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NITROGEN MINERALIZATION PATTERNS OF BOREAL FOREST SOILS

by

JILENE LORETTA OFFORD

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Nitrogen mineralization patterns of boreal forest soils* submitted by *Jilene Loretta Offord* in partial fulfillment of the requirements for the degree of *Masters of Science in Soil Science.*

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29 Jan, 1999

Date

For Miranda

Set your sights high, and follow your dreams

I love you.

ABSTRACT

Soil temperatures and moistures were monitored in two Alberta field sites from May, 1997 to September 1998. Nitrogen (N) mineralization rates were measured using ion exchange membranes in the field from June 1997 to May 1998. In association with this monitoring intact organic horizon cores (LFH) and homogenized Ae cores from Alberta and Quebec were incubated under various conditions between 231 and 313 days. Every 14 - 28 days, each core was leached with 0.01 M $CaCl_2$ for mineral N determination. To accommodate variability in soil N content and site history, results were normalized to a soil N basis. Results indicate net N mineralization is horizon specific not site specific; net N mineralization over long times was weakly related to lower soil temperatures; and differences in moisture tension did not create differences in specific net N mineralization. A protocol is proposed to estimate N mineralization from soils across Canada for use by present and future forest managers.

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When I first came to Edmonton for my Bachelor of Science in the academic year of 92-93, I was planning on staying for 3 years. Well, 7 years later I have BSc and a MSc! I owe this great feat to many people, but first and foremost to my supervisor and mentor Bill McGill. I remember attending ENCS 475 the first time it was offered. And there was Bill showing me they world of soils. I was (and still am) captivated by your knowledge of soils. Thank you for introducing me to the world of soils! How did I ever survive before this? I cherish the friendship we have and I cannot thank you enough for giving me the opportunity to achieve all that I have.

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Chapter 1 : GENERAL INTRODUCTION

Between 1986 and 1994, the forest sector in Alberta received over $4 billion of new investment and is now Alberta's third largest primary economic sector (Alberta Environmental Protection, 1996). This raises the question whether the current harvesting levels are sustainable. The Sustainable Forest Management - Network of Centers of Excellence (SFM-NCE) was established in 1995 focusing on preserving the ecological variability and biodiversity of Canada's boreal forest while maintaining the nation's forest-based economy. The network's purpose is to ensure that Canada's boreal forest is effectively managed, its biological diversity preserved, and its resources sustained for future generations. The SFM -NCE has four research themes: Ecological Basis of Sustainable Forest Management; Minimal Impact Techniques for Forest Materials Processing; Socio-Economic Sustainability; and Planning and Practices for Sustainable Forest Management. This project is within the Ecological Basis of Sustainable Forest Management theme, the goal of which is to examine natural ecosystem processes and the impact of human activities on them. This project consists of three groups of sites: natural sites in Alberta; disturbed sites in Alberta; and disturbed sites in Quebec. The main focus of this thesis is on the natural sites in Alberta with some overlap with the disturbed sites in Quebec.

Nitrogen

Nitrogen (N) cycling (Figure 1) is a vital component in the sustainability of long-lived forest systems (Raison and Stottlemyer, 1991). The N cycle is regulated by complex interrelationships among plant uptake of available soil N, the transfer of N from plant litter to soil organic matter (SOM) and the conversion of organic N to NH_4^+ by soil microorganisms (Clark, 1977; Zak et al., 1986). Nitrogen fixation and N deposition throughout the biosphere replenish losses of N from the N cycle. However, N deficiency

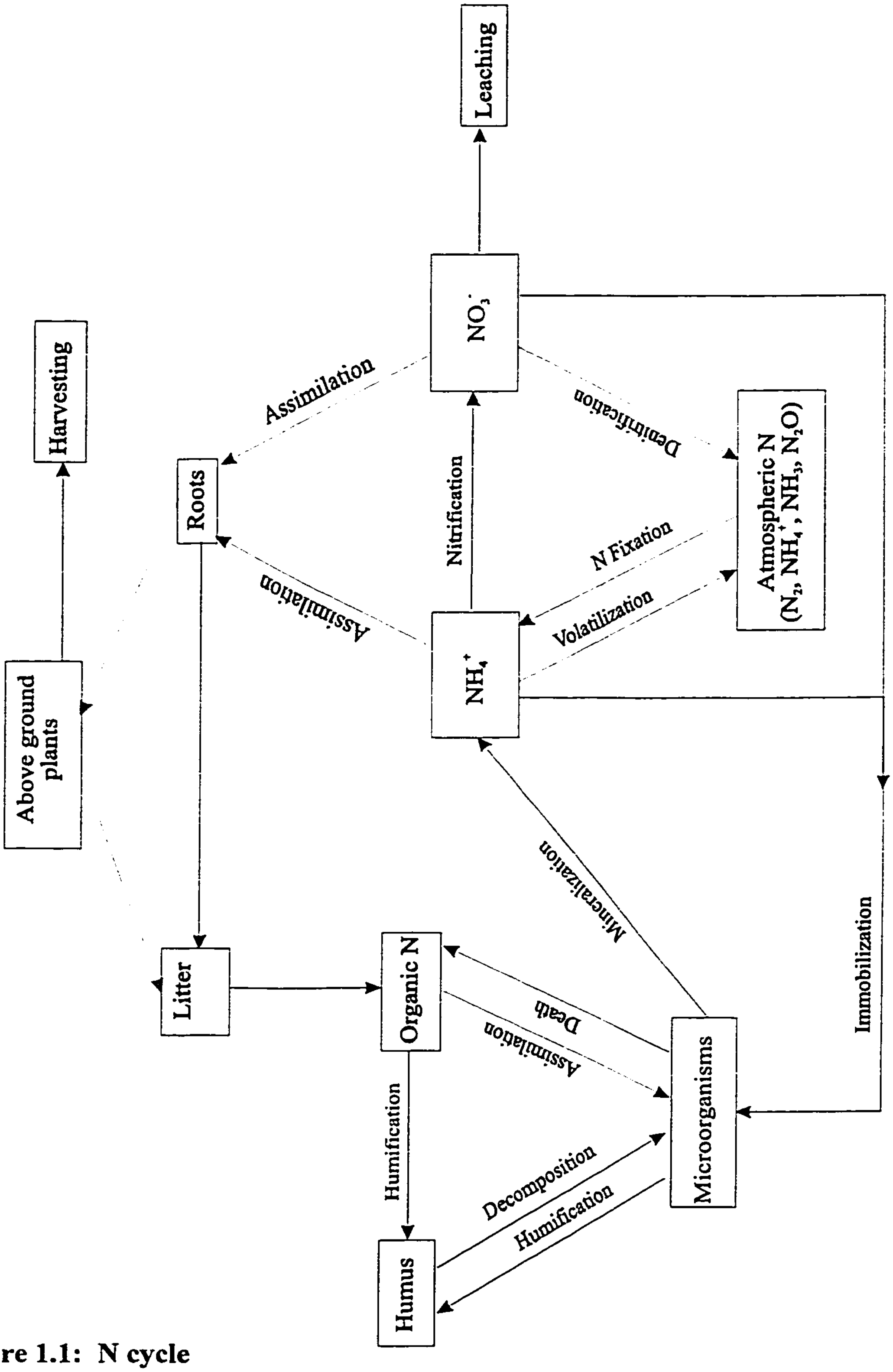

Figure 1.1: N cycle

is common in forest ecosystems (Johnson, 1992b). In temperate forests, N generally limits productivity when water is not limiting (Keenan et al., 1995). Raison and Stottlemyer (1991) stated N availability affects tree productivity by altering the rate of tree canopy development, photosynthetic properties, needle water potentials, and C allocation patterns. Most of the N returned to the forest floor or mineral soil is organic in the form of litter fall or root material (Keenan et al., 1995; Raison and Stottlemyer, 1991).

Additions and Removals

The quantity of organic material stored in ecosystems is the difference between additions and removals. The amount of N available for mineralization is a function of the amount of organic C stored in the soil. The C content or amount of soil organic matter (SOM) is regulated by climatic conditions, and by chemical factors of litter which affect soil microorganism activity. In his classical work Jenny (1928) showed that the accumulation of soil C and N at steady state were positively correlated with precipitation and negatively correlated with temperature at any particular amount of precipitation. Further study of these ideas concluded that soil organic carbon (SOC) and N storage are positively correlated with precipitation and negatively correlated with temperature at any particular amount of precipitation (Post et al, 1985). Smith (1982) stated that forest litter accumulation is related to temperature and moisture. Accumulation was greatest in warm, moist forests taking only a few years to reach steady state, while in cooler, drier climates it may take decades.

Atmospheric Deposition

The amount of atmospheric precipitation of N (NH_4^+, NO_2^-, NO_3^- and organic N) each year is small and not significant when related to plant production. However, it may be of considerable importance when considering the N cycle of mature undisturbed forests or grasslands (Stevenson, 1982). The deposition of N replenishes these undisturbed systems, compensating N loss through erosion, leaching or denitrification. Nitrogen deposition from industrial areas has been recorded up to 50 kg ha^{-1} y^{-1} and contributes a significant fraction of annual tree N requirements in many northern hemisphere temperate forests (Raison and Stottlemyer, 1991).

Nitrogen Fixation

Dinitrogen (N_2) comprises 78 % of the gases in the atmosphere (3.86E+21 g) (Stevenson, 1982). Nitrogen fixation, the conversion of N_2 to NH_4^+ [Eq. 1.1] (Paul and Clark, 1989), can be accomplished: (1) by symbiotic organisms, organisms that live in a mutually beneficial relationship with plants; (2) by nonsymbiotic organisms, free-living organisms in the soil; (3) through lightening discharge; or (4) synthetically, as in the production of chemical fertilizer (Hausenbuiller, 1985).

$$N_2 + 16ATP + 8e^- + 10H^+ \xrightarrow{Mg^{2+}} 2NH_4^+ + H_2 + 16ADP + P_i \qquad [1.1]$$

Legume plants such as alfalfa or clover form symbiotic relationships with N_2 fixing organisms (*Rhizobium sp.*). These organisms may fix 50 - 150 kg N ha^{-1} y^{-1}. Nitrogen fixing non-legume plants such as *Ceanothus* (Tea Bush) or *Alnus* (Alder) are not associated with *Rhizobium*, but form symbiotic relationships with actinomycetes or blue-green algae, fixing up to 200 kg N ha^{-1} y^{-1} (Hausenbuiller, 1985; Raison and Stottlemyer, 1991). Red alder is a pioneering species that generally dominates recently disturbed sites (Cole, 1995) and its N_2 fixation can lead to significant accumulation of C and N in the upper part of the soil profile (Cole, 1995).

Non-symbiotic N fixers are free living organisms which fix N_2 apart from a specific net host (Stevenson, 1982). These include a number of blue-green algae of the family Nostoacaceae, various photosynthetic bacteria (*Rhodospirillum*), several aerobic bacteria belong in the Azotobacteriaceae family (*Azotobacter*, *Beijerinckia*) and certain anaerobic bacteria (genus *Clostridium*) (Stevenson, 1982). These organisms may be responsible for accumulation of 1 to 2 kg N ha^{-1} y^{-1} (Cole, 1995; Raison and Stottlemyer, 1991). Optimum N_2 fixation by these species requires the presence of adequate energy substrates, low levels of available soil N, adequate mineral nutrients, near neutral pH, and suitable moisture (Stevenson, 1982).

Ammonia Volatilization

Losses of N through ammonia volatilization have been estimated between 5 and 40 % following application of urea based fertilizers (Nason et al. 1988). Loss of NH_4^+ from soils is a result of the transformation of NH_4^+ to $NH_{3(g)}$ [Eq. 1.2 and 1.3] (Hausenbuiller, 1985):

$$NH_4^+ + OH^- \rightarrow NH_4OH \qquad [1.2]$$

$$NH_4OH \rightarrow H_2O + NH_3 \uparrow \qquad [1.3]$$

Soils with a high pH, hence a high concentration of OH^- ions, generally experience higher rates of NH_3 volatilization than acidic soils. Volatilization is significant from calcareous soils especially when NH_4^+- or urea-based fertilizers are used (Nason et al, 1988). Losses of NH_4^+ have been recorded from soils with pH 6 to 7 (Stevenson, 1982). Low rates of volatilization are expected from acidic forest soils due to their low concentration of OH^-, which prevents the formation of NH_4OH (Hausenbuiller, 1985). However, forest burning increases soil pH and loss of NH_4^+ as NH_3 may be significant (Scotter, 1963).

Transformations

Mineralization

Mineralization of organic N (R-NH_2) refers to the degradation of protein, amino sugars, and nucleic acids into NH_3 (Paul and Clark, 1989; Jansson and Persson, 1982). In the presence of HOH, NH_3 exists in equilibrium with NH_4^+ [Eq. 1.4].

$$R - NH_2 \xrightarrow{hydrolisis} NH_3 + R - OH \xleftrightarrow{HOH} NH_4^+ + OH^- \qquad [1.4]$$

This transformation is carried out by chemo-heterotrophic organisms seeking C for energy and growth, and NH_4^+ is formed as a by-product (Hausenbuiller, 1985). Once NH_4^+ is formed there are several possible fates: (1) it can be taken up by plants and is preferentially utilized over NO_3^- (Paul and Juma, 1981); (2) it can be utilized for microbial growth and is preferentially utilized over NO_3^-; (3) it can be held on the exchange complex where it can be replaced by other cations in soil solution; (4) it can readily enter the interlayer portions of 2:1 clay because it is the same size as K^+; (5) it can react with SOM to form quinone-NH_2 complexes, which is a significant reaction from a SOM stabilization viewpoint; (6) if present in an unabsorbed state, high rates of $NH_{3(g)}$ volatilization can occur; and (7) it can be utilized by chemo-autotrophs as an energy source in the nitrification process (Paul and Clark, 1989).

Initial decomposition is dominated by immobilization followed by mineralization as the substrate C:N ratio decreases. Net mineralization rates are highest in samples with C:N < 40:1 (Keeney, 1980). Palm and Sanchez (1991) state that net mineralization in litter occurs if the N concentration is above 2% and net immobilization occurs below that concentration. Paul and Juma (1981) stated a C:N ratio of 25:1 is required for degradation without net immobilization.

Immobilization

Nitrogen immobilization is a process that incorporates NH_4^+ or NO_3^- into amino acids or amino sugar [1.5], rendering N not readily available to other organisms or plants (Paul and Juma, 1981; Jansson and Persson, 1982; Paul and Clark, 1989).

$$NH_4^+, NO_3^- \rightarrow Microbial\, biomass \qquad [1.5]$$

Generally mineral N does not accumulate in undisturbed ecosystems since carbon inputs are high and N is the limiting element in decomposition. Therefore measurement of net mineralization and immobilization rates is difficult (Paul and Juma, 1981).

Nitrification

Nitrification occurs in terrestrial, aquatic and sedimentary ecosystems (Schmidt, 1982). Nitrification is predominantly carried out by bacteria of the genera *Nitrosomonas*, *Nitrosospira* and *Nitrosococcus* [1.6] and *Nitrobacter* [1.7] (Paul and Clark, 1989).

These chemoautotrophic bacteria derived C solely from CO_2 or $CO_3^{=}$ and their energy from the oxidation of NH_4^+ to NO_2^- and NO_3^-.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O + Energy \qquad [1.6]$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + Energy \qquad [1.7]$$

This process is self-limiting with the release of 4 H^+ because most observations indicate nitrification is inhibited at a pH below 4 (Schmidt, 1982). At high pH (above pH 8), NH_4^+ inhibits the transformation of NO_2^- to NO_3^-. Aeration is essential for nitrification because nitrifiers are obligate aerobes. This is controlled by factors such as soil moisture and structure. Nitrification has been reported to proceed readily at moisture tensions between 100 to 1000 kPa. Nitrification is also temperature dependent and proceeds slowly at temperatures below 5°C and above 40°C with an optimum temperature around 30°C (Paul and Clark, 1989).

Often low rates of net nitrification are reported in forest soils. This is attributed to low population of nitrifiers (Tamm et al, 1974; Keeney, 1980) or to the potential interaction between mycorrhizae and soil nitrifiers. Mycorrhizae may have a regulatory function as agents of biological control of nitrification due to their preference for NH_4^+ from the soil environment (Verstraete, 1981). Net nitrification commences after a lag period following activities such as liming, urea application, or disturbance (Keeney, 1980). Recently, Stark and Hart (1997) showed that undisturbed forest soils have high rates of nitrification where the NO_3^- is quickly assimilated by microbes and therefore undetected by measuring net nitrification.

Heterotrophic Nitrification

Heterotrophic nitrification is the oxidation of NH_4^+ to NO_2^- and NO_3^-, however energy is not derived for the microorganisms involved (Paul and Clark, 1989). The formation of NO_2^- from the oxime of pyruvic acid has been reported by bacteria of the genera *Achromobacter* and *Corynebacterium*, *Nocardia*, *Agrobacterium*, and *Alcaligenes*

(Schmidt, 1982). A few bacteria such as *Arthrobacter* and fungi *Aspergillus flavus* produce NO_3^- from NH_4^+. The first indication of NO_3^- formation by *Aspergillus flavus* was in 1954 (Scmidt, 1982). It should be mentioned that these herterotrophic bacteria and fungi are isolated from the soil and cultured under optimal conditions that lead to the accumulation of NO_2^- or NO_3^-. There is no evidence that these organisms complete this process *in situ* or what their significance in nature is. However, there are instances where nitrification occurs and the environment is not favorable for nitrifiers. In these instances, heterotrophic nitrification is credited (Schmidt, 1982).

Humification

Humus is a heterogeneous mixture of non-living components resulting from microbial and chemical transformations of organic debris. This transformation known as the humification process produces a mixture of humic substances which is increasingly resistance to further microbial attack (Hayes and Swift, 1978). Isolation of humic substances takes advantage of differences in solubilities, adsorption behavior and molecular weight or charge characteristics either between humic and non-humic substances or between the different components of humic substances (Hayes and Swift, 1978). Humic substances are composed of three fractions: fulvic acids which are soluble in acid and alkali; humic acids which are soluble in alkali but precipitated by acid; and humins which are insoluble in acid and in alkali. These fractions should not be considered as distinct components of humic substances, but as a spectrum of substances with an overlap of soluble properties (Hayes and Swift, 1978).

Detailed structural knowledge of humic substances would allow prediction of humic behavior in different environments and would allow for a more complete understanding of interactions with soil inorganic colloids, sorbed organic molecules, and inorganic ions. As well, structural studies can provide essential information about soil structure and the binding of contaminants in the soil environment (Hayes and Swift, 1978). The nature of humic acid structure is the subject of on going debate. Some humic acid structures proposed are: condensed aromatic and saturated rings substituted on the periphery by carboxyl and hydroxyl groups; aromatic ring substituted by hydroxyl and quinone groups; or aromatic and quinone rings substituted by hydroxyl, carboxyl, and methoxyl groups (Schulten and Schnitzer, 1997).

Current research by Schulten and Schnitzer (1997) demonstrated that humic acids contained carbohydrates, phenols, lignin monomers, lignin dimers, lipids, alkyl aromatics, and N-containing compounds. The alkyl aromatics consisted of aromatic rings covalently linked to aliphatic chains. The elemental composition of humic acid was $C_{308}H_{328}O_{90}N_5$, with a molecular weight of 5539 g mol^{-1}. They converted this 2-D structure to a 3-D structure with a final elemental composition of $C_{308}H_{335}O_{90}N_5$ and a molecular weight of 5547 g mol^{-1}. Schulten and Schnitzer (1997) proposed an improved SOM structural model with high surface activity that was related to the presence of hydrophilic and hydrophobic adsorption sites. Although considerable study has been done in this area, continual study is needed to confirm the latest hypothesis regarding humic acid structure.

Translocations

Leaching

Anions such as HCO_3^-, NO_3^- $SO_4^=$, Cl^- and organic acids are not retained by cation exchange reactions and can be leached from the soil. The production and mobility of anions in soil solution limit leaching of anions. In contrast, cations have to be associated with anions and form electrically neutral complexes in order to be leached out of the soil (Cole, 1995). Leaching losses of NO_3^- are common in soils where excess water percolates through the soil. If NO_3^- leaches out of the rooting zone, it depletes the supply of an important nutrient for forest survival and creates a potential pollution problem. High concentrations of NO_3^- in surface water are toxic to animals i.e. transformation of blood hemoglobin to methemoglobin, or formation of carcinogenic nitrosamines (Tamm et al, 1974), and may foster eutrophication of lakes and streams if complementary nutrients such as P are available. Nutrient leaching losses seldom occur from young, vigorous forests. In contrast, mature to over-mature, harvested or burned ecosystems with high rates of atmospheric N input or high rates of N fixation do experience significant leaching losses (Cole, 1995).

Plant Uptake

It has been hypothesized that plants adapted to growing on nutrient limited sites use nutrients more efficiently (litter-fall mass / litter N) than those adapted to nutritionally richer sites. Keenan et al. (1995) compared the nutrient use and cycling of two different forests on Vancouver Island. They hypothesized that differences in nutrient use and cycling between dominant tree species on each forest type contribute to differences in forest floor nutrient availability. They concluded that western red cedar (*Thuja plicata* Donn) had a higher rate of resorption and satisfied its N demand through resorption to a greater extent than western hemlock (*Tsuga heterophylla* Raf), suggesting that western red cedar may be adapted to lower nutrient conditions by increasing N use efficiency. Interestingly, the cedar litter had a lower N concentration, indicating that there may be a positive feedback leading to less N cycling and less available N in cedar-dominated forests (Keenan et al., 1995).

Plant species may also play an important role in N cycling after disturbances such as clear cutting or wildfires. Generally, soil pH increases and a new microbial community appears which oxidizes NH_4^+ to NO_3^-. Kronzucker et al. (1997) concluded that white spruce seedlings preferentially absorbed 20 times more NH_4^+ than NO_3^-. Consequently there may be a transition from NH_4^+ to NO_3^- in soil of ecosystems where major plant species are at a disadvantage in the presence of NO_3^-. Therefore conifer reforestation projects may be unsuccessful leading to domination of disturbed sites by ‘nitrophilous’ species such as aspen.

Controls on N Mineralization and Immobilization

It is estimated that 80-90% of all net primary production on land is recycled by decomposers (Peterson and Peterson, 1992). However, mineralization rates will differ depending on the type and location of the forest ecosystem. For example, coniferous systems create an acidic soil environment which is less favorable for the proliferation and activity of soil fauna than the soil environment provided by deciduous systems (Berg, 1986). Hart et al. (1993) concluded that the higher rates of N immobilization obtained in a grassland soil compared to a forest soil, may be a result of the higher C availability to microorganisms in the grassland soil. They also indicated that the flow of N from the mineral soil to the decomposing surface litter was greatest in ecosystems which had large accumulations of high C:N litter and high availability of N in underlying mineral soil. Binkley and Vitousek (1989) summarized that rates of mineralization are affected by substrate chemistry (N content, and types of organic compounds), biology (comminuters, microbes and grazers on microbes) and environmental factors (temperature, moisture and aeration). Therefore any changes in these factors created by disturbances could increase or decrease the mineralization rate. Basic understanding of the natural N mineralization of soils across the boreal forest is required if predictions of soil N mineralization from forest soils after disturbances such as clear cutting or wildfires are to be made.

Soil Temperature and Moisture

N availability often increases with an increase in temperature due to an increase in decomposition of SOM (Cole, 1995; Makipaa, 1995). Amount of SOM usually increases with decreasing mean annual temperature. In temperate forest regions, mineralization ranges from 1 to 2% per year of the total SOM pool (Cole, 1995; Raison and Stottlemyer, 1991). Temperature and moisture are considered to be the most influential factors that dictate mineralization rates in soils (Ellert and Bettany, 1992). For example, the temperature dependence of N and S mineralization greatly influence the rates of nutrient cycling and the structure and function of ecosystems such that the availability of these nutrients is more dependent on temperature than on the quantity of these elements in the soil (Ellert and Bettany, 1992).

Smith (1982) indicated that the underlying mechanism to forest litter accumulation was the slow rate of SOM decomposition by soil microorganisms. Kladivko and Keeney (1987) suggested that the optimum water tension for rate of SOM decomposition to be between 10 and 33 kPa. Respiration rates have also been reported to reach a maximum at water tensions ranging from 5 to 15 kPa (Nyhan, 1976). Forest floor accumulation thus SOM accumulation, has be connected with temperature and moisture and depending on the forest type, may require decades or centuries to become established (Smith, 1982).

Substrate Quality

Most organic horizons or litter layers are composed of L, F and H layers in which a C:N ratio ranges from 40 to 60:1 (Keeney, 1980). Organic horizons consist of layers of organic debris (LFH) in varying stages of decomposition (Keeney, 1980). Generally the L layer has a C:N (35 to 60:1) greater than the F or H layer (25 to 49:1). Substrate chemistry of these layers may be the most important factor regulating litter decomposition and N availability in boreal forests (Scott and Binkley, 1997). Lignin content has also been used to characterize substrate quality. In general, higher litter lignin concentration retard litter decay rates. Lignin concentration of plant material has been reported as a much better predictor of plant residue decomposition rate than N concentration alone (Fox et al, 1990). The percent lignin or lignin:N ratio is often an effective index for N mineralization patterns (Palm and Sanchez, 1991). Fox et al (1990) concluded that (lignin + polyphenol):N ratio was an excellent indicator of N mineralization rate for the first 12 weeks after incorporation of litter into the soil. Scott and Binkley (1997) suggested that the litter lignin:N ratio is a good predictor of net N mineralization across a range of forest sites with different climatic regimes. Generally, litter with high N concentration decays faster than litter with low N concentration and equal lignin contents (Kochy and Wilson, 1997).

Gradual Reduction in SOM Turnover Rate

Identifying turnover rates for soil organic carbon (SOC) is a critical step toward the understanding of soil nutrient cycling and global carbon cycles (Hsieh, 1993). Recent data suggest that SOC have a bimodal distribution of active and stable SOC components. According to Hsieh (1992), the active component is believed to be several decades old, whereas the stable component may be as old as several thousand years. However, other studies reveal that there may be more than two components. Townsend et al. (1995) suggested that there are three fractions: 1) a labile or active fraction (~5 %); 2) an intermediate fraction (60-80 %); and 3) a passive fraction (10-40 %). Townsend et al. (1995) also suggested that the active fraction can change quickly in response to changes in climate or land use but is too small to affect total CO_2 stocks on land or in the atmosphere, whereas the passive fraction turns over too slowly to cause any significant change. Therefore, the large intermediate fraction is more likely to respond on a time scale of anthropogenic global change. Such a proliferation of groups of constituents with varying turnover rates suggests a continuum may exist in nature, from the "active" to the "resistant" groups.

The Q theory of organic matter dynamics proposed by Bosatta and Agren (1985, 1994) treats each addition of litter as a cohort that decomposes to progressively more stable products over time. Each fresh litter cohort is characterized by a continuous real variable q, which determines its decay rate. For each cohort, q decreases over time according to a function representing the reduction in substrate quality as soil microorganisms transform C. However the Q model proposes no identifiable chemical constituents, only mathematical representations of declining quality with time (McGill, 1996).

Mineralization Potential (N_o)

The aerobic incubation test of Stanford and Smith (1972) has been widely accepted as a way to measure the quantity of readily mineralizable soil N (Keeney, 1980). This technique determines the amount of N mineralized over time (up to 30 weeks) from which it is possible to calculate mineralization parameters. An exponential model is normally used for mineral soil samples yielding values for potentially mineralizable N (N_o) and mineralization rate coefficient (k). It has been suggested that N_o is soil specific net whereas one k value might be valid for all soils (Dendooven et al, 1995). Other advantages of this method are: 1) it depends on natural biological mechanisms not chemical extractants; and 2) the long incubation time reduces the influences of initial N mineralization (Fyles and McGill, 1987).

Stanford and Smith (1972) proposed that the N mineralization rate (N_m) is proportional to the quantity of mineralizable substrate not the total N contained within the sample. They determined N_0 by fitting a one component first order kinetic model (exponential) to cumulative N mineralized. Simard and N'dayegamiye (1993) stated that there was a definite advantage to fitting cumulative data to the Gompertz model rather than to the first order kinetic model because the N_0 and k were not significantly correlated. Ellert and Bettany (1992) concluded that fitting models to incremental N mineralization data, was superior to fitting cumulative data for the following reasons: (1) it reduces interdependence of observation errors; (2) it allows use of unmodified laboratory data; (3) it permits deletion of missing observations; and (4) it emphasizes mineralization dynamics which tend to be obscured when laboratory data are summed. Dendooven et al. (1995) suggested that care should be used when comparing the N mineralization among soils because N_0 is influenced by the duration of the incubation, its reciprocal relationship with k, and the shape of the N mineralization curve.

Wildfires and Clear Cutting

Compared to managed ecosystems, those that are not managed exhibit nutrient cycling characteristics closer to steady state where additions and removals are equal (Juma and McGill, 1986). Nutrient cycling and soil development are intimately linked. Disruptions or alterations to ecosystems such as clear cutting or wildfires alter the rate of additions changing the nutrient cycling of the ecosystem (Juma and McGill, 1986). Tamm et al. (1974) stated that the ecological effects of clear felling are very similar to those of forest fires and other catastrophes affecting forests. However, how similar or dissimilar these disturbances are from each other or from unmanaged ecosystems has not been established.

Wildfires

Wildfires are a natural process in the aging of a forest ecosystem. Wildfires directly affect nutrient cycling processes by altering rates of nutrient uptake and return (Grier, 1975). This influence on the nutrient status of a forest ecosystem can be substantial because nutrients incorporated in vegetation, litter, and soil can potentially be volatilized during pyrolysis or combustion, mineralized during oxidation, lost by ash convection, or redistributed by wind when a wildfire occurs (Grier, 1975). Dyrness et al. (1989), Grier (1975), and Scotter (1963) indicated that burning results in an increase in soil pH, which Dyrness et al. (1989) concluded was independent of burning severity. However, the net loss of soil C appeared to be dependent upon fire intensity (Johnson, 1992a); the more intense the fire the more loss of C. Scotter (1963) reported an increase in soil surface temperatures after burning with an average increase of 5.8°C at 2.5 cm depth and 5.4°C at 7.5 cm depth than the soil temperature at unburned sites at the same depths. Scotter (1963) suggested that the increase in soil temperature might be due to the addition of charcoal, which has a high capacity to absorb radiant energy. As well, the loss of the insulating litter layer may also bring about an increase in mineral soil temperature. In the same study, total exchange capacity was examined and found to decrease in burned areas, with hydrogen being the most notably reduced cation. Grier (1975) noted losses of calcium, magnesium, potassium, and sodium from the mineral soil after burning. Losses of Ca^{2+} and Mg^{2+} were relatively small compared to losses of Na^+ and K^+. This study suggested that differential volatilization may have occurred with the monovalent cations since they have relatively low vaporization temperatures. For example, potassium and sodium vaporize at 760°C and 880°C respectively, while calcium and magnesium vaporize at 1240°C and 1107°C, respectively. In contrast, available phosphorus concentration has been reported to increase after burning. Dyrness et al. (1989) reported a 27-fold increase in available phosphorus from the heavily burned forest litter of a black spruce stand compared to an adjacent unburned black spruce stand. Modest increases in available P of mineral soils with burning were detected in separate sites of white spruce (heavily burned) and aspen stands (lightly burned). Available P from the white spruce stand increased from 1.25 (adjacent unburned stand) to 3.01 g m^{-2}, and for the aspen stand available P increased from 1.69 (adjacent unburned stand) to 2.80 g m^{-2}. Scotter (1963) reported that for each burned site studied, the available phosphorus was more abundant relative to an adjacent non-burned forest.

A loss of N has also been associated with wildfires and is most likely a result of volatilization. This is most apparent in a study by Grier (1975), where only 3% of the original amount of N was found in the forest floor after burning, and N in the A horizon was reduced by two-thirds. Riggan et al. (1994) reported higher NH_4^+ concentrations in surface soils after a moderate burn than in surface soils from a severe burn. During a low temperature fire pyrolytic mineralization of organic N is less complete whereas at greater temperatures, soil NH_4^+ and NO_3^- are more completely volatilized. They concluded that severe burns would have higher rates of volatilization due to higher soil surface temperatures than moderate burns, explaining the lower concentration of NH_4^+ in soils from severe burns. Dyrness et al. (1989) indicated that after burning total N in mineral soil increased in plots occupied by black spruce and birch, decreased with burning in aspen plots and remained about the same with burning in white spruce plots. However, Knight (1966) stated increases in N values are reports of increased concentration of N in the residual material (i.e. negative enrichment), and not the total amount of N.

Clear Cutting

Clear cutting changes the forest floor and its environment. Removal of trees from an area removes nutrients in the trees; and decreases mineral nutrient demand and the amount of organic input. In combination these changes may alter the nutrient cycles. Clear cutting also alters the hydrologic cycle of an area. Meng et al. (1995) concentrated on soil temperature, soil moisture, snowpack, snowmelt and stream flow. They concluded that soil moisture and temperature were higher in cut areas than in non-cut areas and that an increase in water yield may vary from 3 to 300%. Tamm et al. (1974) examined the consequences of clear cutting on water quality and reported that maximum concentrations of NO_3^- were found in groundwater from clear-felled areas some years after clear cutting. However, there were no reports of NO_3^- concentrations exceeding present health limits for drinking water. Sollins and McCorison (1981) reported an increase over time in NO_3^- and total N in the litter and soil solution. However, NO_3^- values in the stream water were not a health risk. This study also reported an increase in dissolved organic C in the soil solution from the clear cut areas compared to the non-cut areas and stated that this increase was strongly correlated with a decrease in NO_3^- concentration. Johnson (1992a) concluded that forest floor mass could increase or decrease after forest harvesting depending on the amount of slash left behind, however only small changes in C storage in the mineral soil were reported.

Research Objectives

This project aims to quantify N mineralization rates in forest floor and mineral horizons of soils from varying temperature and moisture regimes at two natural sites as well as two sites that were disturbed by fire and logging fifty years ago. It is anticipated that the results from this project will provide a more fundamental understanding of controls on N dynamics of natural sites thereby yielding tools for prediction of N dynamics under a variety of disturbances.

Specific net questions:

1. Does the specific net rate of N mineralization vary in samples from along a catenary sequence at each site and between sites?

2. Does the specific net rate of N mineralization vary among samples of different horizons?

3. Does the specific net rate of N mineralization differ among samples incubated at different soil temperatures?

4. Does the specific net rate of N mineralization differ among samples incubated at different soil moisture tensions?

5. Does the specific net rate of N mineralization differ among samples from different moisture and temperature regimes or from soils with different disturbance regimes?

Chapter 2 describes soil and site characteristics used throughout this thesis; N mineralization from samples of organic and Ae horizons from three slope positions at two sites is described in Chapter 3; N mineralization from samples of organic and Ae horizons incubated at 5 temperatures as well as separately, samples of organic and Ae horizons incubated at 4 moisture tensions from four sites is presented in Chapter 4; Chapter 5 describes measurement of mineral N using ion exchange membranes or exchange resin bags under various conditions as well as measurement of mineral N using ion exchange membranes *in situ* at two sites in Alberta; and finally a synthesis of the entire thesis is described in Chapter 6.

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Chapter 2 : SITE CHARACTERIZATION

Study Sites

Alberta

Sites were chosen based on location, soil, vegetation type and slope. First of all, the goal was to be able to use permanent sampling plots (PSP) from the Alberta Forest Service. This required a location specified to range road and section. It was decided that areas around Lac La Biche and Whitecourt would be appropriate because they represented different temperature regimes within boreal forests and were located within reasonable distance to Edmonton (3 hour driving time). The vegetation at each site was required to be a mixed wood stand (white spruce/aspen) growing on soils with a loamy texture. Soils high in clay were avoided because of difficulty in working with them in the laboratory (i.e. slow drainage). Soil maps were then used to identify areas around Lac La Biche and Whitecourt within a loam, silt loam or sandy loam texture. This information, along with vegetation composition was given to H. Archibald at the Alberta Forest Service, where a computer selection process generated approximately 5 -10 PSP in areas around Lac La Biche and Whitecourt, which fitted our protocol. These areas were then personally inspected for soil texture, vegetation type and checked for a 5 - 10 % slope so that 3 plots could be located in upper, middle and lower slope positions. The following describes the characteristics of each site chosen and the soils from these sites.

The sites chosen were PSP 41 at Whitecourt and PSP 435 at Lac La Biche. Both are classified within the Boreal Mixedwood ecological area (Beckingham and Archibald, 1996). Climate data for this ecological area are summarized in Table 2.1. The data are based on average values from the Low- and Mid-Boreal Mixedwood ecoregions (Beckingham and Archibald, 1996).

Table 2.1: Summary of Climate Data for the Boreal Mixedwood Ecological Area

Summer	
Mean Typical Temperature (°C)	13.7
Minimum Typical Temperature (°C)	7.2
Maximum Typical Temperature (°C)	20.2
Total Precipitation (mm)	238
Winter	
Mean Typical Temperature (°C)	-11.9
Minimum Typical Temperature (°C)	-17.2
Maximum Typical Temperature (°C)	-6.5
Total Precipitation (mm)	63
Annual	
Mean Temperature (°C)	1.5
Total Precipitation (mm)	389

* Adapted from Beckingham and Archibald (1996)

Lac La Biche is located in the Dry Mixedwood natural subregion approximately 300 km NE of Edmonton, and Whitecourt is located in the Central Mixedwood natural subregion approximately 300 km NW of Edmonton (Beckingham and Archibald, 1996). Both these stands originated from fire, are approximately the same age, and are similar in their soil texture and drainage conditions (Table 2.2).

Table 2.2: Characteristics of the Natural Sites in Alberta

	Whitecourt	Lac La Biche
Origin	Wildfire	Wildfire
Type	*Populus balsamifera / Picea glauca*	*Picea glauca / Populus tremuloides*
Age	80-100 years	70-90 years
Location	PSP #41	PSP #435
	S19 T59 R14 W5	S02 T68 R11 W4
	elevation: 955 masl*	Elevation: 750 masl
Soil Texture	loam	Silt loam
Slope	5 %	8 %
Soil Classification		
Upper	Gleyed Dark Gray Luvisol	Orthic Gray Luvisol
Middle	Dark Gray Luvisol	Gleyed Gray Luvisol
Lower	Dark Gray Luvisol	Orthic Luvic Gleysol
Aspect	NW	NW

*masl: meters above sea level

Plot Location

A catena is a sequence of soils about the same age, derived from similar parent material, and occurring under similar climatic conditions, but having different characteristics due to variation in relief and drainage (Hausenbuiller, 1985). A catena was identified at each site and three plots were located along a 50 m slope, representing upper, middle, and lower slope positions. A catena was chosen to represent different moisture regimes. Generally, soil classification will change from the upper slope position to the lower slope position. The site at Lac La Biche indicates a change in soil classification from an Orthic Gray Luvisol at the upper slope position to an Orthic Luvic Gleysol at the lower slope position. Unfortunately Whitecourt did not indicate a change in soil classification, and does not represent a true catena. We continued to use this site because soil samples had already been taken and experiments started.

Soil Sampling

Intact organic layer samples (3) were collected from Lac La Biche and Whitecourt (Table 2.2) in October 1996. An area approximately 0.25 m^2 was cut and lifted intact using a shovel. Garden pruners were used to cut roots that held the sample to the Ae horizon. The samples were placed flat in garbage bags and stored at 4°C prior to the laboratory incubations. Intact cores of Ae horizons were sampled using PVC cores with an internal diameter 7.6 cm. The cores were manually pushed into the ground until the top of the B horizon was reached. Residual B horizon material on the bottom of the core was removed with a knife. The Ae samples were removed from their cores, sieved (3 mm) at their field moisture contents, and stored in clear plastic bags at 4°C. Additional soil samples of Ae horizons were collected in August 1997 for incubation of soil samples at different moisture tensions (Chapter 4). These samples were collected near to the area where the first sets of samples were collected from.

Field Monitoring

Datalogger Setup and Calibration

Thermocouple wire (TX PC / PC20; solid conductor Type TX 20 AWG; All-temp sensors) was cut to approximately 2 m in length. The plastic covering was stripped off with wire cutters and the copper / constantan wires were twisted together. The ends were covered with shrink tubing (activated by heating) to prevent corrosion of the thermocouple. Thermocouples were hooked to a datalogger and tested in the laboratory by measuring temperatures ranging from +32 to -20°C. A random sample of twenty six thermocouples was selected and exposed to temperature changes in a refrigerator over 24 hours (Fig. 2.1). Standard error bars indicate the variation between these thermocouples. Thermocouples that did not record temperatures were inspected and discarded if they could not be fixed.

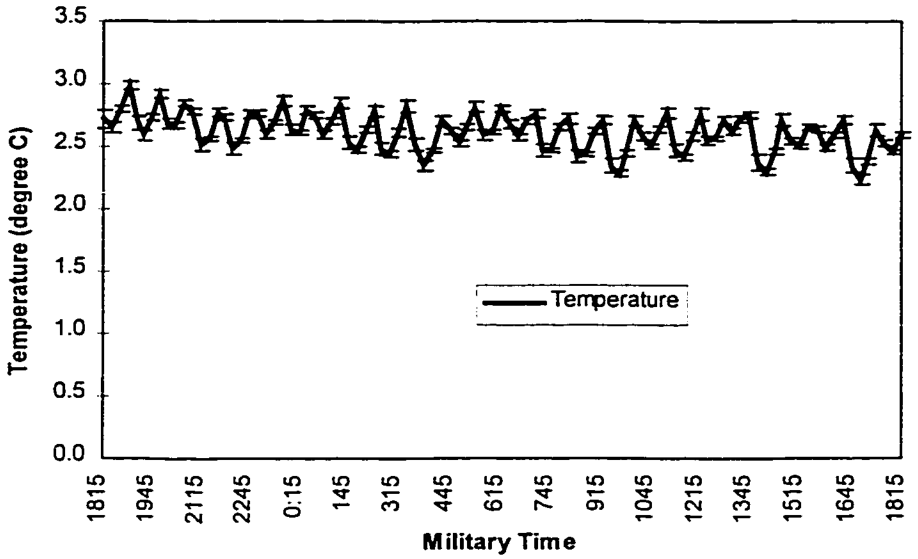

Figure 2.1: Sensitivity of 26 thermocouples to temperature fluctuations over 24 hours in a refrigerator

Time domain reflectometers (TDR) (CS615), provide a measure of volumetric water content. Placing TDR probes in a tub of soil where water was added to the soil and let dry and repeated, tested the sensitivity of TDR probes to water addition and drying. Dataloggers recorded the sensitivity of the TDR probes to fluctuations in soil moisture over 1 month (Fig. 2.2).

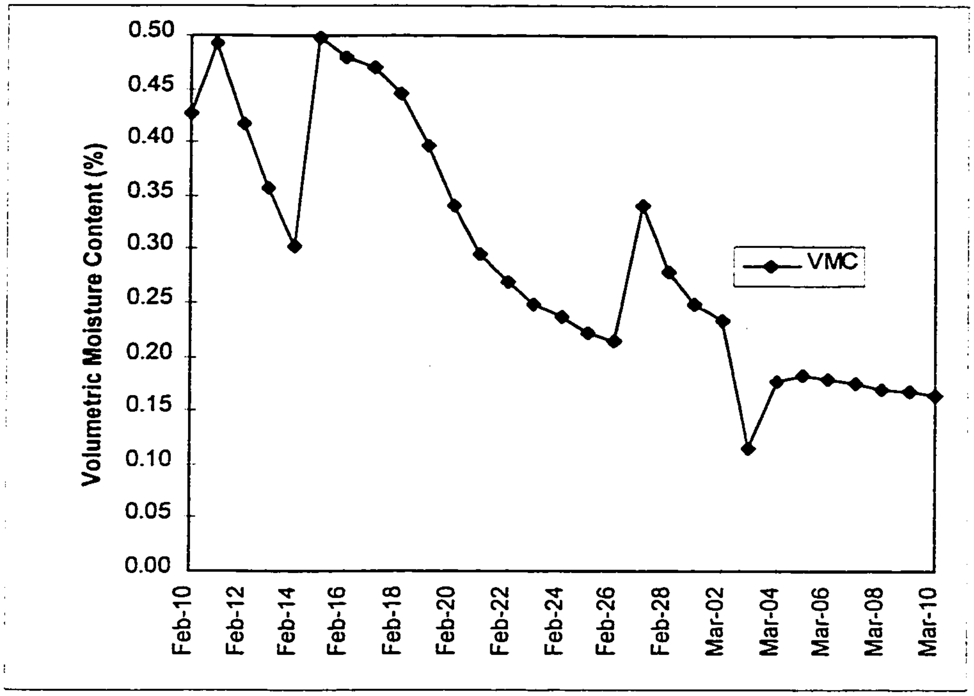

Figure 2.2: Volumetric water content of soil measured by using time domain reflectometers in soil with fluctuating water contents over 1 month

Installation of Thermocouples and Time Domain Reflectometers

Data loggers (Campbell Scientific, CRX10) were installed at each slope position (upper, middle and lower) at Lac La Biche and Whitecourt in May 1997, to monitor soil moisture and temperature. A square soil pit, 35 cm deep and 60 cm wide was excavated, ensuring that one wall of the soil pit was flat. A stake with 7 holes was placed flat against that wall and a thermocouple inserted into the bottom hole. The stake was hammered to a depth so that the thermocouple in the bottom hole of the stake was at 64 cm. The remaining thermocouples were then inserted through the holes and pushed into the profile wall. Thermocouples were installed at depths 0, 2, 4, 8, 16, 32, and 64 cm. TDR were inserted horizontally into the organic horizon (Fig. 2.3).

The hole was then back filled in the original horizon sequence and moderate packing to approximate the original density.

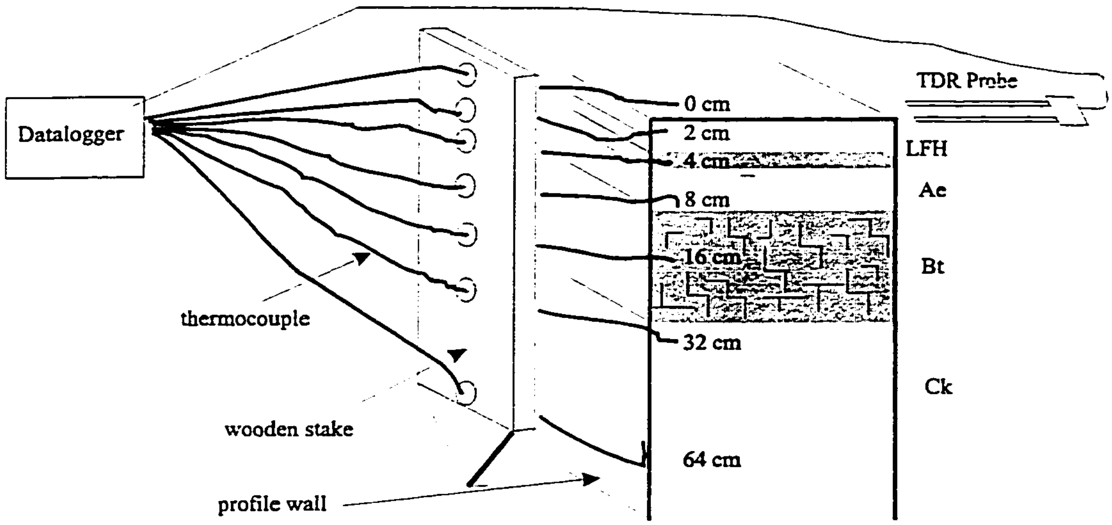

Figure 2.3: Schematic diagram of datalogger setup in the field

Soil Temperature and Moisture Data Collection

Every two weeks, data from the data loggers were downloaded onto a Pentium 120 laptop computer using PC208e data logger software (Campbell Scientific, 1997) until December 1997 when data were down loaded monthly. Soil temperature and moisture were recorded from May 10, 1997 to September 2, 1998. The lower slope position from Lac La Biche consistently had higher recorded soil moisture contents (Fig. 2.4) than the middle or upper slope positions from May to November 1997. Conversely, the upper slope position at Lac La Biche consistently had lower recorded soil moisture contents than the middle or lower slope positions from May to November 1997. The upper slope position from Whitecourt had higher recorded soil moisture contents (Fig. 2.5) than the middle or lower slope positions. The middle slope position had lower recorded soil moisture contents than the upper or lower slope positions. Soil moisture peaked in early June 1997 and May 1998 at both sites and then gradually declined over the summer. The volumetric moisture contents measured over the winter were disregarded because TDR only measures liquid state water not solid state water. However progression of freezing front can be traced.

Snow depth measurements were taken in March 1997 using a snow tube. Snow density was calculated for all slope positions at each site (Table 2.3) according to instructions provided by R. Rothwell. Snow depth was significantly higher at Whitecourt than at Lac La Biche. Snow depths between slope positions at both sites were not significantly different. Snow densities from all slope position were significantly higher at Lac La Biche than at Whitecourt. Note that these measurements were taken before installation of the data loggers in May 1997. Therefore soil temperature and moisture presented does not correspond with this snow depth. Snow measurements the following year (1998) were not measured however personal observation indicated that snow fall was much less at Whitecourt than the previous year.

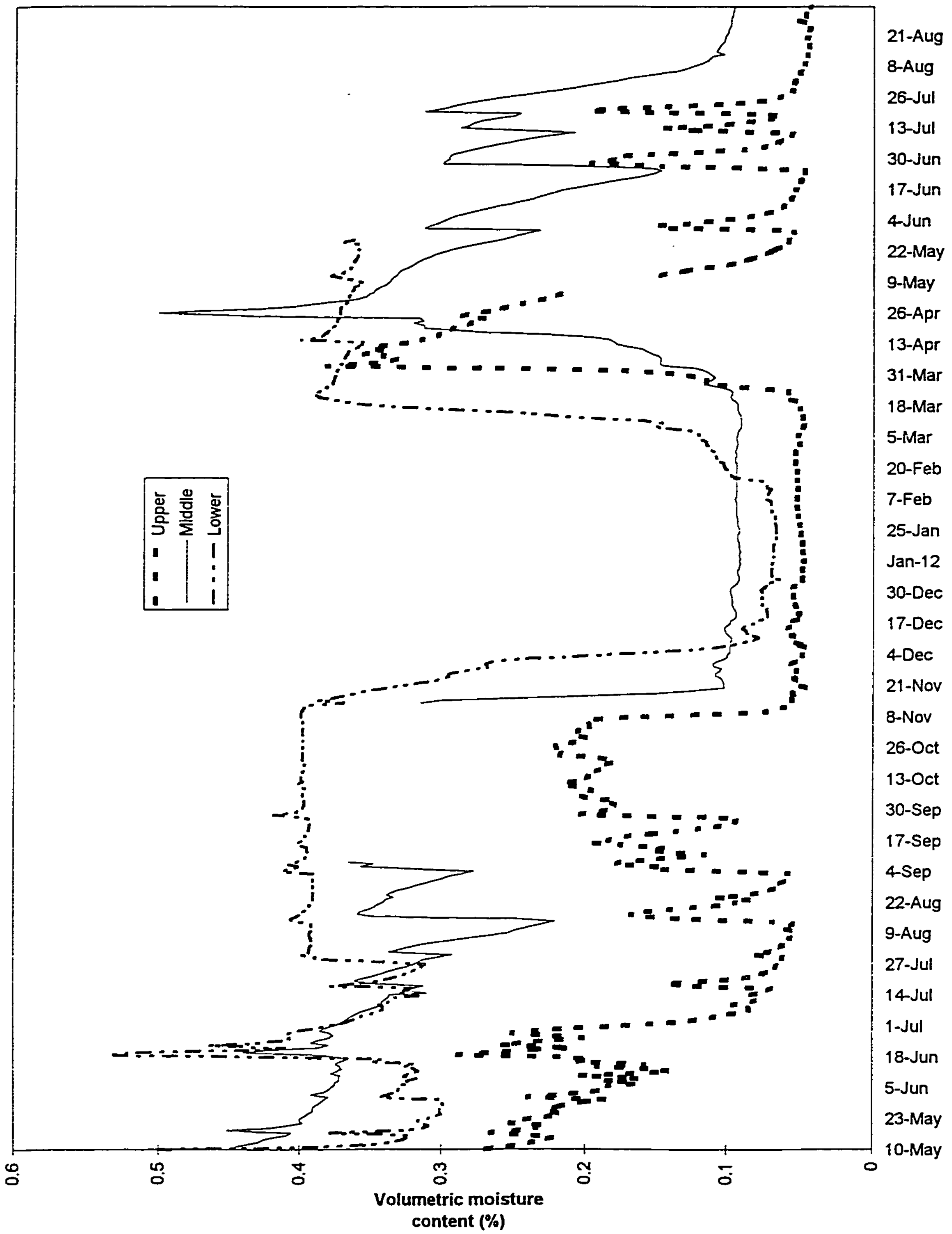

Figure 2.4: Soil moisture at 10 cm measured using TDR from three different slope positions at Lac La Biche, AB from May 10, 1997 to September 2, 1998

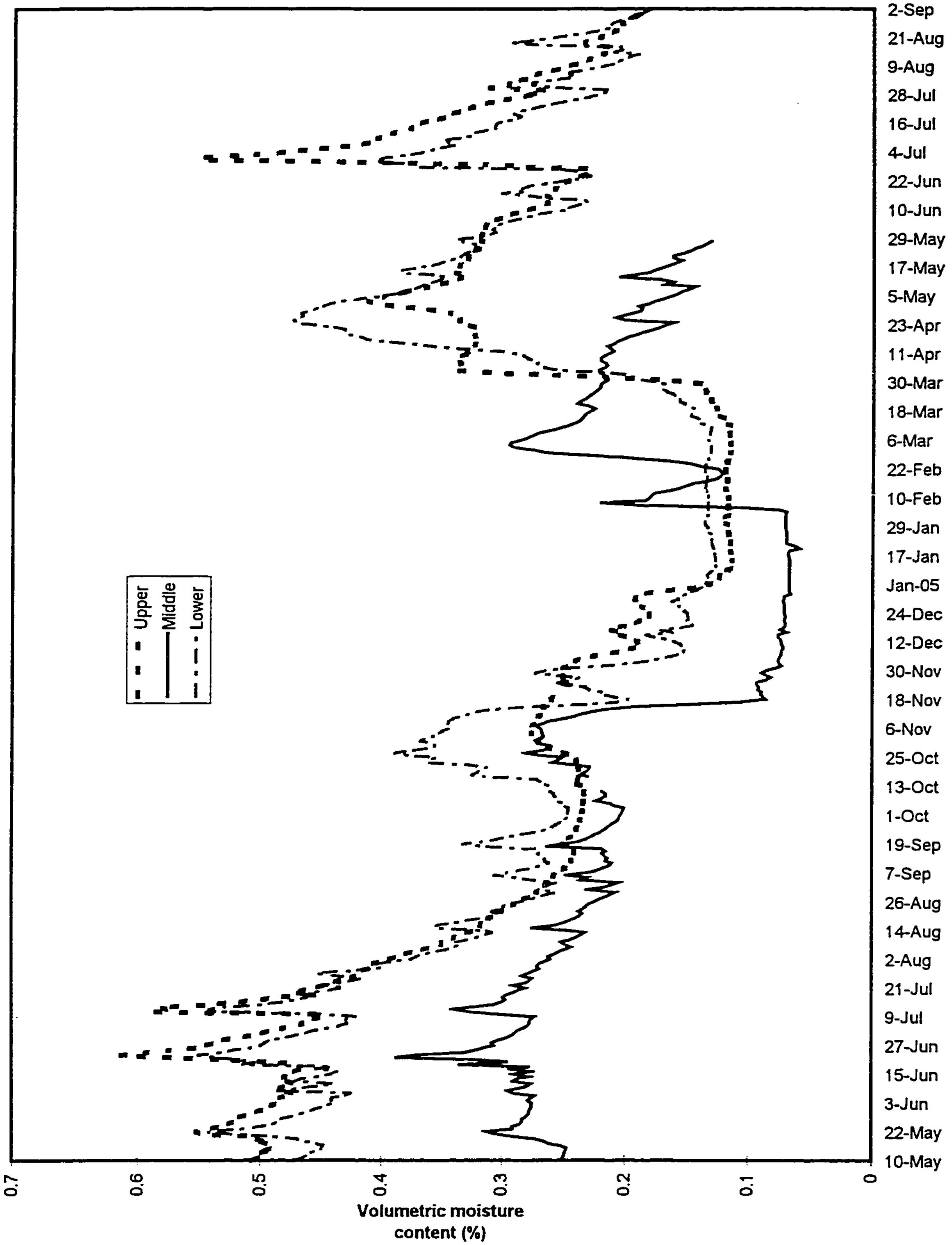

Figure 2.5: Soil moisture measured at 10 cm using TDR from three different slope positions at Whitecourt, AB from May 10, 1997 to September 2, 1998

Table 2.3: Mean snow depth (n=20) and density measurements for Lac Lac Biche and Whitecourt, AB in March 1997

Slope Position	Lac La Biche		Whitecourt	
	snow depth (cm)	snow density (g/cm^3)	snow depth (cm)	snow density (g/cm^3)
Upper	56	0.062	86	0.013
Middle	53	0.065	82	0.012
Lower	54	0.066	80	0.012

Soil temperature at 8 cm depth ranged from 23°C to -17°C (Fig. 2.6) at Lac La Biche and 18°C to -12°C (Fig. 2.7) at Whitecourt. Soil temperature fluctuations decreased as soil depth increased for both sites. For example, the minimum soil temperature at 2 cm from Lac La Biche, lower slope position, was -23°C. However, the minimum soil temperature at 64 cm was -5°C. Conversely, the maximum soil temperature at 2 cm was 17°C and at 64 cm was 10°C. The temperatures measured after February 1998 from the lower slope position at Lac La Biche and the middle slope position at Whitecourt were not expected. The middle slope position at Whitecourt was not sheltered by trees resulting in an earlier snow melt and warmer recorded temperatures. However the lower slope position at Lac La Biche was sheltered by trees. Throughout the winter and following summer this site appeared to be attacked by bears. It is possible that the datalogger misfunctioned resulting in warmer recorded soil temperatures. As of yet, no other explanation has been discovered.

Quebec

Descriptions of the study sites in northern Quebec are presented in Table 2.4. Lac Spencer was burned 50 - 70 years ago while Nicabau was cut 50 - 70 years ago. Both sites are located approximately 600 km north of Quebec City. Both sites are black spruce stands of approximately the same age, and have similar soil texture and drainage properties. These sites were also incorporated into Dr. A. Munson's study from Laval University.

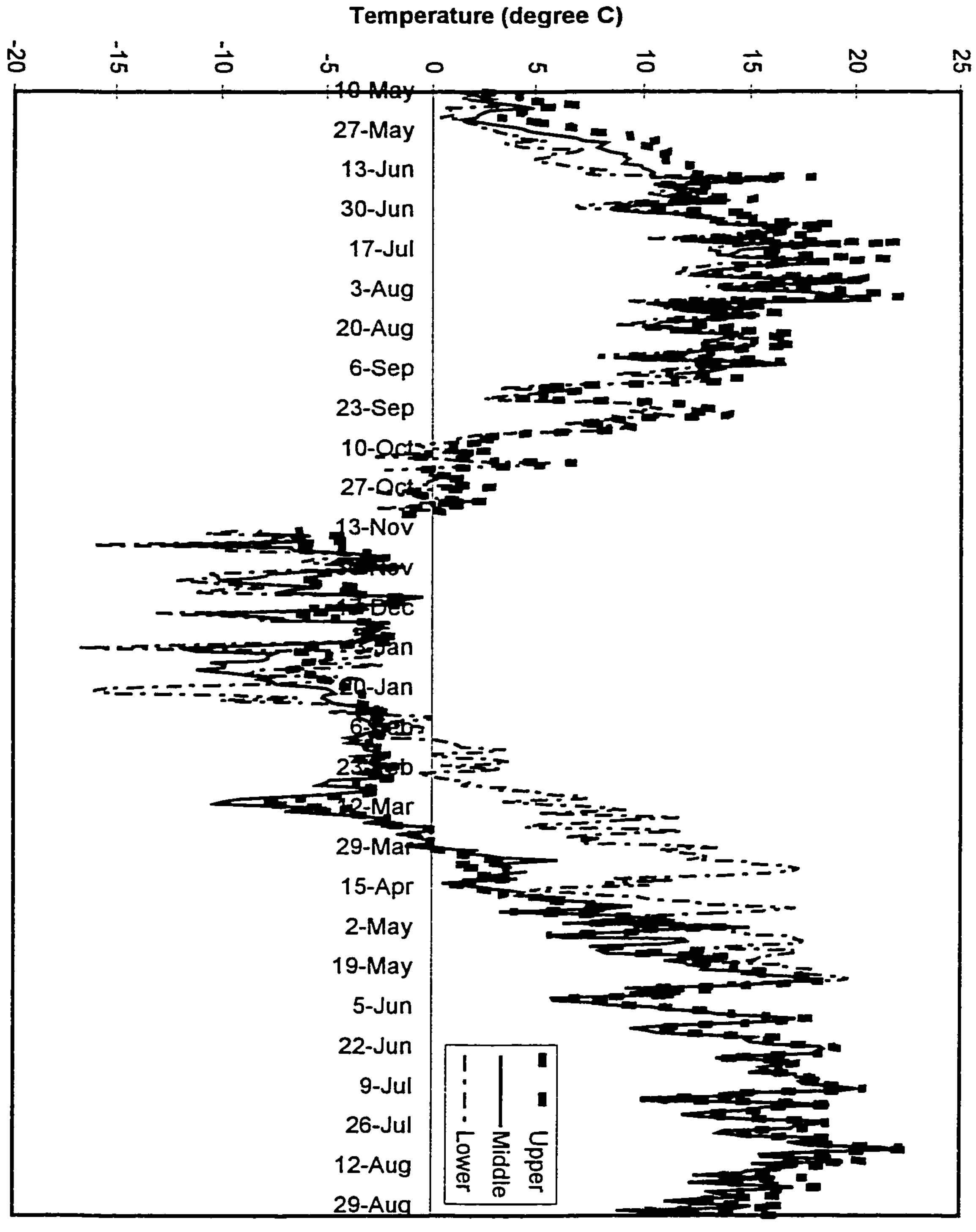

Figure 2.6: Soil temperature at 8 cm depth from Lac La Biche, AB from May 10, 1997 to September 2, 1998

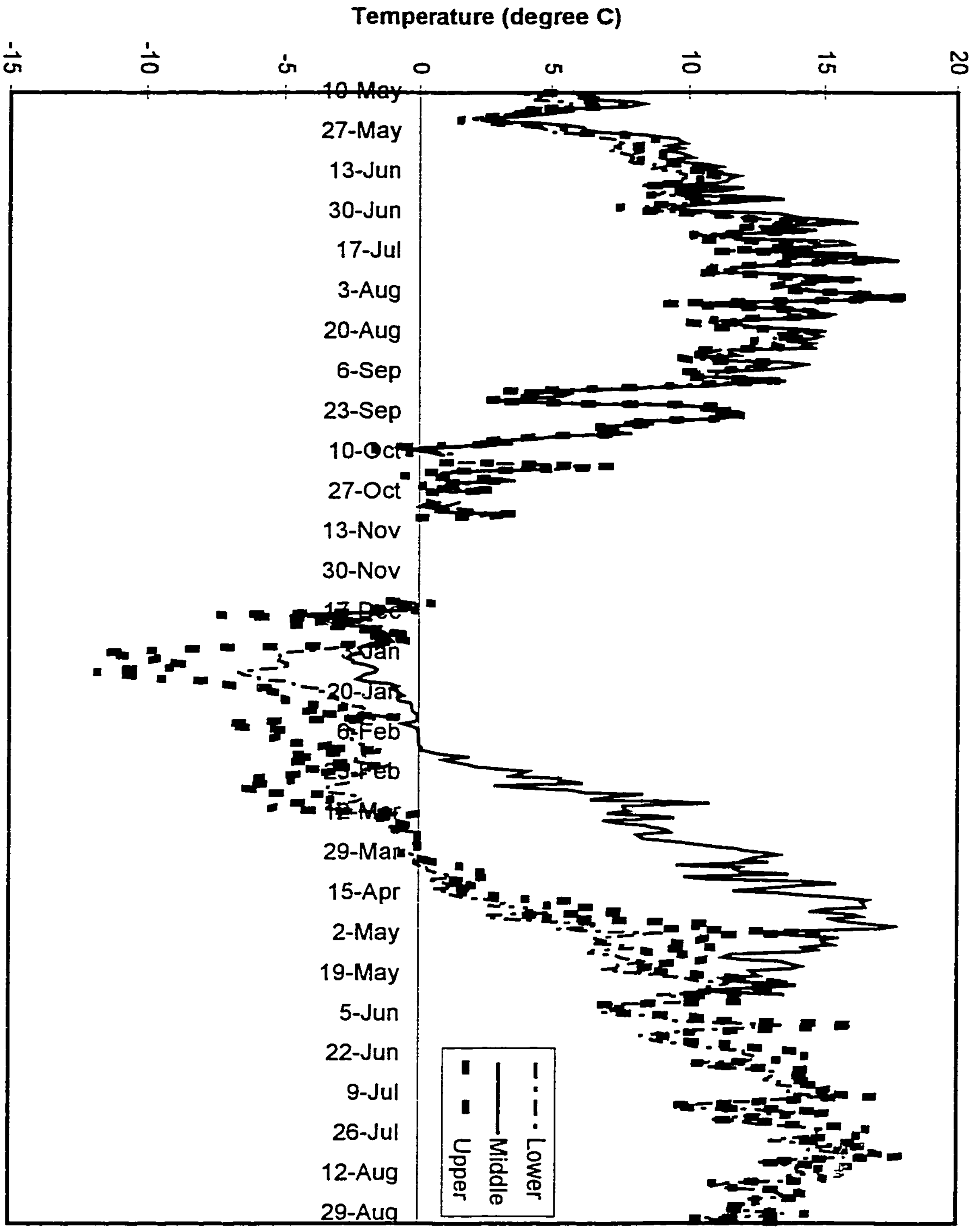

Figure 2.7: Soil temperature at 8 cm depth from Whitecourt, AB from May 10, 1997 to September 2, 1998

Table 2.4: Characteristics of the Disturbed Sites in Quebec

	Lac Spencer - Old Burn	Plien Nicabau - Old Cut
Treatment	Old Burn	Old Cut
Type	Black Spruce	Black Spruce
Age	69-75 years	61-63 years
Location	49°12'39.4" N 73°38'49" W elevation: 370 masl*	49°24'13.2" N 74°03'18.7" W elevation: 202masl
Soil Texture	Loamy fine sand	Loamy fine sand
Slope	2-3%	5%
Soil Classification	Orthic Humo Ferric Podzol	Orthic Humo Ferric Podzol

*masl: meters above sea level

Soil Sampling

In August 1996, intact organic layer samples were collected from two sites in Quebec following the same method as used for the sites in Alberta. The Ae horizons were sampled with a shovel and the soil material was placed in a clear plastic bag and twists tied. These samples were kept at 4°C prior to shipment to the University of Alberta and upon arrival were immediately placed in a 4°C cold room. The Ae samples were sieved (3 mm) at their field moisture contents and stored in clear plastic bags at 4°C. Dr. K. Smith collected additional organic and Ae soil samples in June 1997 for incubation of soil samples at different moisture tensions (Chapter 4).

Vegetation Site Descriptions - Alberta

Vegetation samples were collected from each slope position in August 1998 at Lac La Biche and Whitecourt. Plant samples were dried and key indicator species were identified J. Roberts (Appendix 1.1a to 1.1f). The samples were then discarded. H.A. Lowen classified plant community types for all slope positions according to Beckingham and Archibald (1996) and is summarized below.

Plant Community Types for Lac La Biche

Upper Slope Position

The upper slope position is classified as *Picea glauca / Cornus canadensis* plant community (white spruce / bunchberry). This slope position has more *Populus tremuloides* (trembling aspen) than the middle slope position and is mixed in with *Picea glauca*. The herb layer in the upper slope positions is dominated by *Cornus canadensis* and the moss layer consists of *Pleurozium schreberi* (feather moss), with co-dominant species of *Hylocomium splendens* (step-moss) and *Ptilium crista-castrensis* (knight's plum moss).

Middle Slope Position

The middle slope positions is classified as a *Picea glauca / Cornus canadensis* plant community. This slope position has a few *Populus tremuloides* mixed in with the *Picea glauca*. The shrub layer is dominated by *Cornus canadensis* and the moss layer consists of *Pleurozium schreberi*, with co-dominant species of *Hylocomium splendens* and *Ptilium crista- castrensis*.

Lower Slope Position

The tree canopy of the lower slope position is dominated by *Picea glauca*. The lower slope position is classified as a *Picea glauca / Pleurozium sherberi* plant community. The shrub layer is dominated by *Ledum groenlandicum* (labrador tea) and co-dominated by *Vaccinium vitis-idaea* (bog cranberry). The moss layer at this slope position is dominated by *Pleurozium schreberi*, with co-dominant species of *Hylocomium splenden*, *Ptilium crista- castrensis*, *Peltigera apthosa* (studded leather lichen) and *Cladina mitis* (reindeer lichen).

Plant Community Types for Whitecourt

Upper Slope Position

The upper slope position is located within a *Populus temuloides* stand that is interspersed with *Picea glauca*. This site is classified as a *Populous temuloides-Picea glauca / Lonicera involucrata* plant community (trembling aspen-white spruce / bracted honeysuckle / fern). The shrub layer is abundant and dominated by *Lonicera involucrata* (bracted honeysuckle), with *Ribes lacustre* (black current), *Ribes triste* (wild red current) and *Rosa acicularis* (prickly rose) as co-dominant species. The herbaceous layer consists of *Calamagrostis canadensis* (marsh reed grass), *Gymnocarpium dryopteris* (oak fern), *Athyrium filix-femina* (lady fern) and *Dryopteris carthusian* (shield fern).

Middle Slope Position

Similar to upper slope position.

Lower Slope Position

Similar to upper slope position.

Chemical and Physical Analysis

Soil characteristics for samples of organic (Table 2.5) and Ae horizons (Table 2.6) from Alberta and Quebec sites were determined by the following methods. Dry combustion determined total C and an automated Dumas method determined total N on both samples of organic and Ae horizons using a Carlo ERBA Strumentazione NA1500 Nitrogen, Carbon and Sulfur Analyzer. Field soil moisture contents were determined by measuring the amount of water lost during drying for 24 hours at 105°C. Gravimetric moisture contents (MC) and bulk densities (ρb) were calculated on a dry mass basis (Appendix 1.2a and 1.2b).

Soil pH was measured using a glass electrode with a Corning pH meter (Model 10) in 0.01 M $CaCl_2$ using a 10:1 solution : soil ratio (air dry weight basis) (Carter, 1993). Particle sized analysis (McKeague, 1978) was determined for each Ae horizon and soil texture classified (Appendix 1.3). All forest floor samples had L, F, H horizons present. The average Ae horizon depth for the Alberta sites was 0 - 7 cm the Quebec sites varied in depth from 1 to 5 cm.

Table 2.5: Soil Characteristics for Samples of Organic Horizons from Alberta and Quebec Sites

Site / Position	Horizon Depth (cm)	MC* (w/w)	Bulk Density (Mg/m^3)	pH (0.01 M CaCl$_2$)	Total C (g/kg)	Total N (g/kg)	C:N
Lac La Biche							
Upper	7.4	1.4	0.18	6.1	208	9.0	23.2
Middle	8.4	1.6	0.13	5.2	249	10.2	24.5
Lower	8.9	1.5	0.17	4.2	389	11.6	33.6
Whitecourt							
Upper	10.5	2.0	0.11	5.2	431	24.1	17.9
Middle	8.1	1.7	0.13	5.4	410	23.1	17.8
Lower	8.7	1.2	0.18	5.5	267	15.7	17.0
Lac Spencer	9.0	1.7	0.05	3.1	500	12.8	39.1
Nicabau	11.6	1.8	0.07	3.8	395	10.2	38.8

*MC: moisture content

Table 2.6: Soil Characteristics for Samples of Ae Horizons from Alberta and Quebec Sites

Site / Position	Soil Texture	Horizon Depth (cm)	MC (w/w)	Bulk Density (Mg/m^3)	pH (0.01 M $CaCl_2$)	Total C (g/kg)	Total N (g/kg)	C:N
Lac La Biche								
Upper	Loam	2 - 5	0.18	1.42	5.6	7.9	0.7	11.3
Middle	Loam	2 - 5	0.19	1.27	n.s.*	7.3	0.6	12.2
Lower	Silt Loam	0 - 2	0.16	1.54	5.2	12.3	1.1	11.2
Whitecourt								
Upper	Sandy loam	5 - 7	0.42	0.96	5.0	34.8	2.8	12.4
Middle	Silt Loam	5 - 7	0.35	1.10	4.7	20.2	1.7	11.9
Lower	Loam	5 - 7	0.37	1.03	n.s.*	25.2	1.8	14.0
Lac Spencer	Loam	5 - 10	0.08	1.10	4.0	18.8	0.1	188
Nicabau	Silt Loam	5 - 10	0.20	n.s.	3.8	14.9	0.6	24.8

*n.s: no samples

**MC: moisture content

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Chapter 3 : THE PATTERN OF SOIL N MINERALIZATION FROM THREE SLOPE POSITIONS INCUBATED AT A SINGLE TEMPERATURE

Introduction

During the decomposition of organic substrates, soil respiration is an indicator of microbial growth and maintenance (Smith, 1982). Decomposition of litter may be directly affected through substrate quality or mass, or indirectly through microclimate or decomposer community. Substrate chemistry may be the most important factor regulating litter decomposition and N availability in boreal forests (Scott and Binkley, 1997). Currently, it is debated whether the concentration of N, lignin, polyphenols or some combination of these is the substrate quality factor controlling N mineralization from plant material incorporated into the soil (Northup et al, 1995). Constantinides and Fownes (1994) concluded that initial N concentration from decomposing plant material, which varied in chemical composition was the best predictor of net N accumulation or depletion from that material compared to the concentrations of lignin or soluble polyphenols. In general litter with high N concentration decays faster than litter with low N concentration and equal lignin contents (Kochy and Wilson, 1997). Kochy and Wilson (1997) compared the decomposition rates of aspen (low N concentration) and grass (high N concentration) litter in both forest and prairie environments, and concluded that the decomposition rates were influenced more strongly by litter type than temperature. In addition, analysis of temperature dependence of decomposition rates that are based on seasonal comparisons of soil respiration must be treated with caution because of the seasonal deposition of litter by deciduous plants. In autumn, deciduous forest and grassland plants deposit a large quantity of readily decomposable litter onto the soil surface. This material becomes available at a cool time of the year, and produces higher respiration rates than expected on the basis of temperature due to the high quality substrate (Kirschbaum, 1995). Therefore, differences in decomposition between deciduous and coniferous ecosystems are due to differences in litter quality and seasonal litter deposition.

Lignin content has also been used to characterize substrate quality. Lignin concentrations in plant residue have been suggested as a much better predictor of plant residue decomposition than N concentration (Fox et al, 1990). An earlier study by Herman et al. (1977) concluded lignin decomposition rate was related to C:N ratio, lignin and carbohydrate content of the material through the relationship [(C:N) (% lignin)] (% carbohydrate$^{-1/2}$). Palm and Sanchez (1991) found that lignin concentrations of plant residue were not correlated with N mineralization, and the best predictor was polyphenol:N ratio. Scott and Binkley (1997) suggested that the litter lignin:N ratio was a good predictor of net N mineralization across a range of forest sites with different climatic regimes. Fox et al. (1990) concluded that (lignin + polyphenol):N ratio of legumes was an excellent indicator of mineralization rate compared to polyphenol, lignin or N concentrations alone. Generally higher litter lignin concentrations retard litter decay rates.

Most forest floors are composed of L, F and H layers in which a C:N ratio ranges from 40 to 60:1 (Keeney, 1980). However, the organic horizons used in this research had a C:N ratio from 17 to 40. Organic horizons consist of layers of organic debris (LFH) in varying stages of decomposition (Keeney, 1980). Generally the L layer has a C:N (35 to 60:1) greater than the F or H layer (25 to 49:1). On the other hand, the mineral horizon is characterized by an accumulation of well decomposed organic matter. Typically mineral soil has a C:N of 10:1. Net immobilization will not occur if the soil has C:N ratio of 25:1 or lower (Paul and Juma, 1981). Therefore, N immobilization is expected to be dominant in the organic horizons due to the high amount of C available followed by net mineralization (Binkley and Vitousek, 1989). Nitrogen mineralization will likely occur in the mineral horizon due to the lower C:N ratio.

The objective of this study was to characterize patterns of net N mineralization in organic and mineral soil horizons from three slope positions along a catena. We hope to answer the question: does the specific net rate of N mineralization vary in samples from along a catena at each site and between sites? We expected the specific net rate of N mineralization to be lower in the mineral horizons due to greater degrees of humification. Consequently, the patterns of N mineralization are expected to vary among horizons. It is also expected that the rate of N mineralization will decrease as incubation time increases (Winkler et al., 1995). We hypothesize that the specific net rate of N mineralization will not differ among slope positions.

Materials and Methods

Laboratory Incubation

Soil Sampling

See Chapter 2.

Sample Preparation

In the laboratory, undisturbed organic horizon cores were taken from each intact organic horizon sample using a hand drill and a custom-made soil corer with a diameter of 7.2 cm. Li and Vitt (1997) reported that the moss layer short circuits the N cycle by playing a significant role in the uptake, retention and redistribution of N within the forest system, therefore the green moss layer was removed from the organic samples prior to cutting. Organic samples were then transferred to PVC incubation tubes with an internal diameter of 7.6 cm which had one glass fiber filter pad (Fisherbrand circles G6 #09-804-90A) at the bottom of the tube. Ground silica sand was poured down the sides and on top of the organic samples to prevent preferential flow of water. Approximately 100 g (wet weight) of sieved Ae horizon sample (< 3 mm) was placed in a PVC incubation tube with an internal diameter 5.1 cm, which had one glass fiber filter pad at the bottom of the tube. Glass fiber filter pads were placed on top of both the organic horizon and Ae horizon samples to prevent surface disturbance when the 0.01 M $CaCl_2$ solution was poured into the tube (see Figure 3.1). Tubes were covered with tin foil to exclude light and incubated at 22°C. Holes in the tin foil maintained an aerobic environment.

Leaching Regime

Incubation of Alberta Soil Cores from All Slope Positions at a Single Temperature

In February 1997, intact cores of organic layer samples from upper, middle, and lower slope positions from Lac La Biche and Whitecourt, Alberta (sampled October 1996) were leached prior to incubation by placing each core on top of a side arm flask attached to a vacuum line and allowing 75 ml of 0.01 M $CaCl_2$ ($pH = 7$) to flow through the sample. This was followed by 25 ml of a minus-N solution ($I = 0.09$ mol L^{-1}) (Cabrera and Kissel, 1988). After free drainage ceased (approximately 10 minutes), the cores were evacuated to 33 kPa moisture tensions. Leachate from each core was diluted to a constant volume with deionized water. Following leaching, cores were incubated at 22°C. Subsequent leachings were performed on days 6, 13, 27, 42, 56, 71, 85, 99, 113, 127, 141, 155, 169, 184, 198, 212, and 241. After day 21, the volume of leaching solution was decreased to 45 ml of 0.01 M $CaCl_2$ and 15 ml of minus-N solution (100 and 60 ml of solution is approximately 107 and 60 % of the mean annual summer precipitation, respectively).

98-Day Incubation of Alberta Soil Cores from Lower Slope Position at 22°C

To determine if periodic leaching slowed the establishment of a nitrifier community, because their substrate NH_4^+ was removed, samples of organic and Ae horizons from the lower slope positions from both sites were prepared as above and incubated at 22°C and 33 kPa for 98 days. Leachates were collected from each core on day 0 and 98.

Leachates were analyzed for mineral N. The concentration of NH_4^+-N in leachate was measured by the automated indophenol blue method (Technicon, 1973), and the NO_3^--N concentrations were measured using cadmium reduction method (Technicon, 1977).

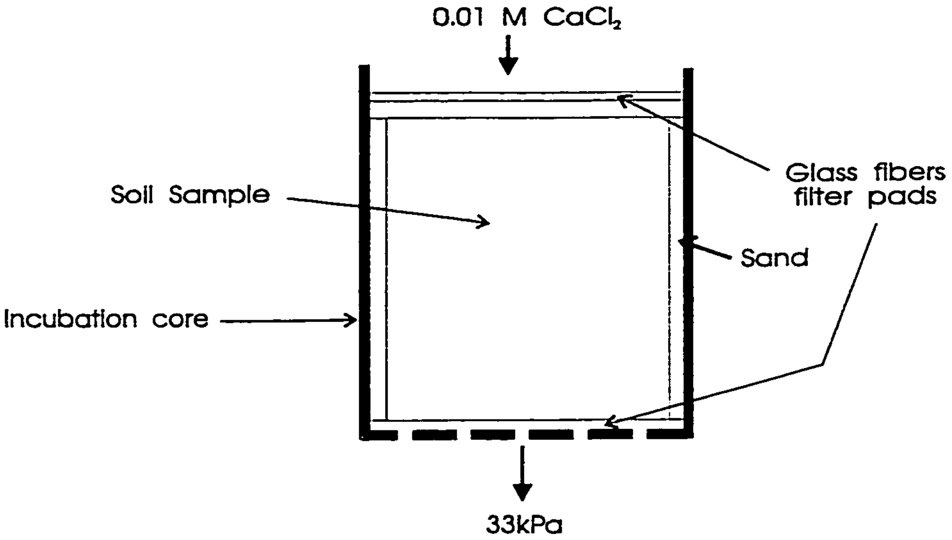

Figure 3.1: Cross-sectional view of undisturbed organic horizon core prepared for incubation

Calculation of Specific net Rate (mg N g^{-1} soil N)

Normally, N mineralization is expressed as μg g soil^{-1}. This takes into account the mass of soil used and organic matter quality. Differences in soil total N may influence rates of N mineralization independently of organic matter quality. Therefore, N mineralized was expressed as a specific net mineralization with units of mg N mineralized g^{-1} soil N at each sample time. Specific net mineralization normalizes the data to a N basis not to a soil mass basis. The concept behind specific net mineralization can be explained by two examples:

Organic Horizon	**Mineral Horizon**
Nt = 0.021 g N g^{-1} soil	Nt = 0.002g N g^{-1} soil
Ms = 100 g soil	Ms = 100 g soil
Nm = 15 mg N	Nm = 3 mg N
$\frac{15mgN}{100gsoil} * \frac{gsoil}{0.021gN}$	$\frac{3mgN}{100gsoil} * \frac{gsoil}{0.002gN}$
Specific net rate = 7.1 mg N g^{-1} soil N	Specific net rate = 15 mg N g^{-1} soil N

where Nt is the total amount of N (g kg^{-1}); Ms is the mass of soil (g); and Nm is the amount of N mineralized.

This example indicates that the mineral horizon mineralization proportionally more N than the organic horizon, even though the amount mineralized from the organic horizon is five times more than from the mineral horizon. This approach allows data to be compared from different sites and horizons because it is normalized to the total amount of N contained within each sample. Therefore varying N content can be treated separately, allowing interpretation about the nature of the N and of the soil environment (Appendix 2.1a).

Statistical Analysis

The mean specific net NH_4^+-N + NO_3^--N mineralization rates presented are derived from 3 replicates per site, per horizon, for the specific net mineralization determined every 14 -

28 days over 241 days. One way simple ANOVA's ($\alpha = 0.05$) were calculated in SAS 6.12 for windows to determine if there were any significant differences between treatments. To determine what treatments were different from each other, mean separations using Student-Newan-Keuls also were calculated.

A variety of models were fitted to incremental mineralization data for each site using a non-linear (NLIN) procedure from the SAS statistical program package (SAS Institute Inc., 1998) to determine mineralization potential (N_o), decay rate (k) or other equation parameters (h or x). The exponential model [Eq. 3.1a and 3.1b] assumes the quantity of growth is proportional to dry weight and growth is at a maximal rate as long as there is substrate available (France and Thornley, 1984).

$$N_m = N_o\left(1 - e^{-kt}\right) \qquad [3.1a]$$

$$N_i = N_o e^{-kt}\left(e^{ki} - 1\right) \qquad [3.1b]$$

Where, N_m = cumulative N mineralized (mg N g^{-1} soil N); N_i =incremental N mineralized (mg N g^{-1} soil N) in interval i preceding time t (both in days); k = rate coefficient (day^{-1}); and N_o = potentially mineralizable N (mg N g^{-1} soil N).

The logistic model [Eq. 3.2a and 3.2b] assumes the quantity of growth is proportional to dry weight and growth increases at a rate proportional to the amount of substrate (France and Thornley, 1984).

$$N_m = \frac{N_0}{1 + \left({N_o}/{x} - 1\right)e^{-kt}} \qquad [3.2a]$$

$$N_i = N_o\left[\frac{1}{1 + \left(\frac{N_o}{x} - 1\right)e^{-kt}} - \frac{1}{1 + \left(\frac{N_0}{x} - 1\right)e^{-k(t-i)}}\right] \qquad [3.2b]$$

Where x = initial weight of substrate that is involved in mineralization (mg N g^{-1} soil N).

The Gompertz model [Eq. 3.3a and 3.3b] assumes substrate is not limiting; the quantity of growth substrate is proportional to dry weight with a constant of proportionality, h; the mineralization rate increases in the early stages; and the efficiency of the mineralization process will decrease with time because of the slower activity of the mineralizing flora or exhaustion of the mineralizable N (Simard and N'dayegamiye, 1993).

$$N_m = N_o e^{-he^{-kt}} - N_o e^{-h} \qquad [3.3a]$$

$$N_i = N_o e^{-h\left[1-e^{k(t-i)}\right]} - N_o e^{h\left(1-e^{kt}\right)} \qquad [3.3b]$$

Where h = proportionality constant (dimensionless). N mineralization patterns were described using these equations.

Incremental data was used for the following reasons: (1) to reduce interdependence of observation errors; (2) to allow use of unmodified laboratory data; (3) to permit deletion of missing observations; and (4) to emphasize mineralization dynamics which tend to be obscured when laboratory data are summed (Ellert and Bettany, 1988).

The best fitting model was identified by the lowest residual sum of squares. To determine if the more complex Model 2 (i.e. Gompertz model) with p_2 parameters explained more variance than the simpler Model 1 (i.e. exponential model) with p_1 parameters, a F_{extra} [Eq. 3.4] was calculated (Ellert and Bettany, 1992):

$$F_{extra} = \frac{RSS1 - RSS2 \big/ p_2 - p_1}{RSS2/n - p_2} \qquad [3.4]$$

where RSS = residual sum of squares in Model 1 or 2; p = number of parameters in Model 1 or 2, with $p_2 > p_1$; and n = number of observations. The additional parameters are warranted if the calculated F_{extra} > tabulated $F_{\alpha[(p2-p1)/(n-p2)]}$.

Time to inflection point, T_{ni} (d) [Eq. 3.5] and maximum rate of N mineralization, R_m (mg N g^{-1} soil N d^{-1}) [Eq. 3.6] were derived from the Gompertz model and calculated as follows:

$$T_{ni} = \frac{1}{k}\ln\left(\frac{k}{\alpha_o}\right) \qquad [3.5]$$

$$R_m = N_o k\left[e^{\left(\frac{\alpha_o}{k}\right)-1}\right] \qquad [3.6]$$

Where α_o [Eq. 3.7] is the specific net rate of mineralization at the start of incubation (d^{-1}):

$$\alpha_o = k * h \qquad [3.7]$$

Results

Incubation of Alberta Soil Cores from All Slope Positions at One Temperature

It is important to note the units used for NH_4^+-N+NO_3^--N mineralization. If mineralization were expressed in mg N g^{-1} soil (Fig. 3.2) the organic horizon would be perceived as the more active horizon, mineralizing more N. However, if mineralization is expressed as mg N g^{-1} soil N, it can be demonstrated that there is no difference in the amount of N mineralized between the Ae horizon and the organic horizon (Fig. 3.3).

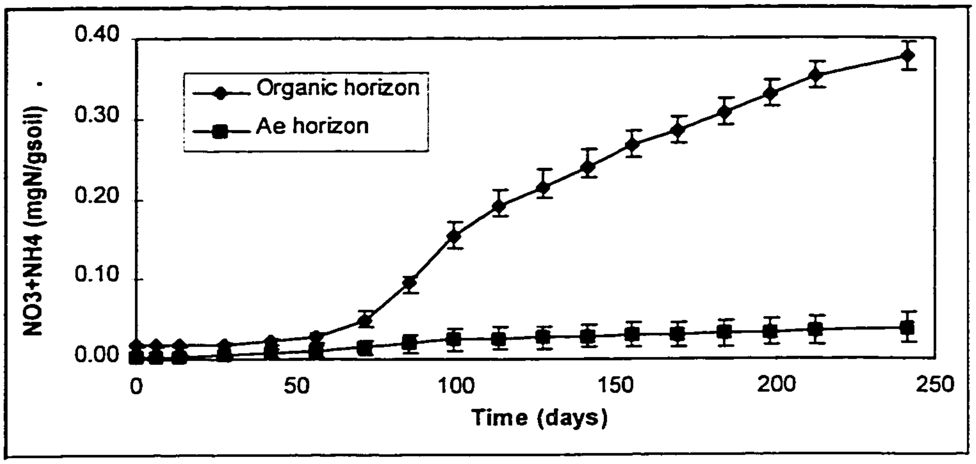

Figure 3.2: Cumulative net NH_4^+-N+NO_3^--N mineralization (mg N g^{-1} soil) during 241 days from samples of organic and Ae horizons from Lac La Biche, upper slope position, incubated at 22°C at 33 kPa moisture tension (n=3)

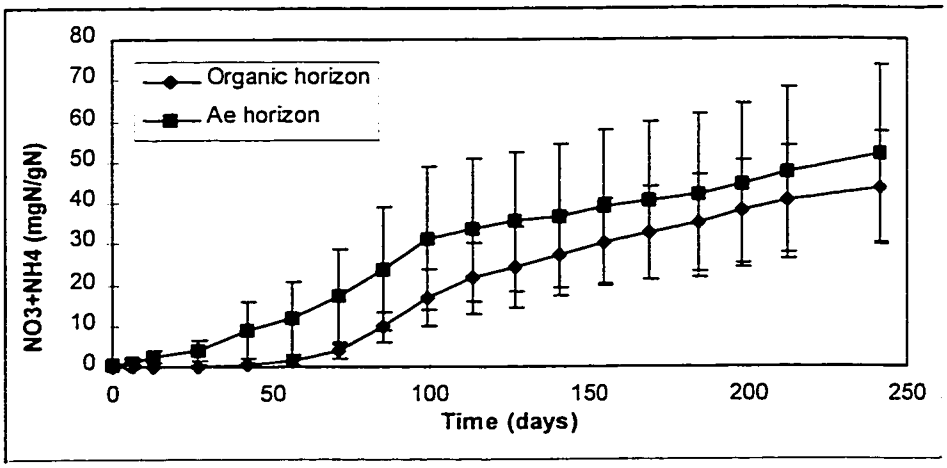

Figure 3.3: Cumulative specific net NH_4^+-N+NO_3^--N mineralization (mg N g^{-1} soil N) during 241 days from samples of organic and Ae horizons from Lac La Biche, upper slope position, incubated at 22°C and 33 kPa moisture tension (n=3)

The cumulative specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons at all slope positions from Lac La Biche (Fig. 3.4) has similar pattern of mineralization over 241 days. Both horizons from Whitecourt, as well as the samples from the Ae horizon from Lac La Biche follow this pattern.

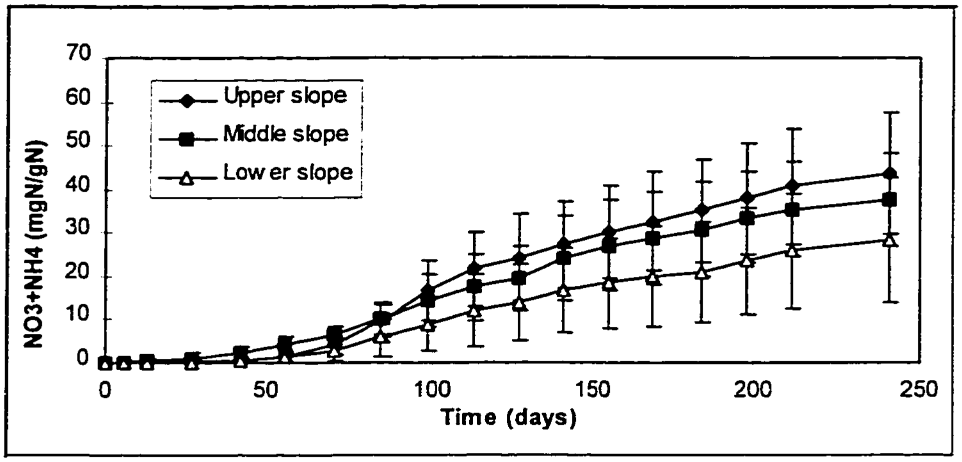

Figure 3.4: Cumulative specific net NH_4^+-N+NO_3^--N mineralization during 241 days from samples of organic horizons at all slope positions from Lac La Biche, AB incubated at 22°C and 33 kPa moisture tension (n=3)

Typically there was a lag period at the beginning of the incubation (approximately 50 days), and gradually leveling off at the end of the incubation. Incremental data for the Lac La Biche site (Fig. 3.5) indicates a peak NH_4^+-N+NO_3^--N mineralization for all slope positions around day 99. This pattern of N mineralization was observed by both horizons in both sites.

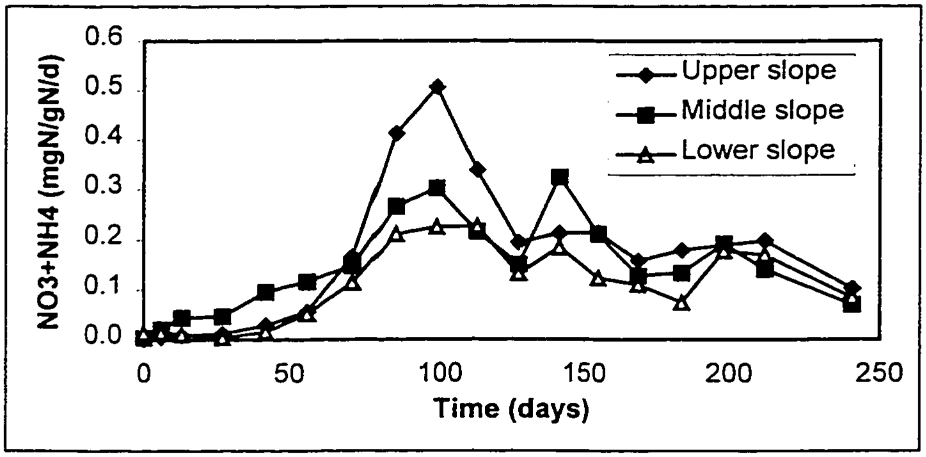

Figure 3.5: Incremental specific net NH_4^+-N+NO_3^--N mineralization during 241 days from samples of organic horizons at all slope positions from Lac La Biche incubated at 22°C and 33 kPa moisture tension (n=3)

Samples of organic horizons from Lac La Biche took approximately 50 days to accumulate NO_3^--N (Fig. 3.6) whereas, it took approximately 25 days for samples of organic horizons from Whitecourt to accumulate NO_3^--N. However, detection of NO_3^--N from samples of Ae horizons took up to 150 days from all slope positions at both sites (Fig 3.7).

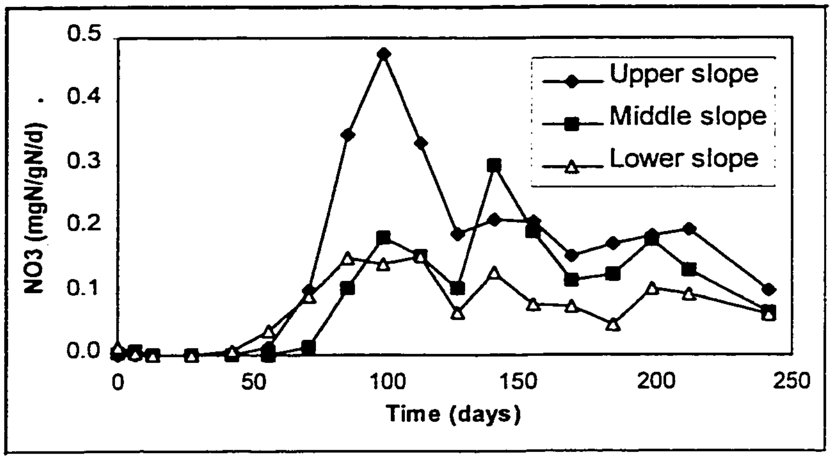

Figure 3.6: Accumulation of NO_3^--N from samples of organic horizons during 241 days from all slope position at Lac La Biche incubated at 22°C and 33kPa moisture tension (n=3)

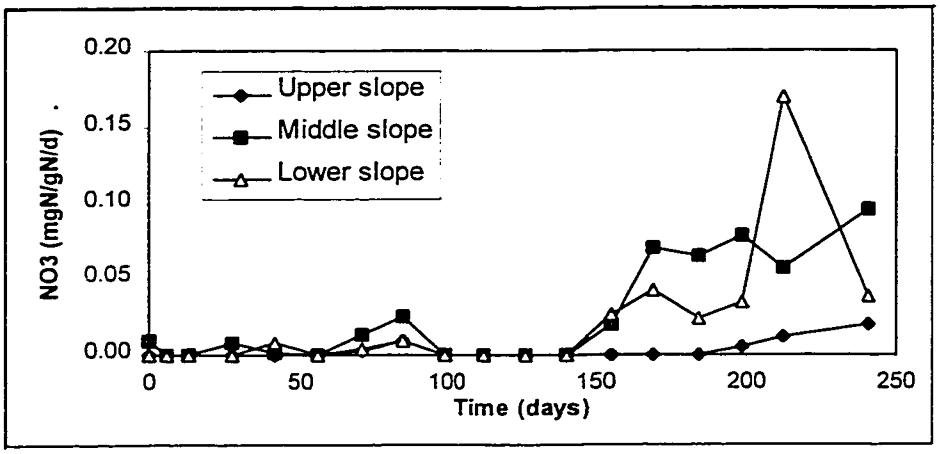

Figure 3.7: Accumulation of NO_3^--N from samples of Ae horizons during 241 days from all slope positions at Whitecourt incubated at 22°C and 33 kPa moisture tension (n=3)

Both samples of organic (Fig. 3.8) and Ae (Fig. 3.9) horizons from Lac La Biche and Whitecourt accumulated NO_3^--N after 98 days. The accumulation of NO_3^--N was significantly higher from samples of organic horizons from Whitecourt compared to samples from Lac La Biche, whereas the reverse was true for samples of Ae horizons.

These results suggest that 98 days was sufficient time for NO_3^--N to accumulate in samples of both horizons from both sites. It is believed that NO_3^--N accumulation in samples of organic and Ae horizons was restricted because periodic leaching of samples removed the NH_4^+ substrate that nitrifers use to oxidize to NO_3^-. An alternative explanation may be that the was net immobilization for the first 50 to 100 days.

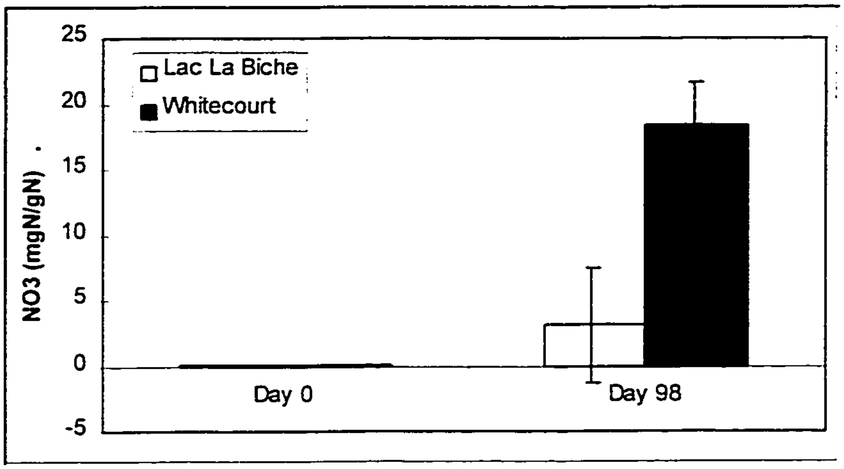

Figure 3.8: Accumulation of NO_3^- from samples of organic horizons after a 98 days incubated at 22°C and 33 kPa moisture tension (n=3)

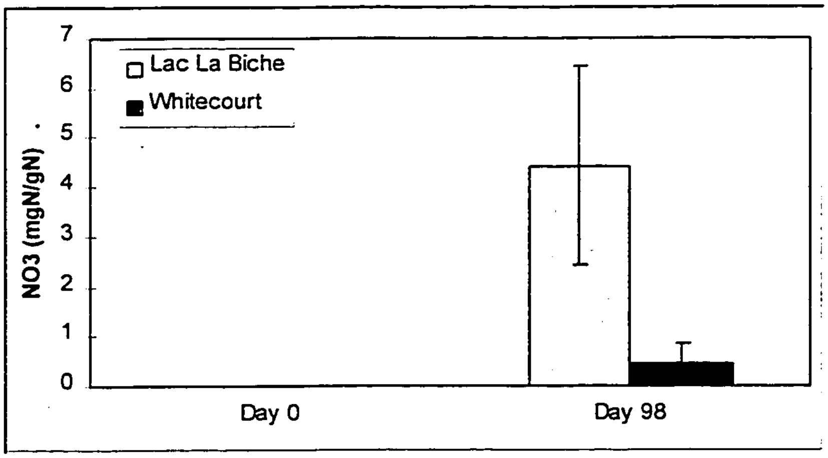

Figure 3.9: Accumulation of NO_3^- from samples of Ae horizons after 98 days incubated at 22°C and 33kPa moisture tension (n=3)

There was no significant difference in mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic or Ae horizons at any slope position from Lac La Biche (Fig.

3.10). Samples of organic and Ae horizons mineralized between 20 and 52 mg N g^{-1} soil N.

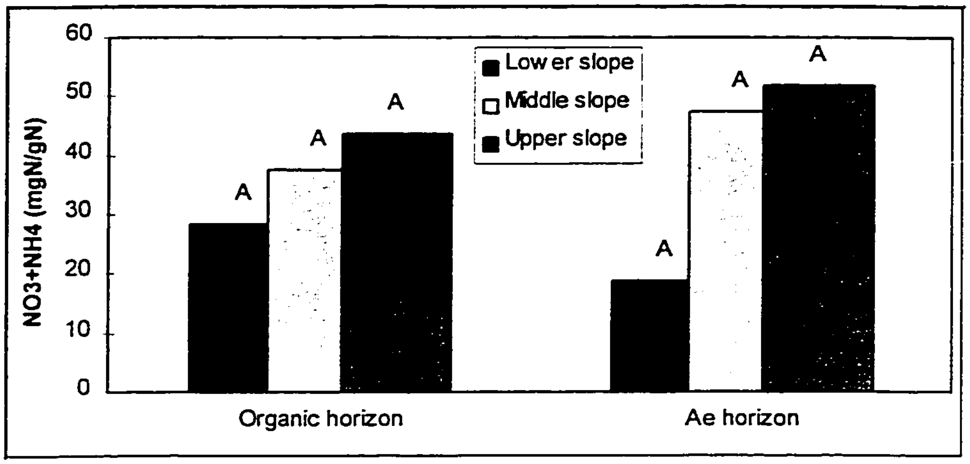

Figure 3.10: Mean specific net NH_4^+-N+NO_3^--N mineralization after 241 days from samples of organic and Ae horizons from Lac La Biche incubated at 22°C and 33 kPa moisture tension (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The samples of organic horizons from the lower slope position from Whitecourt mineralization more NH_4^+-N+NO_3^--N than the upper slope position did (Fig. 3.11). There was no difference in NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons from any slope position. Generally samples from both the Ae and organic horizons mineralization between 22 to 43 mg N g soil N^{-1}. Since there was little or no difference in the NH_4^+-N+NO_3^--N mineralization between slope positions, later experiments were completed with only one slope position from each of these sites.

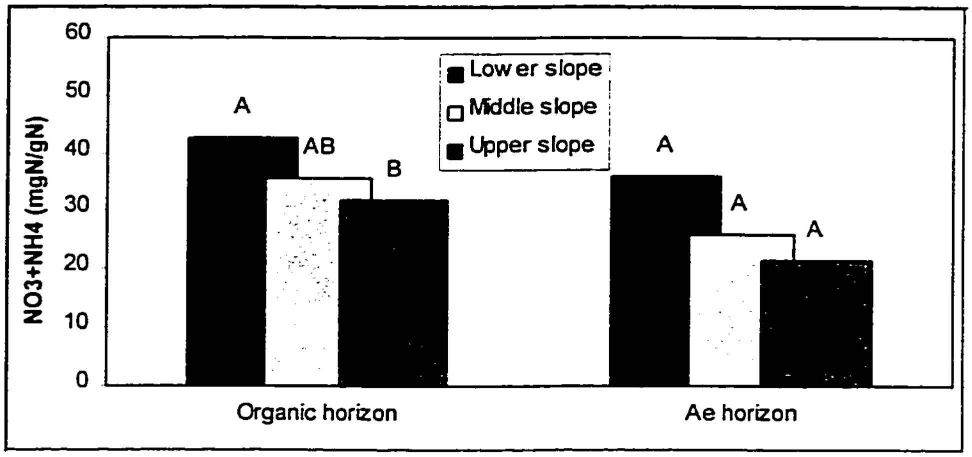

Figure 3.11: Mean specific net NH_4^+-N+NO_3^--N mineralization after 241 days from samples of organic and Ae horizons from Whitecourt incubated at 22°C and 33 kPa moisture tension (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The logistic model [Eq. 3.2b] gave a better fit than the Gompertz [Eq. 3.3b] model, however for the following 2 experiments the Gompertz model gave a better fit than the logistic (approximately 70 % of the time). Therefore in order to be consistent, the results from the Gompertz model are presented throughout this thesis. The incremental Gompertz model predicted N_0 values close to the observed total (Fig.3.12). The samples of Ae horizons from Whitecourt (Fig. 3.13) from the lower slope position were the exception where it was less than the observed total.

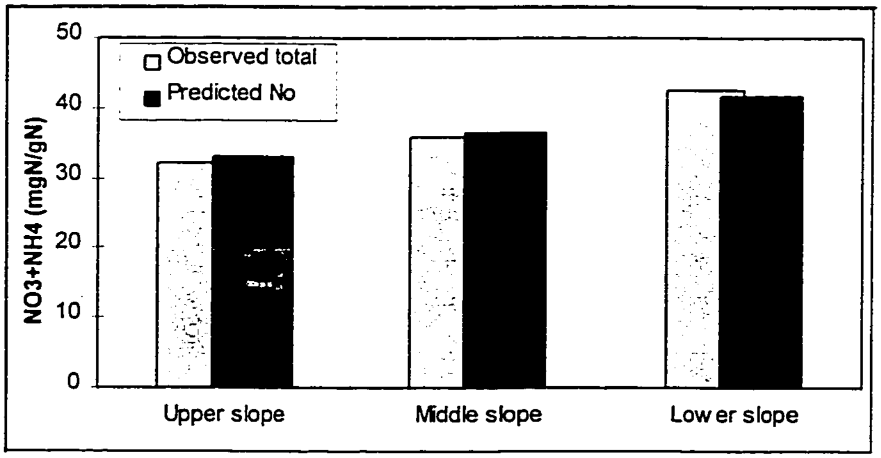

Figure 3.12: Comparison between observed net NH_4^+-N+NO_3^--N mineralization after 241 days from samples of organic horizons from Whitecourt and N_0 predicted by the Gompertz model

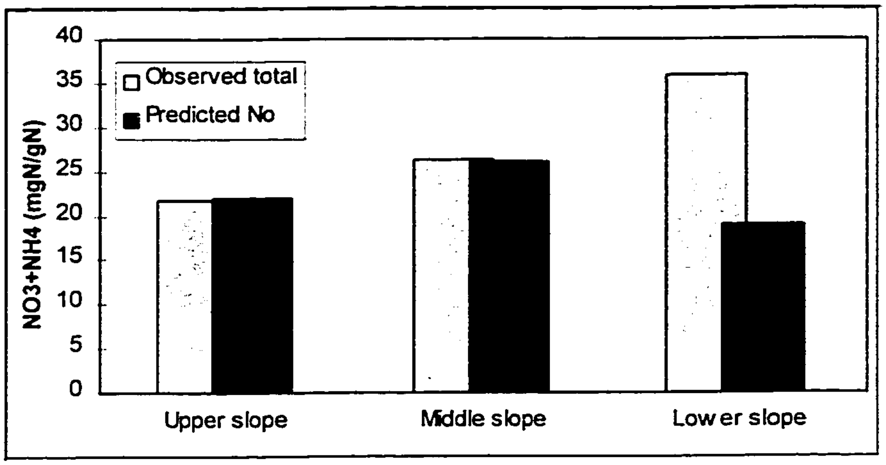

Figure 3.13: Comparison between observed net NH_4^+-N+NO_3^--N mineralization after 241 days from samples of Ae horizons from Whitecourt and N_0 predicted by the Gompertz model

The predicted cumulative mineralization (Fig. 3.14) and the predicted incremental mineralization (Fig. 3.15) from the Gompertz model had r^2 values ranging from 0.78 to 0.94 (mean = 0.87) for both horizons and both sites.

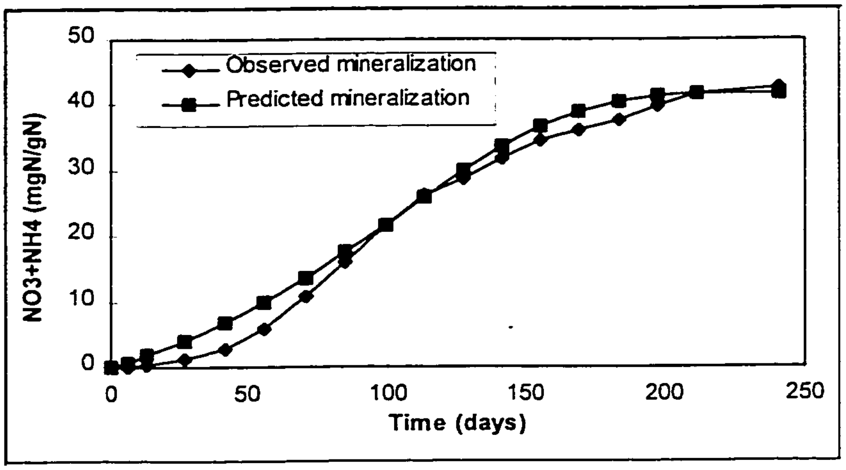

Figure 3.14: Predicted and observed cumulative specific net NH_4^+-N+NO_3^--N mineralization during 241 days from samples of organic horizons from Whitecourt lower slope position

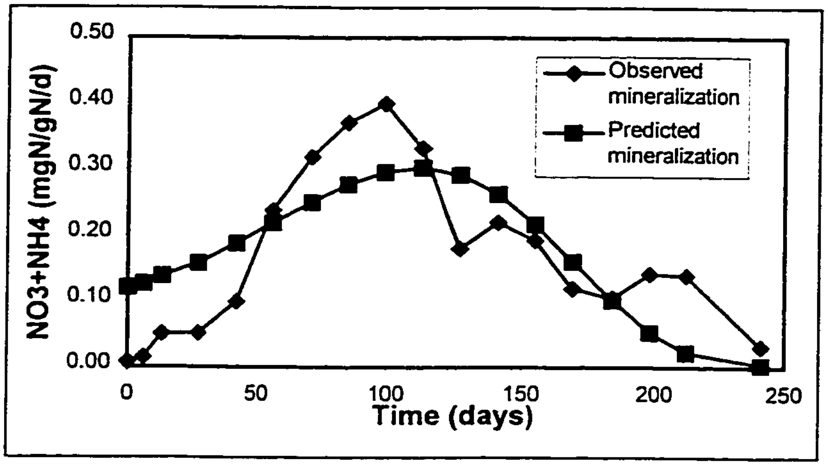

Figure 3.15: Predicted and observed incremental specific net NH_4^+-N+NO_3^--N mineralization after 241 days from samples of organic horizons from Whitecourt lower slope position

Rate coefficients, k, for net N mineralization were similar among slope positions and were horizon specific not site specific (Appendix 2.2a and 2.2b). For samples of organic horizons, k ranged from 0.013 to 0.017 day^{-1}. For samples of Ae horizons, k ranged from 0.005 to 0.025 day^{-1}. There was more variability in the h value from samples at different sites and different horizons although no pattern was apparent. The samples of organic horizons from both sites had h values ranging from 0.147 to 0.255 (unitless). The samples of Ae horizons had h values ranging from 0.004 to 0.889 (unitless).

Values of h, k and N_o are correlated with each other. Therefore comparisons among soils or sites cannot use one parameter alone. Derived variables that include 2 or 3 of the parameters are more appropriate for comparing among soils or sites. The time to inflection point (T_{ni}; d) (i.e. time to maximum N mineralization rate) contains k and α_o; and maximum rate of N mineralization (R_m; mg N g^{-1} soil N d^{-1}) incorporates N_o as well as k and α_o. They were calculated and are used here for comparative purposes (Tables 3.1 - 3.4). Time to inflection [3.7] among samples of organic horizons between sites (Table 3.1), ranged from 105 to 148 days. Time to inflection was more variable for samples of Ae horizons than the organic horizons, ranging from 23 to 437 days.

Table 3.1: Time to Inflection Point for Samples of Organic Horizons (days) incubated at 22°C

Slope Position	Lac La Biche	Whitecourt
Upper	135	117
Middle	133	109
Lower	148	105

Table 3.2: Time to Inflection Point from Samples of Ae Horizons (days) incubated at 22°C

Slope Position	Lac La Biche	Whitecourt
Upper	23	110
Middle	140	437
Lower	164	212

The maximum NH_4^+-N+NO_3^--N mineralization rates at inflection were calculated [Eq. 3.8] for samples of organic (Tables 3.3) and Ae horizons (Table 3.4). The maximum NH_4^+-N+NO_3^--N mineralization rates were similar from samples of organic and Ae horizons from Lac La Biche and Whitecourt, and ranged from 0.09 to 0.30 mg N g^{-1} soil N d^{-1}. The maximum NH_4^+-N+NO_3^--N mineralization rates from samples of organic and Ae horizons decreased from the upper slope position to the lower slope position from Lac La Biche. In contrast, the reverse is true for Whitecourt.

Table 3.3: Maximum Rate of NH_4^+-N+NO_3^--N Mineralization at Inflection from Samples of Organic Horizons (mg N g soil N^{-1} d^{-1})

Slope Position	Lac La Biche	Whitecourt
Upper	0.27	0.21
Middle	0.23	0.22
Lower	0.17	0.30

Table 3.4: Maximum Rate of NH_4^+-N+NO_3^--N Mineralization at Inflection from Samples of Ae Horizons (mg N g soil N^{-1} d^{-1})

Slope Position	Lac La Biche	Whitecourt
Upper	0.28	0.10
Middle	0.24	0.23
Lower	0.09	0.18

Discussion

The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of either organic or Ae horizons varied little among slope positions. This suggests either *in situ* soil environment along the catena did not affect the nature of substrate and microbial communities in these soil horizons at either site, or incubation of these soil cores under controlled laboratory conditions eliminated any differences between these sites and horizons.

Low rates of net nitrification are often reported for forest soils. This is usually attributed to low populations of nitrifiers (Tamm et al, 1974; Keeney, 1980) or to low soil pH (Lodhi and Killingbeck, 1980). Stark and Hart (1997) demonstrated that undisturbed forest soils have high rates of nitrification, but microbes quickly assimilate NO_3^- therefore net nitrification is undetected. Accumulation of NO_3^--N reported here took approximately 50 to 100 days to be detected from these soils. Soil pH for samples of organic and Ae horizons from Alberta ranged from 4 to 6. Lodhi and Killingbeck (1980) stated that nitrification is inhibited below soil pH 6 and can become negligible at pH 5. This suggests that nitrification was not inhibited by pH, and we hypothesize that low rates of nitrification was more likely due to a small population of nitrifiers, which took approximately 50 -100 days to get established. This raises the question whether low nitrification rates in forest soils are a result of low supply of NH_4^+-N (due to uptake of NH_4^+ by plants)? Evidence here suggests this may be the case, however soil microorganisms are usually more efficient at absorbing soil N than vascular plants (Lodhi and Killingbeck, 1980), therefore a low supply of NH_4^+ due to plant uptake is not likely. Another factor influencing nitrification is substrate quality. Lodhi and Killingbeck (1980) stated condensed tannins are extremely toxic to nitrifiers thereby preventing nitrification. They suggested high concentration of condensed tannins in the needles and bark of ponderosa pines may be an ecosystem strategy to increase retention of N in upper soil horizons and preventing loss of N through leaching. Rice and Pancholy (1973) determined the concentration of tannins were higher in the top 15 cm of soil in a climax community than in an intermediate succession stage community. This corresponded with the concentration of soil NO_3^-, which was lowest in the climax community and highest in first successional stage community. Further characterization of samples of organic and Ae horizons is needed to test these conjectures.

Conclusions

In summary, the specific net rate of N mineralization was not significantly different between sites or slope positions. Low rates of nitrification may be due to low population of nitrifiers or substrate quality, rather than low soil pH.

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Chapter 4 : THE PATTERN OF SOIL N MINERALIZATION AT INCREASING SOIL TEMPERATURE AND MOISTURE TENSION

Introduction

Soil moisture influences soil organic N mineralization (Stanford and Epstein, 1974). The amount of N available for mineralization is in turn a function of the amount of organic C stored in the soil. The C content or amount of soil organic matter (SOM) is regulated by climatic conditions, and by chemical factors of the litter which affect activity of soil microorganisms. The two most important limiting factors to growth in boreal forests are low N availability and low air temperatures (Makipaa, 1995). The plant availability of N within a growing season may be more dependent on the temperature sensitivity of mineralization than the quantities of N in the mineralizable fraction of SOM (Ellert and Bettany, 1992). N availability often increases with an increase in temperature due to an increase in decomposition of SOM (Cole, 1995; Makipaa, 1995). Amount of SOM usually increases with decreasing mean annual temperature.

The Arrhenius equation describes the influence of temperature on rate constants for most chemical and biological reactions. However, for biological systems it can only be applied to a limited temperature range. For example, the Arrhenius equation predicts that soil respiration rates increase exponentially for temperatures between 20 and 40°C. At higher temperatures essential proteins are denatured, killing microorganisms (Winkler et al., 1996). The Arrhenius equation:

$$K = A_e^{\left(-E/RT\right)} \qquad [4.1]$$

where K is the rate constant, A_e is a constant, R is the universal gas constant, T is the temperature in degree Kelvin, and E is the activation energy. Winkler et al. (1996) reported that the Arrhenius equation modeled the initial rates of respiration from the A horizon at temperatures between 4°C and 38°C. However, when the Arrhenius equation was used to model initial respiration rates from Ae and B horizons it fit only at a lower temperature range between 4°C and 22°C.

The Q_{10} function (Kirchbaum, 1995):

$$Q_{10}=\left(\frac{k_2}{k_1}\right)^{\left(\frac{10}{T_2-T_1}\right)} \qquad [4.2]$$

where k_1 and k_2 are constants for a process of interest at two observed temperatures, T_1 and T_2. Given a Q_{10} value of 2, the rate of a particular process would occur twice as fast at 15°C than at 5°C. The development of the Q_{10} relationship using the Arrhenius equation, predicted that the Q_{10} is higher at incubation temperatures between 5 to 15°C and lower at incubation temperatures above 25°C (Winkler et al., 1996).

Townsend et al. (1995) suggested all decomposition rates increase exponentially with temperature such that a Q_{10} value equal to 2 seems to represent both the labile and recalcitrant pools in the soil. Kirschbaum (1995) observed that the Q_{10} was not constant across a range of temperatures, but greater at temperatures below 10°C than at temperatures between 20 to 30°C. At temperatures higher than 40°C, the relationship was not exponential and is consistent with the denaturation of enzymes (Winkler et al., 1996).

Quemada and Cabrera (1997) incubated a mineral soil at 4 different temperatures and 5 different moisture tensions. Their results indicate the highest N mineralization rate to be at a soil tension of 27 kPa (20°C). However, Theodorou and Bowen (1983) reported the maximum rate of N mineralization in mineral soil to be at a moisture tension between 5 and 7 kPa. The optimum soil moisture range of N mineralization reported by Stanford and Epstein (1974) was between 10 and 33 kPa. Other studies have reported a broader range of optimum soil moisture tension, ranging from 15 to 50 kPa (Stanford and Epstein, 1974). They reported that N mineralization increased as water content increased up to saturation where N mineralization then decreased.

N mineralization has been reported in soils with water tensions as high as 3000 kPa (Theodorou and Bowen, 1983). Denitrification has been detected at 1500 kPa moisture tension, indicating that denitrification may take place in soils under aerobic conditions (Malhi et al, 1990). Generally, N mineralization decreases as the soil dries.

In forested ecosystems, mineral nutrients are accumulated in and cycled through vegetation (Grier, 1975). As long as the ecosystem is not disturbed by external factors such as timber harvesting or wildfires, nutrient cycling and accumulation processes continue. During a forest fire, soil moisture is reduced near the surface by evaporation. A decrease in surface cover after a fire exposes more soil to radiation and decreases insulation creating higher soil temperatures. As a result of the higher soil temperatures, not only is microbial activity increased, so is the rate of water evaporation from the soil surface. However, without transpiration, water may accumulate in the lower horizons increasing the probability of leaching ions from the soil profile (Woodmansee and Wallach, 1981). Post fire, there may or may not be an increase in available water. Scotter (1963) indicated that soil infiltration rates were higher on burned soils than on unburned soils. Meng et al (1995) concluded that soil moisture contents were higher in cut areas than in noncut areas for the first 5 years post harvest.

Studies indicated an increase loss of nutrients due to leaching after clear cutting. Tamm et al. (1974) examined the consequences of clear cutting on water quality and reported that maximum concentrations of NO_3^- were found in groundwater from clear-felled areas some years after clear cutting. However, there were no reports of NO_3^- concentrations exceeding present health limits for drinking water. Leaching of NO_3^- into the groundwater may appear as soon as 1 year after clear cutting but may be delayed up to 10 years post harvest (Wiklander, 1981). However, some studies reported very small losses of NO_3^- after clear cutting.

Any changes to the forest ecosystem created by disturbances could increase or decrease the N mineralization rate by changing the soil temperature and / or moisture regime. Basic understanding of the natural N mineralization of soils across boreal forests are required if predictions of soil N mineralization from forest soils after disturbances such as clear cutting or wildfires are to be made in relation to their soil temperature moisture regimes.

The first objective of the work reported here was to document the course of N accumulation from forest soil horizons incubated at five temperatures. We hypothesize that samples incubated at higher temperatures will have a higher maximum specific net N mineralization than those samples incubated at lower temperatures. Ellert and Bettany (1992), Kirschbaum (1995), and Winkler et al. (1996) hypothesized that N mineralization, organic matter decomposition and soil respiration rates, is temperature dependent. We interpret our data in the context of the hypotheses set out by these authors. The second objective was to document the course of N accumulation from forest soil horizons incubated at four moisture tensions. We hypothesize that N mineralization is moisture dependent and will increase as moisture tension decreases, and will reach a maximum before saturation where N mineralization will then decrease.

Materials and Methods

Laboratory Incubation

Soil Sampling

See Chapter 2.

Sample Preparation

Same as presented in Chapter 3.

Leaching Regime

Incubation of Soil Cores from Alberta and Quebec at Five Different Temperatures

In May 1997, intact organic and disturbed Ae horizon samples from Lac Spencer and Nicabau, Quebec, and samples from mid-slope positions from Lac La Biche and Whitecourt, Alberta, were prepared and leached according to the methods described in

Chapter 3, with one modification: the Ae horizon samples from Alberta had approximately 50 g of sand mixed into them because of their fine texture. Following initial leaching, 3 replicate horizons from each site were incubated at 0, 6, 12, 22 and 32°C. Both samples of organic and Ae horizons were placed in the same incubator for the entire experiment. Subsequent leachings were performed on days 15, 29, 43, 57, 71, 85, 99, 113, 127, 141, 170, 199, 228, 257, 285, and 313. After day 0 (Ae samples) and day 15 (organic samples), the volume of leaching solution was decreased to 45 ml of 0.01 M $CaCl_2$ and 15 ml of minus-N solution. All samples were diluted to a constant volume with deionized water.

Incubation of Soil Cores from Alberta and Quebec at Four Moisture Tensions

In Oct 1997, intact organic and disturbed Ae horizon samples from Lac Spencer and Nicabau, Quebec, and samples from lower slope position at Lac La Biche and Whitecourt, Alberta, were prepared and leached according to the methods described in Chapter 3, with two modifications: 1) the Ae horizon samples from Alberta had approximately 50 g of sand mixed into them because of their fine texture; 2) after free drainage ceased (approximately 10 minutes), the cores were evacuated to the appropriate moisture tension (except the 0 kPa treatment), 20 kPa, 33 kPa, or 60 kPa. The organic cores to be maintained at 0 kPa were immediately placed in plastic buckets and the Ae cores to be maintained at 0 kPa were placed in 400 ml beakers. The vacant space surrounding the 0 kPa cores was filled with Fisher Scientific glass beads, 6 mm beads on the bottom (organic cores only) and 4 mm beads on the sides. The containers were then filled with 3:1 $CaCl_2$: minus N solution to the height of the soil sample within the core. Following initial leaching, 3 replicate horizons from each site were incubated at 22°C. Subsequent leachings were performed on days 14, 28, 42, 56, 70, 90, 119, 147, 175, 203, 231. After day 14 the volume of leaching solution was decreased to 45 ml of 0.01 M $CaCl_2$ and 15 ml of minus N solution. All samples were diluted to a constant volume with deionized water.

Leachates were analyzed for mineral N as in Chapter 3.

Calculation of Specific net Rate (mg N g^{-1} soil N)

See Chapter 3.

Statistical Analysis

See Chapter 3.

Results

Incubation of Soil Cores from Alberta and Quebec at Five Different Temperatures

Expressed as mg N g^{-1} soil, the cumulative net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons exceeded the cumulative net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons (Fig. 4.1). Conversely, the same data expressed as mg N g^{-1} soil N (Fig. 4.2), indicate the samples of Ae horizons mineralized a greater proportion of soil N than did the samples of organic horizons. Samples of organic horizons were leached on day 85, however the sample was lost therefore there is no data point for that day.

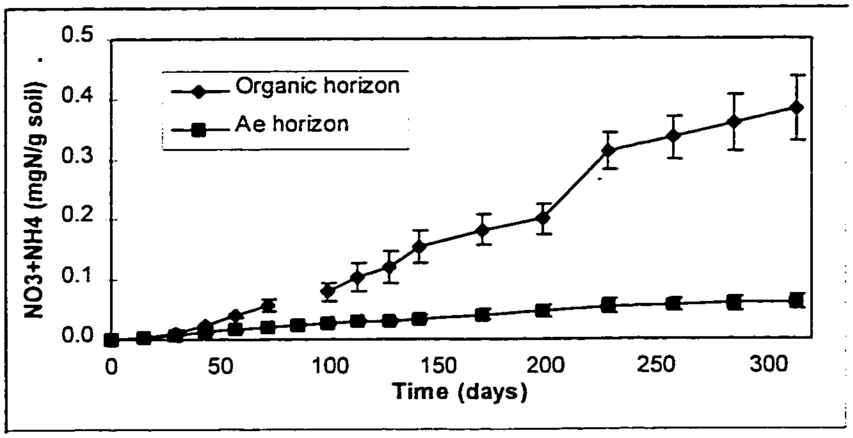

Figure 4.1: Cumulative net NH_4^+-N+NO_3^--N mineralization (mg N g $soil^{-1}$) during 313 days from samples of organic and Ae horizons from Lac Spencer incubated at 12°C (n=3)

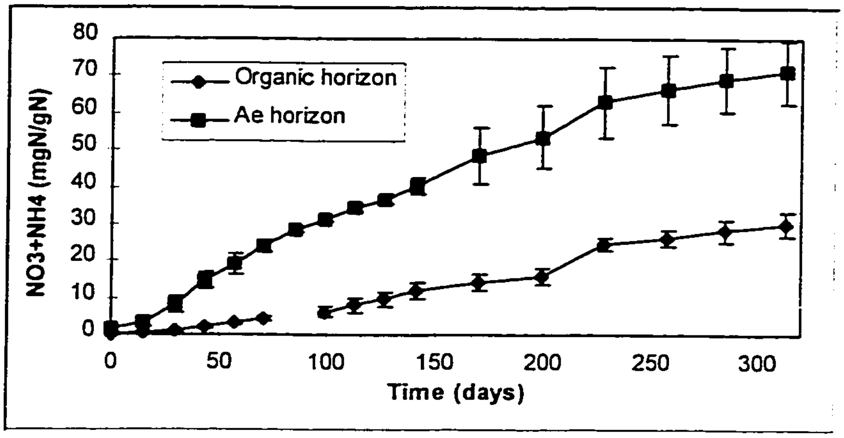

Figure 4.2: Cumulative specific net NH_4^+-N+NO_3^--N mineralization (mg N g soil N^{-1}) during 313 days from samples of organic and Ae horizons from Lac Spencer incubated at 12°C (n=3)

The cumulative specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons from all temperatures followed the same mineralization patterns (Fig. 4.3). These patterns were similar among sites for samples of organic horizons. Generally the specific net mineralization rate from samples of organic horizons incubated at 32°C was greater than the specific net rate at 0°C. The incremental specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons had the same pattern from all sites and was similar at all temperatures (Fig. 4.4). Typically there was a lag period of 25 days for samples of organic horizons before mineralization was detected for all incubation temperatures at all sites.

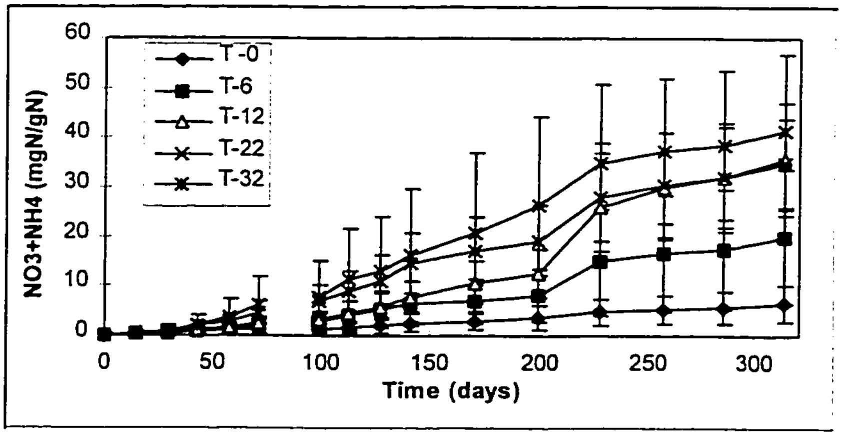

Figure 4.3: Cumulative specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of organic horizons from Lac La Biche (n=3)

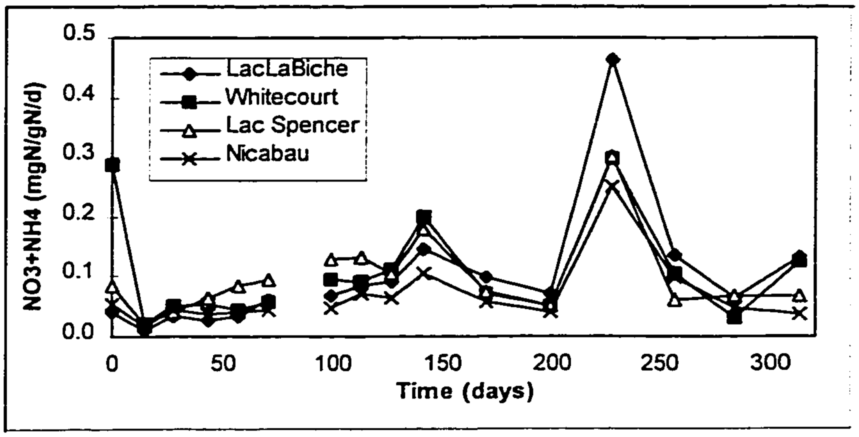

Figure 4.4: Incremental specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of organic horizons from all sites incubated at 12°C (n=3)

On the other hand, the cumulative specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons did not differ with temperature with exception to the 6°C treatment (Fig. 4.5). These patterns were similar between sites. The incremental specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons had the same pattern from all sites and were similar at all temperatures (Fig. 4.6). The incremental data indicate there were no lag periods for samples of Ae horizons. However, NO_3^--N accumulation in samples of organic and Ae horizons took approximately 100 days to be detected at all incubation temperatures at all sites.

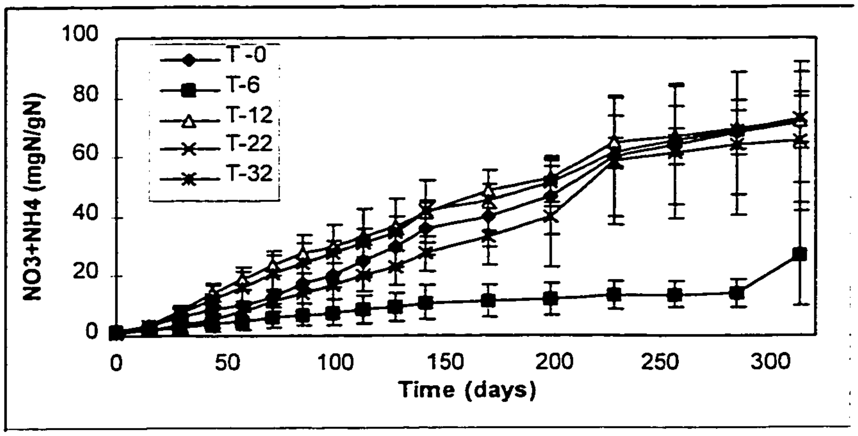

Figure 4.5: Cumulative specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of Ae horizons from Lac La Biche (n=3)

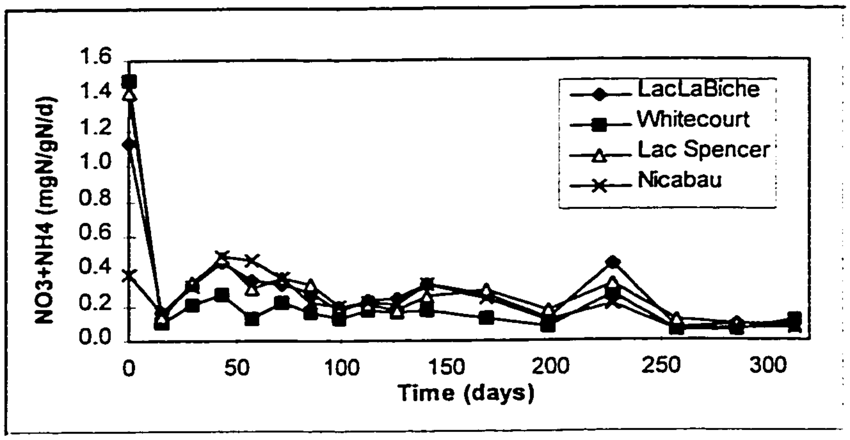

Figure 4.6: Incremental specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of Ae horizons from all sites incubated at 12°C (n=3)

There was no significant difference in the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons from Lac La Biche when incubated at 0,6, 12, 22 or 32°C (Fig 4.7) after 313 days. Mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons ranged from 6.5 to 41.4 mg N g^{-1} soil N. There was no difference in the total specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons when incubated at 0, 12, 22 and 32°C. The total specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0, 12, 22 and 32°C ranged from 65.4 to 72.9 mg N g^{-1} soil N. All exceeded the total specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons incubated at any temperature. The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 6°C was 27.2 mg N g^{-1} soil N.

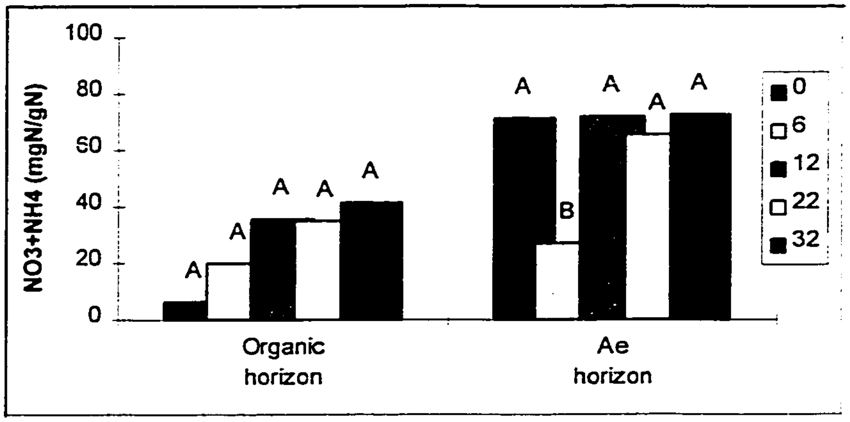

Figure 4.7: Mean specific net NH_4^+-N+NO_3^--N mineralization after 313 days from samples of organic and Ae horizons from Lac La Biche (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

There was no significant difference in the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic from Whitecourt (Fig. 4.8) incubated at 6, 12, 22 or 32°C. The samples of organic horizons incubated at 32°C was significantly higher than those samples incubated at 0°C. The rate of NH_4^+-N+NO_3^--N mineralization from samples of organic horizons ranged from 9.2 to 34.8 mg N g^{-1} soil N. There was no significant difference in the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0, 6, 12, 22 or 32°C. The rate of NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons ranged from 21.8 to 48.4 mg N g^{-1} soil N.

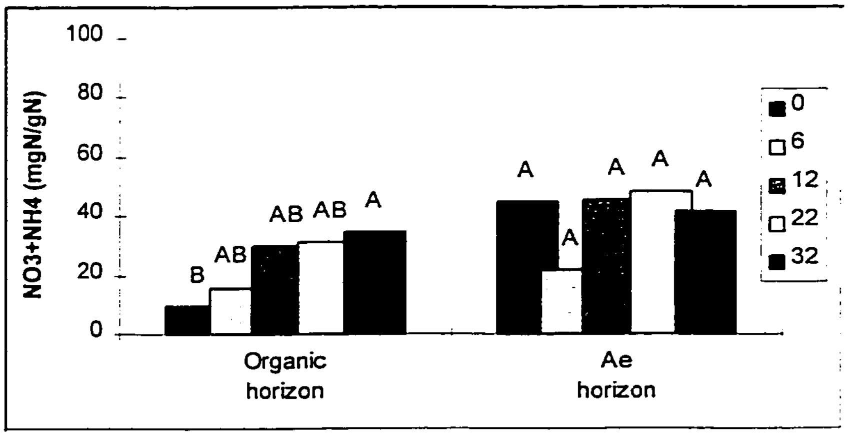

Figure 4.8: Mean specific net NH_4^+-N+NO_3^--N mineralization after 313 days from samples of organic and Ae horizons from Whitecourt (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0, 12, 22, and 32°C from Lac Spencer (Fig. 4.9) exceeded the rate from samples of organic horizons. Samples of organic horizons incubated at 22°C exceeded samples incubated 0, 6, and 12°C. Samples of organic horizons incubated at 12°C exceeded samples incubated 0 and 6°C. The mean specific net N mineralization from samples of organic horizons ranged from 10.7 to 32.3 mg N g^{-1} soil N. There was no sample of organic horizons incubated at 32°C from this site. The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0, 12, 22, 32°C ranged from 64.8 to 82.6 mg N g^{-1} soil N. The mean specific net NH_4^+-N+NO_3^--N mineralization rate from samples of Ae horizons incubated at 32°C exceeded the rate at 6°C, which was 27.7 mg N g^{-1} soil N.

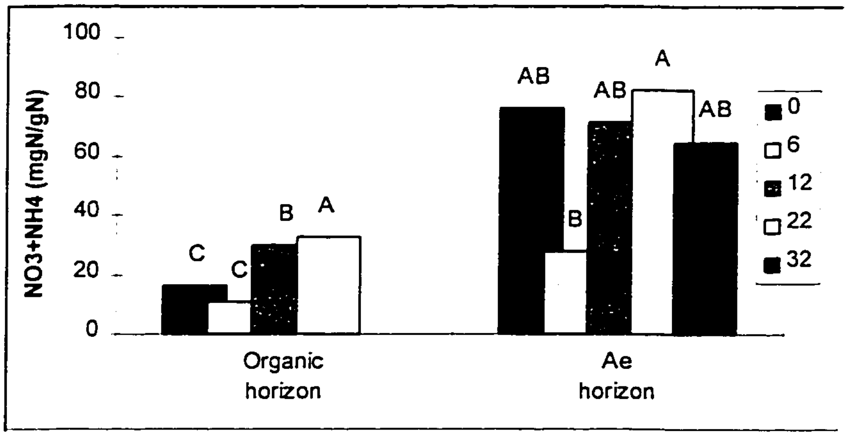

Figure 4.9: Mean specific net NH_4^+-N+NO_3^--N mineralization after 313 days from samples of organic and Ae horizons from Lac Spencer (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0, 12, 22 and 32°C exceeded the rates from samples of organic horizons (Fig. 4.10). There was no significant difference in the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic horizons incubated at 0, 6, 12, 22 or 32°C. Mineralization rates from sample of organic horizons ranged from 1.1 to 27.7 mg N g^{-1} soil N. The mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons ranged from 22.6 to 70.3 mg N g^{-1} soil N. The mean specific net NH_4^+-N+NO_3^--

N mineralization from samples of Ae horizons incubated at 0°C was significantly greater than samples incubated at 6°C.

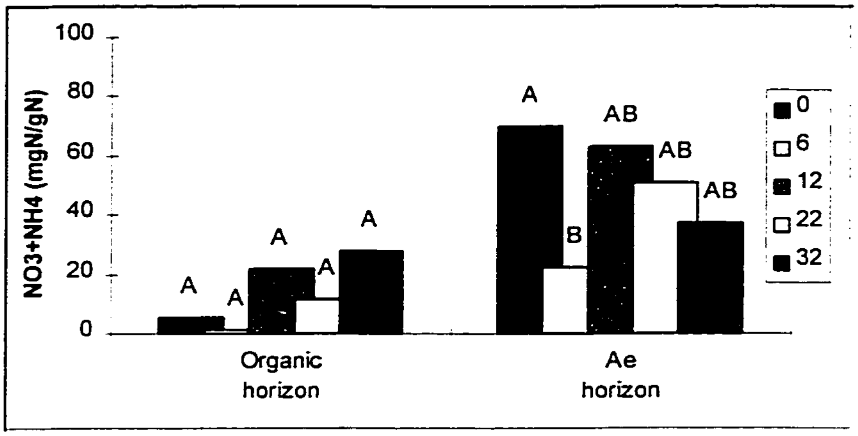

Figure 4.10: Mean specific net NH_4^+-N+NO_3^--N mineralization after 313 days from samples of organic and Ae horizons from Nicabau (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

Except for the 6°C treatments, the mean specific net rate of mineralization from samples of Ae horizons (37 - 83 mg N g^{-1} soil N) generally exceeded the mean specific net rate of mineralization from samples of organic horizons (1 - 42 mg N g^{-1} soil N). In general the mean specific net NH_4^+-N+NO_3^--N mineralization did not differ between sites of the same horizon, suggesting that the amount mineralized over 231 days was horizon specific not site specific. As well, the mean specific net rate of mineralization from samples of organic horizons appeared to increase with temperature. Conversely, except for the 6°C treatments, mean specific net mineralization rates from samples of Ae horizons remained constant as temperature increased.

Compared to the logistic model, the Gompertz model [Eq. 3.3] gave the better fit, 67 % of the samples of organic horizons and 77 % of samples of Ae horizons. The cumulative specific net mineralization values predicted by the Gompertz model slightly underestimated mineralization throughout the incubation (Fig. 4.11). The cumulative and incremental (Fig. 4.12) specific net mineralization values predicted by the Gompertz model had r^2 ranging from 0.43 to 0.98 (mean = 0.74) for samples of organic horizons for all treatments, both horizons and all sites. The r^2 values for samples of Ae horizons ranged from 0.39 to 0.90 (mean = 0.76), for all treatments, both horizons and all sites.

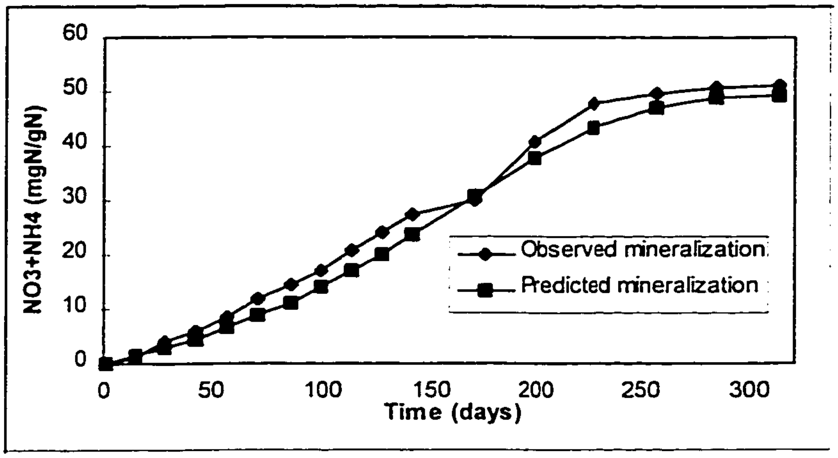

Figure 4.11: Predicted and observed cumulative specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of Ae horizons from Nicabau incubated at 22°C

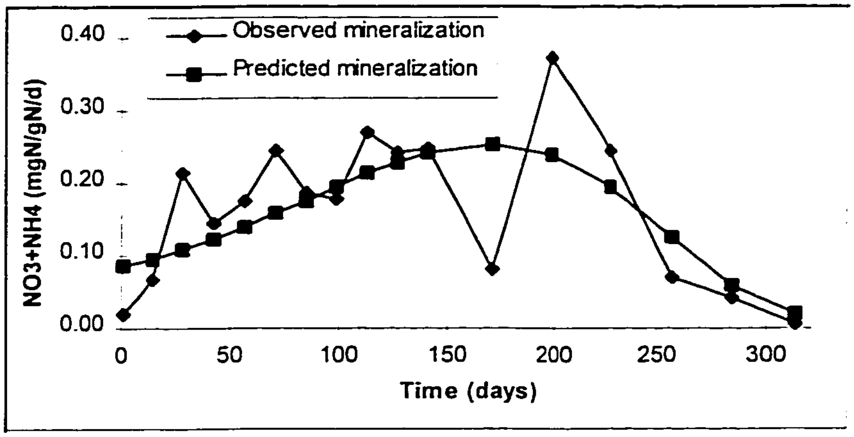

Figure 4.12: Predicted and observed incremental specific net NH_4^+-N+NO_3^--N mineralization during 313 days from samples of Ae horizons from Nicabau incubated at 22°C

The Gompertz model predicted N_0 values close to the observed cumulative total for both organic (Fig 4.13) and Ae horizons (Fig. 4.14).

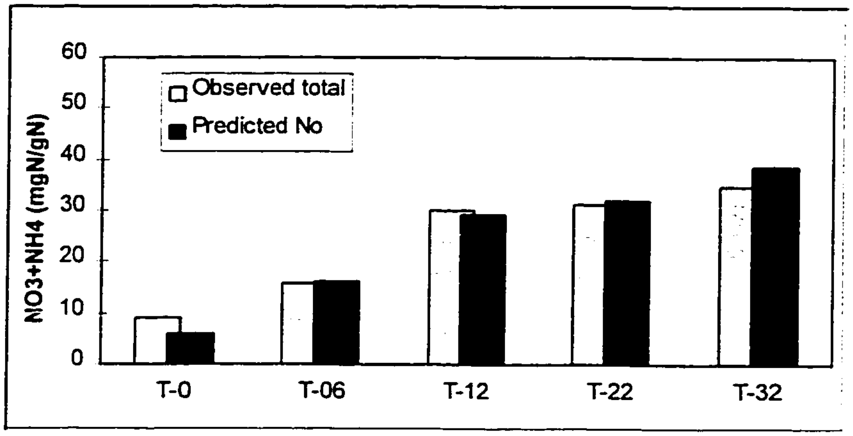

Figure 4.13: Comparison between observed NH_4^+-N+NO_3^--N mineralization after 313 days from samples of organic horizons from Whitecourt and N_0 predicted by the Gompertz model

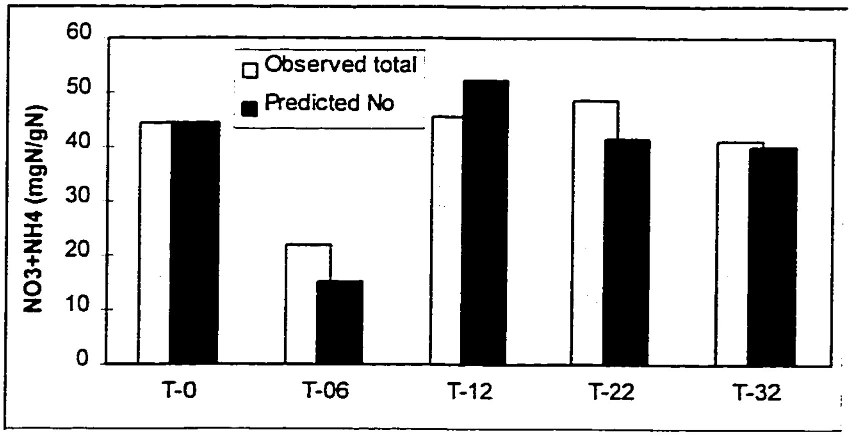

Figure 4.14: Comparison between observed NH_4^+-N+NO_3^--N mineralization after 313 days from samples of Ae horizons from Whitecourt and N_0 predicted by the Gompertz model

For samples of organic horizons, k ranged from 0.006 to 0.038 day^{-1} and h ranged from 0.0002 to 0.65 (unitless) (Appendix 3.1a to 3.1d). For samples of Ae horizons, k ranged from 0.003 to 0.024 day^{-1} and h ranged from 0.003 to 1.04 (unitless).

The time to inflection (T_{ni}) was calculated for samples of organic and Ae horizons from each site at each temperature. For samples of organic horizons (Table 4.1) all sites required between 72 to 479 days to reach inflection point with a mean value of 205 days.

Table 4.1: Time to Inflection Point for Samples of Organic Horizons (days)

Incubation Temperature	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0	228	217	177	479
6	224	201	181	244
12	219	219	205	222
22	195	72	84	200
32	182	216		171

Time to inflection for samples of Ae horizons (Table 4.2) varied more than did samples of organic horizons. Inflection time ranged from 13 to 309 days. However, two treatments had negative times to inflections. This resulted from having a h value greater than 1. This length of time is unrealistic and is not a reliable value. Except for Whitecourt, it appears that the shortest time to inflection for samples of Ae horizons was during the 12°C incubation.

Table 4.2: Time to Inflection Point from Samples of Ae Horizons (days)

Incubation Temperature	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0	252	144	147	168
6	309	27	47	67
12	87	-9	84	13
22	206	211	137	160
32	79	32	37	-16

The maximum rate of NH_4^+-N+NO_3^--N mineralization at inflection (R_m) from samples of organic horizons (Table 4.3) ranged between 0.001 to 0.33 mg N g soil N^{-1} d^{-1}. The highest rate of mineralization from samples of organic horizons from each site was during the 12°C incubation and ranged from 0.14 to 0.33 mg N g^{-1} soil N d^{-1}. The lowest maximum rate of mineralization from samples of organic horizons was during the 0°C incubation and ranged from 0.01 to 0.06 mg N g^{-1} soil N d^{-1}.

Table 4.3: Maximum Rate of NH_4^+-N+NO_3^--N Mineralization from Samples of Organic Horizons (mg N g soil N^{-1} d^{-1})

Incubation Temperature	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0	0.03	0.06	0.06	0.01
6	0.11	0.07	0.05	0.01
12	0.33	0.15	0.14	0.17
22	0.16	0.13	0.14	0.06
32	0.21	0.17		0.14

The maximum rate of NH_4^+-N+NO_3^--N mineralization at inflection from samples of Ae horizons ranged between 0.11 to 0.45 mg N g^{-1} soil N d^{-1} (Table 4.4). In general, samples of Ae horizons had higher maximum rates of NH_4^+-N+NO_3^--N mineralization at inflection than did samples of organic horizons. Except for the Nicabau site, the highest rate of NH_4^+-N+NO_3^--N mineralization at inflection from samples of Ae horizons was found during the 22°C incubation.

Table 4.4: Maximum Rate of NH_4^+-N+NO_3^--N Mineralization from samples of Ae Horizons (mg N g soil N^{-1} d^{-1})

Incubation Temperature	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0	0.19	0.16	0.30	0.29
6	0.12	0.11	0.12	0.11
12	0.29	0.17	0.29	0.32
22	0.45	0.30	0.35	0.25
32	0.26	0.19	0.30	0.14

Incubation of Alberta and Quebec Soil Cores at Four Moisture Tensions

The cumulative NH_4^+-N + NO_3^--N mineralization from samples of organic horizons expressed as mg N g $soil^{-1}$, exceeds the cumulative NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons (Fig. 4.15). Conversely, the same data expressed as mg N g^{-1} soil N (Fig. 4.16) indicate samples of Ae horizons mineralized a greater proportion of the soil

N than did samples of organic horizons. Note the mineralization rate from this soil is lower than the soil presented in Chapter 3 (Fig. 3.1). This may be due to slope position. The slope position presented here is from the lower slope position at Lac La Biche, yet the slope position presented in Fig. 3.1 is from the upper slope position. This is not surprising because results from Chapter 3 indicated that soil samples from the lower slope position at Lac La Biche had a lower total mineralization than other slope positions.

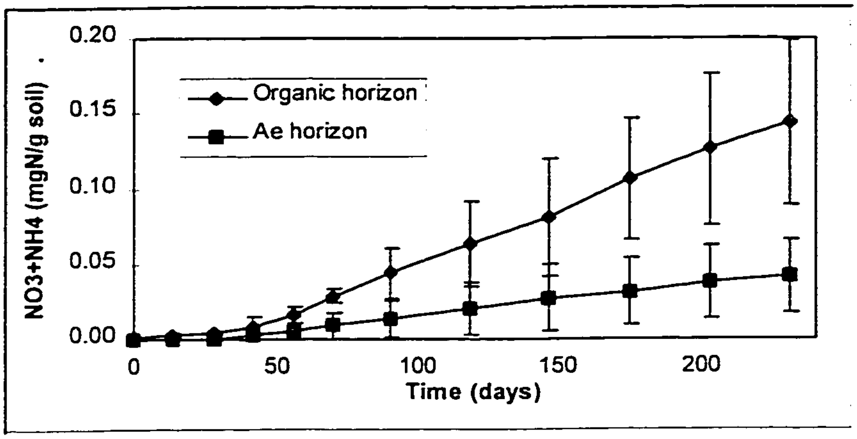

Figure 4.15: Cumulative net NH_4^+-N + NO_3^--N mineralization (mg N g soil^{-1}) during 231 days from samples of organic and Ae horizons from Lac La Biche lower slope position incubated at 33 kPa and 22°C (n=3)

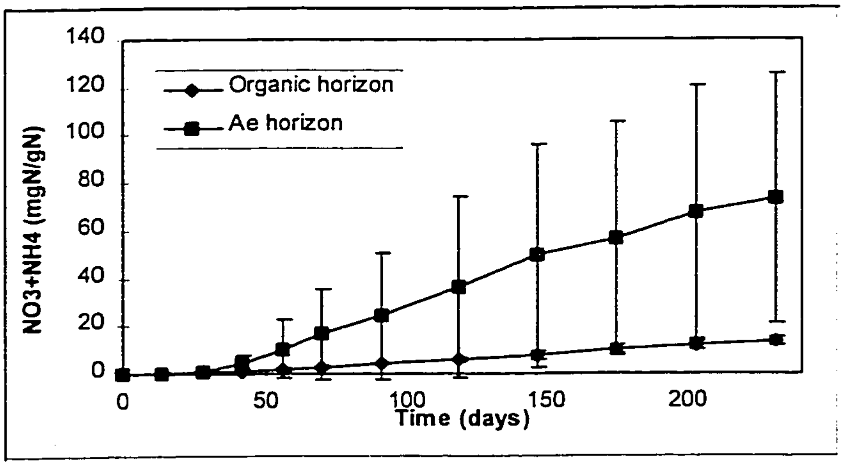

Figure 4.16: Cumulative specific net NH_4^+-N + NO_3^--N mineralization (mg N g soil N^{-1}) during 231 days from samples of organic and Ae horizons Lac La Biche incubated at 33 kPa and 22°C (n=3)

Generally, the cumulative specific net NH_4^+-N + NO_3^--N mineralization from samples of organic and Ae horizons from all sites have a lag period at the beginning of the incubation and gradually level off at the end of the incubation. These dynamics are more apparent with incremental data (Fig. 4.17), which indicate approximately a lag period of 25 days before mineralization was detected.

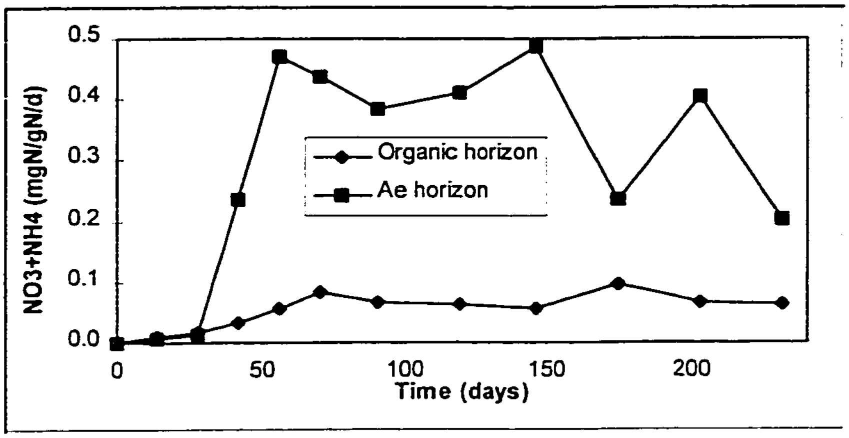

Figure 4.17: Incremental specific net NH_4^+-N + NO_3^--N mineralization (mg N g soil N^{-1}) during 231 days from samples of organic and Ae horizons Lac La Biche lower slope position incubated at 33 kPa and 22°C (n=3)

The cumulative specific net NH_4^+-N + NO_3^--N mineralization from samples of organic and Ae horizons at all moisture tensions followed the same mineralization pattern (Fig. 4.18). This pattern was similar among sites. There is no difference in the pattern of specific net mineralization as moisture tension increases from 0 to 60 kPa. The one exception was from samples of Ae horizons incubated at 0 kPa moisture tension from Lac La Biche (Fig. 4.19).

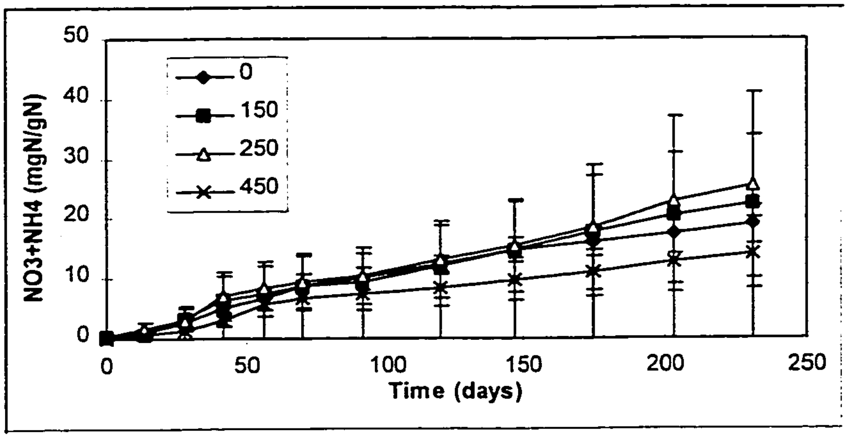

Figure 4.18: Cumulative specific net NH_4^+-N+NO_3^- -N mineralization during 241 days from samples of organic horizons from Lac Spencer (n=3)

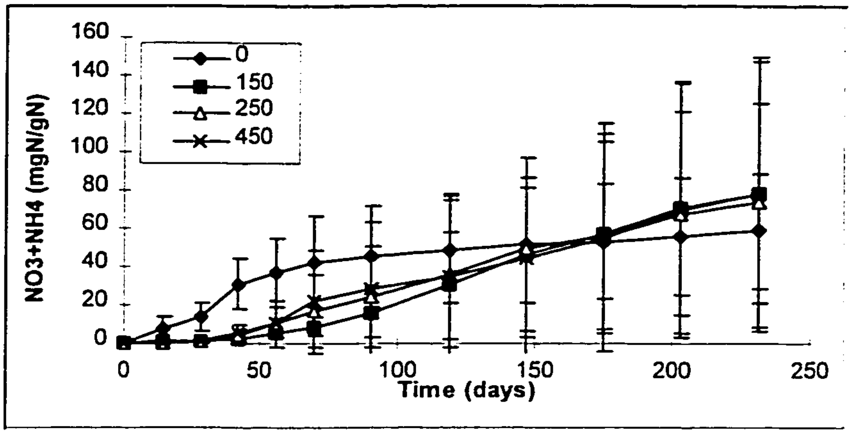

Figure 4.19: Cumulative specific net NH_4^+-N+NO_3^- -N mineralization during 241 days from samples of Ae horizons from Lac La Biche (n=3)

Accumulation of NO_3^--N from Alberta soil horizons incubated at 20 kPa and drier took approximately 50 - 70 days to be detected (Fig. 4.20). In contrast, negligible NO_3^--N was detected from samples of organic or Ae horizons from Quebec.

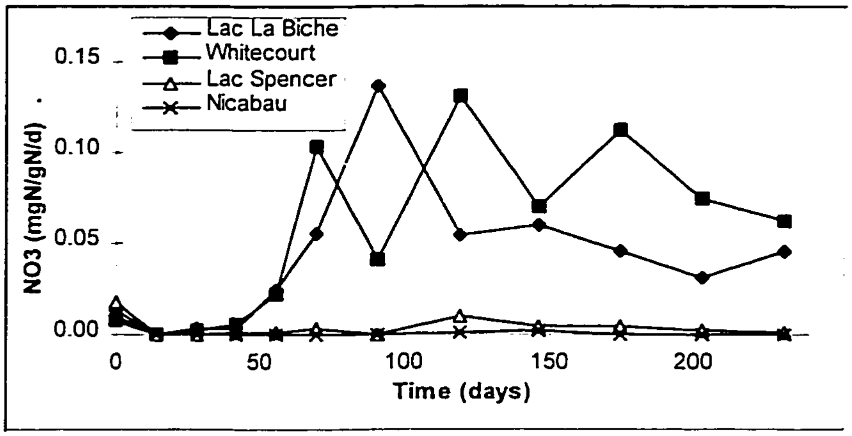

Figure 4.20: Incremental specific net NO_3^--N mineralization (mg N g soil N^{-1}) during 231 days from samples of organic horizons from all sites incubated at 20 kPa and 22°C (n=3)

The mean specific net NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons ranged from 59 to 78 mg N g soil N^{-1} and significantly exceeded the specific net mineralization from samples of organic horizons, which ranged from 14 to 31 mg N g soil N^{-1} (Fig. 4.21). There was no significant difference in mean specific net NH_4^+-N + NO_3^--N mineralization between treatments within each horizon.

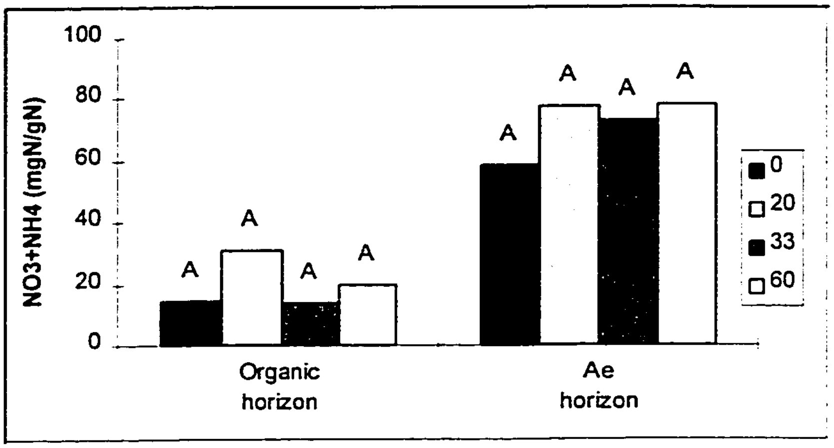

Figure 4.21: Mean specific net NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic and Ae horizons from Lac La Biche lower slope position incubated at 22°C (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The mean specific net NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons ranged from 47 to 80 mg N g soil N^{-1} and was significantly higher than from samples of organic horizons incubated at 0, 20 and 33 kPa moisture tensions (Fig. 4.22). The mean specific net NH_4^+-N + NO_3^--N mineralization from samples of organic horizons ranged from 14 to 34 mg N g soil N^{-1}. There was no significant difference between treatments within each horizon.

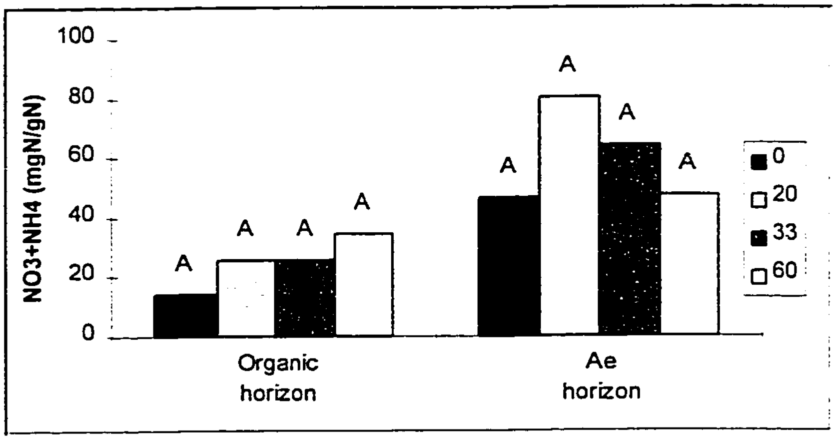

Figure 4.22: Mean specific net NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic and Ae horizons from Whitecourt lower slope position incubated at 22°C (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The mean specific net NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons from Lac Spencer ranged from 17 to 38 mg N g soil N^{-1} and was not different from the rate in samples of organic horizons, which ranged from 14 to 25 mg N g soil N^{-1} (Fig. 4.23).

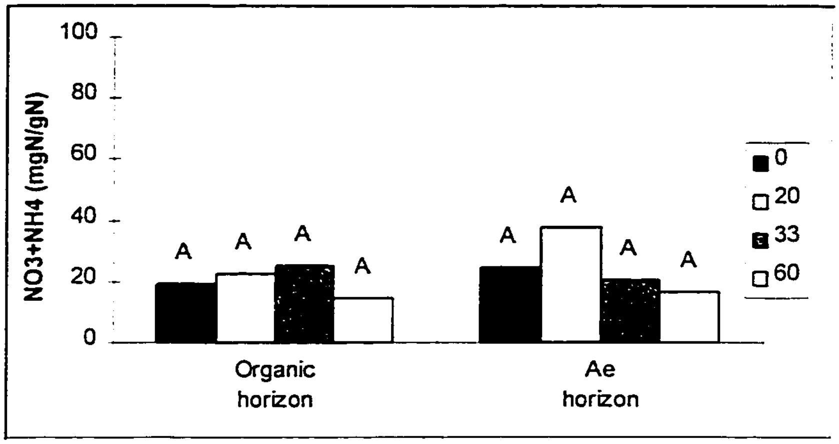

Figure 4.23: Mean specific net NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic and Ae horizons from Lac Spencer incubated at 22°C for 231 days (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

The mean specific net NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons from Nicabou ranged from 42 to 89 mg N g soil N^{-1}. This rate significantly exceeded the total specific net rate from samples of organic horizons, which ranged from 6 to 12 mg N g soil N^{-1} (Fig. 4.24). There was no significant difference among treatments within samples of Ae horizons. The most rapid rate of N mineralization for organic samples was observed at 20 kPa moisture tension.

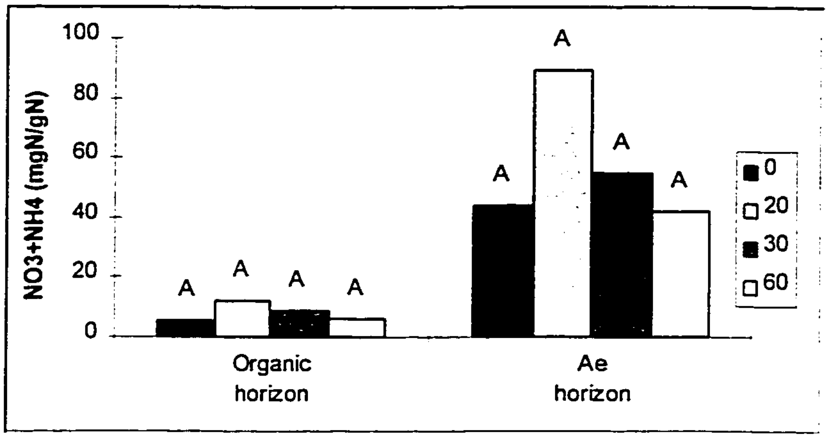

Figure 4.24: Mean specific net NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic and Ae horizons from Nicabau incubated at 22°C (n=3). Bars within the same horizon with the same letter do not differ significantly ($\alpha = 0.05$)

Except for the Lac Spencer site, mean specific rate of net mineralization from samples of Ae horizons (42 - 89 mg N g^{-1} soil N) significantly exceeded the mean specific rate of net mineralization from samples of organic horizons (6 - 34 mg N g^{-1} soil N). The total specific rate of net N mineralization from samples of Ae horizons did not differ among Lac La Biche, Whitecourt or Nicabau and all exhibited higher mean specific net NH_4^+-N + NO_3^--N mineralization than was observed from the Lac Spencer site. In general, the total specific net NH_4^+-N + NO_3^--N mineralization did not differ between sites of the same horizon, suggesting that the amount mineralized over 231 days was horizon specific not site specific.

Compared to the logistic model, the Gompertz model [Eq. 3.3] gave the best fit, 73 % of the samples of organic horizons and 75% of samples of Ae horizons. The cumulative (Fig 4.25) and incremental (Fig. 4.26) specific net mineralization values predicted by the Gompertz model had r^2 values ranging from 0.78 to 0.98 (mean = 0.91) for samples of organic horizons and r^2 values for samples of Ae horizons ranged from 0.58 to 0.96 (mean = 0.81).

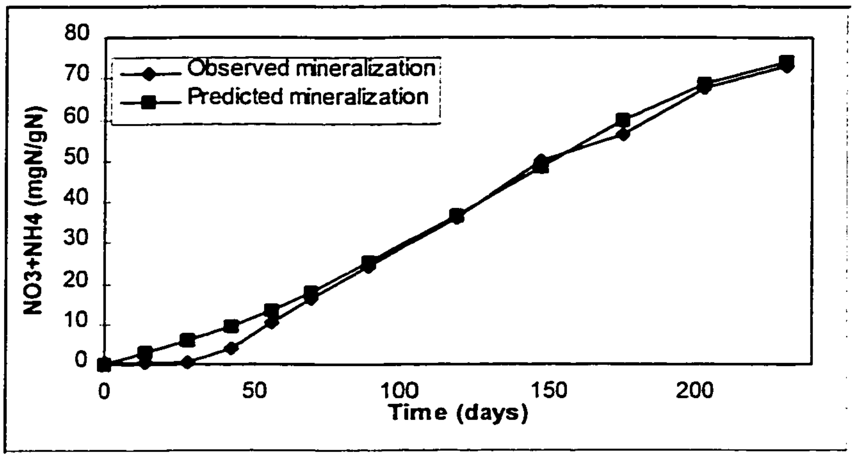

Figure 4.25: Predicted and observed cumulative specific net NH_4^+-N + NO_3^--N mineralization during 231 days from samples of Ae horizons from Lac La Biche incubated at 20 kPa and 22°C

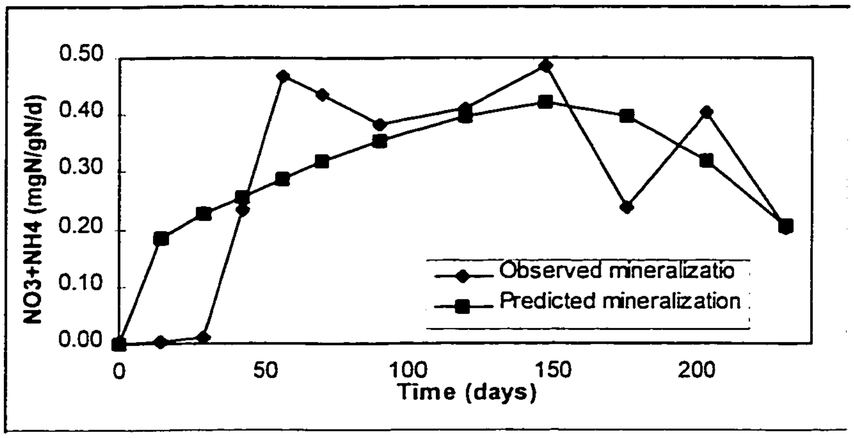

Figure 4.26: Predicted and observed incremental specific net NH_4^+-N + NO_3^--N mineralization during 231 days from samples of Ae horizons from Lac La Biche incubated at 20 kPa and 22°C

The predicted N_0 values were close to what was observed after 231 days of laboratory incubation from samples of both organic and Ae horizons (Fig. 4.27 and 4.28).

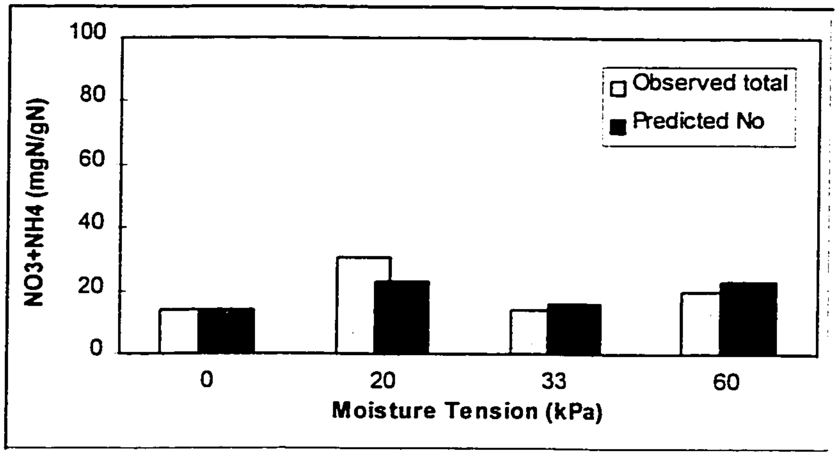

Figure 4.27: Comparison between observed NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic horizons from Lac La Biche and N_0 predicted by the Gompertz model

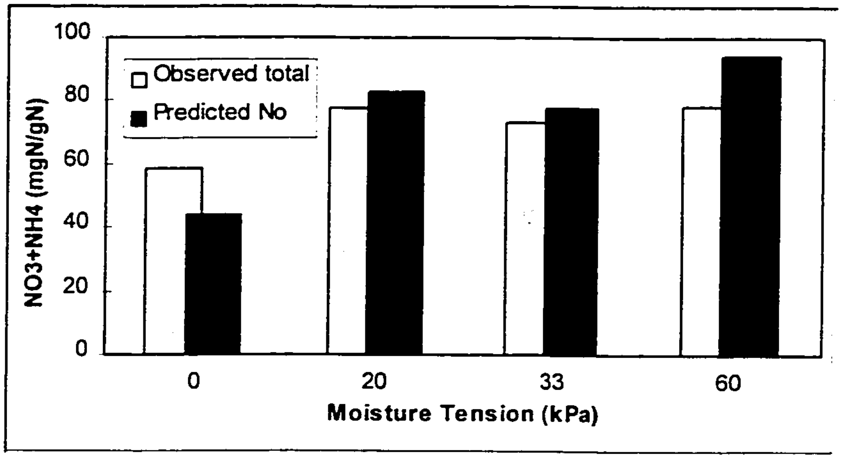

Figure 4.28: Comparison between observed NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of Ae horizons from Lac La Biche and N_0 predicted by the Gompertz model

The largest difference in observed total and predicted N_0 were for samples of organic horizons from Lac Spencer suggesting that the incubation time was not long enough for this soil horizon (Fig. 4.29).

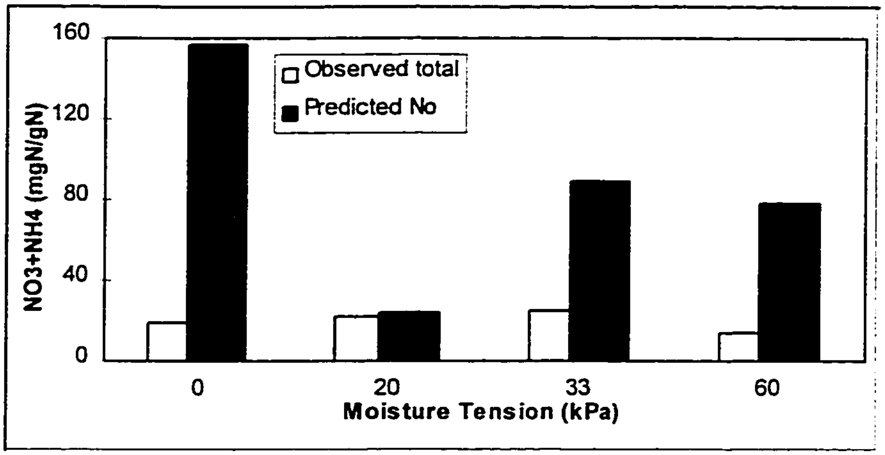

Figure 4.29: Comparison between observed NH_4^+-N + NO_3^- -N mineralization after 231 days from samples of organic horizons from Lac Spencer and N_0 predicted by the Gompertz model

Rate coefficients, k, for samples of organic horizons ranged from 0.001 to 0.07 day^{-1} and for samples of Ae horizons ranged from 0.0002 to 0.10 day^{-1} (Appendix 3.2a, to 3.2d). The h values for samples of organic horizons range from 0.004 to 0.95 (unitless). There were 3 samples of Ae horizons which had h values greater than 1: 0 kPa Whitecourt; 0 kPa Lac Spencer and 60 kPa Nicabau. The other sites had h values ranging from 0.008 to 0.94 (unitless).

The time to inflection point (T_{ni}) from samples of organic horizons ranged from 7.6 to 544 days (Table 4.5). There was no consistent pattern with treatment.

Table 4.5: Time to Inflection Point from samples of Organic Horizons (days)

	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0 kPa	7.6	51	544	80
20 kPa	141	29	138	194
33 kPa	164	552	104	226
60 kPa	175	77	520	179

The time to inflection for samples of Ae horizons from Alberta sites ranged from 0.71 to 171 days (Table 4.6) except for the 0 kPa treatment for Whitecourt. The time to inflection point from samples of Ae horizons from Lac La Biche and Whitecourt tended to increase as moisture tension increased. Time to inflection point for the Quebec sites ranged from 10 to 273 days, disregarding the negative values predicted for Lac Spencer and Nicabau. Again, these negative values are associated with a h value greater than 1 and should be disregarded.

Table 4.6: Time to Inflection Point from Samples of Ae Horizons (days)

	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0 kPa	37	-643	-15264	273
20 kPa	152	0.71	32	26
33 kPa	134	54	10	10
60 kPa	171	104	12	-1267

Generally the maximum N mineralization rate at inflection (R_m) from samples of organic horizons were similar between sites and treatments (Table 4.7) ranging from 0.03 to 0.61 mg N g^{-1} soil N d^{-1}. There was no consistent pattern between sites or treatments.

Table 4.7: Maximum NH_4^+-N + NO_3^- -N Mineralization Rate from Samples of Organic Horizons (mg N g^{-1} soil N d^{-1})

	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0 kPa	0.10	0.14	0.44	0.10
20 kPa	0.13	0.15	0.10	0.08
33 kPa	0.08	0.15	0.11	0.05
60 kPa	0.11	0.17	0.61	0.03

The maximum N mineralization rates were higher from samples of Ae horizons (Table 4.8) than from samples of organic horizons. Samples of Ae horizons from Lac La Biche ranged from 0.41 to 0.83 mg N g^{-1} soil N d^{-1} and were not different from the maximum N mineralization rates from samples of Ae horizons from Whitecourt, which ranged from

0.25 to 0.43 mg N g^{-1} soil N d^{-1}. There were no consistent patterns with treatment for any soil

Table 4.8: Maximum Rate of NH_4^+-N + NO_3^- -N mineralization from samples of Ae Horizons (mg N g^{-1} soil N d^{-1})

	Lac La Biche	Whitecourt	Lac Spencer	Nicabau
0 kPa	0.83	0.34	1..4E+11	0.12
20 kPa	0.54	0.43	0.86	3.3
33 kPa	0.42	0.32	0.11	0.11
60 kPa	0.41	0.25	0.09	12

Discussion

The Ae horizon is often thought as N deficient, however differences were observed here in the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of organic and Ae horizons. There was one exception to this observation: samples from Lac Spencer incubated at different moisture tensions (Fig. 4.19). Initially the low amount of N mineralized from samples of Ae horizons incubated at a range of moisture tensions from Lac Spencer, was thought to be a result of burning 50 to 70 years ago, which created a mineral soil of poorer quality. In general, burning of the forest floor results in loss of N through volatilization (Knight, 1966), with the more severe fires producing the greatest rate of volatilization and the greatest loss of NH_4^+ (Riggan, 1994). However samples of organic and Ae horizons from Lac Spencer incubated at a range of temperatures (Fig. 4.7) did not predict this pattern. These samples indicated that the specific net NH_4^+-N + NO_3^--N mineralization was significantly higher from samples of Ae horizon than samples of organic horizons. As well, samples from other sites and treatments had the same conclusion. Therefore the results from samples of Ae horizons incubated at a range of moisture tensions from Lac Spencer may not be accurate.

Samples of Ae horizons consistently had a higher specific rate than did samples of organic horizons, suggesting more immobilization during early stages of decomposition in samples of organic horizons. These immobilizing conditions would be expected to decrease the specific net NH_4^+-N + NO_3^--N mineralization from samples of organic horizons. In contrast, samples of Ae horizons have lower C:N ratios suggesting specific net NH_4^+-N + NO_3^--N mineralization exceeding that of the organic horizon.

Different horizons also have different physical and chemical environments, which can influence the microbial community established. Heah and Dighton (1986) stated that during ecosystem succession the physico-chemical environment changes cause the composition and activity of the decomposer community to change. Differences in horizon pH may also contribute to the differences in specific net NH_4^+-N + NO_3^--N mineralization from either horizon since substrate chemistry could change with pH.

Substrate quality also may influence specific net N mineralization. Palm and Sanchez (1991) suggest that polyphenols may create net immobilization in leguminous litter due to the reaction of polyphenols with organic N. Polyphenols are reactive compounds that can form stable polymers with organic N (Palm and Sanchez, 1991). As a result lower amounts of N are mineralized. Therefore, lower substrate quality may be related to litters with higher polyphenolic contents than other litters. Higher specific net NH_4^+-N + NO_3^--N mineralization from samples of Ae horizons indicates a higher substrate quality than from samples of organic horizons. Therefore specific net rate of N mineralization appear to be horizon-specific net not site-specific net. This could be a result of differences in C:N ratio, microbial communities, pH, or substrate quality between horizons. Further characterization of samples from the organic and Ae horizons is needed to test this hypothesis.

The highest maximum mineralization rates (R_m) from samples of organic horizons occurred during the 12°C incubation while the highest maximum mineralization rate from samples of Ae horizons occurred during the 22°C incubation. These rates correspond with the shortest time to inflection point (T_{ni}). With the exception of Whitecourt, the time to inflection for samples of organic horizons decreased as temperature increased to 12°C, and then increased as temperature rose to 32°C. This relationship was not apparent for samples from the Ae horizons.

It was expected that the mean cumulative specific net NH_4^+-N+NO_3^--N mineralization would increase with an increase in temperature for samples of both organic and Ae horizons. In the work reported here, specific rate of net N mineralization from samples of organic horizons increased as temperature increased from 0 to 32°C. However, the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons was constant among temperatures with the exception of the 6°C incubation. In contrast, Campbell et al. (1981) reported an increase in the cumulative amount of NH_4^+-N mineralized from agricultural soils with an increase in temperature to 40°C using soils from Austrailia. Addiscott (1983) reported an increase in the net amount of NH_4^+-N+NO_3^--N mineralized with time as temperature of agricultural soils increased from 5 to 25°C. Nadelhoffer et al (1991) incubated surface (organic) and subsurface (mineral or organic) horizons at temperatures from 3 to 15°C. They concluded, mineral N mineralization from surface and subsurface soil samples increased as temperature increased with the largest increase from soil samples incubated between 9 and 15°C.

Is it possible that some experimental conditions obscured temperature relations? Both samples of organic and Ae horizons were place in the same incubators therefore differences in specific rates between samples of organic and Ae horizons for one treatment were not caused by a difference in incubation temperature. Temperature of the incubators were monitored on rotation basis approximately every 2 weeks with four thermocouples hooked up to a Campbell Scientific data logger (CRX10). All incubators had different temperatures throughout the experiment and fluctuated approximately 0.2 °C from their set temperature. Therefore samples were incubated at different temperatures. Samples from each treatment were extracted at different times throughout the week, therefore the chance to switch samples into different incubators was small to none. Freeze thaw cycles may have increased the mean specific net NH_4^+-N+NO_3^--N mineralization from samples of Ae horizons incubated at 0°C compared to samples incubated at 6°C because extraction of samples took approximately 4 hours, allowing time for samples to warm to room temperature. As well, the 0.01 M $CaCl_2$ solution used in the extraction had a temperature of 22°C. This solution was made in large quantities in the same flask throughout the duration of all experiments. Therefore, contamination from other sources of N was minimized. The same mineralization patterns were obtained from samples of organic and Ae horizons incubated at 22°C from Lac La Biche and Whitecourt compared to the results presented in Chapter 3 for these sites at the middle slope position. Therefore I believe these results are reproducible.

At the end of the incubations, the mean cumulative NH_4^+-N+NO_3^--N mineralization from samples of either organic or Ae horizons, varied little among different moisture tensions. Although not significantly different, there was a tendency for the specific net NH_4^+-N + NO_3^--N mineralization to be greater from samples of both organic and Ae horizons incubated at 20 kPa. Kladivko and Keeney (1987) suggested the optimum water tension was between 10 and 33 kPa. Respiration rates have also been reported to reach a maximum at water tensions ranging from 5 to 15 kPa (Nyhan, 1976). However maximum rate of N mineralization (R_m) from samples of organic or Ae horizons from Alberta did not change with moisture tension. Results from the Quebec sites are inconclusive at this time and need further investigation. Generally, maximum N mineralization rates from samples of Ae horizons were higher than from samples of organic horizons at all moisture tensions.

Conclusions

The specific net rate of N mineralization from samples of Ae horizons exceeded the specific net rate from samples of organic horizons. The specific net NH_4^+-N + NO_3^--N mineralization from the organic and Ae horizons were horizon-specific net not site-specific net. Differences in maximum specific net rate of N mineralization and time to inflection for organic horizons incubated at different temperatures, suggests that NH_4^+-N+NO_3^--N mineralization rates are altered by temperature, however the cumulative amount of NH_4^+-N+NO_3^--N that can be mineralized is not. The cumulative specific net

NH_4^+-N + NO_3^--N mineralization from organic and Ae horizons was similar among moisture tensions. Maximum specific net rates of N mineralization from samples of Ae horizons incubated at all moisture tensions were higher than from samples of organic horizons.

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Chapter 5 : MEASUREMENT OF MINERAL N USING ION EXCHANGE MEMBRANES OR EXCHANGE RESIN BAGS UNDER VARIOUS CONDITIONS

Introduction

The quantity of available N in forest soils can be measured a variety of ways. Total N, anaerobic incubations, aerobic incubations followed by extraction with 0.01 M $CaCl_2$, and extraction of NH_4^+ and NO_3^- using KCl, are some examples (Binkley and Matson, 1983; Keeney, 1980). Flux of available N can be monitored *in situ* using exchange resin bags (Binkley and Matson, 1983), or the recently developed ion exchange membranes (Subler et al, 1995).

Exchange resin bags (ERB) are nylon bags that enclose exchange resins in bead form, and have been used to estimate N ion fluxes in soils (DiStefano and Gholz, 1986). In a greenhouse study, Binkley and Matson (1983) compared the ERB technique with other conventional methods, and concluded that under controlled conditions the ERB technique was comparable. However, there was a divergence between field results and greenhouse results, demonstrating sensitivity to on-site factors. Further investigation by Binkley (1984) concluded that use of ERB were appropriate for field estimations if both N mineralization and transport are of interest. However, results obtained from the ERB technique may be confounded by soil disturbance created during placement of bags in the soil (Subler et al, 1995). Further, the effort required to place ERB properly in soil may limit their effectiveness by altering the flow of water and nutrients through or around the bag (Subler et al, 1995). As well, ERB are time consuming and expensive to assemble (Binkley and Matson, 1983).

Ion exchange membrane probes (IEM) are plastic shields with an exposed center that house ion exchange resins in membrane form. They have the advantage of being easier to install than ERB. IEM are promising for measurement of N mineralization, and appear to predict phosphorus availability in soil as well as ERB do (Liang and Schoenau, 1995).

However, Subler et al. (1995) noted that adsorption of ions to resin membranes may be limited by competition for nutrient ions by microbes and plant roots, and by the diffusion rate of the soil. Further, under conditions of strong N immobilization, ions may be removed from resin membranes by microbes (Subler et al, 1995). On the other hand, IEM may simulate the availability of nutrient ions to plant roots (Qian and Schoenau, 1995) providing a good estimate of N availability to plants. In general, IEM are easy to use, allow more samples to be taken with the same effort, and reduce the overall cost per sample (Western Ag Innovations, 1997).

This chapter reports on a laboratory study designed to compare IEM, ERB and 0.01 M $CaCl_2$ extraction techniques for measurement of soil mineral N availability under varied physical and chemical soil conditions. The following hypotheses were tested: under immobilizing condition, N ions will be removed from the exchange resin; N sorption onto exchange resins will be reduced as soil ped size increases; and N sorption onto exchange resins will be reduced as leaching intensity increases. As well, this chapter reports field data collected between May 1997 and May 1998 from sites at Lac La Biche and Whitecourt, AB at all slope positions. The laboratory study was used to calibrate the IEM, thereby allowing the field data to be reported on a volumetric basis. The field data provided insight into temporal changes in available N at the sites investigated.

Materials and Methods

Sample Preparation

The top 30 cm of mineral soil (Ae + Bt horizons) from an Orthic Grey Luvisol was sampled from an upper slope position near Lac La Biche, Alberta, in May 1997. The soil was spread onto trays and air dried for 5 days. Soil was passed through three sieves, separating the soil into 3 size fractions: coarse (5.0 mm to 25 mm); medium (2 mm to 5.0 mm); and fine (less than 2 mm). Combining equal portions of all three size fractions made a complete sample. The soil was then stored at room temperature in 16 L buckets until commencement of the experiment.

Experimental Procedure

Hypothesis #1: Varied Ped Sizes

It was hypothesized that as ped size increased, N sorption onto the ERB or IEM would be reduced due to a decrease in soil contact to the exchange resins. This experiment was a completely randomized design with 4 size fractions (complete, coarse, medium and fine); 3 techniques (0.01 M $CaCl_2$, ERB and IEM); and 3 replicates. Four 5.4 kg (air dry) piles of fine, medium, coarse and complete sample fractions were sprayed with casein (36 g L^{-1}) using a fine mist spray bottle. Total volume of water added to each 5.4 kg pile was 750 ml. Continuously turning the pile by hand ensured homogeneity and penetration of amendment into the soil aggregates. After equilibrating at room temperature (approximately 1 hour), 9 sub-samples (600 g air dried soil) from each pile were placed into PVC incubation cores (7.6 x 15.2 cm) which had one glass fiber filter pad (Fisherbrand circles G6 #09-804-90A), cut to size on the bottom. Dry combustion determined total C and an automated Dumas method determined total N for amended soil samples using a Carlo ERBA Strumentazione NA1500 Nitrogen, Carbon and Sulfur Analyzer. The cores were placed in a 3 cm water bath until saturated, and then allowed to drain for one hour before commencing the experiment. Soil C:N ratios were not determined after wetting and it is possible that some of the amendment leached out of the cores into the water bath. However, the amount lost is assumed to be relatively small because the amendment would sorb to the soil. As well, casein (or starch, see below) are macromolecular substrates and are likely entrapped in the soil pores making them less likely to move out of the soil core.

$CaCl_2$ Leaching

A glass fiber filter pad was placed on top of the soil in each of 9 cores (3 rep x 3 amendments) to prevent surface disturbance. Each core was placed on top of a funnel attached to a vacuum flask and leached with 100 ml, 0.01 M $CaCl_2$. The incubation cores were allowed to drain freely for 1 hour, and then evacuated to 33 kPa moisture tension. The leachate was diluted to 100 ml with deionized water, transferred to 125 ml nalgene bottles and frozen until analysis could be completed. Subsequent leachings were made on day 5 and 10.

ERB or IEM

Resin bags were prepared by weighing 4 g of cationic resin (Dowex 50WX2-100 strongly acidic cation exchanger; H^+ counter ion; total exchange capacity = 4.8 meq g^{-1}) and 2 g of anionic resin (Dowex 1X2-100; strongly basic exchanger; Cl^- counter ion; total exchange capacity = 3.5 meq g^{-1}) into separate nylon bags (approximately 25 cm^2). Prior to incubation, anion and cation IEM (supplied by Western Ag Innovations) and anion and cation ERB were soaked overnight in 0.5 M $NaCO_3$. Both were rinsed with distilled water, prior to insertion into the cores. The IEM were inserted vertically into nine cores while the ERB were buried in nine cores. After 1 hour, a time 0 measurement for both the ERB and IEM probes were taken. Soil adhering to the IEM or ERB was rinsed off with distilled water. The IEM (anion and cation) from the same core were then placed in 1000 ml naglene bottles containing 100 ml of 0.5 M HCl. Both ERB (anion and cation) from the same core were placed in a 250 ml nalgene bottle containing 100 ml of 0.5 M HCl. These bottles were placed horizontally on a reciprocal shaker (140 shakes / minute) for 1 hour. The N-containing HCl solutions were then transferred to 125 ml nalgene bottles and frozen until analysis could be completed. ERB were not regenerated. IEM were regenerated by rinsing the used IEM with distilled water and then washing them three times in 0.5 M $NaHCO_3$ solution to replenish the exchange capacity of the resin membranes (Figure 5.1) (Qian and Schoenau, 1995). New ERB and regenerated IEM were inserted into their respective cores until the next measurement was made. Subsequent measurements were taken on days 5 and 10.

All of the cores ($CaCl_2$, ERB and IEM) were incubated under laboratory conditions. Fungal development was observed throughout the duration of the experiment. Samples were analyzed for mineral N. The concentration of NH_4^+-N in leachate was measured by the automated indophenol blue method (Technicon, 1973), and the NO_3^--N concentrations were measured using cadmium reduction method (Technicon, 1977). Modification had to

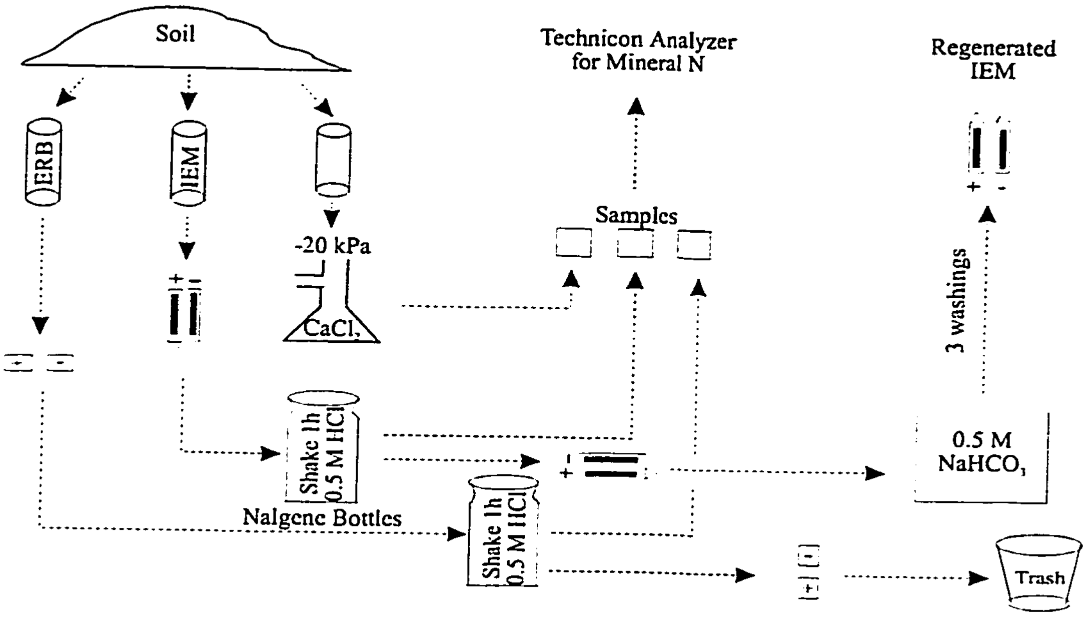

Figure 5.1: Three Techniques for Measuring Available N

be made for analysis of mineral N because HCl was used as an extracting solution (Appendix 4.1).

Hypothesis #2: Different Intensities of Leaching

It was hypothesized that as leaching intensity increased, N sorption onto ERB or IEM would decrease. This experiment was a completely randomized design with 3 leaching intensities (50 ml of water every 8 h, 150 ml of water every 24 h, and 350 ml of water every 48 h); 3 techniques (0.01 M $CaCl_2$, ERB and IEM); and 3 replicates. Incubation cores were prepared as outlined above. Each incubation core received the same total amount of water (30 cm week^{-1}; 1050 ml week^{-1}), but the treatment was defined as how often each core was watered. For example, the leaching intensity denoted 8 h, received 50 ml of water every 8 h, while the 24 h leaching intensity receive 150 ml of water every 24 h, and so on. Hence, the 48 h treatment had a higher leaching intensity because more water was applied to the incubation cores at one time. The incubation cores were set on stands with 700 ml bucket underneath each core to collect leachate. The incubation cores were evenly divided by treatment for measurement of mineral N as described above. The leachate accumulated from each core in the 700 ml bucket was collected on day 5 and 10 for analysis. IEM and ERB measurements were made at time 0, day 5 and 10.

Hypothesis #3: Conditions of Mineralization and Immobilization

It was hypothesized that under immobilizing conditions, N ions would be removed from the exchange resin. This experiment was a completely randomized design with 3 amendments (control, casein, and starch); 3 techniques (0.01 M $CaCl_2$, ERB and IEM); and 3 replicates. A complete sample was separated into three 5.4 kg (air dry) piles. Casein (36 g L^{-1}) with a C:N = 3:1; starch (36 g L^{-1}) with a C:N = 177:1; or deionized water was applied to separate piles respectively, in a fine mist spray. The final soil C:N ratios for the casein amended soil was 6:1; starch amended soil was 13:1; and the control soil was 8:1. Although the soil C:N ratios do not seem different, these selected amendments are quickly metabolized and will create conditions of mineralization or immobilization. The incubation cores were evenly divided by treatment for measurement of mineral N as described above.

Dynamics of NH_4^++NO_3^- Under Field Conditions

Sites located at Lac La Biche and Whitecourt, AB had a 0.09 m^2 hole excavated at all slope positions exposing the organic and Ae horizons. IEM were inserted horizontally at the bottom of each of the organic and Ae horizons (Figure 5.2). Soil was then placed back in the hole in the original horizon sequence with packing to near the original density. After 2 weeks, the holes were re-opened, the exposed IEM were removed, and were replaced by regenerated IEM. Regenerated IEM were inserted into the soil horizontally, but in a different radial location in the hole. This ensured that the soil was as undisturbed as possible and allowed for greatest soil contact with the IEM. If needed a new hole was excavated approximately every 6 weeks to ensure proper horizon placement and to minimize soil disturbance. Sampling occurred every 2 weeks until October 1997, when IEM were allowed to incubate over the winter and were removed in May 1998 when the soil thawed enough to remove the IEM.

Soil Volume Calculation

Each of these techniques measures NH_4^+ and NO_3^- but yields characteristic base units. The $CaCl_2$ extraction is expressed as mg N per volume soil or per g of soil (Ellert and Bettany, 1992); ERB are three-dimensional and have been reported as mg N per bag or per g resin (Binkley and Matson, 1983); IEM are two-dimensional and have been reported as mg N per 10 cm^2 (Huang and Schoenau, 1996). The $CaCl_2$ extraction has been proposed as a standard method of determining the mineralizable soil N pool (Keeney, 1980), therefore it was used as a control or standard for the other techniques. Consequently some way is needed to calibrate ERB and IEM to the $CaCl_2$ extraction so that comparable units may be used. It is known that the 0.01 M $CaCl_2$ extraction potentially samples the entire soil volume. Water held in the inter-aggregate pores is sometimes called nonmobile because water may move preferentially through intra-aggregate pores and not enter inter-aggregate pores. Consequently some of the $CaCl_2$

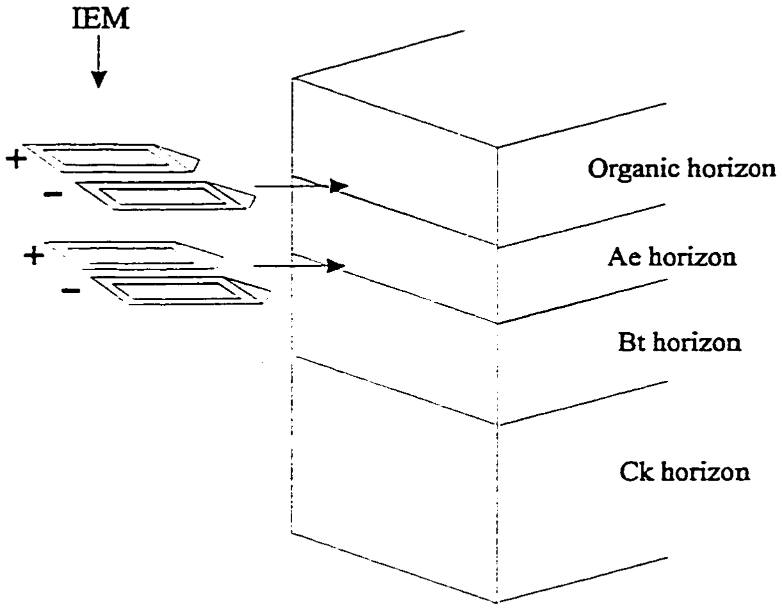

Figure 5.2: IEM Placement in the Field

solution used for leaching may have bypassed the inter-aggregate pores. Such preferential flow could result in NH_4^+ or NO_3^- remaining within aggregates following 0.01 M $CaCl_2$ extraction. We consider this to be a minor problem because: we used a slow leaching protocol (until free drainage ceased) that allowed at least partial equilibration of the leaching solution with inter-aggregate water. Consequently we did not correct for the nonmobile species. We proposed to calibrate the ERB and IEM with 0.01 M $CaCl_2$ extraction by using the 0.01 M $CaCl_2$ extraction data to calculate the effective volume sampled by the ERB or IEM. This volume can be calculated from the ratio of the ERB or IEM results (μg N) to the 0.01 M $CaCl_2$ extraction results (μg N cm^{-3}) according to:

$$V = \frac{Y}{X} \qquad [5.1]$$

where V is the effective volume sampled by the ERB or IEM (cm^3); Y is the mass of N recovered from the ERB or IEM (μg); and X is the N recovered from the $CaCl_2$ extraction (μg cm^{-3}).

This converts all techniques into the same base unit, cm^3. It was expected that each technique would have a characteristic effective soil volume and the volume should not exceed the $CaCl_2$ extraction volume. It was also expected that the calculated volume for the ERB might be greater than the calculated volume for the IEM technique because the ERB had an NH_4^+ charge capacity 90 fold greater and a NO_3^- charge capacity 31 fold larger than the IEM.

Using this equation, special consideration needed to be given to the effective volume calculation for NO_3^-. The day 0 M $CaCl_2$ extraction removes all NO_3^- available in the soil core. Previous studies (Chapter 3 and 4) indicate that accumulation of NO_3^- may take up to 100 days. Since the extent of this experiment was only 10 days, the day 0 values from 0.01 M $CaCl_2$ extraction for NO_3^- are used in the effective volume calculation. For example, to calculate the NO_3^- effective volumes for IEM or ERB, only the time 0 NO_3^- value measured from the 0.01 M $CaCl_2$ extraction was used because NO_3^- was not measured on days 5 or 10. However, to calculate the NH_4^+ effective volumes for IEM or ERB the day 5 and 10 values from the 0.01 M $CaCl_2$ extraction were used in the denominator.

Statistical Analysis

Average mineral N values measured by 0.01 M $CaCl_2$ extraction and predicted by IEM or ERB were calculated. NO_3^- means were calculated using time 0, day 5 and 10 values whereas, NH_4^+ means were calculated using day 5 and 10 values for all techniques. This was because time 0 (1 hour) measurements were not accurate in measuring NH_4^+ for either the ERB or IEM. One way simple ANOVA's ($\alpha = 0.05$) were calculated in Microsoft Excel version 5 using these average values to determine if there were any significant differences between treatments or techniques. Significant differences were determined if the $F_{value} > F_{critical}$. To determine what treatments or techniques were different from each other, mean separations using the Student-Newan-Keuls were calculated in SAS version 6.1 (SAS Institute Inc., 1998).

Results and Discussion

Effective Soil Volume for a Normal Soil

A normal soil was defined as the complete treatment used in varied ped experiment. Therefore, the average effective soil volume for a normal soil (Table 1) was calculated using the values measured from the complete soil treatment (Appendix 4.2). The average effective soil volume for a normal soil can then be used to compare the amount of mineral N using identical units ($\mu g\ cm^{-3}$) for either ERB or IEM. This allows predicted mineral N values from IEM or ERB to be compared to the actual mineral N values from the 0.01 M $CaCl_2$ extraction under various conditions. There was no significant difference in NO_3^- and NH_4^+ effective volumes sampled by IEM or ERB. However, the effective volumes sampled by ERB were significantly larger than the effective volumes sampled by IEM.

Table 5.1: Average Effective Soil Volumes for Normal Soil Conditions

	NO_3^- (cm^3)	NH_4^+ (cm^3)
IEM	27^{a*}	17^a
ERB	99^b	127^b

*different letters in columns and rows represent significant differences ($\alpha = 0.05$)

Varied Ped Size

There were no significant differences in the amount of NH_4^+ measured by the 0.01 M $CaCl_2$ extraction between treatments (Table 2; Appendix 4.3a). The amount of NH_4^+ predicted by IEM from the fine treatments were significantly higher than the amount of NH_4^+ predicted from the medium or coarse treatments. There were no significant differences between the complete and fine treatments as predicted by the IEM. There were no significant differences in the amount of NH_4^+ predicted by using ERB between treatments. Since IEM predicted slightly less NH_4^+ for the coarse and medium treatments, a decrease in soil contact may underestimate the amount of NH_4^+ present. However, it is not expected that these techniques would be used to assess N in the field with all ped sizes larger than 2 mm. As well, there were no significant differences in the amount of NH_4^+ predicted by IEM or ERB for any treatments compared to the actual amount measured from the 0.01 M $CaCl_2$ extraction for the same treatment. Therefore a change in ped size does not change the amount of NH_4^+ measured by 0.01 M $CaCl_2$ extraction, or predicted by IEM or ERB.

Table 5.2: The actual amount of NH_4^+ as determined by the 0.01 M $CaCl_2$ extraction as well as the predicted amounts calculated from ERB and IEM effective soil volumes for different ped sizes

	Soil Volume	0.01 M $CaCl_2$ Extraction (actual)	IEM (predicted)	ERB (predicted)
	cm^3	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$
Complete*	398	17^{a1**}	17^{ab1}	17^{a1}
Coarse (5 to 25 mm)	530	13^{a1}	13^{b1}	15^{a1}
Medium (2 to 5 mm)	508	13^{a1}	12^{b1}	13^{a1}
Fine (< 2mm)	398	14^{a1}	20^{a1}	18^{a1}

* equal portions of coarse, medium and fine particle size fractions

** different letters in columns or different numbers in rows represent significant differences ($\alpha = 0.05$)

The 0.01 M $CaCl_2$ extraction measured the amount of NO_3^- to be significantly different between treatments (Table 3; Appendix 4.3a). The complete treatments > fine treatments > medium treatments > coarse treatments. The IEM predicted significantly higher amounts of NO_3^- from the complete treatment than all other treatments. There were no significant differences in the amount of NO_3^- predicted by ERB between treatments. There were no significant differences in the amount of NO_3^- predicted by IEM or ERB for any treatment compared to the $CaCl_2$ extraction for the same treatment. Therefore a change in ped size does not change the amount of NO_3^- measured by 0.01 M $CaCl_2$ extraction, IEM or ERB.

Table 5.3: The actual amount of NO_3^- as determined by 0.01 M $CaCl_2$ extraction and the predicted amount calculated from ERB and IEM effective soil volumes for different ped sizes

	Soil Volume	0.01 M $CaCl_2$ Extraction (actual)	IEM (predicted)	ERB (predicted)
	cm^3	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$
Complete*	398	0.050^{a1**}	0.29^{a1}	0.09^{a1}
Coarse (5 to 25 mm)	530	0.014^{d1}	0.03^{b1}	0.10^{a1}
Medium (2 to 5 mm)	508	0.017^{c1}	0.05^{b1}	0.10^{a1}
Fine (< 2 mm)	398	0.034^{b1}	0.04^{b1}	0.62^{a1}

* equal portions of coarse, medium and fine particle size fractions

** different letters in columns or different numbers in rows represent significant differences ($\alpha = 0.05$)

Different Intensities of Leaching

There were significant differences in the amount of NH_4^+ detected in the leachates from IEM incubation cores (Table 4; Appendix 4.3b). The leachates from the 24 h and 48 h treatment cores were significantly higher NH_4^+ than the leachates from the 8 h treatment cores. There were no significant differences in the amount of NH_4^+ detected in the leachates from the ERB incubation cores. The amount of NH_4^+ predicted by IEM from the 8 h treatments were significantly higher than the amount of NH_4^+ predicted by the 24h or 48 h treatments. There were no significant differences in the amount of NH_4^+ predicted by ERB between treatments. The amount of NH_4^+ predicted by IEM was not significantly different from the amount of NH_4^+ predicted by ERB for any treatment. These results suggest that the IEM and ERB are very efficient in measuring NH_4^+ as leaching intensity increases. However, the amount of NH_4^+ in the leachates may have been converted into microbial biomass between sampling times because the leachates were not collected for 5 days, allowing time for microbes to assimilate NH_4^+. Therefore NH_4^+ should have been measured after free drainage ceased.

Table 5.4: The amount of NH_4^+ in leachate from IEM and ERB incubation cores and the predicted amounts from ERB and IEM effective soil volumes for different leaching intensities

	Soil Volume	Leachate from IEM cores	Leachate from ERB cores	IEM (predicted)	ERB (predicted)
	cm^3	μg N cm^{-3}	μg N cm^{-3}	μg N cm^{-3}	μg N cm^{-3}
50 ml water every 8 h	398	0.02^{a1*}	0.03^{a1}	18^{a2}	27^{a2}
150 ml water every 24 h	398	0.03^{b1}	0.02^{a1}	14^{b2}	21^{a2}
350 ml water every 48 h	398	0.05^{b1}	0.02^{a1}	12^{b2}	20^{a2}

* different letters in columns or different numbers in rows represent significant differences ($\alpha = 0.05$)

NO_3^- was not detected in the leachates from the IEM or ERB incubation cores (Table 5; Appendix 4.3b). The amount of NO_3^- predicted by IEM or ERB were significantly higher than the amount of NO_3^- in the their respective leachates. The amount of NO_3^- predicted by IEM or ERB were not significantly different between treatments. The amount of NO_3^- predicted by using IEM were not significantly different from the amount of NO_3^- predicted by using ERB for any treatment. These results suggest that the IEM and ERB are able to measure NO_3^- as leaching intensity increases. However it is possible that as leaching intensity increased, mobile species such as NO_3^- were removed, which in the leachate were assimilated by microbes between measurements (5 days). As well, denitrification may have occurred because the incubation cores were periodically saturated throughout the experiment, resulting in the low amount of NO_3^- predicted by the IEM or ERB. However the NO_3^- values predicted by the IEM or ERB were not significantly different than the NO_3^- values predicted by either the IEM or ERB from the complete or casein treatments, suggesting that the amount of NO_3^- predicted by using IEM and ERB were accurate.

Table 5.5: The amount of NO_3^- in leachate from IEM or ERB incubation cores and the predicted amounts from ERB and IEM effective soil volumes for different leaching intensities

	Soil Volume	Leachate from IEM cores	Leachate from ERB cores	IEM (predicted)	ERB (predicted)
	cm^3	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$
50 ml water every 8 h	398	0.0^{a1*}	0.0^{a1}	0.03^{a2}	0.04^{a2}
150 ml water every 24 h	398	0.0^{a1}	0.0^{a1}	0.02^{a2}	0.04^{a2}
350 ml water every 48 h	398	0.0^{a1}	0.0^{a1}	0.02^{a2}	0.04^{a2}

* different letters in columns or different numbers in rows represent significant differences ($\alpha = 0.05$)

Conditions of Mineralization and Immobilization

The amount of NH_4^+ measured by the 0.01 M $CaCl_2$ extraction was significantly different between treatments (Table 6; Appendix 4.3c). The amount of NH_4^+ measured from the casein treatments were significantly higher than the amount of NH_4^+ measured from the control or starch treatments. The amount of NH_4^+ predicted by using IEM or ERB were significantly higher in the casein treatments than that in the control or starch treatments.

There were no significant differences in the amount of NH_4^+ predicted by using IEM or ERB for the control or starch treatments compared to the 0.01 M $CaCl_2$ extraction. The amount of NH_4^+ measured using 0.01 M $CaCl_2$ extraction was significantly higher than the amount of NH_4^+ predicted by using ERB. The amount of NH_4^+ measured by the 0.01 M $CaCl_2$ extraction, and predicted by IEM were the same. Therefore, IEM and ERB were able to detect mineralization as well as immobilization, however the ERB may be less accurate in measuring the amount of NH_4^+. There was no evidence suggesting that either the IEM or ERB retains NH_4^+ ions. It should be noted that there was little N mineralized by the normal soil. Consequently, there was little N to be immobilized in the starch treatments. Hence, immobilization cannot reduce N retained by the IEM or ERB if there wasn't much there to begin with. Regardless, the large variability associated with this experiment warrants further investigation.

Table 5.6: The actual amount of NH_4^+ determined by the 0.01 M $CaCl_2$ extraction and the predicted amounts from ERB and IEM effective soil volumes for different levels of N

	Soil Volume	0.01 M $CaCl_2$ Extraction (actual)	IEM (predicted)	ERB (predicted)
	cm^3	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$	$\mu g\ N\ cm^{-3}$
Control	398	0.10^{a1*}	0.09^{a1}	0.13^{a1}
Casein	398	19^{b1}	17^{b12}	12^{b2}
Starch	398	0.00^{a1}	0.18^{a1}	0.05^{a1}

* different letters in columns or different numbers in rows represent significant differences ($\alpha = 0.05$)

The amount of NO_3^- measured by the 0.01 M $CaCl_2$ extraction was significantly different between treatments (Table 7; Appendix 4.3c). There was significantly more NO_3^- measured by the 0.01 M $CaCl_2$ extraction in the casein treatments than either the starch or control treatments. The predicted amounts of NO_3^- by both IEM and ERB were not significantly different between treatments. Therefore, IEM or ERB did not predict an increase in the amount of NO_3^- in the casein treatments, as did the 0.01 M $CaCl_2$ extraction. However, the amount of NO_3^- predicted by using IEM or ERB for the casein treatments was not significantly different than the amount measured by $CaCl_2$ extraction. Subler et al (1995) reported that under strongly immobilizing conditions, ion exchange resins didn't compete well with microbes for available N suggesting that ions may be removed from the exchange resins by microbes. However these results suggest that NO_3^- ion removal did not occur from the exchange resins, because the amount of NO_3^- predicted by IEM or ERB from the control and starch treatments was the same as the amount of NO_3^- predicted by IEM or ERB from the casein treatment. Therefore the IEM or ERB did predict an increase in the amount of NO_3^- from the casein treatments, but did not predict a decrease in the amount of NO_3^- from the starch or control treatments as compared to the 0.01 M $CaCl_2$ extraction.

Table 5.7: The actual amount of NO_3^- determined by the 0.01 M $CaCl_2$ extraction and the predicted amounts from ERB and IEM effective soil volumes for different levels of N

	Soil Volume	0.01 M $CaCl_2$ Extraction (actual)	IEM (predicted)	ERB (predicted)
	cm^3	μg N cm^{-3}	μg N cm^{-3}	μg N cm^{-3}
Control	398	0.02^{a1}[*]	0.10^{a1}	0.07^{a1}
Casein	398	0.19^{b1}	0.26^{a1}	0.09^{a1}
Starch	398	0.01^{a1}	0.21^{a1}	0.15^{a1}

[*] different letters in columns and different numbers in rows represent significant differences ($\alpha = 0.05$)

Field Incubations

Amount of NO_3^- and NH_4^+ mineralization from organic and Ae horizons from Lac La Biche and Whitecourt, at all three slope positions were measured using IEM reported on a volume basis, using the effective soil volumes from Table 5.1. Note that the effective soil volumes calculated in Table 5.1 are from the top 30 cm of mineral soil from Lac La Biche upper slope position and the values reported are for both sites, all slope positions and both soil horizons. The effective volumes used may not pertain to all these conditions. The relationships over time and among horizons are not altered by any error in effective volume, because we used a constant value for the conversion. The effective volume is reported in Table 5.1, and the original data expressed as μg N cm^{-2} can be derived using the effective volume and the area of the IEM (17.5 cm^2).

The amount of NH_4^+ mineralization from both horizons from Whitecourt and Lac La Biche ranged from 0.5 to 5.0 μg NH_4^+ cm^{-3} with the exception of the lower slope position at Whitecourt, which mineralization 13.3 μg NH_4^+ cm^{-3} in the middle of July (Figure 5.3 to 5.6). The pattern of NH_4^+ mineralization from both organic and Ae horizons at both sites was similar. Both the organic and Ae horizons had a flush of NH_4^+ between September and October 1997 releasing between 3 to 4 μg NH_4^+ cm^{-3}. This may be due to mineralization from the input of fresh litter during the fall season. There was an earlier flush of NH_4^+ from Whitecourt organic horizons in the middle of July. A slight increase in the amount of NH_4^+ in the Ae horizon could also be observed around this time. An earlier NH_4^+ flush was also detected from Lac La Biche from the Ae horizon in the middle of June 1997.

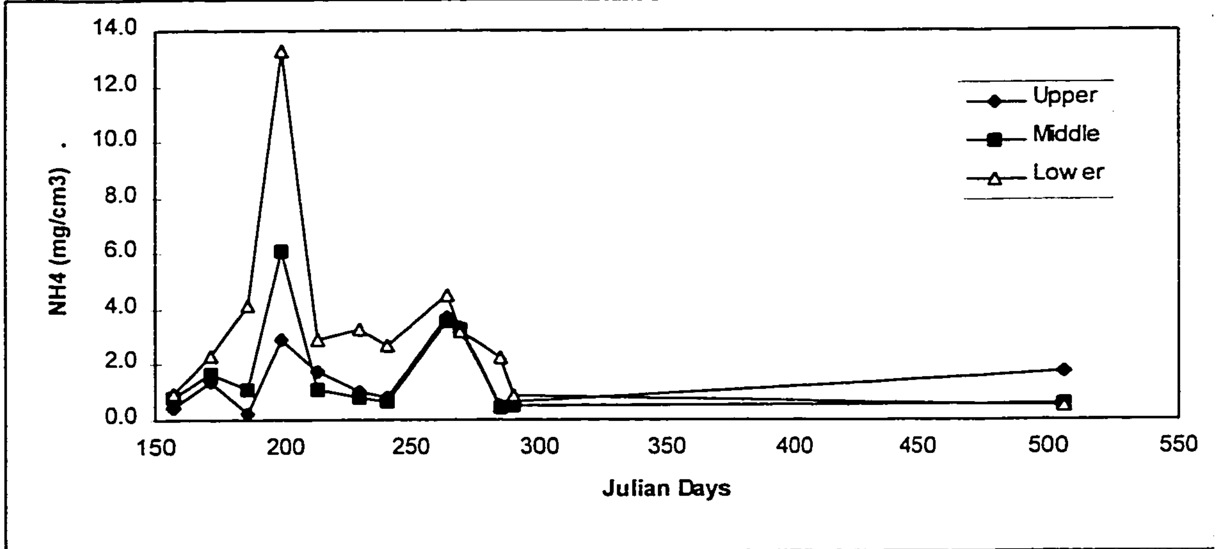

Figure 5.3: NH_4^+ Mineralization from Organic Horizon at Whitecourt from June 1997 to May 1998

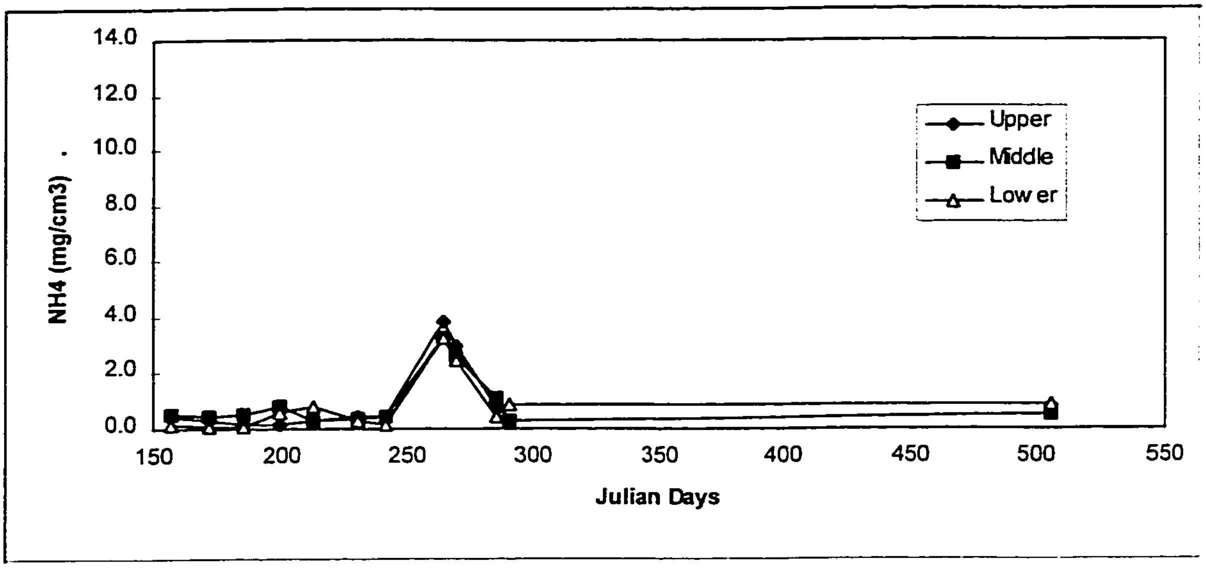

Figure 5.4: NH_4^+ Mineralization from Ae Horizon at Whitecourt from June 1997 to May 1998

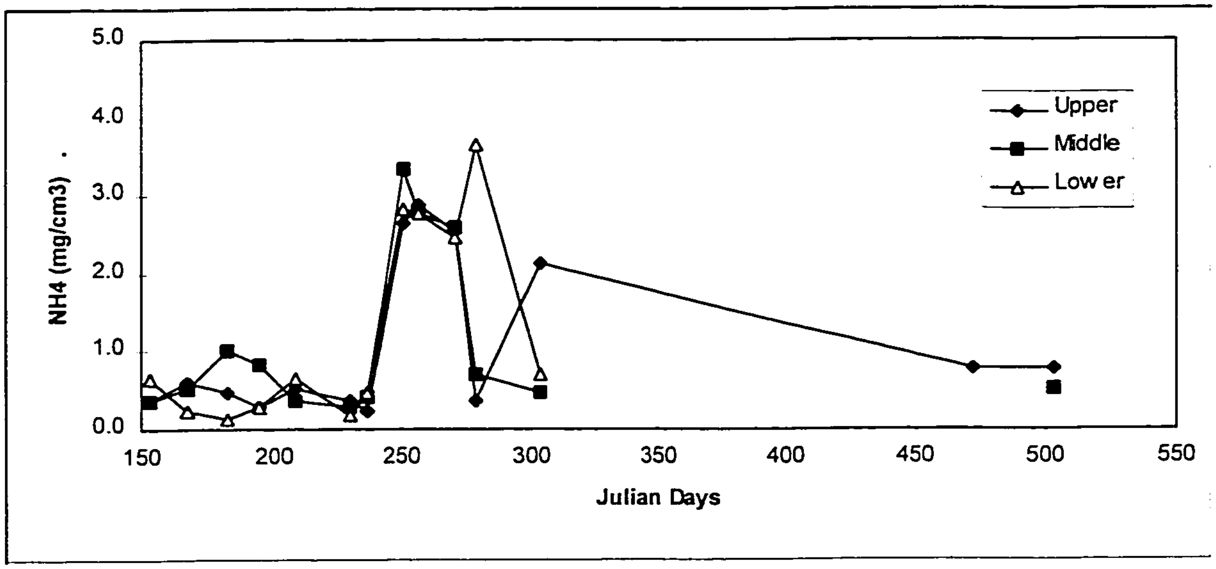

Figure 5.5: NH_4^+ Mineralization from Organic Horizon at Lac La Biche from June 1997 to May 1998

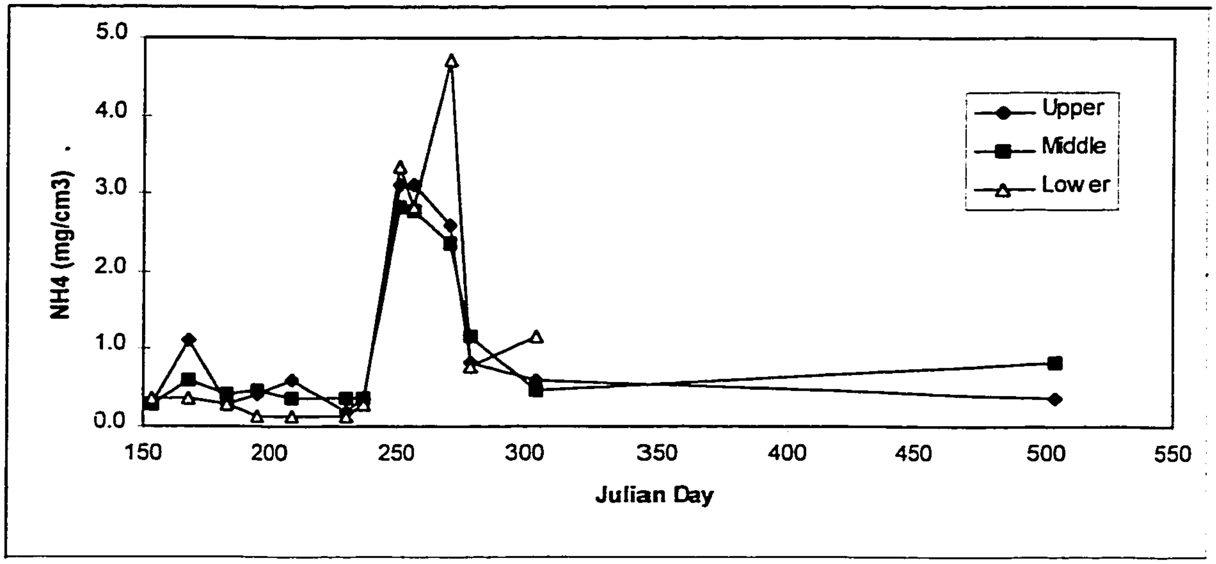

Figure 5.6: NH_4^+ Mineralization from Ae Horizon at Lac La Biche from June 1997 to May 1998

For both horizons, the amount of NO_3^- mineralization from Whitecourt was greater than from soil at Lac La Biche (Figure 5.7 to 5.10). Both horizons from Whitecourt mineralization between 0 and 6.1 µg NO_3^- cm^{-3} from June 1997 to May 1998. In contrast, the organic and Ae horizons from Lac La Biche mineralization between 0 to 0.26 µg NO_3^- cm^{-3}. The pattern of mineralization for NO_3^- was similar between slope positions for the Ae horizon at both sites. There was a flush of NO_3^- from Whitecourt Ae horizon in early July from all slope positions with the largest mineralization from the upper slope position. We observed a similar mineralization at Lac La Biche approximately 2 weeks later. This 2 week delay may be related to soil temperature because Whitecourt warmed earlier than Lac La Biche. There was no consistent NO_3^- pattern from the organic horizon from either site. NO_3^- production is dependent on NH_4^+ production. This is apparent from Whitecourt upper slope organic horizon and from Lac La Biche at all slope positions, both horizons. During the fall the flush of NH_4^+ corresponds with a flush of NO_3^-.

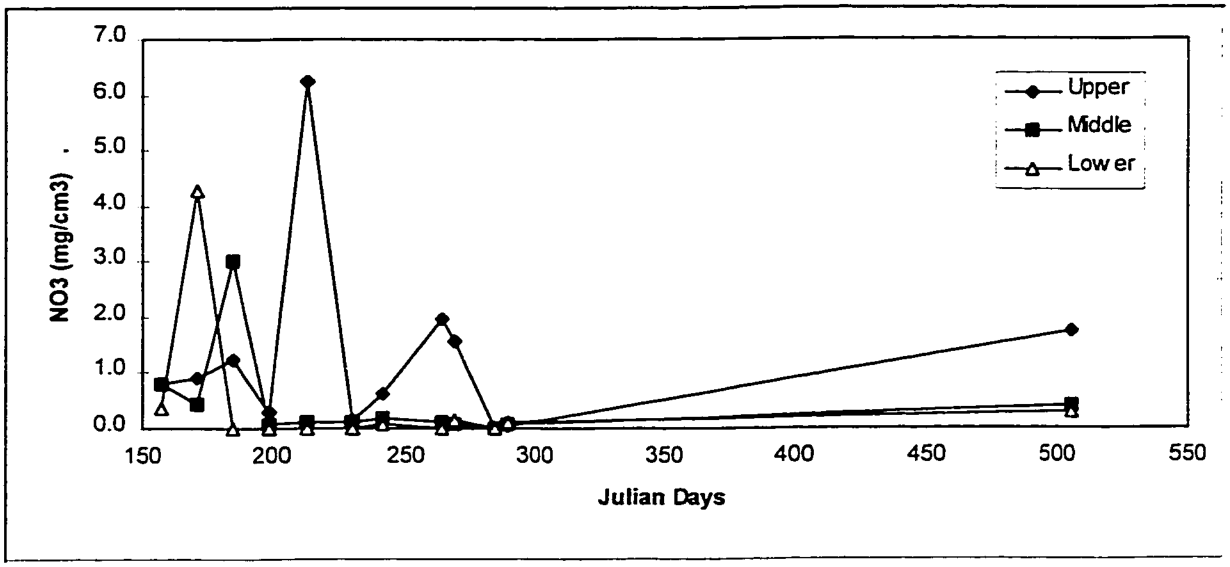

Figure 5.7: NO_3^- Mineralization from Organic Horizon at Whitecourt from June 1997 to May 1998

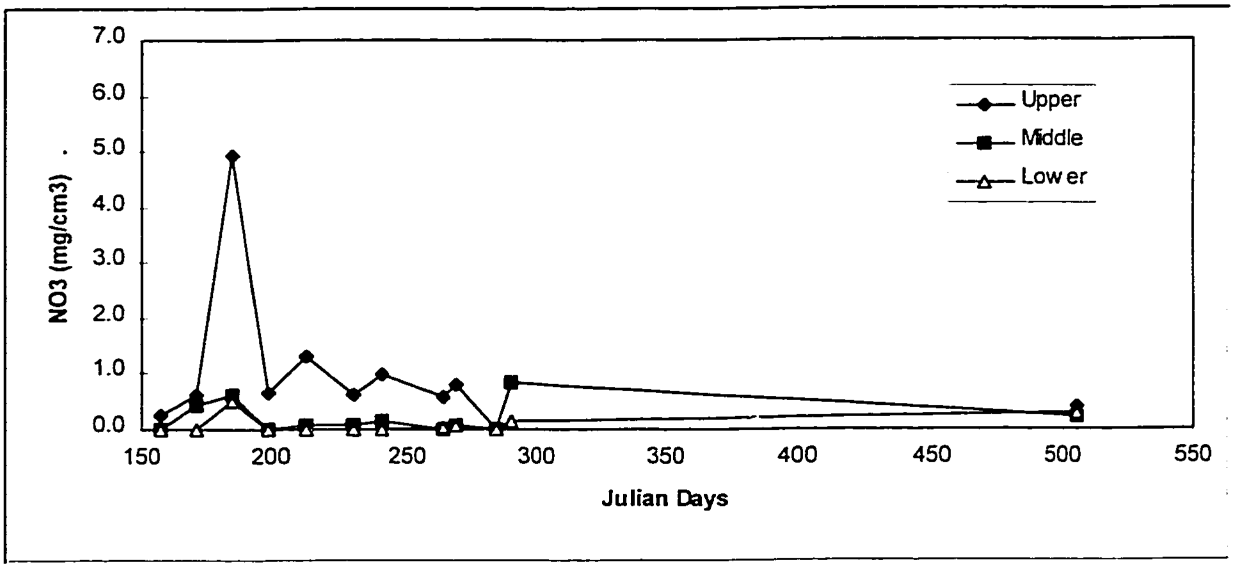

Figure 5.8: NO_3^- Mineralization from Mineral Ae Horizon at Whitecourt from June 1997 to May 1998

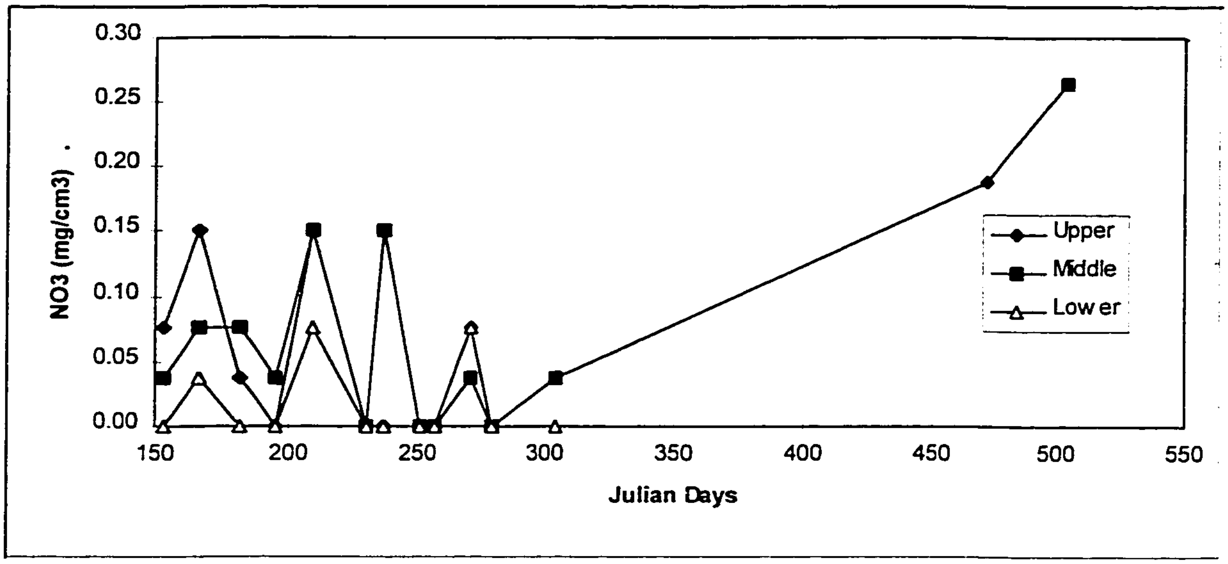

Figure 5.9: NO$_3^-$ Mineralization from Organic Horizon at Lac La Biche from June 1997 to May 1998

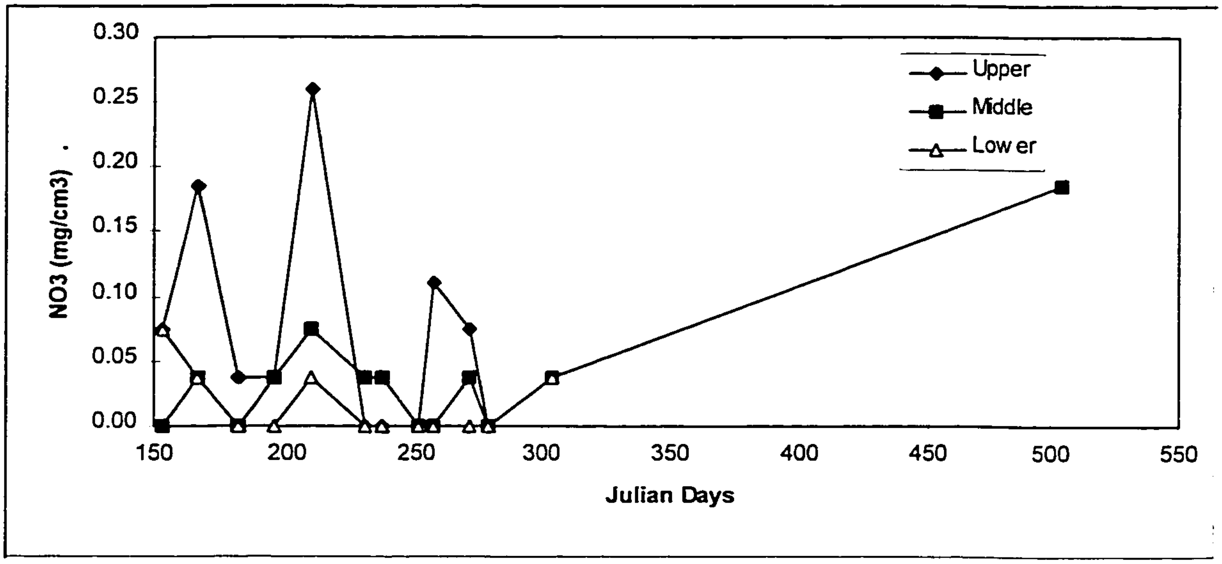

Figure 5.10: NO$_3^-$ Mineralization from Mineral Ae Horizon at Lac La Biche from June 1997 to May 1998

An attempt was made to remove the IEM from the organic and Ae horizons before the soil fully thawed in order to detect any mineralization that may have occurred over the winter incubation. However only one IEM was removed and replaced. On April 17, 1998, an IEM from the upper slope position organic horizon at Lac La Biche was replaced with a regenerated IEM (Table 8). The latter was left until May 19, 1998 when all IEM from Lac La Biche were removed. Measurements of NH_4^+ and NO_3^- on May 19, 1998 from each site were all above zero. There was no measurement of mineral N for the lower slope position at Lac La Biche because no IEM was in place for incubation over the winter. Both slope positions from Lac La Biche indicated a mineralization of NO_3^- in May most likely because of the growth rate of plants is low at this time. Results indicated that N mineralization may have occurred over the winter. However, the N measured by the IEM may have been mineralized in the late fall and retained by the IEM over the winter.

Table 5.8: Mineral N mineralization from Lac La Biche upper slope position pre- and post thaw from the organic horizon

Date	NO_3^- (μg cm^{-3})	NH_4^+ (μg cm^{-3})
April 17, 1998	0.05	0.13
May 19, 1998	0.07	0.13

Conclusion

IEM and ERB were very accurate in predicting the amount of N as compared to the 0.01 M $CaCl_2$ extraction. The only discrepancy was with ERB, which predicted significantly less NH_4^+ than the 0.01 M $CaCl_2$ extraction for the casein treatment. As ped size increased, NH_4^+ or NO_3^- sorption onto IEM or ERB did not decrease. As leaching intensity increased, the amount of NH_4^+ or NO_3^- predicted by using IEM or ERB did not decrease. In fact the IEM and ERB appear to be efficient predictors of the amount of NH_4^+ and NO_3^- in soil. There was no evidence suggesting that NH_4^+ or NO_3^- ions were removed from the exchange resins under conditions of immobilization. Furthermore the results suggest that the exchange resins retain NO_3^- ions. Further study of these methods needs to be completed and experimental variation associated with these experiments needs to be minimized.

Mineralization of NO_3^- from both sites and horizons fluctuates from 0 to 6 μg NO_3^- cm^{-3} and NH_4^+ fluctuates from 0 to 13 μg NH_4^+ cm^{-3} throughout the year. Mineralization of

NH_4^+ between sites and horizons is very similar both flushing between September to October, which corresponds with high inputs of litter.

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Chapter 6 : SYNTHESIS

Quantification of nutrient cycling processes of forested ecosystems has the potential to identify nutrients most likely to limit site productivity in current or future forests. However N concentrations within forested sites vary considerably. McNabb et al (1986) concluded that there was considerable variation in the N and C concentrations of surface soil within small forested sites in the Cascade Mountains of Oregon. They determined that this variation could not be accounted for by simple characterization of microsites around a sampling point. Given that there is large variation in N concentration from site to site, we hoped that this research could aid in the prediction of specific net N mineralization rates from sites across Canada.

The Gompertz model predicted parameters N_o, k and h. Because these parameters are correlated with each other, comparisons among soils cannot use one parameter alone. These were then used to calculate time to inflection point (T_{ni}) and maximum rate of N mineralization at inflection point (R_m). The proportionality constant, h, varied between sites and treatments ranging from 0.0002 to 24.67. Values of h greater than 1 were predicted for 5 treatments. As observed in Chapter 4, h values greater than 1 predicted negative times to inflection and it was concluded that these values are unreliable. Therefore, these values were deleted. If we limit analysis to the Alberta sites because Alberta samples were used in all three experiments, h values for samples of organic horizons ranged from 0.008 to 0.95 (median = 0.186) and for samples of Ae horizons h values ranged from 0.002 to 0.99 (median = 0.447). Rate coefficients, k, ranged from 0.005 to 0.038 d^{-1} for samples of organic horizons and 0.001 to 0.041 d^{-1} for samples of Ae horizons. It has been suggested that one k value might be valid for all soils (Dendooven et al, 1995). With this in mind, the median k value for both organic and Ae ($k = 0.009\ d^{-1}$) horizons was selected to represent all soils. Median N_o values for the organic (30.93 mg N g^{-1} soil N) and Ae (42.85 mg N g^{-1} soil N) horizons were also selected. To test the sensitivity of the Gompertz model with varying values of h, median values for k (0.009 d^{-1}) and N_o (42.85 mg N g^{-1} soil N) were held constant as h ranged from 0.19 to 0.99 (dimensionless) (Figs. 6.1 and 6.2). As h increased from 0.19 to 0.99 (dimensionless), the time to inflection point increased from 1.1 to 184 days, and the maximum rate of N mineralization increased from 0.17 to 0.38 mg N g^{-1} soil N d^{-1}. Therefore, the Gompertz model is sensitive to changes in h.

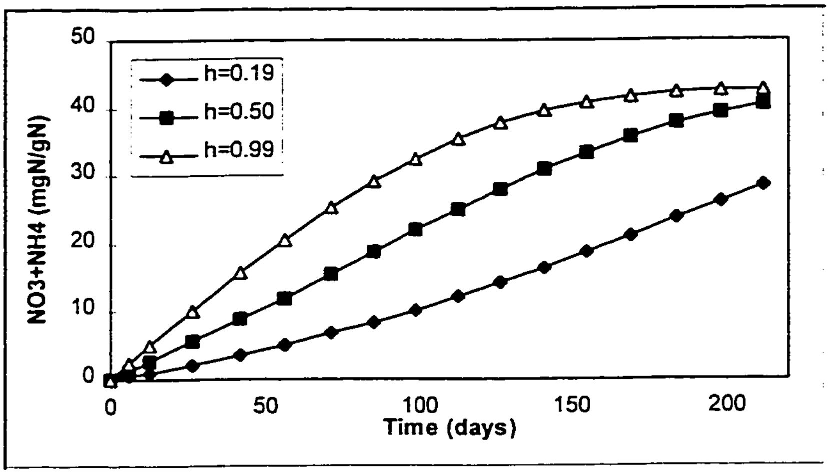

Figure 6.1: Cumulative specific net NH_4^++NO_3^- -N mineralization as h varied from 0.19 to 0.99 (dimensionless) during 212 days where N_o = 42.85 mg N g^{-1} soil N and k = 0.009 d^{-1}

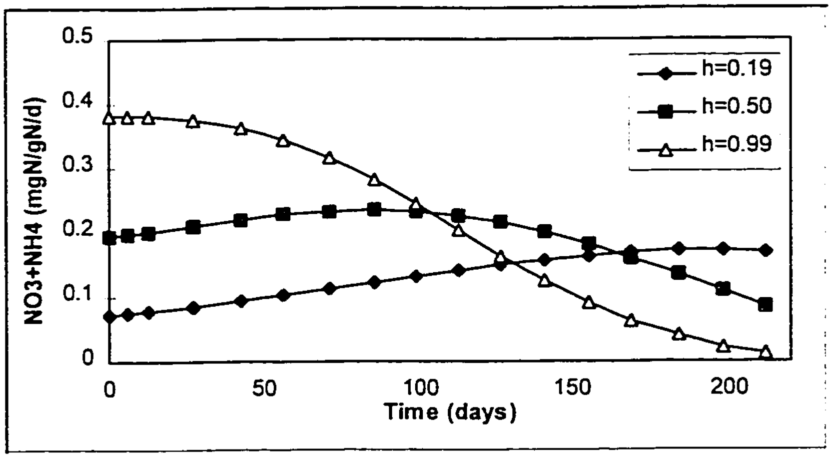

Figure 6.2: Incremental specific net NH_4^++NO_3^- -N mineralization as h varied from 0.19 to 0.99 (dimensionless) during 212 days where N_o = 42.85 mg N g^{-1} soil N and k = 0.009 d^{-1}

However, if median values of k (0.009 d^{-1}), and horizon-specific h (0.186) and N_0 (30.93 mg N g^{-1} N) values are used to predict the cumulative amount of N mineralized over 313 days, the outcome is similar to what was actually measured (Fig. 6.3).

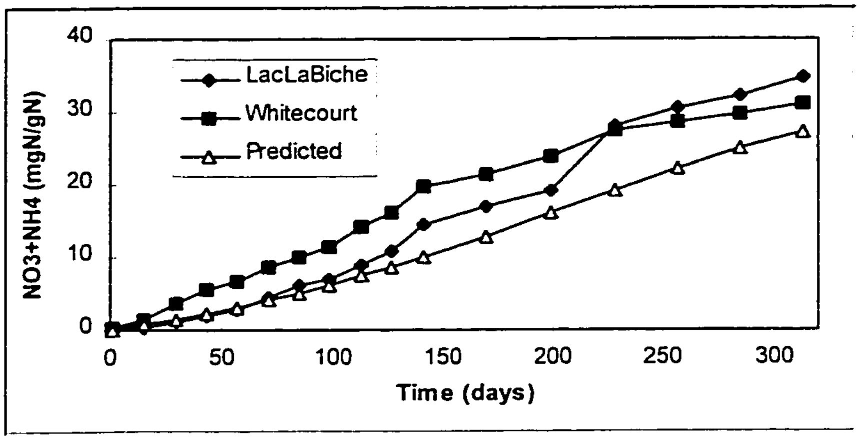

Figure 6.3: Predicted and actual cumulative specific net NH_4^++NO_3^- -N mineralization during 313 days from samples of organic horizons incubated at 22°C

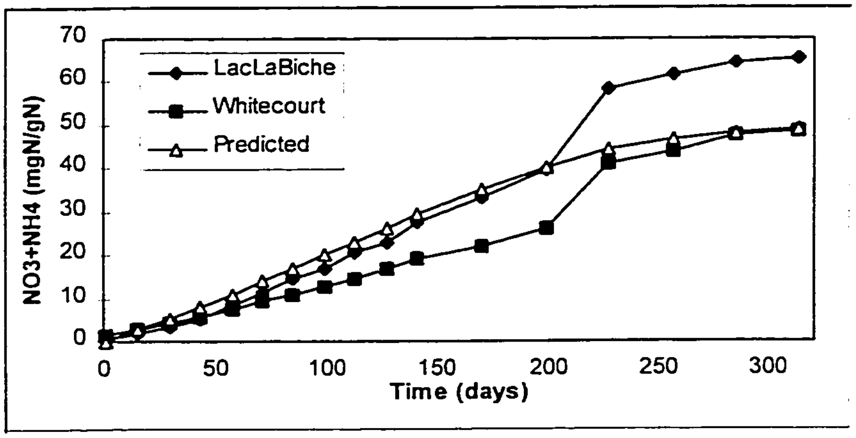

Figure 6.4: Predicted and actual cumulative specific net NH_4^++NO_3^- -N mineralization during 313 days from samples of Ae horizons incubated at 22°C

Using the following assumptions: k can be used to describe soils from both organic and Ae horizons; and N_0 and h are horizon-specific; the amount of N mineralized (mg N cm^{-2}) can be estimated for different sites if the total N (g N kg^{-1} soil) and ρb (g cm^{-3}) of a soil is known [Eq 6.1]:

$$Mineralized\ N\left(\frac{mg\,N}{cm^2}\right)=\frac{g\,soil\,N}{kg\,soil}*\rho b\left(\frac{g\,soil}{cm^3}\right)*\left(\frac{kg\,soil}{10^3\,g\,soil}\right)*depth(cm)*predicted\ N\left(\frac{mg\,N}{g\,soil\,N}\right)$$

For example, if a site with the following properties was to be harvested (compares to the organic horizon from the upper site at Whitecourt), the amount of N mineralized from the organic horizon could be predicted:

Total N = 24.1 g N kg^{-1}	Organic horizon depth = 10.5 cm
$\rho b = 0.11$ g cm^{-3}	Predicted N_o = 30.93 mg N g^{-1} soil N

$$Mineralized\ N=\frac{24.1\,g\,soil}{kg}*\frac{0.11\,g}{cm^3}*\frac{kg\,soil}{10^3\ g\,soil}*10.5\,cm*\frac{42.85\,mg\,N}{g\,soil\,N}$$

$$Mineralized\ N=\frac{0.86\,mg\,N}{cm^2}$$

$$Mineralized\ N=\frac{86\,kg\,N}{ha}$$

Therefore, quantification of the amount of N mineralized from different horizons can be compared (Table 6.1). As well, the total amount of N mineralized from both horizons can be estimated. In addition, N mineralization from different sites can be compared (Table 6.2). From both sites, the mineralization potential from the organic horizon was higher than the Ae horizon. Further analysis of these assumptions are needed. They were used here to illustrate how N mineralization on an aerial basis may be predicted.

Table 6.1: Estimated N mineralization Potential of Organic and Ae Horizons from Whitecourt

Variable	Units	Upper	Middle	Lower
Organic Horizon				
Depth	cm	10.5	8.1	8.7
Bulk Density	g cm^{-3}	0.11	0.13	0.18
Total N	g kg^{-1}	24.1	23.1	15.7
N_o	mg N (g soil $N)^{-1}$	30.93	30.93	30.93
N_o	kg N ha^{-1}	86	75	76
Ae Horizon				
Depth	cm	6	5	5
Bulk Density	g cm^{-3}	0.96	1.1	1.03
Total N	g kg^{-1}	2.8	1.7	1.8
N_o	mg N (g soil $N)^{-1}$	42.85	42.85	42.85
N_o	kg N ha^{-1}	69	40	40
Total	kg N ha^{-1}	155	115	116

Table 6.2: Estimated N mineralization Potential of Organic and Ae Horizons from Lac La Biche

Variable	Units	Upper	Middle	Lower
Organic Horizon				
Depth	cm	7	8	9
Bulk Density	g cm^{-3}	0.18	0.13	0.17
Total N	g kg^{-1}	9	10	11
N_o	mg N (g soil $N)^{-1}$	30.93	30.93	30.93
N_o	kg N ha^{-1}	35	32	52
Ae Horizon				
Depth	cm	4	3	2
Bulk Density	g cm^{-3}	1.42	1.27	1.54
Total N	g kg^{-1}	0.7	0.6	1.1
N_o	mg N (g soil $N)^{-1}$	42.85	42.85	42.85
N_o	kg N ha^{-1}	17	9	14
Total	kg N ha^{-1}	52	41	66

Generally, values of h greater than 1 were associated with samples of Ae horizons from Nicabau and Lac Spencer incubated at different moisture conditions. Is it possible that h is sensitive to soil moisture, soil classification or past disturbance history? Or was there an external variable during these experiments not identified? Additional work needs to clarify if h values greater than 1 are related to moisture conditions or some other factor.

Laboratory incubations in this research provided an understanding of N mineralization from samples of organic and Ae horizons without the presence of vegetation. In the absence of vegetation, this research indicated that samples of Ae horizons mineralized proportionally more N than samples of organic horizons. This suggests the specific net mineralization of N is horizon-specific not site-specific.

The major implications is that much of the variability among sites may be taken into account by readily accessible site data such as horizon thickness, density and N concentration. The decomposition rate data, being more universal may then be obtained from fewer samples and used widely with site data. This yields rate specific N mineralization rates expressed as kg ha^{-1}. Consequently the cost of estimating N mineralization over large areas can be reduced mainly to the cost of obtaining sites characteristics that determine total N present in organic and mineral horizons.

After disturbances such as cutting, soil pH generally increases and a new microbial community appears which oxidizes NH_4^+ to NO_3^-. As well, many site preparation operations are aimed at removing organic layers from sites and exposing the mineral soil because it is considered to be a reliable seed bed. On one hand, proportionally more N will be mineralization in the Ae horizon providing N to the new vegetation. However, boreal forest are characterized by low temperatures and short growing seasons. For these sites, there were 138 days above 2°C, therefore vegetation establishment may be limited within the first growing season, allowing N mineralization to proceed without adequate vegetation present. In addition, there was evidence that nitrification rates would increase after 50 to 100 days. We hypothesized that this was because establishment of nitrifier communities took 50 to 100 days. If forest management practices do not include or permit the establishment of quick growing vegetation nitrate may leach into streams, rivers, lakes or aquifers. High concentrations of NO_3^- in surface water is toxic to animals i.e. transformation of blood hemoglobin to methemoglobin, or formation of carcinogenic nitrosamines (Tamm et al, 1974), and may foster eutrophication of lakes and streams if complementary nutrients such as P are available.

It was demonstrated by Kronzucker et al. (1997) that white spruce seedlings preferentially absorbed 20 times more NH_4^+ than NO_3^-. If white spruce seedlings were planted the following season after cutting, the production of NO_3^- would be at its highest therefore decreasing chance for survival and forest regeneration.

Generally there was no difference in total specific net N mineralized from samples of organic horizons incubated at 12°C or higher. However, there were differences in maximum specific rate of net N mineralization and time to reach the maximum rate for organic horizons incubated at different temperatures. This suggests that maximum N mineralization rates are altered by temperature, however the cumulative amount of N that can be mineralized was not. One hypothesis was that the microbial communities established in samples of organic horizons are more adapted to an environment with a temperature of 12°C. Malhi et al (1990) indicated that there was a climatic control over temperature activity relations of denitrification in soils and the optimum temperature for denitrification in Alberta soils was lower than in soils from warmer regions.

On the other hand there was no difference in mean specific net N mineralization as temperature increased (except the 6°C treatment) for samples of Ae horizons. I believe the higher mean specific net rate obtained from samples of Ae horizons incubated at 0°C was due to freeze thaw cycles. It may be possible to obtain the same N mineralization patterns as samples of organic horizons if soil was incubated where freeze thaw cycles did no occur (i.e. incubation at 1°C). The mean specific net N mineralization from samples of Ae horizons incubated at 0 and 6°C may then be significantly less than the samples incubated between 12 and 32°C which were not significantly different. There is evidence that soil temperature increases following disturbances (Meng et al, 1995; Tamm et al, 1974). The microbial community adaptation to lower soil temperatures may be beneficial if with an increase in temperature, an increase in N mineralization does not always occur. Of course the microbial community may adapt to these changes as well, however there is limited knowledge to know how long this would take. Further study of microbial community adaptation in forest soils to changes in temperature and moisture are needed.

If these experiments were to be repeated, it is recommended that both horizons would consist of 17 to 19 replications per treatment. The number of replicates required was determined by [Eq.6.2] (McNabb et al, 1986):

$$n = \left[\frac{t * s}{E} \right]^2 \qquad [6.2]$$

where n is the number of replicates; t is the student's t-value, approximately 2.1 at p = 0.10; s is the mean standard deviation for all treatments per experiment; E is the allowable error from the mean. However this large volume of replication may be difficult to manage and would require firm financial support.

Another component of this research was the calibration of ion exchange membranes (IEM), exchange resin bags (ERB) with 0.01 $CaCl_2$ extraction. Both the IEM and ERB provided an *in situ* measurement of N mineralization rate. Use of IEM in the field were easy and efficient. Extraction and analysis were also less cumbersome than using ERB. However confusion still exists about the use of IEM because it is not clear what type of measurement is taken with the IEM. This confusion applies to the ERB, but because IEM are relatively new products, questions regarding their use have been raised.

The volume of soil sampled using the IEM is a question that many researchers have asked. Does the IEM sample N from the soil it comes into contact with? Results suggest ped size fractions greater than 2 mm may decrease the amount of N predicted by the IEM. Does this imply that IEM sample from an area? Is a diffusion gradient created by the

IEM and N ions from the surrounding soil move toward the IEM, therefore sampling a volume of soil? Do IEM out compete microorganisms for N and retain N ions on the surface of the membrane? The results of this research provided one way to calibrate the IEM to a standard laboratory method and the calculated effective volumes were consistent throughout the experiments completed in Chapter 5. However further analysis and replication of these experiments using IEM should be completed.

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APPENDIX 1.0

1.1a: Vegetation Composition from Upper Slope Position at Lac La Biche

Species scientific name	Species common name
Achillea millefolium	yarrow
Aralia nudicaulis	wild sarsaparilla
Arctostaphylos uva-ursi	common bearberry
Aster ciliolatus	fringed aster
Brachythecium salebrosum	yellow feather moss
Calamagrostis canadensis	grass
Circaea alpina	enchanter's nightshade
Cornus canadensis	bunchberry
Epilobium angustifolia	fireweed
Galium borealis	sweet scented bedstraw
Hylocomium splendens	step-moss
Lathyrus ochroleucus	vetchling
Linnaea borealis	twinflower
Lonicera involucrata	back twinned honesuckle
Petasites palmatus	palmate colt's foot
Picea glauca	white spruce
Pleurozium schreberi	feather moss
Populus tremuloides	trembling aspen
Ptilium crista- castrensis	knight's plume moss
Rosa acicularis	prickly rose
Rosa woodsii	common wild rose
Rubus pubescens	dewberry
Vaccinium myrtilloides	common blueberry
Viburnum edule	low bush cranberry

* Samples were not kept

1.1b: Vegetation Composition from Middle Slope Position Lac La Biche

Species scientific name	Species common name
Cornus canadensis	bunchberry
Galium boreale	northern bedstraw
Hylocomium splendens	step-moss
Ledum groenlandicum	Labrador tea
Linnaea borealis	twin flower
Lonicera involucrata	black twinberry
Parmelia sulcata	waxpaper lichen
Petasites palmatus	palmate colt's foot
Picea glauca	white spruce
Pinus banksiana	jack pine
Pleurozium schreberi	feather moss
Populus balsamifera	balsam poplar
Populus tremuloides	trembling aspen
Ptilium crista- castrensis	knight's plume moss
Rubus pubescens	dewberry
Salix exigua	silver willow
Vaccinium myrtilloides	Canada blueberry
Viburnum edule	low bush cranberry
Viola renifolia	kidney-leaved violet

* Samples were not kept

1.1c: Vegetation Composition from Lower Slope Position Lac La Biche

Species scientific name	Species common name
Alnus crispa	green alder
Arctostaphylos uva-ursi	bear berry
Astragalus americanus	milk vetch
Calamagrostis canadensis	grass
Cladina mitis	reindeer lichen
Cornus stolonifera	red osier dogwood
Epilobium angustifolia	fireweed
Equisetum arvensis	common horsetail
Fragaria virginiana	wild strawberry
Hylocomium splendens	step-moss
Ledum groenlandica	Labrador tea
Lonicera involucrata	back twinned honeysuckle
Peltigera apthosa	studded leather lichen
Petasites palmatus	palmate colt's foot
Petasites vitifolius	vine-leaved coltsfoot
Picea glauca	white spruce
Pinus banksiana	jack pine
Pleurozium schreberi	feather moss
Populus tremuloides	aspen
Ptilium crista- castrensis	knight's plume moss
Ribes lacustre	black gooseberry
Rosa acicularis	prickly rose
Salix barclayi	willow
Salix bebbiana	beaked willow
Vaccinium vitisidaea	bog cranberry

* Samples were not kept

1.1d: Vegetation Composition from Upper Slope Position Whitecourt

Species scientific name	Species common name
Alnus crispa	green alder
Aster ciliolatus	fringed aster
Athyrium filix-femina	lady fern
Calamagrostis canadensis	marsh reed grass
Circaea alpina	small enchanter's nightshade
Cornus canadensis	bunchberry
Dryopteris carthusian	shield fern
Epilobium angustifolium	fireweed
Equisetum arvense	common horsetail
Fragaria vesca	woodland strawberry
Galium triflorum	sweet scented bedstraw
Gymnocarpium dryopteris	oak fern
Heracleum lanatum	cow-parsnip
Lonicera involucrata	black twinberry
Mertensia paniculata	tall bluebells
Petasites palmatus	palmate coltsfoot
Picea glauca	white spruce
Populus basimifera	balsam poplar
Populus tremuloides	trembling aspen
Pyrola asarifolia	common pink wintergreen
Ribes lacustre	black current
Ribes oxyacanthoides	Northern gooseberry
Ribes triste	wild red current
Rosa acicularis	prickly rose
Rosa woodsii	common wild rose
Rubus pubescens	dewberry
Viburnum edule	low-bush cranberry

* Samples were not kept

1.1e: Vegetation Composition from Middle Slope Position Whitecourt

Species scientific name	Species common name
Alnus crispa	green alder
Athyrium filix-femina	lady fern
Betula papyrifera	white birch
Calamagrostis canadensis	marsh reed grass
Cladonia gracilis	slender cup lichen
Cornus canadensis	bunchberry
Dryopteris carthusian	shield fern
Epilobium angustifolium	fireweed
Equisetum arvense	common horsetail
Galium triflorum	sweet scented bedstraw
Gymnocarpium dryopteris	oak fern
Heracleum lanatum	cow-parsnip
Lonicera involucrata	black twinberry
Mertensia paniculata	tall bluebells
Mitella nuda	common mitrewort
Peltegria neopolydactyla	frog pelt lichen
Petasites palmatus	palmate coltsfoot
Picea glauca	white spruce
Populus tremuloides	trembling aspen
Pyrola asarifolia	common pink wintergreen
Ribes lacustre	black current
Ribes triste	wild red current
Rosa acicularis	prickly rose
Rubus idaeus	wild red raspberry
Rubus pubescens	dewberry
Viburnum edule	low-bush cranberry

* Samples were not kept

1.1f: Vegetation Composition from Lower Slope Position Whitecourt

Species scientific name	Species common name
Alnus crispa	green alder
Athyrium filix-femina	lady fern
Calamagrostis canadensis	marsh reed grass
Cornus canadensis	bunchberry
Disporum trachycarpum	fairey bells
Dryopteris carthusian	shield fern
Epilobium angustifolium	fireweed
Equisetum arvense	common horsetail
Fragaria virginiana	wild strawberry
Galium triflorum	sweet scented bedstraw
Gymnocarpium dryopteris	oak fern
Heracleum lanatum	cow-parsnip
Linnaea borealis	twinflower
Lonicera involucrata	black twinberry
Maianthemum canadense	two-leaved solomon's seal
Mertensia paniculata	tall bluebells
Petasites palmatus	palmate coltsfoot
Picea glauca	white spruce
Populus basimifera	balsam poplar
Populus tremuloides	trembling aspen
Pyrola asarifolia	common pink wintergreen
Ribes lacustre	black current
Ribes oxyacanthoides	Northern gooseberry
Ribes triste	wild red current
Rosa acicularis	prickly rose
Viburnum edule	low-bush cranberry

* Samples were not kept

1.2a: Soil Moisture Content

$$\text{Moisture content} = \frac{\text{Mass soil wet}\,(g) - \text{Mass soil dry}\,(g)}{\text{Mass soil dry}\,(g)}$$

where Mw = mass of soil wet; Ms = mass of soil dry

1.2b: Bulk Density

$$\text{Mass wet soil}\,(g) = \text{Mass core w/ soil wet}\,(g) - \text{Mass core}\,(g)$$

$$\text{Volume soil}\,(cm^3) = \pi\, r^2\,(cm^2) * L\,(cm)$$

$$\text{Mass water}\,(g) = \frac{\text{Mass wet soil}\,(g)}{\dfrac{1}{\text{Fraction water}} + 1}$$

$$\text{Mass solids}\,(g) = \text{Mass wet soil}\,(g) - \text{Mass water}\,(g)$$

$$\text{Bulk Density}\left(\frac{g}{cm^3}\right) = \frac{\text{Mass solids}\,(g)}{\text{Volume wet soil}\,(cm^3)}$$

1.3: Particle Size Analysis for Ae Horizons from Alberta and Quebec Sites

Site Name	Estimated Particle Size (µm)	Fraction	% of soil	Soil Texture	Comments
Lac La Biche upper 1	65.16	silt+clay(<50µm)	57.23	Silt Loam	
	47.21	total clay(<2µm)	16.57		
	3.75	total silt(2-50µm)	40.65		
	1.10	total sand(>50µm)	42.77		
upper 2					can not conduct PSA due to lack of sample
upper 3	64.92	silt+clay(<50µm)	64.47	Silt Loam	
	46.24	total clay(<2µm)	18.61		
	3.74	total silt(2-50µm)	45.85		
	1.10	total sand(>50µm)	35.53		
Lac La Biche middle 1	65.16	silt+clay(<50µm)	52.12	Loam	
	47.85	total clay(<2µm)	12.42		
	3.83	total silt(2-50µm)	39.70		
	1.11	total sand(>50µm)	47.88		
middle 2	66.77	silt+clay(<50µm)	50.68	Loam	
	47.85	total clay(<2µm)	12.56		
	3.86	total silt(2-50µm)	38.12		
	1.10	total sand(>50µm)	49.32		
middle 3	67.68	silt+clay(<50µm)	42.24	Sandy Loam	can not repeat due to lack of sample
	48.80	total clay(<2µm)	14.60		
	3.84	total silt(2-50µm)	27.65		
	1.10	total sand(>50µm)	57.76		
Lac La Biche lower 1	66.31	silt+clay(<50µm)	53.57	Loam	
	47.53	total clay(<2µm)	15.20		
	3.83	total silt(2-50µm)	38.37		
	1.10	total sand(>50µm)	46.43		
lower 2	66.77	silt+clay(<50µm)	51.92	Loam	
	47.69	total clay(<2µm)	13.22		
	3.88	total silt(2-50µm)	38.70		
	1.10	total sand(>50µm)	48.08		
lower 3	64.92	silt+clay(<50µm)	52.70	Loam	
	47.53	total clay(<2µm)	10.69		
	4.41	total silt(2-50µm)	42.01		
	1.55	total sand(>50µm)	47.30		

Sample ID	Estimated Particle Size (µm)	Fraction	% of soil	Soil Texture	Comments
Whitecourt upper 1	64.92	silt+clay(<50µm)	54.00	Loam	
	47.37	total clay(<2µm)	10.34		
	4.44	total silt(2-50µm)	43.67		
	1.55	total sand(>50µm)	46.00		
upper 2	65.72	silt+clay(<50µm)	53.33	Loam	
	47.95	total clay(<2µm)	13.80		
	4.37	total silt(2-50µm)	39.53		
	1.44	total sand(>50µm)	46.67		
upper 3	66.66	silt+clay(<50µm)	51.25	Loam	
	48.12	total clay(<2µm)	13.81		
	4.34	total silt(2-50µm)	37.44		
	1.44	total sand(>50µm)	48.75		
Whitecourt middle 1	64.76	silt+clay(<50µm)	65.46	Silt Loam	
	46.47	total clay(<2µm)	11.00		
	4.35	total silt(2-50µm)	54.46		
	1.45	total sand(>50µm)	34.54		
middle 2	64.22	silt+clay(<50µm)	57.42	Silt Loam	
	47.05	total clay(<2µm)	9.65		
	4.48	total silt(2-50µm)	47.77		
	1.55	total sand(>50µm)	42.58		
middle 3	63.74	silt+clay(<50µm)	56.76	Silt Loam	
	47.21	total clay(<2µm)	8.90		
	4.50	total silt(2-50µm)	47.86		
	1.56	total sand(>50µm)	43.24		
lower 1	67.00	silt+clay(<50µm)	45.54	Sandy Loam	
	48.17	total clay(<2µm)	9.97		
	4.52	total silt(2-50µm)	35.58		
	1.56	total sand(>50µm)	54.46		
lower 2	59.76	silt+clay(<50µm)	36.62	Sandy Loam	
	49.11	total clay(<2µm)	4.64		
	4.57	total silt(2-50µm)	31.98		
	1.58	total sand(>50µm)	63.38		
lower 3					can not conduct due to lack of sample

Sample ID	Estimated Particle Size (µm)	Fraction	% of soil	Soil Texture	Comments
Lac Spencer 1	65.72	silt+clay(<50µm)	47.64	Loam	
	48.76	total clay(<2µm)	10.10		
	3.48	total silt(2-50µm)	37.53		
	1.43	total sand(>50µm)	52.36		
2	65.24	silt+clay(<50µm)	53.68	Loam	
	48.12	total clay(<2µm)	8.36		
	3.49	total silt(2-50µm)	45.32		
	1.44	total sand(>50µm)	46.32		
3	67.35	silt+clay(<50µm)	46.75	Loam	
	48.76	total clay(<2µm)	10.11		
	3.51	total silt(2-50µm)	36.64		
	1.43	total sand(>50µm)	53.25		
Nicabau 1	63.30	silt+clay(<50µm)	68.81	Silt Loam	
	46.47	total clay(<2µm)	10.44		
	3.47	total silt(2-50µm)	58.37		
	1.44	total sand(>50µm)	31.19		
2	65.95	silt+clay(<50µm)	53.10	Loam	a replicate of this sample will be processed
	48.12	total clay(<2µm)	10.27		
	3.51	total silt(2-50µm)	42.83		
	1.44	total sand(>50µm)	46.90		
3	63.79	silt+clay(<50µm)	68.08	Silt Loam	
	46.47	total clay(<2µm)	5.27		
	3.53	total silt(2-50µm)	62.81		
	1.46	total sand(>50µm)	31.92		

APPENDIX 2.0

2.1a: Mineral N (μg N g^{-1} soil, μg N g^{-1} N) Calculations

$$\frac{\mu g\ N}{g\ soil} = \frac{Mineral\ N\left(\frac{\mu g}{ml}\right) * Diluted\ volume\ (ml)}{Mass\ soil\ (g)}$$

$$\frac{\mu g\ N}{g\ N} = \frac{Mineral\ N\left(\frac{\mu g\ N}{g\ soil}\right)}{Total\ N\left(\frac{g\ N}{g\ soil}\right)}$$

Example: Day 141 NO_3^- values from LLB middle 3 organic horizon (see Appendix 2.1b)

$$\frac{108.04\ \frac{\mu g\ NO_3^- - N}{ml} * 60\ ml}{156.65 g} = 41.381\ \frac{\mu g\ NO_3^- - N}{g\ soil}$$

$$\frac{41.381\ \frac{\mu g\ NO_3^- - N}{g\ soil}}{0.014\ \frac{g\ N}{g\ soil}} = 2985.635\ \frac{\mu g\ NO_3^- - N}{g\ N}$$

$$2985.635 \frac{\mu g\ NO_3^- - N}{g\ N} * \frac{1\ mg}{1000\ \mu g} = 2.99\ \frac{mg\ NO_3^- - N}{g\ N}$$

2.2a: Parameters for the Gompertz equation (N_o, k, h) from samples of organic horizons from Lac La Biche and Whitecourt

	Lac La Biche			Whitecourt		
	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
Upper	44	0.014	0.158	52	0.005	0.889
Middle	37	0.014	0.157	48	0.009	0.291
Lower	28	0.013	0.147	19	0.007	0.308

2.2b: Parameters for the Gompertz equation (N_o, k, h) from samples of Ae horizons from Lac La Biche and Whitecourt

	Lac La Biche			Whitecourt		
	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
Upper	32	0.014	0.199	22	0.006	0.519
Middle	36	0.013	0.255	26	0.005	0.099
Lower	43	0.017	0.174	19	0.025	0.004

2.3: Mineral N ($\mu g\ ml^{-1}$) values for all extraction days for samples of organic and Ae horizons from three slope positions

LLB = Lac La Biche
WC = Whitecourt

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil) Organic	Total N (g N/g soil) Ae	Day 0 Mineral N (ug/ml) NO3- Organic	Day 0 NO3- Ae	Day 0 NH4+ Organic	Day 0 NH4+ Ae
LLB upper 1	168.92	101.79	0.013	0.001	0.00	0.00	0.00	0.00
LLB upper 2	139.14	39.97	0.007	0.001	0.00	0.00	0.00	0.25
LLB upper 3	136.75	100.68	0.007	0.001	0.00	0.00	0.00	0.11
LLB middle 1	107.90	102.54	0.008	0.001	0.04	0.00	0.00	0.00
LLB middle 2	128.02	103.05	0.008	0.000	0.09	0.00	0.00	0.06
LLB middle 3	156.65	84.86	0.014	0.001	0.00	0.00	0.00	0.03
LLB lower 1	115.94	70.43	0.007	0.001	0.26	0.00	0.00	0.02
LLB lower 2	115.83	*	0.013	0.000	0.07	*	0.00	*
LLB lower 3	242.49	95.69	0.015	0.002	0.00	0.02	0.00	0.01
WC upper 1	157.33	101.52	0.026	0.003	0.45	0.00	0.00	0.63
WC upper 2	110.81	103.04	0.027	0.004	0.05	0.00	0.00	0.42
WC upper 3	197.54	102.28	0.020	0.002	0.15	0.00	0.00	0.26
WC middle 1	163.04	69.45	0.025	0.002	5.57	0.03	0.66	1.51
WC middle 2	119.52	103.32	0.019	0.002	0.26	0.00	0.00	0.10
WC middle 3	104.85	90.73	0.025	0.001	0.00	0.00	0.00	0.27
WC lower 1	149.59	58.45	0.015	0.002	0.11	0.00	0.11	0.48
WC lower 2	164.06	102.51	0.016	0.003	0.07	0.00	0.00	0.55
WC lower 3	132.51	42.73	0.016	0.001	0.15	0.00	0.11	0.48

Sample	Day 6 Mineral N (ug/ml) NO3- Organic	Day 6 NO3- Ae	Day 6 NH4+ Organic	Day 6 NH4+ Ae	Day 13 Mineral N (ug/ml) NO3- Organic	Day 13 NO3- Ae	Day 13 NH4+ Organic	Day 13 NH4+ Ae
LLB upper 1	0.09	0.00	0.51	1.07	0.00	0.00	1.07	0.90
LLB upper 2	0.04	0.00	0.28	0.30	0.00	0.00	0.89	0.53
LLB upper 3	0.11	0.00	0.07	0.05	0.00	0.00	0.41	0.23
LLB middle 1	0.61	0.00	2.11	0.02	0.00	0.00	7.04	0.08
LLB middle 2	0.10	0.00	0.52	0.08	0.00	0.00	1.77	0.31
LLB middle 3	0.39	0.00	0.85	0.16	0.00	0.00	0.86	0.47
LLB lower 1	0.34	0.00	1.75	0.00	0.00	0.00	1.34	0.05
LLB lower 2	0.12	*	0.31	*	0.00	*	0.62	*
LLB lower 3	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.10
WC upper 1	0.00	0.00	0.59	1.22	0.00	0.00	4.25	1.92
WC upper 2	0.01	0.00	0.55	1.32	0.00	0.00	4.06	1.89
WC upper 3	0.00	0.00	0.88	0.86	0.00	0.00	2.87	1.11
WC middle 1	22.95	0.00	6.40	1.31	33.26	0.00	14.74	1.06
WC middle 2	0.38	0.00	0.24	0.37	0.62	0.00	2.86	0.52
WC middle 3	0.05	0.00	0.43	0.59	0.96	0.00	1.56	0.60
WC lower 1	0.06	0.00	2.93	0.91	0.23	0.00	7.38	0.91
WC lower 2	0.05	0.00	1.10	0.52	0.94	0.00	6.04	1.05
WC lower 3	0.14	0.00	2.42	0.84	1.58	0.00	8.76	0.84

	Day 27 Mineral N (ug/ml)				Day 42 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	0.00	0.70	3.15	1.08	0.00	5.05	7.15	1.61
LLB upper 2	0.00	0.04	4.96	1.62	1.41	0.29	14.83	4.96
LLB upper 3	0.00	0.03	2.15	0.70	0.00	0.00	6.45	0.66
LLB middle 1	0.00	0.32	20.31	0.75	0.00	0.00	33.88	1.24
LLB middle 2	0.00	0.00	9.30	1.19	0.00	0.00	22.61	1.86
LLB middle 3	0.00	0.00	10.58	1.79	0.00	0.00	61.71	3.35
LLB lower 1	0.00	0.00	0.95	0.38	0.00	0.00	2.40	0.90
LLB lower 2	0.00	*	2.88	*	6.42	*	7.38	*
LLB lower 3	0.00	0.33	0.24	0.06	5.49	0.00	0.28	0.00
WC upper 1	3.44	0.00	17.19	5.19	17.51	0.00	36.75	8.70
WC upper 2	5.65	0.00	10.33	4.50	71.04	0.00	19.33	5.77
WC upper 3	12.32	0.00	7.40	2.11	61.54	0.00	11.22	2.78
WC middle 1	92.32	0.61	8.21	2.03	221.94	0.00	5.86	2.46
WC middle 2	6.56	0.00	11.29	2.23	33.32	0.00	25.06	4.52
WC middle 3	18.54	0.00	2.02	1.46	46.57	0.08	1.88	1.99
WC lower 1	16.49	0.00	10.61	2.58	70.82	0.22	3.56	2.53
WC lower 2	13.35	0.00	12.26	2.51	58.03	0.64	16.71	4.43
WC lower 3	17.53	0.00	18.83	1.82	31.35	0.06	26.59	4.14

	Day 56 Mineral N (ug/ml)				Day 71 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	1.91	1.24	12.66	1.89	49.93	0.93	17.62	7.75
LLB upper 2	9.18	0.00	14.53	3.28	58.47	0.27	14.80	3.65
LLB upper 3	0.16	0.00	11.71	1.25	11.18	0.20	32.35	2.29
LLB middle 1	0.00	0.00	32.00	1.62	7.36	0.22	41.27	2.50
LLB middle 2	0.00	0.00	28.38	2.08	4.58	0.00	39.54	2.54
LLB middle 3	0.00	0.00	59.73	3.84	0.46	0.30	82.35	3.41
LLB lower 1	0.00	0.00	5.74	1.41	0.07	0.00	12.65	1.27
LLB lower 2	35.07	*	6.14	*	104.92	*	3.63	*
LLB lower 3	21.28	0.40	0.06	0.00	58.11	2.38	0.52	0.00
WC upper 1	104.20	0.00	55.77	11.21	227.58	0.17	31.86	11.57
WC upper 2	115.36	0.00	5.09	6.85	207.62	0.17	2.04	7.98
WC upper 3	116.38	0.00	10.02	3.73	219.65	0.21	3.35	4.62
WC middle 1	167.87	0.00	11.23	2.96	234.63	1.01	3.47	2.68
WC middle 2	103.39	0.00	46.98	5.52	221.44	0.10	16.88	6.84
WC middle 3	117.63	0.00	0.10	1.60	168.36	0.10	0.29	1.02
WC lower 1	115.83	0.00	1.17	3.54	211.98	0.18	0.80	3.50
WC lower 2	133.72	0.00	31.26	3.92	213.81	0.00	3.21	3.84
WC lower 3	106.55	0.00	34.03	2.56	220.42	0.05	12.32	2.19

	Day 85 Mineral N (ug/ml)				Day 99 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	133.78	4.74	0.27	5.69	129.30	7.03	2.93	6.78
LLB upper 2	103.44	2.56	7.54	3.01	102.93	0.00	6.78	3.36
LLB upper 3	95.82	0.70	39.16	2.63	158.57	0.00	13.70	4.36
LLB middle 1	52.86	0.32	42.85	3.65	81.94	0.00	22.16	3.86
LLB middle 2	23.00	0.06	34.16	2.80	41.42	0.00	27.59	4.04
LLB middle 3	1.08	0.34	98.59	7.40	3.69	0.00	69.05	5.57
LLB lower 1	0.02	0.08	33.03	2.14	0.00	0.00	40.97	2.91
LLB lower 2	143.28	*	3.26	*	126.82	*	2.39	*
LLB lower 3	85.57	2.23	0.98	0.13	61.91	0.00	1.03	1.44
WC upper 1	207.19	0.15	19.31	12.71	240.36	0.00	7.93	10.78
WC upper 2	167.74	2.15	1.48	11.38	148.51	0.00	2.50	9.99
WC upper 3	232.18	0.13	3.88	4.44	312.24	0.00	6.92	5.94
WC middle 1	233.25	1.81	3.38	3.13	266.70	0.00	3.97	3.63
WC middle 2	213.82	0.11	8.19	7.99	6.63	0.00	11.62	9.44
WC middle 3	209.96	0.13	0.34	2.02	120.80	0.00	1.45	3.07
WC lower 1	216.25	0.26	0.59	4.23	173.62	0.00	1.72	4.72
WC lower 2	227.90	0.00	1.81	4.74	216.94	0.00	4.69	5.65
WC lower 3	208.63	0.18	2.99	3.54	244.46	0.00	4.85	3.93

	Day 113 Mineral N (ug/ml)				Day 127 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	105.56	0.00	0.66	3.42	42.77	0.00	0.22	2.74
LLB upper 2	83.83	0.00	2.47	0.72	63.77	0.00	0.71	0.44
LLB upper 3	95.76	0.00	1.12	2.46	48.31	0.00	0.73	2.83
LLB middle 1	62.09	0.00	8.63	4.82	22.07	0.00	5.24	4.57
LLB middle 2	34.89	0.00	16.42	1.45	32.32	0.00	14.71	0.92
LLB middle 3	17.33	0.00	38.66	4.92	44.27	0.00	24.58	4.30
LLB lower 1	1.04	0.00	36.06	1.32	0.83	0.00	35.65	1.24
LLB lower 2	124.78	*	3.63	*	48.05	*	0.86	*
LLB lower 3	75.75	0.00	0.54	0.13	51.38	0.00	0.01	0.36
WC upper 1	278.59	0.00	6.15	8.05	134.87	0.00	2.82	3.37
WC upper 2	151.60	0.00	1.30	7.79	78.14	0.00	0.91	7.21
WC upper 3	304.37	0.00	3.24	3.60	163.16	0.00	1.78	3.41
WC middle 1	198.86	0.00	2.89	1.62	128.23	0.00	1.89	1.27
WC middle 2	229.42	0.00	4.00	4.89	88.96	0.00	1.86	3.82
WC middle 3	104.90	0.00	0.82	0.99	94.46	0.00	0.15	1.24
WC lower 1	128.21	0.00	0.97	2.30	77.76	0.00	0.32	1.93
WC lower 2	195.66	0.00	1.92	3.26	97.41	0.00	1.44	3.70
WC lower 3	210.80	0.00	2.78	2.99	112.20	0.00	1.27	2.26

	Day 141 Mineral N (ug/ml)				Day 155 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	91.95	0.00	0.00	2.78	81.17	1.50	0.87	1.70
LLB upper 2	109.05	0.00	0.00	0.52	51.86	1.55	1.32	0.13
LLB upper 3	**	0.00	0.00	0.87	55.00	0.00	0.83	0.71
LLB middle 1	103.16	0.00	3.10	4.67	53.31	0.00	1.76	2.68
LLB middle 2	48.97	0.00	13.91	1.56	43.12	0.00	9.65	1.55
LLB middle 3	108.04	0.00	5.67	3.19	81.62	0.00	1.32	4.21
LLB lower 1	4.21	0.00	28.17	0.89	1.99	0.00	23.34	1.91
LLB lower 2	88.12	*	0.36	*	58.64	*	1.52	*
LLB lower 3	90.20	0.00	2.43	0.25	54.29	1.16	0.89	0.00
WC upper 1	225.21	0.00	5.37	3.03	155.41	0.00	3.22	1.86
WC upper 2	138.22	0.00	1.24	6.28	86.35	0.00	1.45	9.49
WC upper 3	205.19	0.00	2.07	3.89	193.97	0.00	1.42	3.19
WC middle 1	164.61	0.00	1.40	1.13	140.31	1.45	2.33	0.84
WC middle 2	155.98	0.00	1.87	4.16	161.40	0.00	2.08	5.58
WC middle 3	103.56	0.00	0.00	1.12	138.47	0.00	0.40	1.67
WC lower 1	90.54	0.00	0.00	0.97	74.79	2.07	0.19	2.00
WC lower 2	128.09	0.00	0.12	4.85	97.45	0.00	1.51	4.57
WC lower 3	137.91	0.00	0.01	0.03	135.29	0.00	1.13	0.29

	Day 169 Mineral N (ug/ml)				Day 184 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	51.34	0.56	0.46	0.13	76.59	1.83	0.70	0.57
LLB upper 2	40.58	1.22	0.77	0.11	53.06	0.94	0.51	0.07
LLB upper 3	41.97	0.00	0.79	1.08	42.22	0.00	0.65	0.72
LLB middle 1	31.43	0.00	1.39	1.72	32.00	0.00	1.32	1.52
LLB middle 2	25.25	0.00	5.27	1.11	32.62	0.00	4.02	1.22
LLB middle 3	53.25	0.00	1.04	2.83	63.13	0.00	0.77	2.81
LLB lower 1	0.64	0.00	17.34	1.28	0.94	0.00	15.27	0.57
LLB lower 2	65.67	*	1.60	*	31.87	*	0.91	*
LLB lower 3	39.11	1.13	0.52	0.02	46.11	0.53	0.27	0.02
WC upper 1	0.00	0.00	2.32	0.95	113.01	0.00	2.59	1.54
WC upper 2	4.32	0.00	1.29	7.41	67.77	0.00	0.89	5.60
WC upper 3	5.79	0.00	1.52	3.81	113.60	0.00	1.03	3.69
WC middle 1	0.00	5.11	1.31	0.77	59.39	4.98	1.74	0.05
WC middle 2	0.00	0.25	2.00	5.03	88.10	0.25	1.16	4.37
WC middle 3	0.00	0.00	0.49	1.78	86.00	0.00	0.57	3.19
WC lower 1	51.08	3.10	0.63	0.45	44.54	1.99	0.66	0.05
WC lower 2	68.96	0.00	1.19	2.50	61.90	0.00	1.19	3.05
WC lower 3	70.07	0.00	1.34	2.02	72.13	0.00	1.14	0.88

	Day 198 Mineral N (ug/ml)				Day 212 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB upper 1	65.26	2.03	0.47	0.69	58.67	2.68	0.46	0.49
LLB upper 2	45.65	1.09	0.22	0.21	49.71	1.84	0.42	0.14
LLB upper 3	49.02	0.08	0.68	2.75	45.35	0.41	0.66	1.86
LLB middle 1	34.45	0.04	1.61	2.82	30.72	0.02	1.63	1.38
LLB middle 2	34.71	0.02	3.12	2.17	30.78	0.40	2.57	1.84
LLB middle 3	110.91	0.24	1.77	4.41	63.02	0.71	1.33	5.52
LLB lower 1	12.98	0.05	39.61	1.59	13.14	0.42	32.31	0.50
LLB lower 2	63.62	*	0.49	*	52.14	*	0.00	*
LLB lower 3	55.97	0.79	0.07	0.32	47.01	0.58	0.15	0.00
WC upper 1	175.24	0.09	2.49	5.64	63.56	0.56	2.97	10.70
WC upper 2	76.27	0.20	1.00	9.64	83.90	0.16	1.07	6.79
WC upper 3	160.46	0.52	1.04	5.08	52.01	0.96	1.42	4.03
WC middle 1	79.10	5.02	0.97	0.03	68.46	2.84	0.96	0.01
WC middle 2	135.77	0.75	1.68	6.38	36.86	1.83	1.70	5.71
WC middle 3	123.37	0.40	0.63	4.59	74.34	0.64	0.56	1.43
WC lower 1	58.73	1.86	0.77	1.04	57.54	10.34	0.44	0.11
WC lower 2	82.06	0.27	0.70	4.50	95.20	0.86	1.57	4.65
WC lower 3	79.44	0.23	1.27	1.86	61.54	0.87	1.05	3.17

	Day 241 Mineral N (ug/ml)			
	NO3-		NH4+	
Sample	Organic	Ae	Organic	Ae
LLB upper 1	74.96	3.39	0.01	1.59
LLB upper 2	56.68	2.30	0.33	0.67
LLB upper 3	54.07	0.68	0.23	3.49
LLB middle 1	20.25	0.45	1.27	3.44
LLB middle 2	49.49	0.47	3.44	2.60
LLB middle 3	52.58	1.06	0.56	6.66
LLB lower 1	10.70	1.42	24.50	1.84
LLB lower 2	90.43	*	0.45	*
LLB lower 3	68.61	1.00	0.12	0.09
WC upper 1	154.93	0.42	2.57	8.52
WC upper 2	53.52	0.11	0.66	6.40
WC upper 3	95.62	4.14	1.30	4.25
WC middle 1	46.07	6.02	0.77	0.08
WC middle 2	91.68	11.01	1.89	3.53
WC middle 3	79.58	3.83	0.07	8.15
WC lower 1	9.74	2.86	0.15	0.52
WC lower 2	54.67	1.56	0.98	6.28
WC lower 3	39.34	0.93	2.33	2.73

APPENDIX 3.0

3.1a: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Lac La Biche at five different temperatures

Temp.	Organic Horizon			Ae Horizon		
°C	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	9	0.007	0.211	71	0.006	0.229
6	19	0.016	0.028	17	0.019	0.003
12	23	0.038	0.0002	75	0.006	0.601
22	35	0.011	0.123	50	0.024	0.007
32	42	0.012	0.105	78	0.005	0.696

3.1b: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Whitecourt at five different temperatures

Temp.	Organic Horizon			Ae Horizon		
°C	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	6	0.019	0.014	44	0.007	0.374
6	16	0.010	0.139	15	0.009	0.781
12	29	0.013	0.058	52	0.003	1.030
22	32	0.006	0.654	41	0.019	0.016
32	39	0.011	0.090	40	0.006	0.835

3.1c: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Lac Spencer at five different temperatures

Temp.	Organic Horizon			Ae Horizon		
°C	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	16	0.009	0.213	75	0.008	0.306
6	11	0.012	0.120	20	0.008	0.691
12	28	0.013	0.072	73	0.006	0.609
22	34	0.006	0.594	82	0.009	0.306
32				67	0.005	0.818

3.1d: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Nicabau at five different temperatures

Temp.	Organic Horizon			Ae Horizon		
°C	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	6	0.008	0.206	69	0.009	0.211
6	1	0.017	0.017	16	0.012	0.448
12	16	0.029	0.002	64	0.005	0.932
22	12	0.014	0.066	49	0.012	0.144
32	28	0.013	0.114	52	0.003	1.042

3.2a: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Lac La Biche at four different moisture tensions

Moisture	Organic Horizon			Ae Horizon		
(kPa)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	14	0.007	0.946	44	0.041	0.219
20	23	0.013	0.151	84	0.016	0.087
33	16	0.011	0.154	78	0.012	0.197
60	23	0.011	0.133	94	0.010	0.190

3.2b: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Whitecourt at four different moisture tensions

Moisture	Organic Horizon			Ae Horizon		
(kPa)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	11	0.025	0.282	87	0.001	2.179
20	30	0.006	0.845	91	0.005	0.997
33	46	0.009	0.008	70	0.006	0.720
60	36	0.007	0.590	45	0.011	0.323

3.2c: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Lac Spencer at four different moisture tensions

Moisture	Organic Horizon			Ae Horizon		
(kPa)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	157	0.008	0.017	34	0.0002	24.67
20	24	0.007	0.348	22	0.10	0.039
33	89	0.001	0.868	20	0.006	0.938
60	278	0.006	0.051	15	0.006	0.924

3.2d: Parameters for the Gompertz equation (N_o, k, h) from samples of organic and Ae horizons from Nicabau at four different moisture tensions

Moisture	Organic Horizon			Ae Horizon		
(kPa)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)	N_o (mg N g^{-1} soil N)	k (d^{-1})	h (unitless)
0	4	0.070	0.004	25	0.103	0.027
20	16	0.011	0.115	48	0.190	0.008
33	15	0.008	0.147	95	0.003	0.430
60	9	0.007	0.279	40	0.001	6.360

3.3: *Mineral N ($\mu g\ ml^{-1}$) values for all extraction days for samples of organic and Ae horizons incubated at 5 different temperatures*

3.3a: Temperature 0°C

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB middle 1	115.14	41.73	0.008	0.001	0.02	0.00	2.46	0.31
LLB middle 2	164.54	64.63	0.008	0.000	0.00	0.00	9.13	0.59
LLB middle 3	152.06	31.30	0.014	0.001	0.02	0.00	1.29	0.86
WC middle 1	160.36	25.10	0.025	0.002	12.22	0.11	16.55	2.15
WC middle 2	113.06	38.75	0.019	0.002	0.66	0.05	5.40	0.76
WC middle 3	71.71	33.13	0.025	0.001	0.56	0.00	9.03	0.44
Lac Spencer 1	54.95	33.68	0.012	0.001	0.19	0.00	7.06	0.58
Lac Spencer 2	68.00	63.64	0.014	0.001	0.14	0.00	6.19	2.92
Lac Spencer 3	50.16	63.57	0.013	0.001	0.00	0.00	1.50	0.99
Nicabau 1	63.26	64.01	0.014	0.001	0.00	0.00	0.48	0.16
Nicabau 2	70.13	64.60	0.009	0.001	0.00	0.00	0.52	0.15
Nicabau 3	121.57	63.76	0.008	0.000	0.00	0.00	2.89	0.88

Sample	Day 15 Mineral N (ug/ml)				Day 29 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	1.67	0.81	0.00	0.75	2.73	0.51
LLB middle 2	0.00	0.00	4.80	0.84	0.00	0.00	9.30	1.26
LLB middle 3	0.00	0.00	0.82	1.09	0.00	0.00	2.24	1.22
WC middle 1	9.52	0.00	11.98	1.97	4.54	0.00	12.94	2.16
WC middle 2	0.00	0.00	1.78	1.31	0.00	0.00	2.27	1.53
WC middle 3	0.00	0.00	2.01	1.01	0.00	0.00	4.87	1.48
Lac Spencer 1	0.00	0.00	4.60	2.02	0.00	0.00	5.66	3.99
Lac Spencer 2	0.00	0.00	2.90	2.49	0.36	0.00	7.89	2.01
Lac Spencer 3	0.00	0.00	2.20	2.18	0.00	0.00	2.12	2.32
Nicabau 1	0.00	0.00	0.20	0.91	0.00	0.00	0.14	1.51
Nicabau 2	0.00	0.00	0.39	1.15	0.00	0.00	0.99	1.99
Nicabau 3	0.00	0.00	2.09	1.46	0.00	0.00	3.59	1.66

Sample	Day 43 Mineral N (ug/ml)				Day 57 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.59	0.00	2.95	1.33	0.00	0.00	3.83	0.63
LLB middle 2	0.13	0.00	6.34	0.98	0.00	0.00	7.51	0.76
LLB middle 3	0.05	0.00	1.33	0.67	0.00	0.00	1.96	0.56
WC middle 1	5.64	0.00	10.74	1.53	5.12	0.00	13.59	1.17
WC middle 2	0.37	0.00	4.67	1.42	0.20	0.00	6.86	1.03
WC middle 3	0.01	0.00	4.85	0.93		0.00		0.46
Lac Spencer 1	0.10	0.00	2.92	2.10	0.00	0.00	4.51	2.39
Lac Spencer 2	0.67	0.00	6.38	1.77	0.00	0.00	5.11	1.69
Lac Spencer 3	0.05	0.00	4.60	2.09	0.00	0.00	4.10	2.05
Nicabau 1	0.07	0.00	0.09	1.41	0.00	0.00	0.52	1.07
Nicabau 2	0.01	0.00	0.74	1.54	0.00	0.00	0.97	1.66
Nicabau 3	0.00	0.00	3.65	1.18	0.00	0.00	5.89	1.74

Sample	Day 71 Mineral N (ug/ml)				Day 85 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	2.74	1.62	**	0.00	**	1.94
LLB middle 2	0.00	0.00	6.16	1.63	**	0.00	**	1.56
LLB middle 3	0.00	0.00	1.52	0.61	**	0.00	**	1.79
WC middle 1	4.56	0.00	14.17	2.33	**	0.00	**	2.28
WC middle 2	0.02	0.00	6.21	1.67	**	0.00	**	1.56
WC middle 3	0.00	0.00	3.61	1.62	**	0.00	**	1.70
Lac Spencer 1	0.00	0.00	3.53	2.57	**	0.00	**	2.57
Lac Spencer 2	0.00	0.00	5.38	1.60	**	0.00	**	1.54
Lac Spencer 3	0.00	0.00	4.23	2.25	**	0.00	**	1.79
Nicabau 1	0.00	0.00	0.17	1.81	**	0.00	**	1.85
Nicabau 2	0.00	0.00	0.82	0.77	**	0.00	**	1.44
Nicabau 3	0.00	0.00	5.10	2.20	**	0.00	**	1.53

Sample	Day 99 Mineral N (ug/ml)				Day 113 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	3.30	1.30	0.12	0.01	7.28	1.91
LLB middle 2	0.00	0.00	7.69	0.79	0.02	0.01	11.45	1.67
LLB middle 3	0.00	0.01	1.31	1.48	0.04	0.03	2.61	2.23
WC middle 1	3.90	0.00	14.94	2.60	2.41	0.03	9.23	3.03
WC middle 2	0.17	0.00	7.34	1.45	0.13	0.02	10.47	1.54
WC middle 3	0.05	0.00	3.63	1.36	0.11	0.02	4.58	1.92
Lac Spencer 1	0.04	0.00	3.31	2.44	0.19	0.03	9.02	3.36
Lac Spencer 2	0.04	0.00	6.05	0.19	0.06	0.05	6.90	5.99
Lac Spencer 3	0.02	0.00	3.65	2.28	0.00	0.03	4.30	4.74
Nicabau 1	0.02	0.00	0.31	1.68	0.00	0.02	0.64	1.79
Nicabau 2	0.00	0.00	1.14	2.85	0.00	0.02	2.67	2.10
Nicabau 3	0.00	0.00	7.32	1.70	0.00	0.01	9.27	1.70

Sample	Day 127 Mineral N (ug/ml)				Day 141 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.15	0.17	6.29	1.75	0.42	0.37	8.92	2.11
LLB middle 2	0.31	0.02	12.14	1.48	0.50	0.00	13.43	2.09
LLB middle 3	0.17	0.24	2.82	2.01	0.39	0.24	4.97	2.54
WC middle 1	5.85	0.21	16.35	2.13	13.24	0.37	24.49	1.88
WC middle 2	0.53	0.02	12.97	1.77	0.68	0.39	18.65	2.60
WC middle 3	0.28	0.25	4.85	2.49	1.28	0.42	7.23	3.07
Lac Spencer 1	0.30	0.22	10.31	3.54	3.50	0.28	79.44	3.69
Lac Spencer 2	0.35	0.24	9.14	2.75	2.83	0.22	62.70	3.47
Lac Spencer 3	0.27	0.22	4.36	2.92	2.29	0.35	33.34	4.00
Nicabau 1	0.20	0.18	0.37	3.07	0.42	0.32	0.55	4.49
Nicabau 2	0.19	0.18	2.68	1.71	0.48	0.39	3.12	4.18
Nicabau 3	0.51	0.14	8.93	1.61	0.46	0.70	16.16	2.70

Sample	Day 170 Mineral N (ug/ml)				Day 199 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.32	0.03	9.53	1.59	0.00	0.00	11.35	1.95
LLB middle 2	0.04	0.04	13.23	0.91	0.00	0.00	18.25	2.18
LLB middle 3	0.05	0.06	5.64	2.31	0.02	0.02	5.27	3.16
WC middle 1	11.04	0.16	10.05	1.36	26.07	0.03	6.42	1.97
WC middle 2	0.36	0.13	17.19	1.92	0.73	0.00	15.61	2.01
WC middle 3	0.50	0.06	6.14	1.46	0.18	0.02	8.10	2.25
Lac Spencer 1	0.16	0.02	6.67	2.13	0.22	0.00	12.36	4.99
Lac Spencer 2	0.08	0.11	7.86	3.12	0.16	0.00	10.45	4.95
Lac Spencer 3	0.06	0.05	8.76	6.81	0.00	0.00	4.62	5.10
Nicabau 1	0.01	0.05	0.44	5.04	0.00	0.00	0.62	4.42
Nicabau 2	0.16	0.03	4.77	1.81	0.06	0.01	2.36	4.04
Nicabau 3	0.13	0.04	15.98	2.00	0.01	0.01	10.06	3.69

Sample	Day 228 Mineral N (ug/ml)				Day 257 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.24	0.06	18.93	3.79	0.03	0.00	8.55	1.72
LLB middle 2	0.32	0.01	16.01	2.41	0.01	0.02	16.66	1.61
LLB middle 3	0.29	0.41	16.14	6.61	0.00	0.01	6.34	1.05
WC middle 1	431.93	0.29	4.55	5.78	29.86	0.02	1.38	1.18
WC middle 2	2.02	0.00	45.62	2.64	1.34	0.01	18.76	1.00
WC middle 3	0.34	0.50	17.52	5.24	0.18	0.15	4.65	1.03
Lac Spencer 1	1.33	0.42	33.93	4.09	0.45	0.01	15.16	1.25
Lac Spencer 2	0.27	0.36	22.19	5.63	0.11	0.02	11.32	1.33
Lac Spencer 3	0.18	0.75	13.10	12.67	0.00	0.02	4.80	0.80
Nicabau 1	0.00	0.80	1.30	5.74	0.01	0.04	1.39	1.81
Nicabau 2	0.11	0.45	6.18	5.30	0.01	0.06	3.65	1.54
Nicabau 3	0.09	0.40	22.75	5.76	0.04	0.02	11.27	0.97

Sample	Day 285 Mineral N (ug/ml)				Day 313 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.10	6.35	1.40	0.59	0.27	14.80	1.28
LLB middle 2	0.07	0.03	13.89	1.68	0.58	0.04	20.24	1.86
LLB middle 3	0.00	0.03	5.88	1.55	0.65	0.04	10.56	0.98
WC middle 1	19.93	0.03	0.80	1.42	45.84	0.05	2.07	0.81
WC middle 2	1.26	0.03	18.09	1.38	4.41	0.01	25.51	1.47
WC middle 3	0.16	0.03	6.80	1.65	0.82	0.03	10.18	2.63
Lac Spencer 1	0.05	0.03	11.76	1.92	0.19	0.02	13.00	2.03
Lac Spencer 2	0.01	0.04	7.40	1.83	0.16	0.11	15.15	2.35
Lac Spencer 3	0.00	0.04	3.40	3.43	0.11	0.09	6.69	2.65
Nicabau 1	0.00	0.03	1.02	1.98	0.18	0.05	3.09	2.79
Nicabau 2	0.00	0.02	2.05	1.41	0.10	0.01	3.98	1.90
Nicabau 3	0.00	0.03	3.47	1.11	0.48	0.03	16.40	2.43

** lost sample

LLB = Lac La Biche
WC = Whitecourt

3.3b: Temperature 6°C

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB middle 1	63.95	50.97	0.008	0.001	0.03	0.00	3.36	0.33
LLB middle 2	158.60	64.16	0.008	0.000	0.00	0.00	0.98	0.52
LLB middle 3	119.01	30.73	0.014	0.001	0.11	0.01	2.84	0.92
WC middle 1	153.97	25.34	0.025	0.002	6.46	0.11	6.30	1.88
WC middle 2	114.21	38.70	0.019	0.002	0.13	0.03	6.49	0.64
WC middle 3	84.63	32.29	0.025	0.001	0.54	0.00	9.71	1.33
Lac Spencer 1	*	32.90	0.012	0.001	*	0.00	*	0.61
Lac Spencer 2	53.19	63.36	0.014	0.001	0.00	0.00	0.37	2.39
Lac Spencer 3	55.90	64.11	0.013	0.001	0.00	0.00	0.96	1.74
Nicabau 1	83.05	63.99	0.014	0.001	0.05	0.00	0.26	0.18
Nicabau 2	138.73	63.39	0.009	0.001	0.00	0.00	0.17	0.19
Nicabau 3	*	63.85	0.008	0.000	*	0.00	*	0.81

Sample	Day 15 Mineral N (ug/ml)				Day 29 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.03	2.10	0.11	0.00	0.00	2.52	0.20
LLB middle 2	0.00	0.06	3.91	0.30	0.00	0.00	10.02	0.29
LLB middle 3	0.00	0.14	0.11	0.54	0.00	0.00	0.43	0.57
WC middle 1	16.86	0.21	30.46	0.68	7.84	0.00	22.03	1.54
WC middle 2	0.00	0.23	5.92	0.43	0.33	0.00	12.72	0.42
WC middle 3	0.00	0.30	2.61	1.29	0.00	0.00	4.86	1.05
Lac Spencer 1	*	0.00	*	0.38	*	0.00	*	0.96
Lac Spencer 2	0.00	0.00	0.15	0.61	0.00	0.00	0.71	1.22
Lac Spencer 3	0.00	0.00	0.86	0.78	0.00	0.00	1.81	1.30
Nicabau 1	0.00	0.00	0.01	0.06	0.00	0.00	0.05	0.07
Nicabau 2	0.00	0.00	0.07	0.16	0.00	0.00	0.30	0.63
Nicabau 3	*	0.00	*	0.54	*	0.00	*	0.31

Sample	Day 43 Mineral N (ug/ml)				Day 57 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	2.97	0.17	0.00	0.00	5.66	0.24
LLB middle 2	0.00	0.00	8.36	0.45	0.00	0.00	17.24	0.94
LLB middle 3	0.04	0.00	0.55	0.44	0.00	0.00	1.30	0.62
WC middle 1	7.84	0.00	22.03	1.63	11.54	0.00	22.77	2.29
WC middle 2	0.62	0.00	19.09	0.55	0.60	0.00	7.59	1.64
WC middle 3	0.00	0.00	6.97	1.35	0.00	0.00	11.13	1.62
Lac Spencer 1	*	0.00	*	1.12	*	0.00	*	1.50
Lac Spencer 2	0.05	0.00	2.08	1.39	0.00	0.00	4.05	1.77
Lac Spencer 3	0.00	0.00	2.48	2.73	0.00	0.00	3.09	3.35
Nicabau 1	0.00	0.00	0.00	0.13	0.00	0.00	0.04	0.74
Nicabau 2	0.00	0.00	0.66	0.61	0.00	0.00	1.07	0.93
Nicabau 3	*	0.00	*	3.06	*	0.00	*	1.53

	Day 71 Mineral N (ug/ml)				Day 85 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	10.77	0.38	**	0.00	**	0.32
LLB middle 2	0.00	0.00	17.97	0.48	**	0.00	**	0.29
LLB middle 3	0.00	0.00	1.15	0.62	**	0.00	**	0.56
WC middle 1	26.79	0.00	22.75	1.66	**	0.00	**	0.95
WC middle 2	0.48	0.00	21.30	0.41	**	0.00	**	0.17
WC middle 3	0.38	0.00	12.02	1.44	**	0.00	**	0.90
Lac Spencer 1		0.00		0.70	**	0.00	**	0.33
Lac Spencer 2	0.00	0.00	5.72	1.17	**	0.00	**	0.76
Lac Spencer 3	0.00	0.00	4.39	3.36	**	0.00	**	1.44
Nicabau 1	0.00	0.00	0.02	0.52	**	0.00	**	0.36
Nicabau 2	0.00	0.00	0.87	0.52	**	0.00	**	1.34
Nicabau 3		0.00		2.48	**	0.00	**	1.23

	Day 99 Mineral N (ug/ml)				Day 113 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	12.30	0.02	0.13	0.01	25.39	0.22
LLB middle 2	0.01	0.00	25.62	0.32	0.01	0.02	30.73	0.53
LLB middle 3	0.00	0.00	3.84	0.47	0.00	0.02	5.56	0.49
WC middle 1	24.57	0.01	14.17	0.62	48.83	0.02	12.10	0.76
WC middle 2	1.54	0.03	34.22	0.68	0.87	0.04	37.68	0.97
WC middle 3	3.01	0.00	20.27	0.52	7.09	0.02	24.32	0.97
Lac Spencer 1	*	0.00	*	0.13	*	0.02	*	0.60
Lac Spencer 2	0.16	0.00	13.49	0.46	0.38	0.03	15.90	0.79
Lac Spencer 3	0.05	0.00	8.81	0.77	0.11	0.04	9.40	3.14
Nicabau 1	0.00	0.02	0.11	0.07	0.00	0.02	0.60	0.55
Nicabau 2	0.00	0.04	0.69	1.08	0.04	0.02	0.79	0.90
Nicabau 3	*	0.01	*	0.33	*	0.02	*	0.76

	Day 127 Mineral N (ug/ml)				Day 141 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.31	0.00	20.09	0.23	0.49	0.02	16.88	0.35
LLB middle 2	0.16	0.21	34.47	0.44	0.46	0.39	42.79	0.49
LLB middle 3	0.20	0.02	6.13	0.28	0.30	0.42	7.91	0.54
WC middle 1	48.70	0.19	7.24	0.27	103.54	0.45	4.55	1.18
WC middle 2	1.07	0.35	37.97	0.73	2.56	0.42	72.77	0.17
WC middle 3	7.62	0.30	24.38	0.71	21.65	0.03	32.01	0.93
Lac Spencer 1	*	0.23	*	0.28	*	0.37	*	0.47
Lac Spencer 2	0.67	0.23	18.15	0.79	0.87	0.39	36.17	1.13
Lac Spencer 3	0.37	0.19	7.52	0.94	0.47	0.43	7.60	1.09
Nicabau 1	0.26	0.29	0.35	0.28	0.47	0.45	0.49	0.42
Nicabau 2	0.24	0.26	0.67	0.51	0.04	0.40	1.13	0.74
Nicabau 3	*	0.21	*	0.31	*	0.03	*	0.31

Sample	Day 170 Mineral N (ug/ml)				Day 199 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	2.18	0.06	9.42	0.42	4.05	0.00	15.37	0.10
LLB middle 2	0.64	0.05	8.70	0.19	0.87	0.25	38.78	0.13
LLB middle 3	0.38	0.08	20.87	0.14	0.41	0.02	7.97	0.02
WC middle 1	47.05	0.15	1.78	0.76	72.88	0.26	0.30	0.00
WC middle 2	2.22	0.10	40.49	0.23	2.42	0.15	37.72	0.17
WC middle 3	51.76	0.08	17.32	0.51	71.86	0.26	2.90	0.15
Lac Spencer 1	*	0.12	*	1.12	*	0.30	*	0.35
Lac Spencer 2	1.68	0.08	23.36	0.41	1.76	0.34	26.44	1.08
Lac Spencer 3	0.63	0.08	17.53	1.63	0.22	0.38	4.89	0.72
Nicabau 1	0.21	0.10	1.20	0.51	0.23	0.28	0.57	0.15
Nicabau 2	0.10	0.09	2.33	0.65	0.00	0.24	0.75	0.34
Nicabau 3	*	0.09	*	0.24	*	0.23	*	0.16

Sample	Day 228 Mineral N (ug/ml)				Day 257 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	49.66	0.35	64.59	0.31	18.61	0.01	9.74	0.02
LLB middle 2	7.22	0.38	91.67	0.17	4.04	0.32	32.63	0.19
LLB middle 3	2.29	0.09	16.72	0.11	1.93	0.00	11.94	0.02
WC middle 1	200.38	0.33	3.56	0.03	28.54	0.01	5.38	0.04
WC middle 2	17.07	0.45	72.85	0.20	14.53	0.00	28.00	0.07
WC middle 3	146.13	0.03	2.70	0.00	28.21	0.00	4.13	0.09
Lac Spencer 1	*	0.33	*	0.00	*	0.01	*	0.02
Lac Spencer 2	2.56	0.45	40.49	0.74	0.75	0.01	19.93	0.08
Lac Spencer 3	2.40	0.21	12.17	0.43	0.25	0.00	3.62	0.04
Nicabau 1	1.00	0.45	3.16	0.08	0.11	0.31	3.16	0.03
Nicabau 2	0.52	0.26	4.91	0.00	0.35	0.23	3.60	0.00
Nicabau 3	*	0.29	*	0.00	*	0.32	*	0.07

Sample	Day 285 Mineral N (ug/ml)				Day 313 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	11.34	0.01	2.13	0.19	34.17	0.86	2.78	0.98
LLB middle 2	9.80	0.01	24.97	0.12	37.25	2.66	23.75	1.05
LLB middle 3	3.01	0.02	4.20	0.08	11.76	10.51	5.98	0.53
WC middle 1	46.05	0.02	0.85	0.08	51.11	2.71	0.88	0.49
WC middle 2	31.82	0.02	13.89	0.10	73.84	6.09	4.75	0.35
WC middle 3	40.53	0.02	0.00	0.05	42.32	1.86	1.12	0.00
Lac Spencer 1	*	0.01	*	0.14	*	0.77	*	1.01
Lac Spencer 2	1.12	0.02	15.47	1.07	2.04	0.00	14.70	1.37
Lac Spencer 3	0.15	0.01	1.03	0.05	0.39	1.26	1.89	6.94
Nicabau 1	0.06	0.01	0.48	0.02	0.30	1.39	1.35	1.62
Nicabau 2	0.07	0.00	2.23	0.01	0.00	2.05	5.02	0.92
Nicabau 3	*	0.01	*	0.03	*	1.04	*	0.36

* no sample incubated
** lost sample

LLB = Lac La Biche
WC = Whitecourt

3.3c: Temperature 12°C

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB middle 1	63.95	50.97	0.008	0.001	0.00	0.00	0.40	0.28
LLB middle 2	158.60	64.16	0.008	0.000	0.00	0.00	1.53	0.65
LLB middle 3	119.01	30.73	0.014	0.001	0.23	0.01	0.81	0.89
WC middle 1	153.97	25.34	0.025	0.002	22.73	0.22	17.51	2.25
WC middle 2	114.21	38.70	0.019	0.002	0.90	0.07	6.15	0.77
WC middle 3	84.63	32.29	0.025	0.001	0.00	0.00	1.23	0.62
Lac Spencer 1		32.90	0.012	0.001	0.00	0.00	2.13	0.67
Lac Spencer 2	53.19	63.36	0.014	0.001	0.00	0.00	0.76	2.11
Lac Spencer 3	55.90	64.11	0.013	0.001	0.01	0.00	1.49	1.14
Nicabau 1	83.05	63.99	0.014	0.001	0.05	0.00	0.45	0.00
Nicabau 2	138.73	63.39	0.009	0.001	0.00	0.00	0.36	0.00
Nicabau 3		63.85	0.008	0.000	0.00	0.00	2.35	0.61

Sample	Day 15 Mineral N (ug/ml)				Day 29 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	1.37	0.70	0.00	0.00	5.79	1.72
LLB middle 2	0.00	0.00	3.42	1.47	0.23	0.00	9.75	2.53
LLB middle 3	0.00	0.00	0.76	1.18	0.00	0.00	1.78	2.05
WC middle 1	0.06	0.00	19.95	1.63	28.19	0.00	33.72	2.27
WC middle 2	0.00	0.00	5.30	1.34	1.07	0.00	15.15	2.78
WC middle 3	0.00	0.00	1.16	0.89	0.00	0.00	3.73	2.16
Lac Spencer 1	0.00	0.00	4.74	0.86	0.00	0.00	14.15	1.97
Lac Spencer 2	0.00	0.00	1.39	2.14	0.00	0.00	2.65	4.78
Lac Spencer 3	0.00	0.00	2.34	1.61	0.00	0.00	4.40	3.97
Nicabau 1	0.00	0.00	0.74	0.46	0.13	0.00	8.33	1.97
Nicabau 2	0.00	0.00	0.30	1.55	0.00	0.00	1.61	2.25
Nicabau 3	0.00	0.00	6.03	1.90	0.00	0.00	12.12	3.15

Sample	Day 43 Mineral N (ug/ml)				Day 57 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	6.54	2.60	0.00	0.00	1.58	2.45
LLB middle 2	0.00	0.00	11.27	3.31	0.00	0.00	20.66	1.60
LLB middle 3	2.74	0.00	3.64	2.76	0.00	0.00	7.66	2.49
WC middle 1	87.53	0.00	19.72	2.99	20.23	0.00	7.24	1.21
WC middle 2	2.61	0.00	20.48	3.75	3.27	0.00	35.64	1.68
WC middle 3	0.23	0.00	6.93	2.63	0.00	0.00	13.96	1.45
Lac Spencer 1	0.24	0.00	21.30	3.84	0.00	0.00	23.75	1.14
Lac Spencer 2	0.28	0.00	10.71	5.32	0.00	0.00	16.83	4.12
Lac Spencer 3	0.09	0.00	11.66	5.67	0.00	0.00	10.50	5.09
Nicabau 1	0.00	0.00	9.05	4.24	0.00	0.00	5.07	2.98
Nicabau 2	0.00	0.00	4.23	4.06	0.00	0.00	3.98	5.37
Nicabau 3	0.08	0.00	15.24	3.63	0.00	0.00	18.56	3.27

	Day 71 Mineral N (ug/ml)				Day 85 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	14.11	2.21	**	0.00	**	1.96
LLB middle 2	0.00	0.00	20.19	2.26	**	0.00	**	2.08
LLB middle 3	0.00	0.00	10.17	1.80	**	0.00	**	1.48
WC middle 1	93.46	0.00	1.98	2.27	**	0.00	**	1.62
WC middle 2	1.76	0.00	21.58	2.92	**	0.00	**	2.19
WC middle 3	0.65	0.00	12.15	2.34	**	0.00	**	1.89
Lac Spencer 1	0.00	0.00	30.49	2.94	**	0.00	**	3.10
Lac Spencer 2	0.00	0.00	17.23	3.11	**	0.00	**	2.26
Lac Spencer 3	0.00	0.00	10.17	5.32	**	0.00	**	4.48
Nicabau 1	0.00	0.00	3.26	2.57	**	0.00	**	2.04
Nicabau 2	0.00	0.00	3.81	3.86	**	0.00	**	1.92
Nicabau 3	0.00	0.00	23.73	2.51	**	0.00	**	1.55

	Day 99 Mineral N (ug/ml)				Day 113 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.09	0.03	16.16	1.90	0.77	0.01	24.93	1.59
LLB middle 2	0.05	0.00	22.68	1.39	0.35	0.02	22.05	1.47
LLB middle 3	0.00	0.01	12.52	0.09	0.06	0.02	10.08	1.34
WC middle 1	61.62	0.05	1.90	1.17	75.41	0.08	2.34	1.61
WC middle 2	3.17	0.03	70.70	1.31	6.88	0.04	58.00	2.26
WC middle 3	41.02	0.02	2.98	1.77	38.34	0.02	0.79	2.15
Lac Spencer 1	1.17	0.02	46.17	1.57	1.47	0.01	39.63	1.45
Lac Spencer 2	0.09	0.02	21.07	1.49	0.00	0.02	25.40	2.42
Lac Spencer 3	0.00	0.01	13.97	3.20	0.00	0.02	15.20	2.86
Nicabau 1	0.00	0.02	3.31	2.06	0.00	0.05	4.07	1.66
Nicabau 2	0.00	0.03	6.00	1.64	0.00	0.05	9.55	1.50
Nicabau 3	0.00	0.00	22.83	1.25	0.00	0.02	34.73	1.87

	Day 127 Mineral N (ug/ml)				Day 141 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	1.29	0.03	14.73	1.66	6.43	0.13	27.86	2.32
LLB middle 2	1.41	0.25	34.84	1.33	4.77	0.27	33.67	1.38
LLB middle 3	0.95	0.35	22.02	1.12	3.19	0.18	37.35	1.94
WC middle 1	71.76	0.50	2.36	1.20	108.67	0.19	2.72	0.99
WC middle 2	17.01	0.07	76.48	1.91	62.11	0.11	111.86	2.14
WC middle 3	45.25	0.22	0.00	1.61	85.62	0.19	0.17	2.45
Lac Spencer 1	2.18	0.03	31.74	1.33	2.50	0.00	53.27	1.51
Lac Spencer 2	0.29	0.02	17.34	1.71	0.51	0.00	24.91	2.06
Lac Spencer 3	0.33	0.01	13.36	2.51	0.50	0.00	29.90	4.95
Nicabau 1	0.00	0.02	1.93	1.39	0.70	0.24	7.19	2.87
Nicabau 2	0.21	0.18	8.94	1.46	0.72	0.29	19.01	1.15
Nicabau 3	0.39	0.32	31.68	1.62	1.02	0.34	44.68	2.73

Sample	Day 170 Mineral N (ug/ml)				Day 199 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	38.17	0.07	32.38	3.79	60.56	0.30	13.38	1.72
LLB middle 2	26.05	0.03	74.65	2.76	45.71	0.10	30.69	0.75
LLB middle 3	37.20	0.03	19.38	3.13	68.26	0.08	7.03	1.42
WC middle 1	136.18	0.03	2.52	3.11	135.83	0.22	1.55	1.82
WC middle 2	154.53	0.03	24.84	2.90	108.05	0.14	4.94	2.34
WC middle 3	105.77	0.03	0.29	2.20	162.29	0.08	0.32	0.74
Lac Spencer 1	4.39	0.02	67.70	7.41	3.77	0.07	64.32	2.78
Lac Spencer 2	0.64	0.03	29.44	5.24	0.59	0.09	27.77	1.56
Lac Spencer 3	0.45	0.01	42.43	1.27	0.36	0.14	27.80	6.17
Nicabau 1	0.87	0.02	11.33	3.82	1.19	0.10	6.81	2.41
Nicabau 2	2.12	0.02	27.28	4.01	4.11	0.17	29.45	1.55
Nicabau 3	3.97	0.02	75.85	3.70	8.65	0.12	59.13	1.32

Sample	Day 228 Mineral N (ug/ml)				Day 257 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	102.42	0.10	6.33	6.30	68.41	0.01	4.26	1.47
LLB middle 2	359.55	0.75	32.51	5.76	43.54	0.02	2.96	0.72
LLB middle 3	151.93	0.54	7.01	4.31	75.10	0.02	0.00	0.71
WC middle 1	311.33	0.77	3.54	6.20	105.12	0.11	3.42	0.89
WC middle 2	321.05	0.49	9.26	7.25	121.27	0.12	7.63	2.13
WC middle 3	384.58	0.41	0.55	3.15	146.54	0.03	0.00	1.17
Lac Spencer 1	7.34	0.21	120.64	4.89	2.98	0.01	33.74	1.45
Lac Spencer 2	6.86	0.39	83.43	6.88	0.42	0.01	19.67	2.36
Lac Spencer 3	3.49	0.08	90.86	8.86	0.27	0.02	14.38	4.37
Nicabau 1	8.26	0.02	20.15	4.02	1.62	0.01	8.23	1.82
Nicabau 2	13.45	0.18	56.20	2.11	8.77	0.01	26.44	0.56
Nicabau 3	47.84	0.19	158.49	3.57	26.48	0.01	58.68	0.70

Sample	Day 285 Mineral N (ug/ml)				Day 313 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	40.18	0.03	0.76	0.98	42.82	0.00	1.38	1.13
LLB middle 2	18.85	0.03	0.80	1.58	75.52	0.00	1.10	1.30
LLB middle 3	31.62	0.04	0.76	0.61	78.59	0.00	0.99	1.53
WC middle 1	31.12	0.11	0.46	0.72	74.52	0.07	1.15	2.81
WC middle 2	45.50	0.12	3.53	1.89	196.44	0.11	3.65	3.50
WC middle 3	38.99	0.03	0.69	1.05	128.56	0.01	0.92	2.22
Lac Spencer 1	2.96	0.01	37.50	0.76	4.05	0.00	50.74	0.87
Lac Spencer 2	0.47	0.03	28.89	1.94	0.45	0.35	22.23	1.61
Lac Spencer 3	0.09	0.03	13.37	2.69	0.15	0.02	12.61	2.95
Nicabau 1	0.97	0.05	3.35	1.49	2.52	0.01	10.22	1.03
Nicabau 2	4.83	0.02	17.04	0.72	5.69	0.29	18.18	0.44
Nicabau 3	11.27	0.03	28.98	0.81	14.21	0.61	26.46	0.91

** lost sample

LLB = Lac La Biche
WC = Whitecourt

3.3d: Temperature 22°C

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB middle 1	63.95	50.97	0.008	0.001	0.00	0.00	1.98	0.00
LLB middle 2	158.60	64.16	0.008	0.000	0.00	0.00	0.45	0.27
LLB middle 3	119.01	30.73	0.014	0.001	0.00	0.03	0.26	0.63
WC middle 1	153.97	25.34	0.025	0.002	9.23	0.15	21.30	1.51
WC middle 2	114.21	38.70	0.019	0.002	0.58	0.02	5.48	0.25
WC middle 3	84.63	32.29	0.025	0.001	0.17	0.01	3.51	1.00
Lac Spencer 1	*	32.90	0.012	0.001	*	0.00	*	0.05
Lac Spencer 2	53.19	63.36	0.014	0.001	0.22	0.00	6.87	1.87
Lac Spencer 3	55.90	64.11	0.013	0.001	0.00	0.00	1.19	1.04
Nicabau 1	83.05	63.99	0.014	0.001	0.00	0.00	0.16	0.00
Nicabau 2	138.73	63.39	0.009	0.001	0.00	0.00	0.15	0.00
Nicabau 3	*	63.85	0.008	0.000	*	0.00	*	0.03

Sample	Day 15 Mineral N (ug/ml)				Day 29 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	2.13	0.26	0.00	0.00	6.72	0.43
LLB middle 2	0.00	0.00	3.06	0.65	0.00	0.00	11.53	0.87
LLB middle 3	0.00	0.00	1.04	0.78	0.00	0.00	11.06	0.76
WC middle 1	9.17	0.00	29.61	0.81	90.53	0.00	51.55	1.40
WC middle 2	0.00	0.00	37.13	0.96	6.91	0.00	51.46	1.35
WC middle 3	7.73	0.00	3.62	1.24	56.97	0.00	2.33	1.27
Lac Spencer 1	*	0.00	*	2.34	*	0.00	*	2.30
Lac Spencer 2	0.00	0.00	4.52	1.11	1.99	0.00	30.07	3.96
Lac Spencer 3	0.00	0.00	4.57	1.58	0.11	0.00	14.25	4.06
Nicabau 1	0.00	0.00	0.03	0.08	0.00	0.00	0.22	0.61
Nicabau 2	0.00	0.00	0.30	0.84	0.00	0.00	0.93	1.87
Nicabau 3	*	0.00	*	0.68	*	0.00	*	2.39

Sample	Day 43 Mineral N (ug/ml)				Day 57 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	10.43	0.32	0.22	0.00	1.99	1.44
LLB middle 2	0.00	0.00	24.67	1.32	0.00	0.00	46.21	1.52
LLB middle 3	0.00	0.00	10.74	0.69	0.00	0.00	3.66	1.41
WC middle 1	159.29	0.00	28.03	0.49	28.34	0.00	16.36	1.63
WC middle 2	6.42	0.00	49.81	1.08	18.33	0.00	49.21	1.96
WC middle 3	58.90	0.00	0.51	1.28	10.38	0.00	0.56	1.02
Lac Spencer 1	*	0.00	*	0.84	*	0.00	*	1.15
Lac Spencer 2	3.60	0.00	27.92	3.19	7.05	0.00	39.96	2.32
Lac Spencer 3	0.37	0.00	15.38	2.87	0.00	0.00	23.38	3.93
Nicabau 1	0.00	0.00	1.98	1.14	0.00	0.00	5.28	1.86
Nicabau 2	0.00	0.00	1.26	1.49	0.00	0.00	2.62	1.04
Nicabau 3	*	0.00	*	0.96	*	0.00	*	1.34

	Day 71 Mineral N (ug/ml)				Day 85 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	13.90	0.00	5.33	1.26	**	0.00	**	1.18
LLB middle 2	0.42	0.00	44.19	1.22	**	0.00	**	1.68
LLB middle 3	0.00	0.00	23.55	1.54	**	0.00	**	1.27
WC middle 1	91.42	0.00	7.04	1.73	**	0.00	**	1.42
WC middle 2	34.14	0.00	50.83	2.49	**	0.00	**	1.91
WC middle 3	91.85	0.00	0.29	1.09	**	0.00	**	0.79
Lac Spencer 1	*	0.00	*	3.64	**	0.00	**	1.14
Lac Spencer 2	0.00	0.00	27.26	8.39	**	0.00	**	3.08
Lac Spencer 3	0.00	0.00	7.75	11.70	**	0.00	**	4.98
Nicabau 1	0.00	0.00	21.70	2.07	**	0.00	**	1.77
Nicabau 2	0.00	0.00	3.28	1.34	**	0.00	**	0.91
Nicabau 3	*	0.00	*	2.34	**	0.00	**	1.73

	Day 99 Mineral N (ug/ml)				Day 113 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	34.53	0.01	0.77	0.61	26.92	0.02	1.08	1.13
LLB middle 2	8.19	0.03	30.19	1.69	12.83	0.02	21.55	1.58
LLB middle 3	1.92	0.03	30.91	0.85	5.9	0.05	34.88	2.29
WC middle 1	108.46	0.21	3.67	1.76	104.02	0.10	3.06	1.55
WC middle 2	131.17	0.06	12.87	1.77	133.75	0.10	5.88	2.04
WC middle 3	67.43	0.03	0.28	0.44	94.26	0.06	0.75	0.96
Lac Spencer 1	*	0.03	*	1.49	*	0.03	*	1.99
Lac Spencer 2	0.00	0.02	27.94	2.67	0.22	0.03	21.68	2.7
Lac Spencer 3	0.00	0.01	36.58	3.59	0.09	0.06	30.62	6.01
Nicabau 1	0.00	0.03	16.1	1.65	0.03	0.03	21.82	1.96
Nicabau 2	0.00	0.03	7.91	1.34	0.04	0.02	11.62	1.05
Nicabau 3	*	0.02	*	1.30	*	0.05	*	2.62

	Day 127 Mineral N (ug/ml)				Day 141 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	29.03	0.32	0.36	1.05	41.53	0.07	0.55	2.39
LLB middle 2	23.25	0.36	21.28	0.39	44.11	0.07	29.06	1.72
LLB middle 3	9.79	0.47	16.54	0.29	61.77	0.56	14.21	1.63
WC middle 1	71.38	0.71	2.21	1.23	149.59	0.45	3.24	1.32
WC middle 2	104.49	0.51	2.64	1.95	164.70	0.16	3.21	1.88
WC middle 3	53.41	0.51	1.84	1.01	146.49	0.17	0.33	0.97
Lac Spencer 1	*	0.30	*	1.58	*	0.04	*	1.22
Lac Spencer 2	0.20	0.41	16.93	2.43	3.18	0.04	25.49	2.98
Lac Spencer 3	0.32	0.30	28.82	5.82	0.38	0.04	51.23	8.34
Nicabau 1	0.29	0.35	18.63	1.81	0.16	0.04	29.28	2.96
Nicabau 2	0.26	0.36	10.09	0.89	0.10	0.05	26.64	1.04
Nicabau 3	*	0.36	*	1.94	*	0.06	*	1.87

Sample	Day 170 Mineral N (ug/ml)				Day 199 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	37.91	0.12	0.49	1.30	23.91	0.30	0.43	0.87
LLB middle 2	55.54	0.09	14.71	1.73	32.02	0.60	6.41	0.40
LLB middle 3	60.11	3.21	0.76	0.62	61.00	5.46	0.68	0.03
WC middle 1	141.24	1.78	2.05	0.60	68.19	4.54	1.09	0.00
WC middle 2	24.16	0.45	2.52	2.97	82.81	0.73	1.07	2.80
WC middle 3	94.44	0.84	0.53	0.81	141.91	1.72	0.29	0.21
Lac Spencer 1	*	0.10	*	2.03	*	0.37	*	1.20
Lac Spencer 2	2.43	0.11	18.01	2.65	1.67	0.35	14.68	1.75
Lac Spencer 3	0.43	0.08	43.28	14.39	1.14	0.36	45.91	13.39
Nicabau 1	0.21	0.08	16.35	1.97	0.40	0.31	23.54	7.69
Nicabau 2	0.23	0.15	30.23	1.64	0.48	0.61	28.22	5.76
Nicabau 3	*	0.04	*	0.53	*	0.21	*	3.21

Sample	Day 228 Mineral N (ug/ml)				Day 257 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	81.65	2.44	1.25	5.69	18.66	0.61	4.35	1.00
LLB middle 2	158.30	2.05	6.36	4.28	58.48	0.38	5.07	0.61
LLB middle 3	91.00	7.21	1.17	0.90	89.54	1.76	4.73	0.00
WC middle 1	120.74	5.19	3.13	0.71	39.25	1.22	4.44	0.02
WC middle 2	152.81	3.17	2.85	7.76	45.78	1.82	5.32	1.94
WC middle 3	134.91	14.83	0.89	0.71	55.57	3.19	4.09	0.03
Lac Spencer 1	*	1.76	*	3.60	*	0.77	*	1.04
Lac Spencer 2	5.92	1.07	12.07	4.17	1.99	0.06	9.22	0.82
Lac Spencer 3	4.18	1.18	68.29	21.32	0.39	0.04	32.49	3.64
Nicabau 1	2.55	1.01	37.50	3.27	0.55	0.43	30.17	1.03
Nicabau 2	2.35	0.72	49.00	4.59	1.22	0.42	32.56	0.90
Nicabau 3	*	0.69	*	1.75	*	0.56	*	0.33

Sample	Day 285 Mineral N (ug/ml)				Day 313 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	14.75	0.15	1.45	1.06	64.00	0.02	0.29	0.23
LLB middle 2	52.10	0.59	1.27	0.13	62.44	0.58	1.16	0.43
LLB middle 3	80.17	1.41	1.08	0.08	124.85	0.05	1.38	0.15
WC middle 1	47.22	1.21	2.13	0.01	65.04	0.50	2.03	0.35
WC middle 2	84.05	5.08	1.59	1.42	155.15	0.57	2.44	0.46
WC middle 3	47.63	2.45	1.22	0.05	92.28	0.46	1.81	0.21
Lac Spencer 1	*	0.24	*	0.98	*	0.53	*	0.54
Lac Spencer 2	0.41	0.11	4.01	1.36	1.41	0.48	9.09	0.56
Lac Spencer 3	0.00	0.11	20.90	5.07	0.00	0.02	26.38	0.19
Nicabau 1	0.00	0.12	18.83	0.55	0.00	0.01	0.04	0.08
Nicabau 2	0.35	0.15	20.58	1.13	0.00	0.01	23.05	0.09
Nicabau 3	*	0.11	*	0.15	*	0.01	*	0.10

* no sample incubated
** lost sample

LLB = Lac La Biche
WC = Whitecourt

3.3e: Temperature 32°C

Sample	Initial Organi weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB middle 1	181.74	53.45	0.008	0.001	0.00	0.00	2.96	0.00
LLB middle 2	86.12	63.95	0.008	0.000	0.02	0.00	1.68	0.53
LLB middle 3	222.38	31.08	0.014	0.001	0.00	0.00	0.19	0.82
WC middle 1	226.44	24.88	0.025	0.002	7.56	0.15	12.69	1.94
WC middle 2	128.96	37.16	0.019	0.002	0.46	0.09	6.64	0.76
WC middle 3	120.81	32.79	0.025	0.001	0.13	0.00	2.31	1.69
Lac Spencer 1	*	34.15	0.012	0.001	*	0.00	*	0.67
Lac Spencer 2	*	63.13	0.014	0.001	*	0.00	*	2.88
Lac Spencer 3	*	63.95	0.013	0.001	*	0.00	*	1.34
Nicabau 1	79.70	64.46	0.014	0.001	0.11	0.00	1.94	0.08
Nicabau 2	*	63.95	0.009	0.001	*	0.00	*	0.02
Nicabau 3	*	63.97	0.008	0.000	*	0.00	*	0.73

Sample	Day 15 Mineral N (ug/ml)				Day 29 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	3.54	0.77	0.00	0.00	11.01	1.37
LLB middle 2	0.00	0.00	2.45	1.24	0.00	0.00	17.31	1.66
LLB middle 3	0.00	0.00	1.79	1.00	0.00	0.00	6.69	2.42
WC middle 1	6.51	0.00	9.92	1.07	2.36	0.00	16.29	2.90
WC middle 2	0.00	0.00	11.10	1.74	0.23	0.00	32.76	4.25
WC middle 3	0.00	0.00	3.04	1.06	0.00	0.00	14.04	1.85
Lac Spencer 1	*	0.00	*	1.53	*	0.00	*	3.12
Lac Spencer 2	*	0.00	*	3.34	*	0.00	*	5.78
Lac Spencer 3	*	0.00	*	3.75	*	0.00	*	5.56
Nicabau 1	0.00	0.00	1.60	1.01	0.00	0.00	25.96	1.25
Nicabau 2	*	0.00	*	3.32	*	0.00	*	1.42
Nicabau 3	*	0.00	*	2.58	*	0.00	*	1.09

Sample	Day 43 Mineral N (ug/ml)				Day 57 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	0.00	0.00	14.60	1.79	3.46	0.00	37.84	1.52
LLB middle 2	0.00	0.00	26.44	1.88	0.00	0.00	40.53	1.90
LLB middle 3	0.00	0.00	9.51	3.02	0.00	0.00	15.79	1.71
WC middle 1	9.33	0.00	25.12	2.94	7.41	0.00	27.64	2.78
WC middle 2	0.42	0.00	59.08	3.75	0.00	0.00	72.34	5.33
WC middle 3	0.00	0.00	15.82	2.30	0.00	0.00	51.86	2.05
Lac Spencer 1	*	0.00	*	1.74	*	0.00	*	2.25
Lac Spencer 2	*	0.00	*	3.40	*	0.00	*	5.11
Lac Spencer 3	*	0.00	*	6.53	*	0.00	*	5.14
Nicabau 1	0.00	0.00	18.71	1.47	0.00	0.00	23.94	1.49
Nicabau 2	*	0.00	*	2.93	*	0.00	*	2.24
Nicabau 3	*	0.00	*	1.32	*	0.00	*	1.04

Sample	Day 71 Mineral N (ug/ml)				Day 85 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	4.09	0.00	42.81	1.84	**	0.00	**	1.36
LLB middle 2	0.18	0.00	57.27	2.22	**	0.00	**	1.55
LLB middle 3	0.00	0.00	18.31	2.72	**	0.00	**	2.09
WC middle 1	7.11	0.00	30.00	2.09	**	0.00	**	1.35
WC middle 2	0.00	0.00	60.70	3.62	**	0.00	**	3.09
WC middle 3	0.00	0.00	15.83	2.30	**	0.00	**	0.71
Lac Spencer 1	*	0.00	*	1.43	**	0.00	**	0.69
Lac Spencer 2	*	0.00	*	4.59	**	0.00	**	1.59
Lac Spencer 3	*	0.00	*	3.33	**	0.00	**	2.39
Nicabau 1	0.00	0.00	19.29	1.65	**	0.00	**	0.74
Nicabau 2	*	0.00	*	1.50	**	0.00	**	0.86
Nicabau 3	*	0.00	*	0.94	**	0.00	**	0.58

c	Day 99 Mineral N (ug/ml)				Day 113 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	4.38	0.03	23.53	1.04	29.52	0.03	51.26	1.57
LLB middle 2	8.46	0.02	32.62	1.32	36.32	0.05	46.57	1.62
LLB middle 3	0.26	0.03	25.96	1.55	1.77	0.03	28.12	2.00
WC middle 1	10.06	0.02	25.25	0.46	43.09	0.02	89.46	0.73
WC middle 2	4.76	0.02	76.43	1.48	15.61	0.04	110.78	2.09
WC middle 3	0.62	0.04	12.35	1.6	2.70	0.03	25.33	1.06
Lac Spencer 1	*	0.03	*	0.35	*	0.04	*	1.92
Lac Spencer 2	*	0.03	*	2.01	*	0.04	*	3.75
Lac Spencer 3	*	0.03	*	1.48	*	0.03	*	2.23
Nicabau 1	0.03	0.02	15.76	0.39	0.56	0.03	61.14	0.69
Nicabau 2	*	0.02	*	0.34	*	0.04	*	1.69
Nicabau 3	*	0.03	*	0.18	*	0.03	*	0.83

Sample	Day 127 Mineral N (ug/ml)				Day 141 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	21.08	0.35	26.81	0.58	64.02	0.11	22.38	3.94
LLB middle 2	20.18	0.34	10.20	1.94	39.40	0.05	24.48	3.38
LLB middle 3	1.14	0.38	30.91	0.94	0.88	0.05	45.88	2.27
WC middle 1	21.53	0.37	34.08	0.33	42.29	0.02	47.44	0.11
WC middle 2	12.92	0.29	79.00	2.32	23.28	0.04	111.56	3.47
WC middle 3	4.04	0.30	25.07	2.54	14.79	0.04	57.70	2.45
Lac Spencer 1	*	0.31	*	0.88	*	0.02	*	1.25
Lac Spencer 2	*	0.33	*	1.28	*	0.38	*	4.22
Lac Spencer 3	*	0.36	*	1.44	*	0.49	*	1.87
Nicabau 1	0.36	0.28	10.31	0.45	0.35	0.04	48.92	0.49
Nicabau 2	*	0.33	*	0.72	*	0.04	*	0.68
Nicabau 3	*	0.22	*	0.43	*	0.03	*	0.38

	Day 170 Mineral N (ug/ml)				Day 199 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	131.25	0.26	76.91	1.49	166.51	0.37	40.84	2.46
LLB middle 2	92.23	0.15	27.65	1.63	63.39	0.16	9.26	3.17
LLB middle 3	6.15	0.15	84.44	1.08	44.33	0.18	124.70	0.92
WC middle 1	158.47	0.18	106.43	2.72	151.62	0.23	66.09	2.15
WC middle 2	140.67	0.14	184.45	4.78	179.13	0.14	131.66	3.48
WC middle 3	26.67	0.09	40.01	1.14	169.70	0.07	110.78	0.57
Lac Spencer 1	*	0.16	*	5.71	*	0.07	*	1.30
Lac Spencer 2	*	0.09	*	5.63	*	0.16	*	5.18
Lac Spencer 3	*	0.11	*	7.35	*	0.20	*	2.94
Nicabau 1	1.28	0.16	79.78	1.47	3.88	0.07	51.75	1.40
Nicabau 2	*	0.10	*	1.38	*	0.10	*	2.49
Nicabau 3	*	0.09	*	0.85	*	0.05	*	1.24

	Day 228 Mineral N (ug/ml)				Day 257 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	258.70	0.79	36.34	4.86	65.00	0.10	11.50	1.83
LLB middle 2	50.80	0.16	2.68	7.54	9.00	0.03	4.50	2.42
LLB middle 3	467.25	0.59	11.47	1.40	158.50	0.05	3.00	0.67
WC middle 1	412.18	0.51	115.56	2.01	110.50	0.30	18.50	0.13
WC middle 2	450.62	1.41	123.97	8.82	60.00	0.30	5.00	1.17
WC middle 3	467.98	0.44	21.23	1.64	86.00	0.26	2.00	0.72
Lac Spencer 1	*	0.42	*	1.29	*	0.53	*	0.61
Lac Spencer 2	*	0.45	*	1.42	*	0.45	*	0.51
Lac Spencer 3	*	0.81	*	11.54	*	0.39	*	2.86
Nicabau 1	29.81	0.35	78.21	2.19	5.50	0.21	10.50	0.24
Nicabau 2	*	0.87	*	5.40	*	0.15	*	0.61
Nicabau 3	*	0.00	*	2.12	*	0.01	*	0.71

	Day 285 Mineral N (ug/ml)				Day 313 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	organic	Ae	organic	Ae	organic	Ae	organic	Ae
LLB middle 1	80.61	0.27	5.63	0.87	77.84	0.84	5.63	0.78
LLB middle 2	18.31	0.12	1.40	4.00	32.26	0.02	5.13	2.79
LLB middle 3	93.61	0.13	1.17	0.55	111.77	0.21	6.15	0.72
WC middle 1	120.97	0.06	4.69	0.41	270.98	0.05	11.07	1.25
WC middle 2	162.42	0.07	9.31	0.86	316.92	0.15	21.10	2.29
WC middle 3	52.66	0.11	0.71	0.32	243.41	0.05	5.61	1.17
Lac Spencer 1	*	0.04	*	0.30	*	0.00	*	0.73
Lac Spencer 2	*	0.04	*	0.30	*	0.34	*	2.07
Lac Spencer 3	*	0.09	*	1.95	*	0.10	*	2.81
Nicabau 1	5.92	0.04	8.85	0.19	17.53	0.14	13.09	1.86
Nicabau 2	*	0.04	*	1.09	*	0.07	*	1.77
Nicabau 3	*	0.02	*	0.29	*	0.00	*	1.40

* no sample incubated
** lost sample

LLB = Lac La Biche
WC = Whitecourt

3.4: Mineral N ($\mu g\ ml^{-1}$) values for all extraction days for samples of organic and Ae horizons incubated at 4 different moisture tensions

3.4a: 0 kPa Moisture Tension

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	158.55	125.26	0.008	0.001	0.24	0.24	2.28	0.06
LLB lower 2	142.04	125.74	0.008	0.000	0.30	0.15	3.09	0.16
LLB lower 3	223.32	118.47	0.014	0.001	0.00	0.24	1.05	0.33
WC lower 1	145.77	125.75	0.025	0.002	0.45	0.12	8.82	0.49
WC lower 2	134.81	125.60	0.019	0.002	0.60	0.32	32.58	0.61
WC lower 3	93.84	125.60	0.025	0.001	1.02	0.09	33.12	1.24
Lac Spencer 1	242.35	99.94	0.012	0.001	0.00	0.02	0.75	0.00
Lac Spencer 2	99.01	100.27	0.014	0.001	0.96	0.17	11.67	0.03
Lac Spencer 3	94.78	100.34	0.013	0.001	0.15	0.05	1.44	0.94
Nicabau 1	141.95	100.60	0.014	0.001	0.36	0.05	1.11	0.32
Nicabau 2	203.10	100.17	0.009	0.001	0.33	0.61	0.27	3.47
Nicabau 3	217.46	100.57	0.008	0.000	0.00	0.11	0.27	3.09

Sample	Day 14 Mineral N (ug/ml)				Day 28 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.02	0.35	11.65	9.66	0.12	0.00	15.55	3.97
LLB lower 2	0.02	0.01	8.37	2.06	0.11	0.00	5.18	5.77
LLB lower 3	0.02	0.00	1.99	2.00	0.13	0.00	2.60	3.19
WC lower 1	0.03	0.00	15.91	1.33	0.08	0.00	18.48	3.96
WC lower 2	0.06	0.00	32.25	1.74	0.16	0.00	49.00	2.89
WC lower 3	0.05	0.00	27.63	2.23	0.12	0.09	46.70	5.88
Lac Spencer 1	0.05	0.00	6.60	0.91	0.02	0.07	9.05	1.65
Lac Spencer 2	0.04	0.00	5.68	0.39	0.00	0.00	16.61	1.86
Lac Spencer 3	0.07	0.00	6.59	4.61	0.06	0.00	15.54	2.30
Nicabau 1	0.01	0.00	5.03	0.83	0.00	0.00	4.88	1.74
Nicabau 2	0.03	0.00	1.06	1.49	0.00	0.02	3.78	3.95
Nicabau 3	0.04	0.00	0.53	2.26	0.00	0.05	1.00	4.65

Sample	Day 42 Mineral N (ug/ml)				Day 56 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.21	0.16	26.66	7.68	0.17	0.01	15.77	1.34
LLB lower 2	0.15	0.11	19.13	15.95	0.10	0.12	6.74	6.37
LLB lower 3	0.16	0.03	3.23	8.36	0.16	0.20	3.38	2.00
WC lower 1	0.37	0.02	47.09	15.48	0.28	0.14	24.20	3.97
WC lower 2	0.22	0.07	70.34	10.80	0.15	0.14	41.49	2.59
WC lower 3	0.25	0.01	86.01	24.35	0.54	0.14	47.56	6.49
Lac Spencer 1	0.17	0.12	15.01	3.30	0.29	0.15	7.06	1.08
Lac Spencer 2	0.13	0.20	19.03	4.69	0.31	0.11	18.82	1.14
Lac Spencer 3	0.11	0.28	15.61	3.61	0.30	0.19	7.97	1.11
Nicabau 1	0.20	0.10	5.05	2.45	0.21	0.17	6.36	0.82
Nicabau 2	0.13	0.17	10.26	4.76	0.18	0.13	3.08	0.77
Nicabau 3	0.16	0.19	0.13	9.55	0.24	0.00	1.46	2.17

Sample	Day 70 Mineral N (ug/ml)				Day 90 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.11	0.01	19.96	1.45	0.83	0.01	17.99	0.74
LLB lower 2	0.00	0.01	20.21	7.98	1.66	0.14	4.40	4.15
LLB lower 3	1.33	0.01	4.22	2.29	0.17	0.01	12.00	1.84
WC lower 1	0.02	0.02	37.05	4.37	0.17	0.17	26.64	5.72
WC lower 2	0.13	0.03	72.69	3.02	1.18	0.13	71.44	3.75
WC lower 3	1.46	0.02	71.61	5.59	0.33	0.00	14.01	5.25
Lac Spencer 1	0.07	0.03	17.23	1.11	0.00	0.06	10.54	0.90
Lac Spencer 2	0.02	0.02	18.71	1.03	0.04	0.00	6.13	0.70
Lac Spencer 3	1.09	0.02	9.78	1.01	0.00	0.01	7.53	1.32
Nicabau 1	1.11	0.02	18.27	0.68	0.00	0.01	2.75	0.76
Nicabau 2	0.05	0.04	4.38	0.88	0.00	0.01	2.67	0.65
Nicabau 3	1.09	0.02	8.78	1.42	0.00	0.00	55.49	1.04

Sample	Day 119 Mineral N (ug/ml)				Day 147 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.00	0.03	17.17	0.79	2.17	0.08	13.63	1.08
LLB lower 2	0.00	0.05	18.70	3.82	1.75	0.00	15.40	2.86
LLB lower 3	0.93	0.05	1.60	2.85	3.74	0.00	3.76	1.11
WC lower 1	0.00	0.11	17.13	12.13	2.33	0.00	13.48	10.11
WC lower 2	2.82	0.07	36.30	4.59	5.08	0.02	33.09	3.61
WC lower 3	0.33	0.07	24.97	16.32	0.57	0.00	24.68	11.78
Lac Spencer 1	0.00	0.04	18.50	1.10	0.54	0.01	17.19	1.89
Lac Spencer 2	0.00	0.04	15.23	0.86	0.43	0.02	17.26	1.74
Lac Spencer 3	0.00	0.06	12.41	1.03	0.00	0.02	8.35	2.32
Nicabau 1	0.00	0.05	9.09	1.03	0.00	0.00	5.95	1.22
Nicabau 2	0.00	0.03	2.99	1.00	0.00	0.03	4.02	1.28
Nicabau 3	0.00	0.00	5.96	1.06	0.04	0.02	6.16	1.29

Sample	Day 175 Mineral N (ug/ml)				Day 203 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.00	0.16	14.33	1.26	0.65	0.23	7.30	1.89
LLB lower 2	0.38	0.05	8.89	0.85	0.90	0.29	7.84	2.03
LLB lower 3	0.90	0.00	1.29	1.15	0.97	0.00	0.69	1.84
WC lower 1	0.10	0.06	10.79	0.87	0.33	0.00	4.75	13.17
WC lower 2	2.47	0.00	27.05	11.76	0.39	0.03	12.20	6.90
WC lower 3	0.31	0.10	13.93	1.58	0.07	0.03	7.03	13.05
Lac Spencer 1	0.00	0.01	12.79	12.60	0.11	0.01	14.17	1.01
Lac Spencer 2	0.00	0.02	12.78	0.94	0.04	0.02	10.72	0.98
Lac Spencer 3	0.00	0.03	7.55	1.22	0.04	0.02	1.91	1.13
Nicabau 1	0.00	0.03	6.71	1.02	0.43	0.02	6.15	1.04
Nicabau 2	0.00	0.05	3.33	1.40	0.00	0.02	1.38	1.32
Nicabau 3	0.00	0.04	1.80	1.38	0.01	0.01	2.24	1.46

Sample	Day 231 Mineral N (ug/ml)			
	NO3-		NH4+	
	Organic	Ae	Organic	Ae
LLB lower 1	2.22	0.10	10.26	2.13
LLB lower 2	0.59	0.43	2.36	0.88
LLB lower 3	0.11	0.11	1.55	3.15
WC lower 1	0.00	0.00	6.12	17.84
WC lower 2	0.32	0.00	12.50	8.54
WC lower 3	0.13	0.00	12.01	15.24
Lac Spencer 1	0.00	0.00	20.76	1.34
Lac Spencer 2	0.00	0.00	10.09	1.12
Lac Spencer 3	0.00	0.00	9.76	1.24
Nicabau 1	0.00	0.00	11.50	1.25
Nicabau 2	0.00	0.00	6.27	1.29
Nicabau 3	0.00	0.01	5.85	1.89

3.4b: 20 kPa Moisture Tension

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	158.55	125.26	0.008	0.001	0.42	0.25	6.45	0.00
LLB lower 2	142.04	125.74	0.008	0.000	0.09	0.17	4.47	0.14
LLB lower 3	223.32	118.47	0.014	0.001	0.21	0.24	6.24	0.26
WC lower 1	145.77	125.75	0.025	0.002	0.30	0.09	18.90	1.08
WC lower 2	134.81	125.60	0.019	0.002	0.45	0.28	35.19	0.56
WC lower 3	93.84	125.60	0.025	0.001	0.66	0.07	51.62	1.66
Lac Spencer 1	242.35	99.94	0.012	0.001	0.09	0.00	2.37	0.02
Lac Spencer 2	99.01	100.27	0.014	0.001	0.72	0.00	6.27	0.01
Lac Spencer 3	94.78	100.34	0.013	0.001	0.21	0.17	1.11	0.98
Nicabau 1	141.95	100.60	0.014	0.001	0.09	0.00	2.85	0.37
Nicabau 2	203.10	100.17	0.009	0.001	0.72	0.02	0.09	2.36
Nicabau 3	217.46	100.57	0.008	0.000	0.00	0.16	0.00	3.79

Sample	Day 14 Mineral N (ug/ml)				Day 28 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.06	0.01	32.82	1.27	0.64	0.03	82.75	1.16
LLB lower 2	0.04	0.00	4.31	0.04	0.32	0.00	36.55	0.24
LLB lower 3	0.16	0.01	9.29	0.11	4.13	0.00	46.81	0.27
WC lower 1	0.18	0.02	22.79	4.76	3.72	0.09	96.27	10.41
WC lower 2	0.44	0.04	59.96	2.10	1.16	0.08	127.31	4.56
WC lower 3	0.63	0.03	68.28	5.83	1.58	0.03	148.99	20.83
Lac Spencer 1	0.04	0.00	17.28	0.44	0.11	0.02	65.66	3.81
Lac Spencer 2	0.06	0.00	9.27	0.35	0.15	0.08	34.24	7.81
Lac Spencer 3	0.09	0.01	7.63	2.22	0.06	0.06	24.00	21.60
Nicabau 1	0.02	0.01	9.81	2.53	0.00	0.03	29.32	16.85
Nicabau 2	0.01	0.01	0.29	3.75	0.00	0.04	2.84	18.82
Nicabau 3	0.02	0.05	0.99	5.33	0.00	0.29	4.59	36.45

Sample	Day 42 Mineral N (ug/ml)				Day 56 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.23	0.10	127.96	0.00	0.19	0.01	55.19	0.28
LLB lower 2	3.16	0.09	7.98	0.00	12.08	4.19	4.35	0.29
LLB lower 3	*	0.13	0.36	4.07	28.03	0.10	1.89	3.30
WC lower 1	3.08	0.43	77.90	42.58	6.05	0.12	41.34	15.27
WC lower 2	5.23	0.39	178.75	19.95	23.25	0.38	87.28	14.05
WC lower 3	5.98	1.15	281.38	73.00	18.69	1.72	101.22	26.24
Lac Spencer 1	0.27	0.11	80.86	9.53	0.41	0.05	26.06	3.89
Lac Spencer 2	0.08	0.02	47.55	4.43	0.00	0.02	16.50	2.41
Lac Spencer 3	0.15	0.17	44.65	10.08	0.22	0.02	21.97	3.95
Nicabau 1	0.06	0.10	45.89	7.49	0.58	0.02	18.06	2.99
Nicabau 2	0.12	0.11	8.72	5.67	0.18	0.01	2.82	3.50
Nicabau 3	0.11	0.20	19.20	11.87	0.00	0.13	8.47	4.86

Sample	Day 70 Mineral N (ug/ml)				Day 90 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.07	0.06	78.17	0.69	42.67	0.23	3.38	0.56
LLB lower 2	28.93	7.82	1.81	0.09	78.33	18.01	1.18	0.02
LLB lower 3	72.68	0.21	0.69	5.14	119.10	0.16	31.64	6.94
WC lower 1	45.64	0.13	71.07	13.89	129.00	0.19	11.00	17.07
WC lower 2	115.29	0.30	89.75	11.72	76.11	2.13	2.62	12.63
WC lower 3	93.10	6.17	64.99	16.81	0.30	10.99	29.42	8.14
Lac Spencer 1	1.81	0.19	23.19	3.08	0.00	0.16	8.50	2.63
Lac Spencer 2	0.18	0.05	19.14	1.63	0.00	0.04	14.86	1.17
Lac Spencer 3	0.10	0.04	20.18	2.59	0.00	0.03	43.35	1.72
Nicabau 1	0.00	0.03	26.97	2.14	0.00	0.02	19.46	1.20
Nicabau 2	0.07	0.03	5.02	3.77	0.00	0.02	14.52	2.59
Nicabau 3	0.04	0.04	14.75	6.29	0.00	0.08	14.02	6.20

Sample	Day 119 Mineral N (ug/ml)				Day 147 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.00	1.25	68.74	0.61	0.67	10.70	68.41	0.21
LLB lower 2	61.87	30.94	1.17	0.00	63.71	30.51	5.43	0.24
LLB lower 3	128.07	1.65	4.65	13.99	100.81	0.48	2.84	12.98
WC lower 1	142.48	0.56	14.84	30.90	122.65	0.52	4.26	25.26
WC lower 2	307.74	10.24	4.92	11.33	130.27	19.60	2.58	9.12
WC lower 3	213.60	25.59	3.96	10.10	76.17	33.13	2.39	11.21
Lac Spencer 1	12.43	1.51	69.30	5.25	2.69	0.42	55.79	4.19
Lac Spencer 2	1.47	0.19	31.83	2.62	2.07	0.12	39.52	3.19
Lac Spencer 3	0.98	0.13	33.60	4.86	1.57	0.08	32.13	2.11
Nicabau 1	0.36	0.58	45.12	4.40	2.04	0.08	40.82	3.39
Nicabau 2	0.63	0.15	55.57	5.42	1.32	0.11	62.49	2.90
Nicabau 3	0.69	0.13	18.97	6.18	1.38	0.09	21.42	3.72

Sample	Day 175 Mineral N (ug/ml)				Day 203 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.12	0.00	56.24	0.80	0.15	0.96	31.54	0.41
LLB lower 2	45.53	25.29	3.16	0.30	45.10	27.36	0.00	0.00
LLB lower 3	107.29	0.62	0.61	10.72	41.91	0.71	0.00	16.69
WC lower 1	205.82	2.53	5.57	21.09	191.31	1.99	2.80	23.60
WC lower 2	196.24	20.79	6.61	3.16	142.52	20.57	1.26	1.91
WC lower 3	194.48	25.31	3.11	5.53	91.86	19.50	0.51	2.66
Lac Spencer 1	4.27	0.17	53.81	4.84	2.99	0.12	44.95	4.09
Lac Spencer 2	0.66	0.11	61.95	3.06	0.57	0.08	65.92	3.36
Lac Spencer 3	0.51	0.08	38.54	1.24	0.00	0.07	31.02	2.65
Nicabau 1	0.16	0.17	77.69	6.46	0.00	0.07	109.76	4.86
Nicabau 2	0.50	0.23	60.09	3.45	0.24	0.07	41.77	2.84
Nicabau 3	0.35	0.18	34.27	2.25	0.21	0.09	29.17	3.00

Sample	Day 231 Mineral N (ug/ml)			
	NO3-		NH4+	
	Organic	Ae	Organic	Ae
LLB lower 1	0.77	0.50	39.97	0.35
LLB lower 2	60.49	12.87	2.08	0.14
LLB lower 3	75.01	0.30	1.44	10.74
WC lower 1	145.26	1.92	4.64	17.00
WC lower 2	139.52	23.64	3.91	0.58
WC lower 3	67.03	14.02	2.27	2.24
Lac Spencer 1	1.85	0.09	50.28	4.63
Lac Spencer 2	0.00	0.06	33.83	4.16
Lac Spencer 3	0.07	0.07	30.13	3.22
Nicabau 1	0.00	0.06	70.58	4.12
Nicabau 2	0.14	0.05	52.70	3.41
Nicabau 3	0.27	0.14	43.12	2.74

3.4c: 33 kPa Moisture Tension

			Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
Sample	Initial Organic weight (g)	Initial Ae weight (g)	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	158.55	125.26	0.008	0.001	0.21	0.16	0.30	0.03
LLB lower 2	142.04	125.74	0.008	0.000	0.45	0.15	0.03	0.04
LLB lower 3	223.32	118.47	0.014	0.001	0.36	0.01	4.80	0.35
WC lower 1	145.77	125.75	0.025	0.002	0.51	0.06	23.22	0.37
WC lower 2	134.81	125.60	0.019	0.002	0.45	0.27	4.17	0.29
WC lower 3	93.84	125.60	0.025	0.001	0.63	0.32	49.03	2.14
Lac Spencer 1	242.35	99.94	0.012	0.001	0.42	0.02	2.88	0.00
Lac Spencer 2	99.01	100.27	0.014	0.001	0.75	0.00	11.25	0.00
Lac Spencer 3	94.78	100.34	0.013	0.001	0.57	0.01	0.69	0.95
Nicabau 1	141.95	100.60	0.014	0.001	0.48	0.02	4.17	0.46
Nicabau 2	203.10	100.17	0.009	0.001	0.48	0.05	0.42	2.99
Nicabau 3	217.46	100.57	0.008	0.000	0.00	0.27	0.09	4.97

	Day 14 Mineral N (ug/ml)				Day 28 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.02	0.02	2.85	0.02	0.02	0.00	4.92	0.12
LLB lower 2	0.02	0.02	0.75	0.04	0.00	0.00	2.59	0.24
LLB lower 3	0.13	0.01	7.43	0.13	1.04	0.00	6.95	0.28
WC lower 1	0.60	0.05	45.69	5.69	1.10	0.00	58.45	5.42
WC lower 2	0.49	0.03	56.12	3.29	0.27	0.08	48.03	6.15
WC lower 3	0.29	0.01	76.99	10.05	0.21	0.03	63.54	9.62
Lac Spencer 1	0.12	0.02	34.05	0.37	0.00	0.01	35.63	1.77
Lac Spencer 2	0.18	0.02	23.43	0.34	0.00	2.05	26.94	1.37
Lac Spencer 3	0.04	0.04	8.10	3.98	0.00	0.03	21.28	3.07
Nicabau 1	0.03	0.02	16.94	2.35	0.00	0.00	31.81	3.49
Nicabau 2	0.01	0.04	0.91	5.55	0.00	0.03	3.34	4.93
Nicabau 3	0.01	0.05	0.52	6.28	0.00	0.03	5.31	6.00

	Day 42 Mineral N (ug/ml)				Day 56 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.03	0.13	19.09	0.08	0.19	0.09	12.28	0.06
LLB lower 2	0.00	4.17	0.99	3.70	0.16	14.65	9.90	0.04
LLB lower 3	*	0.22	1.99	2.68	30.43	0.47	0.77	5.38
WC lower 1	25.56	0.21	101.00	13.02	44.39	0.25	32.32	7.17
WC lower 2	10.71	0.42	183.55	22.72	41.99	0.20	57.64	15.54
WC lower 3	11.09	0.37	191.55	29.66	27.63	0.57	79.56	15.00
Lac Spencer 1	0.66	0.28	88.03	3.10	0.25	0.04	19.17	1.96
Lac Spencer 2	0.27	0.18	72.19	3.29	0.20	0.21	33.11	1.97
Lac Spencer 3	0.18	0.05	44.47	6.17	0.00	0.21	17.68	2.91
Nicabau 1	0.15	0.00	45.52	3.54	0.19	0.03	11.98	2.42
Nicabau 2	0.17	0.02	3.23	4.63	0.20	0.02	1.48	2.85
Nicabau 3	0.14	0.05	20.11	11.23	0.34	0.02	17.58	3.77

	Day 70 Mineral N (ug/ml)				Day 90 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.03	0.85	12.08	0.72	0.22	0.49	11.16	0.37
LLB lower 2	0.51	13.90	14.98	0.61	1.70	15.88	10.75	0.00
LLB lower 3	81.56	0.35	0.83	4.02	132.50	0.64	0.25	11.04
WC lower 1	122.61	0.36	18.39	8.06	105.74	0.42	1.83	10.08
WC lower 2	184.14	3.26	22.32	15.76	152.47	4.86	1.58	13.31
WC lower 3	117.14	3.02	61.99	30.61	160.48	28.45	5.39	18.06
Lac Spencer 1	0.81	0.36	18.18	1.08	2.89	0.46	42.91	1.73
Lac Spencer 2	0.54	0.43	27.25	2.48	0.60	0.33	15.03	1.32
Lac Spencer 3	0.07	0.25	33.19	3.50	0.61	0.20	24.22	1.17
Nicabau 1	0.00	0.37	25.20	2.03	0.46	0.03	34.76	1.98
Nicabau 2	0.16	0.25	4.64	1.93	0.23	0.04	1.89	3.23
Nicabau 3	0.15	0.31	17.69	3.10	0.37	0.03	12.01	2.62

	Day 119 Mineral N (ug/ml)				Day 147 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.58	3.23	23.86	0.64	0.15	7.94	20.78	0.31
LLB lower 2	11.40	27.95	9.29	0.44	8.35	22.19	4.66	0.25
LLB lower 3	126.67	1.73	3.93	10.67	118.54	0.81	0.32	12.57
WC lower 1	114.35	0.41	5.59	24.66	138.02	0.87	3.53	18.36
WC lower 2	158.32	11.83	5.76	14.03	163.78	10.56	3.09	6.28
WC lower 3	120.40	25.04	3.01	7.45	49.49	0.00	3.20	5.57
Lac Spencer 1	2.16	1.53	88.68	5.41	0.85	0.87	54.30	1.60
Lac Spencer 2	0.30	0.33	44.88	3.30	0.66	0.66	33.84	1.07
Lac Spencer 3	0.06	0.15	37.38	4.06	0.57	0.51	32.13	2.09
Nicabau 1	0.14	0.48	56.60	4.04	0.00	0.58	32.22	2.24
Nicabau 2	0.04	0.24	15.89	7.70	0.00	0.52	20.39	3.05
Nicabau 3	0.30	0.23	27.32	4.49	0.13	0.65	39.44	3.84

	Day 175 Mineral N (ug/ml)				Day 203 Mineral N (ug/ml)			
Sample	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.81	3.88	26.66	0.05	6.49	9.82	22.77	0.06
LLB lower 2	46.93	8.47	3.82	0.31	14.21	17.71	2.27	0.23
LLB lower 3	107.05	0.22	1.62	12.14	139.06	0.39	1.03	15.15
WC lower 1	116.74	0.23	1.53	19.54	141.14	0.16	1.83	19.90
WC lower 2	162.78	15.34	1.95	7.19	136.05	29.20	2.56	3.89
WC lower 3	122.24	31.27	1.87	5.74	171.86	19.68	4.00	2.76
Lac Spencer 1	2.75	0.21	107.23	5.28	3.52	0.11	133.94	5.35
Lac Spencer 2	1.85	0.98	34.61	1.39	1.36	0.28	63.51	1.77
Lac Spencer 3	0.31	0.53	29.04	1.42	0.10	0.04	41.68	1.54
Nicabau 1	0.37	0.07	56.65	1.07	0.00	0.02	92.72	1.46
Nicabau 2	0.60	0.06	23.48	3.81	0.00	0.02	27.23	4.48
Nicabau 3	0.53	0.08	43.68	4.94	0.00	0.03	37.62	4.20

Sample	Day 231 Mineral N (ug/ml)			
	NO3-		NH4+	
	Organic	Ae	Organic	Ae
LLB lower 1	0.29	8.09	27.43	0.00
LLB lower 2	20.59	4.81	2.06	0.00
LLB lower 3	101.40	0.17	1.02	10.38
WC lower 1	71.84	0.28	1.52	12.25
WC lower 2	112.54	21.50	2.25	1.49
WC lower 3	118.04	10.82	3.26	2.07
Lac Spencer 1	3.60	0.10	64.19	2.04
Lac Spencer 2	0.99	0.10	41.18	0.44
Lac Spencer 3	0.56	0.04	37.71	0.46
Nicabau 1	0.57	0.02	79.61	0.30
Nicabau 2	0.45	0.05	27.15	3.72
Nicabau 3	0.43	0.16	29.15	3.13

3.4d: 60 kPa Moisture Tension

Sample	Initial Organic weight (g)	Initial Ae weight (g)	Total N (g N/g soil)		Day 0 Mineral N (ug/ml)			
					NO3-		NH4+	
			Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	158.55	125.26	0.008	0.001	0.24	0.15	5.40	0.09
LLB lower 2	142.04	125.74	0.008	0.000	0.03	0.15	6.54	0.09
LLB lower 3	223.32	118.47	0.014	0.001	0.48	0.17	6.12	0.37
WC lower 1	145.77	125.75	0.025	0.002	0.42	0.25	21.33	1.20
WC lower 2	134.81	125.60	0.019	0.002	0.75	5.75	55.46	4.43
WC lower 3	93.84	125.60	0.025	0.001	1.26	0.13	25.71	1.77
Lac Spencer 1	242.35	99.94	0.012	0.001	0.06	0.14	2.19	0.02
Lac Spencer 2	99.01	100.27	0.014	0.001	0.54	0.10	4.56	0.02
Lac Spencer 3	94.78	100.34	0.013	0.001	0.39	0.00	1.11	1.19
Nicabau 1	141.95	100.60	0.014	0.001	0.27	0.10	0.69	0.40
Nicabau 2	203.10	100.17	0.009	0.001	0.33	0.10	0.30	2.59
Nicabau 3	217.46	100.57	0.008	0.000	0.00	0.21	0.27	3.85

Sample	Day 14 Mineral N (ug/ml)				Day 28 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.04	0.01	7.00	0.06	0.12	0.08	22.00	0.00
LLB lower 2	0.04	0.01	4.32	0.07	0.54	0.05	6.01	0.20
LLB lower 3	0.09	0.02	4.03	0.13	16.42	0.03	2.18	0.23
WC lower 1	0.34	0.03	74.60	0.24	1.75	0.09	59.41	5.02
WC lower 2	0.41	0.76	35.79	10.71	0.97	0.52	122.46	9.32
WC lower 3	0.04	0.05	16.60	3.65	16.25	0.10	78.61	6.08
Lac Spencer 1	0.80	0.01	29.18	0.14	0.36	0.06	30.62	0.27
Lac Spencer 2	0.05	0.02	12.51	0.17	0.01	0.08	30.86	0.85
Lac Spencer 3	0.10	0.02	8.52	2.16	0.05	0.10	21.16	4.87
Nicabau 1	0.01	0.02	1.21	0.94	0.09	0.08	3.05	1.28
Nicabau 2	0.01	0.03	0.93	3.92	0.05	0.05	2.77	3.95
Nicabau 3	0.01	0.06	2.11	4.53	0.09	0.10	8.45	6.10

Sample	Day 42 Mineral N (ug/ml)				Day 56 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.36	0.00	43.61	0.00	0.42	0.12	31.66	0.13
LLB lower 2	16.62	4.12	8.55	5.77	15.55	12.12	1.88	0.15
LLB lower 3	46.07	0.22	2.33	3.97	50.67	0.24	1.07	3.29
WC lower 1	24.14	0.00	91.41	5.75	1.35	0.31	18.52	8.92
WC lower 2	9.87	1.11	193.41	22.18	40.68	2.50	113.44	19.64
WC lower 3	44.95	0.00	87.24	11.59	92.59	0.63	54.14	12.85
Lac Spencer 1	1.40	0.00	34.15	1.33	87.03	0.15	33.49	0.70
Lac Spencer 2	0.33	0.00	64.30	3.01	2.01	0.21	50.98	1.75
Lac Spencer 3	0.29	0.00	30.64	7.92	1.01	0.16	57.21	3.48
Nicabau 1	0.20	0.00	13.89	2.08	0.50	0.17	30.36	3.15
Nicabau 2	0.18	0.00	4.18	5.44	0.76	0.21	12.59	3.38
Nicabau 3	0.13	0.00	17.75	6.36	0.72	0.15	28.51	3.64

Sample	Day 70 Mineral N (ug/ml)				Day 90 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.15	0.15		0.12	0.30	0.22	42.05	0.08
LLB lower 2	21.67	29.55	1.94	0.35	24.94	17.27	1.83	0.04
LLB lower 3	52.00	0.47	0.42	7.19	54.81	0.45	0.46	5.20
WC lower 1	142.74	0.40	6.04	13.82	142.76	0.38	1.68	2.71
WC lower 2	124.99	1.22	65.89	16.19	259.07	3.16	5.00	7.88
WC lower 3	140.72	3.53	5.36	17.66	100.95	4.96	0.79	15.27
Lac Spencer 1	0.89	0.14	7.83	2.90	2.33	0.35	4.48	0.63
Lac Spencer 2	0.46	0.38	44.48	2.64	0.74	0.31	27.66	1.25
Lac Spencer 3	0.29	0.22	21.41	3.32	0.46	0.35	11.40	1.64
Nicabau 1	0.21	0.02	7.40	2.36	0.39	0.35	10.11	1.68
Nicabau 2	0.07	0.03	2.57	4.20	0.45	0.25	7.92	2.51
Nicabau 3	0.16	0.29	18.93	4.00	0.51	0.21	21.86	2.94

Sample	Day 119 Mineral N (ug/ml)				Day 147 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	0.99	0.97	46.76	0.18	10.86	2.21	73.84	0.19
LLB lower 2	38.93	16.19	2.49	0.04	44.09	20.46	2.27	0.16
LLB lower 3	249.63	0.91	3.66	6.30	129.68	0.85	0.31	7.54
WC lower 1	273.76	0.15	6.35	5.11	268.94	0.76	2.52	7.94
WC lower 2	264.32	4.61	8.38	5.73	181.11	0.94	3.73	2.24
WC lower 3	139.50	13.58	1.84	14.28	156.85	40.13	4.29	20.74
Lac Spencer 1	10.76	0.81	22.47	1.09	2.64	0.79	39.92	1.53
Lac Spencer 2	1.91	0.13	34.88	1.53	1.21	0.63	44.42	1.34
Lac Spencer 3	1.11	0.12	29.24	3.98	1.08	0.66	34.31	2.16
Nicabau 1	0.74	0.06	22.93	1.25	0.22	0.48	26.46	1.92
Nicabau 2	0.42	0.09	21.87	3.23	0.28	0.35	10.22	2.10
Nicabau 3	0.59	0.09	28.01	4.07	0.56	0.67	36.96	4.22

Sample	Day 175 Mineral N (ug/ml)				Day 203 Mineral N (ug/ml)			
	NO3-		NH4+		NO3-		NH4+	
	Organic	Ae	Organic	Ae	Organic	Ae	Organic	Ae
LLB lower 1	9.72	8.81	57.18	0.30	12.51	16.43	69.96	0.20
LLB lower 2	51.35	19.94	4.32	0.01	109.46	25.47	6.90	0.06
LLB lower 3	157.32	0.54	2.35	6.60	137.48	0.84	3.44	10.62
WC lower 1	164.45	0.03	2.29	1.70	160.20	0.20	4.76	2.18
WC lower 2	153.99	1.23	5.62	1.76	243.62	1.39	6.61	2.92
WC lower 3	152.68	30.07	4.49	9.42	207.44	14.63	5.39	3.91
Lac Spencer 1	3.68	0.16	34.53	1.07	5.94	0.07	52.80	2.08
Lac Spencer 2	0.00	0.09	42.00	1.37	1.43	0.04	80.65	1.25
Lac Spencer 3	0.00	0.07	23.90	1.54	0.86	0.06	28.48	2.05
Nicabau 1	0.17	0.08	38.11	1.18	1.00	0.03	25.45	1.08
Nicabau 2	0.00	0.05	8.47	2.08	0.61	0.03	14.82	1.34
Nicabau 3	0.16	0.09	45.52	2.54	1.06	0.08	40.05	2.29

Sample	Day 231 Mineral N (ug/ml)			
	NO3-		NH4+	
	Organic	Ae	Organic	Ae
LLB lower 1	14.35	9.52	70.86	0.00
LLB lower 2	58.98	13.57	2.83	0.07
LLB lower 3	58.28	0.46	0.90	8.47
WC lower 1	101.25	0.06	1.63	3.24
WC lower 2	111.27	0.48	1.42	1.11
WC lower 3	87.97	16.32	0.68	3.15
Lac Spencer 1	2.84	0.10	35.55	2.20
Lac Spencer 2	0.53	0.05	60.09	0.75
Lac Spencer 3	0.55	0.05	20.09	1.54
Nicabau 1	0.62	0.04	28.61	0.46
Nicabau 2	0.65	0.05	12.31	1.58
Nicabau 3	0.45	0.17	38.27	2.43

LLB = Lac La Biche
WC = Whitecourt

APPENDIX 4.0

Modification to Mineral N Analysis

NH_4Cl reagent for NO_3^- analysis

1. Weigh out 10.0 g NH_4Cl (Anal R grade or better).
2. Put in 1L volumetric flask.
3. Add approximately 500 ml deionized water and mix well.
4. When dissolved add 7 to 9 g NaOH.
5. Mix until dissolved. Make to volume with deionized water. Mix well.
6. Add 0.5 ml Brij (surfactent). Mix.
7. Used with color developing solution for NO_3^- analysis with a 0.5 M HCl matrix.

*Does not keep more than 24 hours.

**When diluting sample 10X with deionized water, change wash solution to 0.05 M HCl and only use 0.7 to 0.9 g NaOH for 1L of NH4Cl solution (see below).

$$10\,g\ NaOH + 0.9\,g\ NaOH \xrightarrow{0.5ml\,Brij} 1000ml$$

*Calculation of Effective Soil Volume for Complete Soil**

$CaCl_2$ extraction ($\mu g\ cm^{-3}$):

$$\frac{\left[\min N\left(mgL^{-1}\right) * 0.1\ L\right] * \dfrac{1000\ \mu g}{1\ mg}}{volume\ soil\left(cm^{3}\right)}$$

IEM or ERB effective volume (cm^{-3}):

$$\frac{\left[IEM \min N\left(mg\ L^{-1}\right) * 0.1\ L\right] * \dfrac{1000\ \mu g}{1\ mg}}{CaCl_2\ extraction\left(\mu g\ cm^{-3}\right)}$$

Complete soil 0.01 M CaCl2 Day	soil volume cm3	NO3	NH4	NO3	NH4	NO3	NH4
		mg/L		ug N		ug/cm3	
0	397.6	0.20	0.22	20.00	22.33	0.050	0.056
5	397.6	0.01	61.20	1.33	6120	0.003	15.39
10	397.6	0.03	74.15	3.00	7415	0.008	18.65

IEM Day	NO3	NH4	NO3	NH4	NO3*	NH4**
	mg/L		ug N		ug/cm3	
5	0.02	2.57	1.67	257	33	17
10	0.01	3.22	1.00	322	20	17

ERB Day	NO3	NH4	NO3	NH4	NO3*	NH4**
	mg/L		ug N		ug/cm3	
5	0.06	15.30	5.67	1530	113	99
10	0.04	28.80	4.33	2880	86	154

*NO_3^- values were divided by day 0 $CaCl_2$ values

**NH_4^+ values were divided by respective day 5 and 10 0.01 M $CaCl_2$ extraction values

4.3a: Measured values (mg L^{-1}) for complete, coarse, medium and fine size fractions

Objective 1: Varied Ped Size

CaCl2	NO3				Soil volume
			mg/L		cm3
Day 0	Complete	0.22	0.18	0.20	397.60
	Coarse	0.07	0.05	0.09	530.10
	Medium	0.10	0.08	0.08	508.10
	Fine	0.11	0.12	0.16	397.60
Day 5	Complete	0.01	0.02	0.01	397.60
	Coarse	0.01	0.17	0.00	530.10
	Medium	0.01	0.00	0.01	508.10
	Fine	0.01	0.03	0.01	397.60
Day 10	Complete	0.03	0.03	0.03	397.60
	Coarse	0.02	0.01	0.01	530.10
	Medium	0.02	0.02	0.03	508.10
	Fine	0.01	0.01	0.02	397.60

CaCl2	NH4		mg/L		Soil volume
Day 0	Complete	0.27	0.26	0.14	397.60
	Coarse	0.05	0.12	0.07	530.10
	Medium	0.05	0.02	0.05	508.10
	Fine	0.48	1.38	1.14	397.60
Day 5	Complete	58.64	61.29	63.66	397.60
	Coarse	76.09	64.50	77.21	530.10
	Medium	75.47	66.35	55.15	508.10
	Fine	45.93	53.76	46.53	397.60
Day 10	Complete	69.69	75.39	77.36	397.60
	Coarse	65.84	39.52	77.26	530.10
	Medium	76.75	66.69	56.02	508.10
	Fine	49.53	67.21	82.37	397.60

IEM	NO3		mg/L		Soil volume
Day 0	Complete	0.32	0.08	0.22	397.60
	Coarse	0.01	0.01	0.01	530.10
	Medium	0.00	0.02	0.00	508.10
	Fine	0.03	0.01	0.00	397.60
Day 5	Complete	0.01	0.02	0.02	397.60
	Coarse	0.01	0.01	0.01	530.10
	Medium	0.02	0.02	0.02	508.10
	Fine	0.01	0.01	0.02	397.60
Day 10	Complete	0.01	0.01	0.01	397.60
	Coarse	0.00	0.01	0.01	530.10
	Medium	0.02	0.02	0.01	508.10
	Fine	0.00	0.01	0.01	397.60

IEM	NH4		mg/L		Soil volume
Day 0	Complete	0.03	0.29	0.27	397.60
	Coarse	0.13	0.24	0.30	530.10
	Medium	0.02	0.26	0.34	508.10
	Fine	0.34	0.25	0.36	397.60
Day 5	Complete	2.35	2.22	3.14	397.60
	Coarse	2.01	1.42	1.47	530.10
	Medium	1.80	1.28	1.84	508.10
	Fine	2.83	2.66	2.23	397.60
Day 10	Complete	3.08	2.72	3.87	397.60
	Coarse	2.09	2.35	3.40	530.10
	Medium	2.87	1.85	3.08	508.10
	Fine	5.06	3.95	3.65	397.60

ERB	NO3		mg/L		Soil volume
Day 0	Complete	0.06	0.40	0.07	397.60
	Coarse	0.05	0.43	0.05	530.10
	Medium	0.05	0.41	0.07	508.10
	Fine	0.03	5.04	0.06	397.60
Day 5	Complete	0.06	0.06	0.05	397.60
	Coarse	0.09	0.06	0.05	530.10
	Medium	0.08	0.07	0.07	508.10
	Fine	0.06	0.09	0.07	397.60
Day 10	Complete	0.05	0.04	0.04	397.60
	Coarse	0.05	0.05	0.04	530.10
	Medium	0.04	0.05	0.04	508.10
	Fine	0.09	0.04	0.04	397.60

ERB	NH4		mg/L		Soil volume
Day 0	Complete	0.40	0.07	0.09	397.60
	Coarse	0.43	0.04	0.07	530.10
	Medium	0.41	0.04	0.07	508.10
	Fine	5.04	0.09	0.02	397.60
Day 5	Complete	14.16	14.34	17.41	397.60
	Coarse	11.28	9.24	15.41	530.10
	Medium	8.92	9.52	10.75	508.10
	Fine	14.17	21.49	26.56	397.60
Day 10	Complete	30.88	25.46	30.05	397.60
	Coarse	23.55	29.25	28.19	530.10
	Medium	24.08	24.06	25.41	508.10
	Fine	0.13	36.00	36.17	397.60

4.3b: Measured values (mg L^{-1}) for 8, 24, and 48 hour leaching intensities

Objective 2: Different Leaching Intensities

IEM leaching	NH4				Soil volume
			mg/L		cm3
Day 5	8	0.05	0.02	0.02	397.60
	24	0.09	0.02	0.00	397.60
	48	0.04	0.09	0.09	397.60
Day 10	8	0.11	0.13	0.14	397.60
	24	0.23	0.17	0.13	397.60
	48	0.37	0.33	0.22	397.60

ERB leaching	NH4				Soil volume
Day 5	8	0.05	0.02	0.02	397.60
	24	0.00	0.05	0.02	397.60
	48	0.03	0.04	0.02	397.60
Day 10	8	0.24	0.23	0.13	397.60
	24	0.12	0.10	0.13	397.60
	48	0.06	0.15	0.15	397.60

IEM	NO3		mg/L		Soil volume
Day 0	8 hours	0.01	0.01	0.01	397.60
	24 hours	0.01	0.01	0.00	397.60
	48 hours	0.01	0.01	0.00	397.60
Day 5	8 hours	0.02	0.02	0.00	397.60
	24 hours	0.01	0.01	0.01	397.60
	48 hours	0.01	0.01	0.01	397.60
Day 10	8 hours	0.00	0.00	0.00	397.60
	24 hours	0.00	0.00	0.00	397.60
	48 hours	0.00	0.00	0.00	397.60

IEM	NH4		mg/L		Soil volume
Day 0	8 hours	0.05	0.04	0.03	397.60
	24 hours	0.08	0.03	0.05	397.60
	48 hours	0.00	0.05	0.03	397.60
Day 5	8 hours	2.67	2.09	2.47	397.60
	24 hours	2.00	1.49	1.93	397.60
	48 hours	2.02	1.61	1.70	397.60
Day 10	8 hours	3.62	3.31	4.60	397.60
	24 hours	3.63	2.57	2.35	397.60
	48 hours	2.24	1.92	3.05	397.60

ERB	NO3		mg/L		Soil volume
Day 0	8 hours	0.06	0.07	0.05	397.60
	24 hours	0.05	0.06	0.06	397.60
	48 hours	0.05	0.05	0.05	397.60
Day 5	8 hours	0.04	0.06	0.04	397.60
	24 hours	0.03	0.05	0.04	397.60
	48 hours	0.03	0.04	0.05	397.60
Day 10	8 hours	0.02	0.02	0.02	397.60
	24 hours	0.02	0.02	0.00	397.60
	48 hours	0.02	0.01	0.10	397.60

ERB	NH4		mg/L		Soil volume
Day 0	8 hours	0.10	0.14	0.15	397.60
	24 hours	0.05	0.10	0.12	397.60
	48 hours	0.11	0.08	0.15	397.60
Day 5	8 hours	34.73	34.61	23.75	397.60
	24 hours	36.95	34.16	4.02	397.60
	48 hours	36.44	4.47	4.40	397.60
Day 10	8 hours	35.40	37.01	39.06	397.60
	24 hours	27.84	19.87	40.17	397.60
	48 hours	27.95	39.68	39.93	397.60

4.3c: Measured values (mg L^{-1}) for control, casein and starch treatments

Objective 3: Different Levels of N

CaCl2	NO3				Soil volume
			mg/L		cm3
Day 0	Control	0.14	0.13	0.15	397.60
	Casein	0.15	0.18	0.07	397.60
	Starch	1.85	2.45	2.59	397.60
Day 5	Control	0.07	0.02	0.02	397.60
	Casein	0.00	0.01	0.01	397.60
	Starch	0.00	*	0.00	397.60
Day 10	Control	0.01	0.03	0.02	397.60
	Casein	0.03	0.02	0.02	397.60
	Starch	0.01	0.00	0.01	397.60

CaCl2	NH4		mg/L		Soil volume
Day 0	Control	0.04	0.11	0.15	397.60
	Casein	0.03	0.09		397.60
	Starch	0.02	0.00	0.04	397.60
Day 5	Control	0.27	0.41	0.38	397.60
	Casein	76.84	76.43	73.80	397.60
	Starch	0.00	*	0.00	397.60
Day 10	Control	0.28	0.41	0.57	397.60
	Casein	76.89	67.90	82.01	397.60
	Starch	0.01	0.02	0.02	397.60

IEM	NO3		mg/L		Soil volume
Day 0	Control	0.01	0.00	0.05	397.60
	Casein	0.00	0.01	0.01	397.60
	Starch	0.06	0.05	0.06	397.60
Day 5	Control	0.04	0.02	0.05	397.60
	Casein	0.18	0.03	0.04	397.60
	Starch	0.10	0.07	0.13	397.60
Day 10	Control	0.04	0.02	0.00	397.60
	Casein	0.33	0.01	0.00	397.60
	Starch	0.01	0.00	0.02	397.60

IEM	NH4		mg/L		Soil volume
Day 0	Control	0.04	0.01	0.03	397.60
	Casein	0.01	0.02	0.01	397.60
	Starch	0.02	0.04	0.05	397.60
Day 5	Control	0.00	0.00	0.00	397.60
	Casein	2.44	2.04	2.69	397.60
	Starch	0.00	0.00	0.00	397.60
Day 10	Control	0.01	0.04	0.04	397.60
	Casein	3.78	3.15	3.29	397.60
	Starch	0.05	0.03	0.10	397.60

ERB	NO3		mg/L		Soil volume
Day 0	Control	0.07	0.05	0.08	397.60
	Casein	0.09	0.07	0.05	397.60
	Starch	0.17	0.23	0.18	397.60
Day 5	Control	0.01	0.12	0.12	397.60
	Casein	0.14	0.12	0.13	397.60
	Starch	0.28	0.16	0.21	397.60
Day 10	Control	0.07	0.04	0.09	397.60
	Casein	0.06	0.06	0.09	397.60
	Starch	0.05	0.03	0.02	397.60

ERB	NH4		mg/L		Soil volume
Day 0	Control	0.05	0.06	0.02	397.60
	Casein	0.11	0.08	0.07	397.60
	Starch	0.04	0.06	0.11	397.60
Day 5	Control	0.00	0.00	0.20	397.60
	Casein	14.71	14.22	15.50	397.60
	Starch	0.00	0.00	0.23	397.60
Day 10	Control	0.42	0.14	0.20	397.60
	Casein	17.81	24.56	0.50	397.60
	Starch	0.04	0.02	0.09	397.60