gersper and Arkley[a]

Average values of parameters from five site 2 control plots by sampling dates (PPM in soil solution)

PARAMETER	DEPTH (cm)	DATE 6/18	6/26	7/6	7/16	7/26	8/6	8/15	8/25
Soil pH	0- 5	5.4	5.3	5.5	5.2	5.4	5.1	5.2	5.3
	5-10	---[b]	5.3	5.6	5.4	5.5	5.4	5.4	5.5
	10-15	---	---	5.4	5.6	5.6	5.5	5.4	5.5
Soil Solution pH	0- 5	6.3	6.1	5.9	6.0	5.9	6.1	6.0	6.1
	5-10	---	5.9	5.5	6.0	6.0	6.1	6.0	6.0
	10-15	---	---	5.7	5.7	5.8	6.0	5.8	5.7
Al	0- 5	1.1	1.2	1.9	1.8	3.9	0.9	1.8	1.3
	5-10	---	2.1	1.7	2.9	1.8	1.1	3.8	2.9
	10-15	---	---	1.5	3.9	2.4	2.2	3.6	3.1
FE^{+2}	0- 5	0.20	0.26	0.28	0.63	0.48	0.30	0.20	0.29
	5-10	---	0.52	0.27	0.64	0.44	0.41	0.49	0.41
	10-15	---	---	0.21	0.94	0.75	1.02	0.45	0.55
FE^{+3}	0- 5	2.9	5.1	7.2	7.1	7.2	4.5	7.1	5.0
	5-10	---	6.7	4.1	6.0	4.1	3.3	12.0	4.8
	10-15	---	---	3.4	7.5	5.2	4.4	9.1	8.3
NH_3-N	0- 5	3.0	2.8	4.4	4.8	5.2	2.4	5.1	3.7
	5-10	---	3.6	4.5	6.6	4.0	3.9	8.1	6.2
	10-15	---	---	5.6	14.7	5.9	6.4	8.6	7.6
PO_4	0- 5	0.31	0.28	0.28	0.23	0.38	0.16	0.22	0.23
	5-10	---	0.60	0.23	0.21	0.39	0.27	0.24	0.21
	10-15	---	---	0.24	0.26	0.25	0.37	0.48	0.33
Si	0- 5	3.7	5.2	7.1	7.1	6.8	5.8	5.4	6.5
	5-10	---	9.1	9.9	9.7	9.4	9.2	8.6	9.9
	10-15	---	---	10.3	12.3	9.4	10.1	12.0	11.8
Ortho-PO_4	0- 5	---	0.10	0.11	0.14	---	0.05	0.10	0.11
	5-10	---	0.10	---	0.16	---	0.08	0.09	0.13
	10-15	---	---	---	0.20	---	0.08	0.32	0.10
NA	0- 5	10.5	10.7	10.7	9.0	13.9	11.5	10.8	10.7
	5-10	---	17.7	12.5	10.8	14.5	12.3	12.5	11.6
	10-15	---	---	15.6	12.7	15.3	15.3	13.7	12.0
K	0- 5	1.1	0.8	1.3	1.5	0.7	0.6	0.7	0.4
	5-10	---	1.3	2.5	0.9	0.8	0.5	0.5	0.4
	10-15	---	---	1.9	1.3	1.0	1.0	0.5	0.5

CA	0- 5	8.1	8.8	7.1	8.6	8.3	7.2	8.1	6.5
	5-10	---	10.9	8.9	10.0	8.0	8.0	8.6	9.3
	10-15	---	---	7.8	10.0	10.7	13.6	10.2	10.3
MG	0- 5	4.1	4.3	3.7	3.4	5.1	3.8	4.6	3.5
	5-10	---	5.7	4.2	4.4	3.9	3.7	4.9	4.8
	10-15	---	---	4.2	5.6	5.3	5.8	4.9	5.1
Moisture	0- 5	611	429	375	364	298	282	288	332
at 70 °C	5-10	---	214	142	136	121	106	116	123
(G H20/100G Soil)	10-15	---	---	121	151	135	110	117	137
Temperature	0- 5	2.2	7.0	4.4	5.6	4.5	3.6	3.8	2.9
(° C)	5-10	---	2.4	2.2	4.0	2.3	2.2	2.5	2.3
	10-15	---	---	1.0	2.6	1.4	1.4	1.6	2.3
Bulk Density	0- 5	0.17	0.31	0.35	0.18	0.23	0.26	0.21	0.32
(G/CC)	5-10	---	0.47	0.69	0.31	0.38	0.41	0.32	0.60
	10-15	---	---	0.67	0.28	0.28	0.37	0.31	0.57

[a] These data are preliminary and subject to later revision or correction; no part of these tables may be reprinted or used in any other publication without the written permission from either Rodney J. Arkley or Paul L. Gersper, Department of Soils and Plant Nutrition, University of California, Berkeley, California 94720

[b] Data not available

Appendix II

Unpublished Data by Gersper and Arkley[a]

Average carbon, nitrogen, and C/N ratios in tesseras, sites 1 and 2[b]

SITE	DEPTH	N	AVE PCT CARBON	AVE PCT NITROGEN	AVE PCT C /AVE PCT N	AVERAGE C/N
1	VEGETATION	6	26.8	1.04	25.8	27.7
1	0- 5 CM	6	15.6	0.75	20.8	21.2
1	5-10 CM	6	15.4	0.80	19.3	19.4
1	10-15 CM	6	12.6	0.64	19.7	18.6
1	15-20 CM	6	12.7	0.73	17.4	18.0
1	20-25 CM	6	12.6	0.65	19.4	19.7
1	25-30 CM	5	11.6	0.69	16.8	17.5
1	30-35 CM	4	13.3	0.69	19.3	19.7
2	VEGETATION	22	35.0	1.36	25.7	26.1
2	0- 5 CM	22	29.4	1.43	20.6	21.0
2	5-10 CM	22	19.0	0.97	19.6	20.1
2	10-15 CM	22	14.7	0.70	21.0	21.5
2	15-20 CM	22	17.2	0.88	19.5	19.6
2	20-25 CM	21	19.5	0.90	21.7	21.7
2	25-30 CM	15	19.0	0.82	23.2	24.0
2	30-35 CM		17.7	0.89	19.9	20.0

[a]These data are preliminary and subject to later revision or correction; no part of these tables may be reprinted or used in any other publication without the written permission from either Rodney J. Arkley or Paul L. Gersper, Department of Soils and Plant Nutrition, University of California, Berkeley, California 94720

[b]Based on samples dried at 30 C. Values will be adjusted to a 70 C CR 105 C dry weight when these data become available

Appendix III

Subsample measurements of pH, percent moisture by weight (ω), and NH_4^+-N and NO_3^--N concentration for plots 250, 251, and 252

DATE	SPQ	DEPTH (cm)	pH_a	pH_b	ω (%)	µg/g of Ov Dr Soil			
						Subsample B		Subsample A	
						NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N
6-28-71	25031	0- 4	5.50	5.50	745	4.80	69.00	14.55	64.05
		4-10	5.45	5.40	113	2.80	13.7	2.40	8.90
		10-14	5.40	5.45	89	4.50	6.00	4.50	4.00
	25021	0- 5	5.10	5.25	802	1.20	32.70	3.75	27.75
		5-11	5.20	5.20	505	3.60	8.10	5.20	10.90
		11-14	5.45	5.40	80	1.20	6.50	4.00	3.60
	25194	0- 4	5.35	5.45	769	139.80	61.05	226.80	69.00
		4-10	5.15	5.15	401	6.50	4.80	3.60	6.90
		10-15	5.40	5.35	155	2.00	8.09	0.40	10.90
	25153	0- 5	5.30	5.15	690	114.90	33.30	154.80	61.65
		5-11	5.35	5.40	384	2.80	7.30	5.30	2.80
	25217	0- 4	5.45	5.40	557	2.90	157.20	-0.40	82.30
		4-10	5.50	5.50	324	1.20	24.20	2.00	11.70
		10-15	5.50	5.45	80	4.00	36.30	4.00	39.50
	25263	0- 5	6.20	6.15	796	-3.00	1608.75	-4.80	1091.70
		5-10	5.25	5.00	402	4.00	10.10	4.10	16.90
		10-15	5.45	5.45	81	2.80	7.70	2.80	6.50
7- 8-71	25005	0- 4	5.25	5.25	569	3.00	57.45	9.75	56.85
		4-10	5.35	5.40	394	4.00	8.10	1.20	12.10
	25025	0- 4	5.30	5.40	571	4.95	42.90	7.20	39.30
		4- 9			272	4.50	4.80	3.20	8.10
	25126	0- 4	5.50	5.50	509	89.55	38.10	81.75	61.05
		4- 9	5.45	5.45	354	2.00	3.60	2.50	5.20
	25172	0- 4	5.30	5.30	598	3.00	60.45	2.40	41.10
		4- 9	5.40	5.50	199	3.15	9.00	5.55	6.00
	25209	0- 7	5.10	5.10	558	25.35	35.10	3.60	50.25
		7-13			381	2.40	8.90	1.60	8.10
	25255	0- 5	5.30	5.10	498	3.60	67.80	3.60	60.45
		5-10	5.20	5.10	317	5.50	12.10	6.00	9.30
7-18-71	25042	0- 4	5.45	5.50	585	7.95	26.55	3.00	33.30
		4- 8	5.50	5.40	288	3.60	7.30	3.30	5.60
		8-16	5.35	5.40	75	2.80	6.90	5.20	7.70
		16-23	5.60	5.60	85	3.60	10.50	2.80	10.90

7-18-71	25027	0- 6	5.20	5.20	664	7.80	19.95	6.60	14.55
		6- 9	5.20	5.20	360	3.30	4.00	4.50	5.60
		9-13	5.55	5.55	69	3.30	4.80	2.10	5.60
		13-21	5.25	5.30	90	1.20	12.10	2.00	12.50
	25180	0- 4	5.05	5.10	667	7.20	36.30	2.55	45.30
		4- 8	5.30	5.30	397	1.60	7.30	3.60	7.30
		8-13	5.40	5.40	93	2.40	7.30	0.40	8.90
		13-20	5.15	5.20	135	5.60	8.90	1.20	10.10
	25135	0- 4	5.05	5.05	604	12.75	58.05	6.60	53.25
		4- 9	5.00	5.05	355	4.40	8.90	4.80	8.90
		9-16	5.30	5.35	71	2.40	10.10	2.80	8.50
		16-22	5.35	5.35	68	3.30	31.40	0.00	40.30
	25236	0- 5	5.40	5.40	616	6.00	32.30	4.90	27.40
		5- 9	5.25	5.35	377	2.00	23.80	3.60	25.40
		9-16	5.45	5.00	89	0.40	39.10	2.80	37.10
		16-24	5.20	5.15	105	-2.40	56.40	-1.20	53.20
	25242	0- 5	5.30	5.05	648	1.20	187.50	6.60	169.95
		5- 8	5.10	5.10	318	4.40	20.60	5.20	19.00
		8-13	5.45	5.55	86	3.60	10.10	2.80	8.50
		13-24	5.35	5.45	72	2.80	27.80	4.80	24.20
7-28-71	25083	0- 5	5.20	5.00	843	4.05	42.90	7.80	32.70
		5-10	5.20	5.20	278	3.20	14.10	3.70	16.10
	25077	0- 6	5.10	5.05	774	2.40	32.10	10.80	55.05
		6-10	4.95	4.95	383	3.60	8.10	1.60	10.50
	25147	0- 5	5.30	5.20	701	7.35	42.90	6.75	47.10
		5- 9	5.20	5.35	389	2.00	8.10	3.20	6.50
	25119	0- 4	5.05	5.10	627	3.60	27.40	3.60	24.60
		4-10	5.20	5.15	353	2.40	10.90	0.80	14.10
	25261	0- 4	5.40	5.35	671	10.95	97.35	6.15	99.15
		4-10	5.40	5.50	266	3.60	9.30	6.00	9.30
	25216	0- 5	5.40	5.35	568	29.70	264.30	35.35	260.10
		5-11	5.30	5.30	303	1.70	17.70	8.50	28.20
8- 5-71	25054	0- 4	5.15	5.10	627	1.35	46.50	3.60	56.85
		4-10	5.40	5.45	333	3.20	8.50	1.60	11.30
	25012	0- 4	5.15	5.15	669	4.20	41.70	0.00	37.50
		4-10	5.60	5.50	362	3.70	3.20	3.60	7.70
	25183	0- 5	5.20	5.20	662	6.75	43.50	1.20	43.50
		5-10	5.10	5.05	390	4.50	5.20	8.10	5.60
	25185	0- 5			694	-3.00	42.30	3.75	27.15
		5-10			373	4.90	5.60	3.70	5.60
	25234	0- 4	5.10	5.15	625	-0.40	80.60	4.00	109.30
		4- 9	5.15	5.20	387	7.70	24.20	4.50	28.60
	25277	0- 5	5.00	5.00	913	-0.60	75.00	3.60	72.00
		5-10	5.40	5.05	423	0.80	13.30	1.60	10.10
8-14-71	25045	0- 4	5.50	5.35	606	0.00	34.50	6.60	32.10
		4- 9	5.35	5.30	376	2.40	6.50	2.00	6.90
	25086	0- 4	5.25	5.30	712	5.55	43.50	11.55	36.90
		4- 9	5.15	5.05	400	2.80	12.50	3.20	12.90
	25174	0- 5	5.50	5.50	613	12.75	22.95	6.00	36.30
		5-11	5.40	5.30	397	6.00	9.70	3.60	11.30

8-14-71	25168	0- 4	5.60	5.50	755	6.60	47.85	2.55	45.90
		4- 9	5.35	5.40	446	4.50	8.40	5.60	8.90
	25289	0- 5	5.05	5.00	724	5.55	65.25	1.80	48.45
		5-10	5.30	5.35	446	1.60	8.10	3.60	7.30
	25219	0- 5	5.40	5.20	661	8.40	145.20	11.55	151.20
		5-11	5.05	5.05	390	4.40	25.00	2.80	26.20
8-24-71	25076	0- 5	5.05	5.05	677	4.50	27.40	4.00	26.60
		5-10	5.30	5.20	425	0.00	15.70	3.60	10.90
		10-22	5.65	5.65	77	2.80	28.60	2.80	21.80
	25072	0- 5	5.10	5.15	792	2.55	47.10	1.95	46.50
		5-10	5.40	5.40	405	10.80	16.95	9.00	14.55
	25107	0- 5	5.25	5.25	651	2.40	25.35	2.40	29.10
		5- 9	5.15	5.15	369	1.60	22.60	0.80	24.20
	25131	0- 5	5.30	5.20	592	1.20	31.50	6.75	27.15
		5- 9	4.85	4.90	424	4.40	10.10	1.60	12.50
		9-22	5.40	5.30	48	2.40	8.50	2.40	11.30
		22-27	5.65	5.65	93	2.00	7.30	2.80	6.90
	25241	0- 4	5.15	5.20	552	6.15	99.15	-3.60	102.15
		4- 8	5.35	5.35	381	2.40	12.10	1.20	12.50
	25281	0- 5	5.20	5.15	748	5.40	53.85	9.15	45.90
		5- 9	5.30	5.30	603	12.00	14.55	6.00	14.55
		9-15	5.40	5.40	118	2.00	6.50	0.80	8.10
		15-20	5.35	5.40	119	2.10	4.40	4.00	6.50

Appendix IV

Analyses of Variance by Plot, Horizon, and Form of N for NH_4^+-N and NO_3^--N Measurements Over the Growing Season in the Control Plot, the $Ca(NO_3)_2$ Plot and the Urea Plot

Control plot, NH_4^+-N, O_1 horizon

Source	df	SS	MS	F
Total	27	4726.3574		
Time	6	1900.1668	316.6945	0.9178
Sample	1	284.4844	284.4844	
Error	6	2070.2700	345.0450	
Subsample	14	471.4362	33.6740	

Control plot, NH_4^+-N, O_2 horizon

Source	df	SS	MS	F
Total	27	4157.1950		
Time	6	632.2600	105.3767	3.8950
Sample	1	72.9657	72.9657	
Error	6	162.3243	27.0541	
Subsample	14	53.8950	3.8496	

Control plot, NO_3^--N, O_1 horizon

Source	df	SS	MS	F
Total	27	336.7974		
Time	6	70.2943	11.7157	0.8208
Sample	1	1.0222	1.0222	
Error	6	85.6372	14.2729	
Subsample	14	179.8437	12.8469	

Control plot, NO_3^--N, O_2 horizon

Source	df	SS	MS	F
Total	27	144.3186		
Time	6	38.3586	6.3931	0.7615
Sample	1	37.0300	37.0300	
Error	6	50.3700	8.3950	
Subsample	14	18.5600	1.3257	

$Ca(NO_3)_2$ plot, NH_4^+-N, O_1 horizon

Source	df	SS	MS	F
Total	27	4685.8417		
Time	6	2244.8523	374.1421	1.7875
Sample	1	14.0722	14.0722	
Error	6	1255.8660	209.3110	
Subsample	14	1171.0512	83.6465	

$Ca(NO_3)_2$ plot, NH_4^+-N, O_2 horizon

Source	df	SS	MS	F
Total	27	642.4011		
Time	6	422.5236	70.4206	2.2639
Sample	1	3.0890	3.0890	
Error	6	186.6335	31.1056	
Subsample	14	30.1550	2.1539	

$Ca(NO_3)_2$ plot, NO_3^--N, O_1 horizon

Source	df	SS	MS	F
Total	27	93672.6067		
Time	6	79669.8048	13278.3008	11.9357
Sample	1	2618.0558	2618.0558	
Error	6	6674.9224	1112.4871	
Subsample	14	4709.8237	336.4160	

$Ca(NO_3)_2$ plot, NO_3^--N, O_2 horizon

Source	df	SS	MS	F
Total	27	166.3124		
Time	6	80.7155	13.4526	2.2727
Sample	1	0.8401	0.8401	
Error	6	35.5156	5.9193	
Subsample	14	49.2412	3.5172	

Urea plot, NH_4^+-N, O_1 horizon

Source	df	SS	MS	F
Total	27	3132818.7274		
Time	6	1420458.3643	236743.0607	1.1676
Sample	1	358380.0022	358380.0022	
Error	6	1216575.2197	202762.5366	
Subsample	14	137405.1412	9814.6529	

Urea plot, NH_4^+-N, O_2 horizon

Source	df	SS	MS	F
Total	27	1337.7018		
Time	6	383.0443	63.8407	0.5075
Sample	1	20.7432	20.7432	
Error	6	754.8243	125.8041	
Subsample	14	179.0900	12.7921	

Urea plot, NO_3^--N, O_1 horizon

Source	df	SS	MS	F
Total	27	1666.0925		
Time	6	796.5838	132.7640	1.5977
Sample	1	41.6050	41.6050	
Error	6	498.5862	83.0977	
Subsample	14	329.3175	23.5226	

Urea plot, NO_3^--N, O_2 horizon

Source	df	SS	MS	F
Total	27	177.6486		
Time	6	20.8336	3.4723	0.2568
Sample	1	19.8915	19.8915	
Error	6	81.1134	13.5189	
Subsample	14	55.8100	3.9864	

Appendix V

Tables

Table 10. Ammonium-N concentration (μg/g) in perfusate *vs* time for perfusion of ammonium sulfate through soil samples from the control plot

Field Sampling Date	Sampling Date of Perfusate						
	6- 8-72	6-10-72	6-12-72	6-14-72	6-16-72	6-18-72	6-20-72
6-28-1971	9104.05	9441.23	9238.92	12813.10	8766.86	8025.05	6878.61
7- 8-1971	9892.79	8801.17	8323.59	8323.59	8391.81	8118.91	7777.78
7- 8-1971	8470.92	9193.26	8142.59	8208.26	8536.59	8405.25	7682.93
7-18-1971	22214.61	20776.26	20776.26	19817.35	21415.53	20616.44	17100.46
7-18-1971	9881.47	9428.88	9655.17	10032.33	9353.45	8448.28	9806.03
7-28-1971	21100.48	23110.05	25454.55	21435.41	19090.91	18253.59	17416.27
7-28-1971	12215.35	11349.01	11349.01	11955.45	10136.14	10396.04	7970.30
8- 5-1971	11328.50	10567.63	10314.01	9214.98	10483.09	9299.52	6763.29
8- 5-1971	18315.41	18064.52	16810.04	16684.59	14928.32	15806.45	13799.28
8-14-1971	12809.28	12538.66	11726.80	11546.39	12448.45	10463.92	9110.82
8-14-1971	9355.35	7374.21	7319.18	7044.03	7539.31	7264.15	5448.11
8-24-1971	12438.02	12341.60	12341.60	12534.44	12148.76	11763.08	10316.86
8-24-1971	8721.31	7229.51	7631.15	6770.49	6655.74	7172.13	5106.56

Table 11. Nitrite -N concentration (μg/g) in perfusate *vs* time for perfusion of ammonium sulfate through soil samples from the control plot

Field Sampling Date	Sampling Date of Perfusate						
	6- 8-72	6-10-72	6-12-72	6-14-72	6-16-72	6-18-72	6-20-72
6-28-1971	0.0668	0.0235	0.0235	0.1375	0.1375	0.2201	0.1375
7- 8-1971	0.3856	0.2410	0.2410	0.1170	0.0	0.0	0.0
7- 8-1971	0.0684	0.0684	0.1940	0.0684	0.0	0.0	0.0
7-18-1971	0.0000	0.0000	0.0	0.0	0.0281	0.0	0.0
7-18-1971	0.1051	0.0000	0.1051	0.0371	0.0	0.0	0.0
7-28-1971	0.1095	0.0	0.0386	0.0	0.0	0.0	0.0
7-28-1971	0.0000	0.2113	0.0	0.1026	0.0	0.0	0.0
8- 5-1971	0.2295	0.0699	0.0245	0.0	0.0	0.0	0.0
8- 5-1971	0.0000	0.0	0.0	0.0289	0.0818	0.0	0.0
8-14-1971	0.0000	0.4186	0.0	0.0	0.0	0.0	0.0
8-14-1971	0.0828	0.0828	0.0292	0.0	0.0	0.0	0.0
8-24-1971	0.0323	0.0	0.0915	0.0	0.0	0.0	0.0
8-24-1971	0.0	0.3136	0.0	0.0	0.0	0.0	0.0

VITA

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