The Effect of Nitrogen and Phosphorous Fertilization on the Cation Exchange Capacity of Arctic Soils and Plant Nutrient Content

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Abstract:

The organic horizon of three arctic soils across a pH gradient were compared to determine whether there was a relationship between soil pH and the quantity of base cations in both the organic horizon and the plant material. In addition, all three sites were fertilized with nitrogen (NH_4NO_3), phosphate (P_2O_5) and both nitrogen and phosphate to observe the affect of nutrient addition on the base cation levels of soils and plants across a pH gradient.

The organic horizon had a pH value of 3.4, 5.3 or 6.4. In a lower initial pH led to lower levels of base cations. Nitrogen addition led to an acidification of the soil and a reduction in the number of base cations. Phosphorous addition was found to increase the pH and the cation concentrations of the soil. Nitrogen plus phosphorous addition led to both increases and decreases in both the soil pH and cation concentration. Both calcium and magnesium concentrations within the soil were significantly correlated with the soil pH.

The soil pH affected the calcium concentration within the three plants species sampled *Eriophorum vaginatum*, *Cassiope tetragona* and *Betula nana*, but did significantly affect magnesium, potassium and sodium concentration. Calcium had a significant positive correlation with both soil pH and soil calcium concentration and was very susceptible to changes in the pH of the soil.

Introduction:

The glacial advances over the past hundred thousand years have had a lasting impact upon the arctic region, depositing a layer of glacial till and stratifying the ages of the soil in the Alaskan arctic tundra, creating a large scale patchwork of soil heterogeneity(Arctic LTER Homepage). The litter produced by vegetation growing on the glacial till decomposes slowly creating a thick organic mat that is water saturated. The pH of this organic material has been shown to decrease over time (Viereck 1966). Therefore soils of differing pH exist within the arctic. The pH level of the soil affects the concentration of the other base cations since the soil can only retain a limited quantity known as the cation exchange capacity. The physical properties of the cation and the amount of external input of cations determine their relative quantities within the soil matrix. The lyotropic series is the order in which positively charged cations replace one another in the soil: Al^{+3}>H^{+}>Ca^{+2} >Mg^{+2}>K^{+}> NH_4^{+}>Na^{+}. Therefore more acidic soils with higher hydrogen ion content should have relatively lower quantities of the other cations (Gaston et al 1992).

Some cations; Ca^{+2}, Mg^{+2}, K^{+}, NH_4^{+} are macronutrients which are necessary for plant growth and reproduction (Hopkins page 64). Since nitrogen is the macronutrient demanded in the highest quantity it is the nutrient most likely to limit plant growth (Hopkins page 87). Nitrogen is made available to plants by the decomposition of litter material contained within the organic horizon.

In the arctic, nitrogen is available in limited quantities to the plants due to the slow decomposition rate of the organic material (Chapin and Bledsoe 1992). Even in landscapes characterized by thick organic horizons, such as the moist tussock tundra

(Shaver and Chapin 1992) the confounding limitations of a short growing season, low temperatures during the growing season and saturation of the organic horizon during most of the growing season (Shaver et al 1986), have slowed the decomposition rate of the organic material. How would this system react to increased availability of nitrogen?

Experiments that have fertilized the tundra with ammonium nitrate (NH_4NO_3) resulted in a doubling of *Eriophorum vaginatum* biomass in just three years (Shaver et al 1986). The addition of only phosphorous and only potassium had little effect on the biomass of *Eriophorum vaginatum* (Shaver et al 1986), indicating that the moist tussock tundra is primarily nitrogen limited. Although the biomass of individual species has increased, fertilization with ammonium nitrate has resulted in small increases in net primary productivity of the system because the species composition changed dramatically with nutrient addition (Chapin et al 1995).

The changing of the species composition and the addition of large quantities of ammonium nitrate to the soil could alter the chemical properties of the organic soil horizon. The addition of ammonium, a weak acid, will increase hydrogen ion concentration of the soil, lowering the pH. External inputs of ammonium into the system will also disrupt the H+ ion cycling within the ecosystem. The nitrification of ammonium into nitrate results in a net increase of 1 unit of H+ per unit of ammonium nitrified (Binkley and Richter 1987). The external input of hydrogen ions has been shown to reduce the quantity of base cations within the organic horizon. (Schlesinger page 86-88).

Sarooshi et al (1994) found that fertilizing with NH_4NO_3 increased the acidity of the upper 10 centimeters of the soil horizon. The acidification of the soil caused a reduction in the quantity of exchangeable Ca^{+2} , Mg^{+2}, K^{+}, and Na^{+}. Hetrick and Schwab (1992) found that the long term use of NH_4NO_3 led to a decrease in pH through the nitrification of the soil, causing a reduction in Al^{+3} and Ca^{+2} in the soil as they were removed within the groundwater.

The increased abundance of this weak acid is expected to replace the other base cations within the organic horizon. Additionally there are very few inputs of base cations into the arctic system due to the slow rate of weathering of the parent material (Munroe 1996). With a smaller pool of base cations within the soil, it is anticipated that the plant vascular tissue should also contain lower cation levels. But, the stimulation of plant growth due to increased nitrogen availability should cause an increased demand for the base cations.

Therefore the increased availability of both ammonium and phosphate should have a mixed effect upon the cation levels within the soil and the plant material. After only a three year study, Chapin et al (1995) found that three years of both ammonium nitrate and phosphorous fertilization increased the quantity of Ca, Mg and K in the vascular tissue of the plants in the moist tussock tundra. It is important to tease out the effects of only nitrogen and only phosphorous on the soil and plant material in order to understand the dynamics of the nutrient cycle within the moist tussock tundra.

This study will compare three sites with different pH levels and examine the cation concentration within the upper 10 cm of the soil horizon and the plant vascular tissue. The effect of nitrogen and phosphorous fertilization on the pH and the base cation levels within the soil and the plant material will also be examined at three sites to determine whether there is a relationship the between the initial pH level and the cation concentration within the plants and the soils.

Plots fertilized with nitrogen, phosphorous, nitrogen plus phosphorous and no treatment will be used to compare the relative quantities of Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+} in the soil and in the plant material. Several questions will be addressed:

- Does the pH of the soil affect the quantity of cations within the soil and plant material? Is there a discernible trend?
- Is there a correlation between cation availability within the soil and the concentration within the plant material?
- What will be the effect of nitrogen, phosphorous and nitrogen plus phosphorous fertilizers have on the cation quantity within the soil and the plant material?
- Is the treatment effect uniform across the sites?

Method:

<u>Site and treatment:</u>

The study was conducted at the Toolik Lake Long Term Ecological Research Site in the northern foothills of the Brooks Range in the Alaskan arctic (68°38’ N, 149°34’1 W elevation 760m) on plots located on the west bank of the Sagavanirktok River and near Toolik Lake. The study sites have been classified as moist tussock tundra, the most common vegetation type of the northern foothills (Shaver and Chapin 1991). The vegetation is dominated by cotton tussock *Eriophorum vaginatum*, a sedge, which grows to between 10-30cm in height (Shaver and Chapin 1991). Tussock tundra occurs primarily on gently rolling topography underlain by glaciated and non-glaciated silty gravely soil. The upper 0-20 cm of the soil horizon is comprised of a saturated organic matter (Shaver and Chapin 1991).

At Toolik Lake, the moist tussock tundra has been divided into two subcategories; acidic and non-acidic, based upon the pH of the soil and time since the retreat of the last glacier (Shaver personal (Walker et al 1998). At each of these locations, four replicate treatment blocks were established; in 1988 at the acidic tussock site and 1997 for the non-acidic tussock site, while at the Sagavanirktok River two replicate blocks were established in 1986. The treatment plots within each block are 5 x 20 m^2 with 1 m buffer strips between plots. The plots within each block were randomly assigned one of four treatments; nitrogen addition (N), phosphorous addition (P), both nitrogen and phosphorous addition (NP), and no treatment (Control). The fertilizer has been applied each year immediately following snowmelt: 10 g/m^2 NH_4NO_3 and/or 5 g/m^2 P_2O_5 (Chapin et al 1995). There has also been nitrogen plus phosphorous fertilizer applied to four plots within the acidic tussock tundra since 1997, as part of an unrelated predator exclusion experiment (Shaver personal communication).

<u>Field and Laboratory Method:</u>

Soil samples:

The upper 10 centimeters of the organic horizon in three treatment blocks at the acidic and non-acidic sites and the two blocks at the Sagavanirktok River site were sampled using a 5.5 centimeter diameter corer. From each plot three to four soil cores were taken within the inter-tussock spaces between late July and early August 1999. An additional core was extracted and the depth of the hole noted in order to calculate bulk density.

The soil was composited by plot and the roots were removed. An eight gram subsample (fresh weight) of each composite sample was mixed with 60 ml of 2N KCl, shaken for 1 hour and then the pH was measured.

The remaining soil from each composite was dried at 40 °C and then sieved through a 2mm screen. A 2 gram subsample was mixed with 100 ml of 1M NH_4Cl, shaken for 1 hour, filtered (Whatman GF/F glass microfibre filter) and then the base cation concentration was determined using ICP analysis (Thermo Jarrell Ash 3580 Dual Spectrometer Sequential and Simultaneous).

Plant Samples:

From each plot a sample of *Eriophorum vaginatum, Cassiope tetragona and Betula nana* was collected. There was no *Betula* at the non-acidic site and no *Cassiope* at the Sagavanirktok River site or at the 12 year nitrogen plus phosphorous addition at the acidic tussock site.

The new leaves were removed, dried at 55°C, ground to a consistent texture (Thomas Wiley Intermediate Mill 3383-L10). A 0.5 g subsample (dry weight) was mixed with 10 ml of 70% HNO_3 and digested for 40 minutes at 200 °C (Ethos 1600 Advanced Microwave Lab Station). The resulting digest was diluted 1:7 by weight and then 1:10 by volume for Ca, Mg, and K analysis. The concentration of Ca, Mg, K, and Na in the digest was determined using Atomic Absorption Spectrophotometery (Perkins-Elmer 2380).

Statistical Analysis:

The mean, standard deviation, standard error and coefficient of variation were calculated for the pH of the soil, the cation content of the soil, and the cation content of the plant.

An Analysis of Variance (ANOVA) was used to determine whether the site and/or treatments had a statistically significant effect upon the pH of the soil, the cation levels within the soil and the cation concentration of plant material. The parameters of the ANOVA were Site and Site Nested in Treatment, for a Fixed Effect. A pair-wise test was separately performed post-hoc for each cation to determine which treatments plots contained soil and plants that were statistically different from plants and soil which received different treatments.

In order to determine the relationship between the pH and the cation levels within the soil and the plant material, and the relationship between the cation content of the soil and the plant material regression analysis was used whereby the equation of the line, an R^2 value and a p value were calculated.

Results:

The control plots at the three study sites have significantly different ($p<.05$) pH values: 6.2 at the non-acidic site, 5.3 at the Sagavanirktok River site and 3.4 at the acidic site (Table 1). This significant difference in pH should determine the cation levels within the soil organic horizon and the plant material.

The addition of ammonium nitrate (NH_4NO_3) and phosphate (P_2O_5) significantly altered the pH of the organic horizon ($p<.05$). At the non-acidic and Sagavanirktok River sites the NH_4NO_3 addition acidified the soil, decreasing the pH, except at the acidic site where the pH increased significantly (Chart 1). At all three sites the P_2O_5 addition made the soil more basic, significantly increasing the pH. Nitrogen plus phosphorous addition resulted in a slight increase in pH at the acidic and non-acidic sites while pH decreased at the Sagavanirktok River site.

The Sagavanirktok River has been fertilized with nitrogen plus phosphorous for the longest period of time and the pH of the soil has decreased by 0.4 relative to the control, while at the acidic site 3 years of nitrogen plus phosphorous addition has raised the pH 0.2 and 12 years of nitrogen plus phosphorous addition has only raised the pH by 0.1. Three years of nitrogen plus phosphorous addition at the non-acidic site raised the pH by 0.1 while three years of fertilization at the acidic site raised the pH by 0.2. Table 2 denotes which treatments caused statistically significant changes in the pH.

Table 1: At each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). The table depicts the number of years of fertilization and the pH of the soil using a KCl extraction for the upper 10 cm of the organic horizon at each site and for each treatment. The plus and minus represents the Standard Error. Statistical significance was determined using an ANOVA. Among the control plots for each treatment, sites that differ significantly by $p<0.05$ are denoted with ~. Among the 3 year nitrogen plus phosphorous treatments, sites that differ significantly by $p<0.05$ are denoted with #.

	Years of Treatment	pH using KCl Extraction
Non-Acidic Tussock		
Control	3	6.2 ± .02~
Nitrogen	3	5.9 ± .08
Phosphorous	3	6.0 ± .08
Nitrogen and Phosphorous	3	6.3 ± .08#
Sagavanirktok River		
Control	14	5.3 ± .20~
Nitrogen	14	5.1 ± .08
Phosphorous	14	5.3 ± .16
Nitrogen and Phosphorous	14	4.9 ± .04
Acidic Tussock		
Control	12	3.4 ± .10~
Nitrogen	12	4.1 ± .29
Phosphorous	12	3.5 ± .09
Nitrogen and Phosphorous	12	3.5 ± .04
Nitrogen and Phosphorous	3	3.6 ± .05#

Table 2: At each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). The table depicts which treatments had statistically different pH levels from one another using an ANOVA Test (Analysis of Variance). Both the Site and the Site Nested in Treatment parameters were found to have a $p < .05$. Treatments that differ significantly by $p<0.05$ and $P<.0.10$ are denoted with * and + respectively. NS means not significantly different.

	Nitrogen	**Phosphorous**	**NP**	
Non-Acidic				
Control	*	NS	NS	
Nitrogen		NS	*	
Phosphorous			*	
	Nitrogen	**Phosphorous**	**NP**	
Sagavanirktok				
Control	NS	NS	+	
Nitrogen		NS	NS	
Phosphorous			*	
	Nitrogen	**Phosphorous**	**NP (12 years)**	**NP (3 years)**
Acidic				
Control	NS	*	NS	NS
Nitrogen		*	*	*
Phosphorous			NS	NS
NP (12)				NS

The control treatment of the three sites had significantly different levels of calcium, magnesium, and potassium (Table 3) as measured in g/m^2 of the upper 10 cm of the organic horizon. It was expected that the non-acidic site would have the highest amount of cations followed by the Sagavanirktok River site and then the acidic site, due to the pH. This trend only occurred for calcium. For magnesium the highest levels were found at the non-acidic site,1600 g/m^2, and unexpectedly, the acidic site followed with 630 g/m^2 while the Sagavanirktok River site had only 340 g/m^2 (sodium followed the same trend except the sites were not significantly different). The acidic site had the highest potassium levels 900 g/m^2, while the non-acidic had 610 g/m^2, and the Sagavanirktok River had only 280 g/m^2.

The non-acidic site also had the highest number of g of cations per m^2, followed by the Sagavanirktok River and then the acidic tussock.. Calcium is the dominant base cation in the system, being orders of magnitude greater than the other cations (Chart 2). Since calcium ion and magnesium ion have a charge of +2 the total number of protons in the system is exacerbated by their higher quantities in the soil horizon.

The non-acidic and the Sagavanirktok River followed the lyotropic series in that the relative abundance of the cation was in the expected order: $Ca^{+2} > Mg^{+2} > K^{+} > Na^{+}$. The acidic site deviated from the trend in that there was more potassium available than magnesium.

In some cases, the treatments applied to the moist tussock tundra had a significant effect upon the cation quantities at each site. At all sites, nitrogen addition decreased the cation levels as compared to the control site (except for K and Na at the non-acidic sites). The addition of phosphorous, which elevated the pH, had unexpected results whereby the number of grams of cation decreased at the non-acidic site and for Mg, K, Na at the acidic site while the cation levels increased at the Sagavanirktok River and for calcium at the acidic site. The nitrogen plus phosphorous addition also had these mixed results, a decrease or no change in the cation levels at the non-acidic and the acidic sites (for Mg, K, Na) and an increase in the cation levels at the Sagavanirktok River and for calcium at the acidic site.

Table 3: At each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). Table 2 shows the grams of Ca^{+2}, Mg^{+2}, K^{+}, Na^{+} per m^2 of the upper ten centimeters of the soil horizon for each site and each treatment. The Sum of Cations is equal to the sum of the number of grams of cations at each site for each treatment. The plus and minus represents the Standard Error. Statistical significance was determined using an ANOVA. Among the control plots for each treatment, sites that differ significantly by $p<0.05$ are denoted with ~. Among the 3 year nitrogen plus phosphorous treatments, sites that differ significantly by $p<0.05$ are denoted with #.

	Calcium (g/m^2)	**Magnesium (g/m^2)**	**Potassium (g/m^2)**	**Sodium (g/m^2)**	**Sum (g/m^2)**
Non-Acidic					
Control	31,000 ± 770~	1,600 ± 60~	610 ± 110~	170 ± 18	34,000
Nitrogen	29,000 ± 2700	1,500 ± 130	640 ± 80	180 ± 29	31,000
Phosphorous	28,000 ± 790	1,400 ± 51	560 ± 88	160 ± 21	30,000
NP	30,000 ± 470#	1,500 ± 42#	610 ± 7	160 ± 10	32,000
Sagavanirktok					
Control	7,500 ± 1100~	340 ± 100~	280 ± 73~	88 ± 15	8,000
Nitrogen	6,400 ± 920	260 ± 14	170 ± 36	79 ± 21	7,000
Phosphorous	11,000 ± 1600	430 ± 5	370 ± 43	130 ± 17	12,000
NP	11,000 ± 1700	430 ± 28	310 ± 72	140 ± 10	12,000
Acidic					
Control	2,800 ± 300~	630 ± 39~	900 ± 76~	160 ± 53	4,500
Nitrogen	1,500 ± 90	320 ± 24	470 ± 25	96 ± 8	2,400
Phosphorous	3,700 ± 560	350 ± 20	630 ± 110	120 ± 12	4,800
NP (12 yrs)	4,500 ± 1400	590 ± 200	830 ± 210	150 ± 30	6,000
NP (3 yrs)	2,100 ± 410#	330 ± 59#	580 ± 150	110 ± 27	3,200

Table 4: At each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). At each treatment the Ca, Mg, K, and Na concentrations were recorded. The tables depict, for each cation, which treatments are statistically different from one another using an ANOVA Test (Analysis of Variance). Site was found to be a significant factor in determining all of the cation concentration ($p<.05$) while Site Nested in Treatment was found to be significant for only calcium ($p<.05$) and magnesium ($p<.10$). Treatments that differ significantly by $p<0.05$ and $P<.0.10$ are denoted with * and + respectively. NS means not significantly different.

	Calcium				**Magnesium**			
	N	**P**	**NP**		**N**	**P**	**NP**	
Non-Acidic								
Control	+	*	NS		NS	*	NS	
Nitrogen		NS	NS			NS	NS	
Phosphorous			NS				+	
	N	**P**	**NP**		**N**	**P**	**NP**	
Sagavanirktok								
Control	NS	*	+		NS	NS	NS	
Nitrogen		*	*			*	*	
Phosphorous			NS				NS	
	N	**P**	**NP(12yr)**	**NP(3yr)**	**N**	**P**	**NP(12yr)**	**NP(3yr)**
Acidic								
Control	NS	NS	NS	NS	*	*	NS	*
Nitrogen		NS	+	NS		NS	NS	NS
Phosphorous			NS	NS			NS	NS
NP (12 years)				NS				NS

Treatment did not have a significant effect upon K and Na concentrations in the soil.

A statistically significant positive correlation was found between the natural log of the grams of calcium and the pH of the soil for each treatment and between the log-normal quantity of magnesium and pH for every treatment except the control (Table 5). A positive slope implies that as pH increased the number of grams of cations increased exponentially. Chart 3 and 4 depict all of the regression equations for calcium and magnesium. The calcium regression have a steeper slope and a higher intercept than the magnesium regressions, implying that they are more susceptible to changes in the soil pH. For both calcium and magnesium the regressions from the different treatments have similar slopes.

Potassium and sodium did not show this trend as clearly, probably due to their low abundance in the soil horizon and the fact that hydrogen ions have less of an effect upon K^+ and Na^+ as compared to Ca^{2+} and Mg^{2+}.

Table 5: For each treatment, nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control) the pH was regressed against the natural log of the number of grams cation calcium and magnesium, such that a log-log relationship is plotted. A best-fit line was drawn. The R^2 value of the line, the equation of the line and the p value for the line is recorded in the table below. Only regressions with R^2 values greater than .4 are included in the table.

	R^2 Value	**Equation**	**P value**
Calcium			
Control	0.92	y = .81x + 5.10	0.0104
Nitrogen	0.96	y = 1.58x + .92	0.0148
Phosphorous	0.89	y = .77x + 5.48	0.0044
N plus P	0.83	y = .83x + 5.09	0.004
All Treatments	0.81	y = .88x + 4.75	0.0
Magnesium			
Control	not significant		
Nitrogen	0.64	y = .80x + 2.28	0.0063
Phosphorous	0.69	y = .47x + 4.10	0.0023
N plus P	0.57	y = .42x + 4.46	0.0004
All Treatments	0.47	y = .42x + 4.39	0.0

The percentage cation in the plant leaf vascular tissue is recorded in Table 6. For *Betula* the plants growing at the non-acidic site had almost double the percent calcium in the leaf material than the plants growing at the acidic site, a difference that was statistically significant ($p>.05$) while the concentrations of Mg, K, and Na were similar. The same trend was found for the calcium concentration in *Betula* at the Sagavanirktok River site (.79 %) and the acidic site (.34%) while the Mg, K, and Na, concentrations were indistinguishable. The *Eriophorum* growing at the non-acidic site and the

Sagavanirktok River site had similar calcium concentrations (.27% and .25% respectively) which were indistinguishable from each other but significantly different ($p < .05$) from the acidic site (.14%). These trends were expected as the calcium levels within the soil were highest at the non-acidic site, followed by the Sagavanirktok site and then the acidic site. Unexpectedly, the magnesium concentration in *Eriophorum* at the acidic site was the highest (.16%) and significantly different ($p < .05$) than the concentrations in plants at both the non-acidic site (.08%) and the Sagavanirktok River site (.11%). In addition, although not statistically significant, the acidic site had the highest potassium levels followed by the non-acidic and then the Sagavanirktok River site. This same trend is also seen in the levels of potassium within the organic horizon.

In most cases, nitrogen addition to the moist tussock tundra led to a decrease in the cation concentration within the plants of each species as compared to the control. Phosphorous addition usually caused an increase or no change in the cation concentration of the plant as compared to the control, although in a few cases that cation percentage decreased slightly. The nitrogen plus phosphorous addition had mixed effects, whereby the cation percentage increased for Mg, K for *Cassiope* at the acidic tussock, Ca, Mg, K for *Betula* at the acidic tussock, Mg, K for *Eriophorum* at the non-acidic tussock, and Mg, K for *Eriophorum* at the Sagavanirktok River Site, while for the other plants at all other sites there was a decrease in the cation concentration. Even at the sites where the cation percentage increased or decreased, the change was rather small implying that the addition of both ammonium nitrate and phosphate had a mitigating effect upon one another.

Table 6: For each plant species, *Cassiope tetragona, Betula nana*, and *Eriophorum vaginatum* at the site where the different species are found, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock site four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). For each site and each treatment, the percent calcium, magnesium, potassium and sodium in the vascular plant leaf tissue is recorded. The plus and minus represents the Standard Error. Statistical significance was determined using an ANOVA. Among the control treatments and the 3 year nitrogen plus phosphorous fertilization, values sharing the same superscript (1,2,3,4,5,6,7) differ significantly by at least $p<0.05$

	Calcium %	**Magnesium %**	**Potassium %**	**Sodium %**
Cassiope				
Non-Acidic				
Control	.83 ± .11^{1}	.14 ± .01	.39 ± .02	.002 ± .001
Nitrogen	.74 ± .02	.15 ± 0	.35 ± .01	.002 ± .001
Phosphorous	.85 ± .04	.13 ± 0	.45 ± .02	.004 ± .001
NP	.84 ± .05^{2}	.14 ± .01	.39 ± .04^{2}	.003 ± .001
Acidic				
Control	.43 ± .03^{1}	.12 ± .01	.43 ± .03	.001 ± 0
Nitrogen	.43 ± .04	.17 ± .02	.40 ± .02	.001 ± 0
Phosphorous	.45 ± .07	.11 ± .01	.52 ± .06	.001 ± 0
NP(12)	none in plot	none in plot	none in plot	none in plot
NP(3)	.39 ± .01^{2}	.15 ± .01	.47 ± .01^{2}	.001 ± 0
Betula				
Sagavanirktok				
Control	.79 ± .39^{3}	.28 ± .01	.69 ± .10	.007 ± .005
Nitrogen	.43 ± .20	.24 ± .04	.42 ± .01	.002 ± .001
Phosphorous	.77 ± .06	.33 ± .01	.73 ± .03	.003 ± .001
NP	.55 ± .26	.28 ± .03	.63 ± .08	.002 ± 0
Acidic				
Control	.34 ± .03^{3}	.25 ± .03	.66 ± .09	.001 ± 0
Nitrogen	.27 ± .02	.23 ± .03	.53 ± .02	.001 ± 0
Phosphorous	.47 ± .01	.32 ± .01	.75 ± .03	.001 ± 0
NP(12)	.48 ± .03	.34 ± .01	.62 ± .05	.001 ± 0
NP(3)	.37 ± .03	.29 ± .01	.76 ± .03	.002 ± 0

	Calcium %	Magnesium %	Potassium %	Sodium %
Eriophorum				
Non-Acidic				
Control	.27 ± .04[4]	.08 ± 0	.79 ± .06	.007 ± .004
Nitrogen	.22 ± .02	.12 ± .01	.73 ± .04	.008 ± .002
Phosphorous	.29 ± .01	.10 ± .01	.83 ± .05	.006 ± .001
NP	.26 ± .01[6]	.11 ± .01[6]	.88 ± .04	.004 ± .001
Sagavanirktok				
Control	.25 ± .13[5]	.11 ± .01	.64 ± .08[7]	.007 ± .006
Nitrogen	.17 ± .10	.15 ± .02	.60 ± 0	.002 ± .001
Phosphorous	.25 ± .03	.11 ± .01	.80 ± .03	.002 ± 0
NP	.20 ± .16	.15 ± 0[I]	.79 ± .15	.003 ± .001
Acidic				
Control	.14 ± .01[45]	.16 ± .01	.82 ± .09[7]	.003 ± .001
Nitrogen	.11 ± .01	.13 ± 0	.78 ± .03	.002 ± 0
Phosphorous	.17 ± .01	.15 ± .01	.73 ± .06	.002 ± 0
NP(12)	.16 ± .01	.12 ± .01	.80 ± .02	.002 ± 0
NP(3)	.15 ± .01[6]	.16 ± .02[6]	.84 ± .10	.002 ± 0

Table 7: For each plant species, *Cassiope tetragona, Betula nana*, and *Eriophorum vaginatum*, at each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). For each plant species at each treatment the Ca, Mg, K, and Na concentrations were recorded. An ANOVA was performed with the parameters Site and Site Nested in Treatment. For each plant species and each cation the table below depicts whether Site or Site Nested in Treatment were significant in determining the cation concentrations in the plant material. Parameters that differ significantly by $p<0.05$ and $P<.0.10$ are denoted with * and + respectively. NS means not significantly different.

	Site	**Site Nested in Treatment**
Cassiope		
Calcium	*	**NS**
Magnesium	*	**NS**
Potassium	*	+
Sodium	**NS**	**NS**
Betula		
Calcium	*	*
Magnesium	**NS**	*
Potassium	**NS**	**NS**
Sodium	*	**NS**
Eriophrum		
Calcium	*	*
Magnesium	*	*
Potassium	**NS**	**NS**
Sodium	*	**NS**

Table 8 For each plant species, *Cassiope tetragona*, *Betula nana*, and *Eriophorum vaginatum*, at each site, the Non-Acidic Tussock, the Sagavanirktok River, and the Acidic Tussock, four different treatments were applied to the landscape in a block format: nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition and no treatment (control). For each plant species at each treatment the Ca, Mg, K, and Na concentrations were recorded. The tables depict, for each cation, which treatments are statistically different from one another using an ANOVA Test (Analysis of Variance). Treatments that differ significantly by p<0.05 and P<.0.10 are denoted with * and + respectively. NS means not significantly different.

	Calcium				Magnesium			
	N	**P**	**NP**		**N**	**P**	**NP**	
Cassiope								
Non-Acidic								
Control	NS	NS	NS		NS	NS	NS	
Nitrogen		NS	NS			NS	NS	
Phosphorous			NS				NS	
	N	P	NP(12 yr)	NP (3 yr)	N	P	NP(12 yr)	NP (3 yr)
Acidic								
Control	NS	NS	NS	NS	*	NS	NS	NS
Nitrogen		NS	NS	NS		*	NS	*
Phosphorous			NS	NS			NS	*
NP (12 years)				NS				NS
	N	**P**	**NP**		**N**	**P**	**NP**	
Betula								
Sagavanirktok								
Control	NS	NS	*		NS	NS	NS	
Nitrogen		*	*			NS	NS	
Phosphorous			NS				NS	
	N	**P**	**NP(12 yr)**	**NP (3 yr)**	**N**	**P**	**NP(12 yr)**	**NP (3 yr)**
Acidic								
Control	NS	*	*	NS	NS	*	*	NS
Nitrogen		*	*	+		*	*	*
Phosphorous			NS	+			NS	NS
NP (12 years)				+				NS
	N	**P**	**NP**		**N**	**P**	**NP**	
Eriophorum								
Non-Acidic								
Control	*	NS	NS		*	NS	NS	
Nitrogen		*	*			NS	NS	
Phosphorous			NS				NS	
	N	**P**	**NP**		**N**	**P**	**NP**	
Sagavanirktok								
Control	*	NS	+		+	NS	+	
Nitrogen		*	NS			*	*	
Phosphorous			+				*	

Calcium Magnesium

	N	P	NP(12 yr)	NP (3yr)	N	P	NP(12 yr)	NP (3 yr)
Acidic								
Control	NS	NS	NS	NS	+	*	NS	*
Nitrogen		*	*	+		NS	NS	+
Phosphorous			NS	NS			NS	NS
NP (12 years)				NS				+

	Potassium				Sodium			
	N	P	NP		N	P	NP	
Cassiope								
Non-Acidic								
Control	NS	NS	NS		NS	NS	NS	
Nitrogen		*	NS			NS	NS	
Phosphorous			NS				NS	
	N	P	NP(12 yr)	NP (3 yr)	N	P	NP	NP (3 yr)
Acidic								
Control	NS	+	NS	NS	NS	NS	NS	NS
Nitrogen		*	NS	NS		NS	NS	NS
Phosphorous			NS	NS			NS	NS
NP (12 years)				NS				NS
	N	P	NP		N	P	NP	
Betula								
Sagavanirktok								
Control	NS	NS	NS		NS	NS	NS	
Nitrogen		NS	NS			NS	NS	
Phosphorous			NS				NS	
	N	P	NP(12 yr)	NP (3 yr)	N	P	NP(12 yr)	NP (3 yr)
Acidic								
Control	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen		NS	NS	NS		NS	NS	NS
Phosphorous			NS	NS			NS	NS
NP (12 years)				NS				NS
	N	P	NP		N	P	NP	
Eriophorum								
Non-Acidic								
Control	NS	NS	NS		NS	NS	NS	
Nitrogen		NS	NS			NS	NS	
Phosphorous			NS				NS	
	N	P	NP		N	P	NP	
Sagavanirktok								
Control	NS	NS	NS		NS	NS	NS	
Nitrogen		NS	NS			NS	NS	
Phosphorous			NS				NS	

	Potassium				Sodium			

	N	**P**	**NP(12 yr)**	**NP (3 yr)**	**N**	**P**	**NP(12 yr)**	**NP (3 yr)**
Acidic								
Control	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen		NS	NS	NS		NS	NS	NS
Phosphorous			NS	NS			NS	NS
NP (12 years)				NS				NS

For each species after each treatment a significant positive correlation was found between the calcium concentration of the plant material and the pH of the soil (except for *Betula* after the nitrogen plus phosphorous treatment). This relationship implies that plants are sensitive to the pH level of the soil, such that increasing the pH of the soil led to an increase in the percentage of cations within the leaf material (Table 9). The regression of calcium concentration and soil pH for each treatment all had relatively similar slopes for *Cassiop*e and *Eriophorum* but not for *Betula* (Chart 5, Chart 6, Chart 7). The regressions for magnesium, potassium and sodium did not show significant trends.

Table 9: The cation concentration (Ca, Mg, K, Na) of the different plant species *Cassiope tetragona*, *Betula nana*, and *Eriophorum vaginatum* were grouped by treatment; nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition, and no treatment (control) and the cation concentration from each site was regressed against the pH of that site. A best fit curve was drawn. The R^2 value of the line, the equation of the line and the p value for the line are recorded in the table below. Only regressions with R^2 values greater than .5 are included in the table.

Species	Treatment	R^2	Equation	P Value
Cassiope	Control	.756	y = .14x - .05	0.024
	Nitrogen	.878	y = .17x - .24	0.006
	Phosphorous	.830	y = .16x - .09	0.012
	N+P	.960	y = .17x - .18	0.0006
	All	.823	y = .15x - .12	0.0001
Betula	Control	.746	y = .21x - .35	0.059
	Nitrogen	.808	y = .48x - 1.65	0.038
	Phosphorous	.942	y = .15x - .06	0.006
	N+P	not significant		
	All	.549	y = .18x - .248	0.0
Eriophorum	Control	.713	y = .05x - .007	0.008
	Nitrogen	.824	y = .06x - .13	0.002
	Phosphorous	.935	y = .05x + .006	0.0001
	N plus P	.880	y = .04x + .02	0.0
	All	.655	y = .04x - .007	0.0

The calcium in the plant material also had a significant linear positive correlation for all species after all treatments with the calcium in the organic horizon (Table 10). Therefore cation availability does have an effect upon cation sequestration within the plant material.

The regression of calcium concentration and calcium content of the soil for each treatment all had relatively similar slopes for *Cassiope* and *Eriophorum* but not for *Betula* (Chart 8, Chart 9, Chart 10).

The regressions for magnesium, potassium and sodium did not show significant trends.

Table 10: The cation concentration (Ca, Mg, K, Na) of the different plant species *Cassiope tetragona*, *Betula nana*, and *Eriophorum vaginatum* were grouped by

treatment; nitrogen addition, phosphorous addition, nitrogen plus phosphorous addition, and no treatment (control) and the cation concentration from each site was regressed against the number of g/m^2 of that same cation within the soil. A best fit curve was drawn. The R^2 value of the line, the equation of the line and the p value for the line are recorded in the table below. Only regressions with R^2 values greater than .5 are included in the table.

Species	Treatment	R^2	Equation	P Value
Cassiope	Control	.796	y = 1E-5x + .80	0.017
	Nitrogen	.858	y = 1E-5x + .86	0.008
	Phosphorous	.899	y = 2E-5x + .39	0.004
	N+P	.968	y = 2E-5x + .36	0.004
	All	.857	y = 1E-5x + .39	0.0
Betula	Control	.671	y = 8E-5x + .15	0.090
	Nitrogen	.769	y = 9E-5x + .16	0.051
	Phosphorous	.899	y = 4E-5x + .35	0.014
	N+P	not significant		
	All	.449	y = 4E-5x + .32	0.005
Erophorum	Control	.696	y = 4E-6x + .48	0.010
	Nitrogen	.699	y = 3E-6x+ .12	0.001
	Phosphorous	.812	y = 5E-6x + .17	0.002
	N plus P	.900	y = 4E-6x + .15	0.036
	All	.609	y = 4E-6x + .15	0.0

Discussion:

The initial pH of the soil and the cation content of the soil were shown to have a significant effect upon the cation content of the plant material, whereby more acidic soils with fewer grams of cations had a lower concentration within the plant material. The only deviation from this trend occurred with potassium at the acidic site and Mg, K, and Na at the Sagavanirktok site. Both of these deviations occurred probably due to the different soil parent material and the different physical properties of the organic horizon. A parent material enriched in potassium allowed more potassium to be taken up by the plants. Higher K concentrations in the plant vascular tissue would lead to higher K concentrations in the litter and thus higher levels within the organic horizon. The moist tussock tundra at the Sagavanirktok River site is in a former flood-plain which has altered the soil type and soil moisture. Therefore one of the factors confounding cation concentration of soil and plants is the parent material and the physical characteristics of the soil.

The sum of the base cations within the soil horizon should have an effect upon the pH of the soil, whereby more base cations result in a lower pH (Binkley and Richter 1987). But, as demonstrated above, the non-acidic site has the highest quantity of base cations, but is also the least acidic. Therefore there is some other mechanism controlling the pH of the site. Some possibilities include the parent material underlying the mineral soil, the species composition (the prescience of sphagnum moss primarily at the acidic site), and the differing quantities of nutrients taken up by the plant material.

This paper has demonstrated that regardless of the initial pH of the soil, increased nitrogen and phosphorous availability in the organic horizon will alter the pH of the soil and the relative quantities of the other cations, Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+} within both the soil and the plant vascular tissue. The addition of nitrogen in the form of a weak acid led to a decrease in the pH of the soil and a decrease in the exchangeable cation concentration in the organic horizon relative to the control and in the concentration of cations within the plant material.

This trend was also evident for phosphorous addition whereby, in most cases, higher cation availability in the soil resulted in increased levels within the plant material. Nitrogen plus phosphorous fertilization led to a significant increase in pH at the acidic and non-acidic sites and a decrease in pH at the Sagavanirktok River site. This change in pH resulted in mixed effects, both increases and decreases in the cation concentration within both the soil and the plant material. The use of three different plant species, all of which exhibit the same trend implies that the system as a whole is changing not just individual species. Therefore the addition of nitrogen plus phosphorous will not have as drastic an effect upon the cation cycle in plants and the organic soil as their separate addition.

Comparing the control treatments at the three sites demonstrates a statistically significant link between the initial pH level of the soil and the concentration of Ca, Mg and K in the soil. The soil pH also significantly effects the calcium concentration within the plant material. This is expected because calcium availability at the three sites varies dramatically and is the base cation used in the highest quantity by the plants. The other cations seem to occur in similar abundance in the plant material. Therefore calcium might also be a limiting factor in plant net primary productivity.

The effect of nutrient addition on the plant cation concentration is harder to infer from this data. It appears that nitrogen addition and the subsequent decrease in pH level led to increased leaching of the cations, as seen by the lower cation levels within the soil causing decreased plant uptake as seen by the lower concentration of cations plants grown in nitrogen fertilized plots as compared to the control. The calcium concentration in the plant material seemed to decrease the most precipitously due to nitrogen addition, while in most other cases the decrease in concentration was insignificant, further implying that calcium might be limiting plant net primary productivity.

But the metric of percentage cation in vascular tissue is misleading because it does not examine the biomass of the different plant species. Larger plants due to increased nitrogen availability might not have the mechanism to remove cations from the soil. Therefore the increased productivity might lead to a dilution of the cations within the vascular tissue. This plant would be healthy and thriving but not maximizing its growth potential. In this scenario, plants growing in both the nitrogen addition and the nitrogen plus phosphorous addition should have much lower cation concentrations, as individual species in these treatments have had the greatest change in biomass. The *Betula* and *Eriophorum* at the Sagavanirktok River site exhibits this trend and dilution of cations within the vascular tissue might be occurring, but there are examples of nitrogen fertilization resulting in a decrease in cation concentration in the plant material while nitrogen plus phosphorous fertilization causes no change in the cation concentration: *Cassiope* and *Eriophorum* at the non-acidic tussock and *Betula* and *Eriophorum* at the acidic site. Therefore dilution might only be occurring at the Sagavanirktok River.

Another possibility is that increased plant growth after nitrogen fertilization is leading to an increase in the quantity of cations taken up by the plant material. In order to remain electro-neutrally balanced, the plants release an H+ ion into the soil. Thus the increased growth due to nitrogen addition is leading to increased soil acidity. But, if this were the case the soil with the nitrogen plus phosphorous treatment would also have a lower pH, which is not the case.

The shift in species composition might be affecting the soil acidity. For example at the acidic tussock site nitrogen and nitrogen plus phosphorous addition have resulted in an increase in the *Betula* biomass at the expense of *Eriophorum* and *Cassiope* (Chapin et al 1995). *Betula* contains different quantities of Ca, Mg, K than the other species. Therefore the soil cation pools might change due to the increased biomass of *Betula*.

Soils have been shown to have a discernible relationship between pH levels and cation availability (Sharpley 1991). In the moist tussock tundra, a small change in pH predicted the larger changes in the cation content of the soil, as seen through the exponential relationship between pH and cation level. The highest correlation coefficient was between pH and calcium and magnesium content of the soil. This might be due to the stronger relationship between pH and calcium and magnesium as compared to sodium and potassium (Sharpley 1991). In addition the higher relative abundance of calcium and magnesium might allow this trend to be detected more readily. The concentration of calcium within the plant material was also significantly correlated with the pH of the soil and calcium levels within the soil. The higher calcium requirements by the plants and the drastic changes in calcium availability at the different sites might be controlling this trend.

Global warming might have an affect on the pH and cation content of the soil and therefore could effect the cation concentration within the plant material. It is predicted that elevated temperatures will increase the decomposition rate of soil organic material (Billings 1982) increasing the quantity of nitrogen, as ammonium and nitrate, and phosphorous. The increased nitrogen and phosphorous will alter the soil pH and cation concentration of the soil and possibly the concentration of the plant material.

Given the opportunity to continue this study I would sample all of the plots at the three sites and would add other plant species such as *Ledum palustre, Vaccinium vitis-idaea, Vaccinium uliginosum, Rubus chamaemorus.* This increased sampling would show whether the change in cation availability was having an effect upon the system as a whole or just certain plant species. In addition I would be able to perform more cross-site comparisons. I would also sample the soil water from both within the plot and at lower topographic elevation immediately beneath the plot to see if there has been increased leaching of the soil cations. Finally I would analyze the soil and plant material for aluminum levels to see if a lowering of the pH through fertilization increased the retention of aluminum within the organic horizon and whether higher aluminum levels in the soil lead to increased plant uptake.

Conclusions:

The initial pH of the soil affects the quantity of cations within the soil and the uptake of calcium by the plant material. The addition of nitrogen to the soil was found to decrease the pH and the quantity of cation in the soil and in the plant material. Phosphorous addition was found to increase the pH of the soil, the cation concentration of the soil and cause little change in the cation levels within the plant material. Nitrogen plus phosphorous addition had mixed effects upon the pH and cation concentrations in the soil and plant vascular tissue. The pH of the soil was significantly correlated with the calcium concentration in both the soil and the plant material.

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