

Monument Canyon Research Natural Area:
Soil Nitrogen Cycling Characteristics

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INTRODUCTION

The Nitrogen Cycle

Nitrogen is often the nutrient limiting production in conifer forests (Vitousek and Howarth 1991). To a large extent, the supply of nitrogen for plant growth in terrestrial ecosystems is determined by the rate at which organic-bound soil nitrogen is released in inorganic form; a process termed nitrogen mineralization (Fig. 1). The first inorganic form of nitrogen is ammonia (NH_3), which readily converts to ammonium (NH_4^+) in the soil solution. Ammonium (or ammonia) can be converted to nitrate (NO_3^-) through the two-step process of nitrification. Through the nitrification process, a portion of the ammonium-nitrogen can be lost to the atmosphere as nitrous oxide. Both ammonium and nitrate are assimilated by the soil microbial community and by higher plants. If demand for inorganic nitrogen by the microbial community is high, then concentrations of inorganic nitrogen within the soil may decline, which is termed 'immobilization.' Only when the demand by the microbial population is satisfied can concentrations of inorganic nitrogen increase within the soil, representing net mineralization.

Unlike ammonium, nitrate is negatively charged (an anion) and is mobile within the soil, which can lead to loss of nitrate from the terrestrial system to streams or ground water. Nitrate can be utilized by other microorganisms as a terminal electron acceptor, which results

in the production of nitrous oxide or di-nitrogen (N_2) gas, through the process of denitrification. Di-nitrogen gas can return to the atmosphere, completing the cycle. Nitrous oxide also can escape to the atmosphere, where it can undergo reactions with other chemicals.

Both nitrate and ammonium are assimilated into plant and microbial biomass through growth. Plants and microorganisms can move nitrate towards themselves through diffusion, but they must grow or move to sources of ammonium which is more tightly bound to soil particles. Nitrogen assimilated by a portion of the microbial community contributes to plant growth through mycorrhizal associations (Fig. 1). A portion of the microbial and plant biomass is consumed by animals. Eventually, microorganisms, higher plants, animals and their associated wastes become part of the soil organic matter pool, a portion of which rapidly decomposes and undergoes the process of mineralization to continue the cycle. In general, monoterpenes alter rates of nitrogen cycling by slowing both the mineralization and nitrification processes (see White 1994 for a detailed review of the role of monoterpenes throughout the nitrogen cycle).

Nitrogen Mineralization and Site Productivity

Following field collection of soil samples, Vitousek et al. (1982) demonstrated that the nitrogen mineralization pattern shown by laboratory-incubated soils was nearly identical to the pattern shown in field studies. This pattern production of inorganic nitrogen in soils is represented in Figure 2. The process of nitrogen mineralization begins when ammonium is liberated from previously organic-bound forms of nitrogen. Often there is a slight time lag after the initial buildup of ammonium before nitrate is produced from the inorganic ammonium. If it is not immobilized in new microbial growth or taken up by plant roots, nitrate can move with soil moisture and percolate to lower soil horizons (shown by increase in lysimeter in Fig. 2) and possibly appear in streams.

Vitousek et al. (1982) also demonstrated that different nitrogen mineralization patterns

were characteristic of ecosystems with differing productivity; highly productive systems sharing similar patterns and low productivity systems sharing different patterns. These patterns were a function of how fast the mineralization pattern occurred. In the least productive sites, the mineralization pattern was very slow and had only progressed to the point of increased rates of ammonium production after incubation (Fig. 3). This pattern represents the initial portion of the mineralization pattern up to the dashed line B in Figure 2, at which point only an increase in ammonium occurs and no nitrate production. Sites with intermediate productivity had patterns that showed nearly the entire mineralization pattern compressed into the incubation period (Fig. 3). The mineralization pattern for the most productive sites was compressed to the point that only the final portion of the general pattern was demonstrated (Fig. 3), which represents the portion of the pattern shown in Figure 2 from the dashed line A. Other research has shown that these patterns vary with time and with management practices, which suggests that site productivity may also be a function of management practices, at least in part.

Controls of Nitrogen Mineralization in Ponderosa Pine

White (1991b) proposed a conceptual model for the effects of increasing monoterpene concentrations on the inorganic nitrogen content of a soil. The model also may mimic the effects of fire on soil inorganic nitrogen because natural dynamics of monoterpenes in soils should follow the fire cycle. After fire, monoterpenes are in low concentration and net mineralization and nitrification are high (White 1991a). With time since fire, monoterpenes increase, lowering net mineralization (by increasing immobilization) and inhibiting nitrification by inhibiting the enzyme initially involved in the conversion of ammonium to nitrate (ammonium mono-oxygenase). Eventually, monoterpenes accumulate to the point that nitrogen cycling processes are greatly reduced, while their elevated concentrations concurrently increase the probability of another fire. The occurrence of low net nitrogen mineralization and little or no

net nitrification might indicate when a fire could be beneficial from a nutrient cycling perspective, regardless of the apparent fuel loads. Thus, the forests and their potential productivity could be managed from a soil nutrient perspective with mineralization patterns indicating when management with fire would be appropriate.

As part of the continuing effort to understand soil nitrogen cycling processes and the effects of management practices on these processes, soil samples were collected at Monument Canyon Research Natural Area located in the Jemez Mountains. The area is described in Peterson and Rasmussen (1986). Monument Canyon (approx. 2600 m elevation) lies in northern Sandoval County south of the East Fork of the Jemez River. Interior Ponderosa Pine (Type 20, Peterson and Rasmussen 1986) is the dominant vegetation type. This site was selected for study because the density of ponderosa pine reproduction is very high, yielding a stand that is termed “dog-hair” thick with small diameter stems. The hypothesis was that the buildup of fuels and monoterpenes should be near maximal under such conditions and that nitrogen cycling rates would be at a minimum.

METHODS

Site Selection

The site was selected in part because the New Mexico Natural Heritage Program, Department of Biology, UNM, and the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM, were conducting studies of stand characteristics under a cooperative agreement (#28-C4-807) on the RNA (Esteban Muldavan, personal communication).

Sample Collection

Samples were taken from 8 locations within the study stand (Section 9 of T. 18 N.; R. 3 E.); near E. Muldavin’s stand sites A2, A3, A4, A5, D1, E1, F1, and G1. Samples were collected

about 5 m south of the center point for the respective plots (to avoid disturbance at the center point). Samples included the forest floor horizons beneath a 200-cm² template and the 0- to 10-cm depth mineral soil horizon.

Analytical Methods

Methods detailed in White (1991a) were used to analyze all samples. All mineral soil samples were analyzed for nitrogen mineralization/nitrification potentials by aerobic incubation and subsequent extraction with KCl. The KCl extracts were analyzed for ammonium and nitrate with a Technicon AutoAnalyzer.

Statistical Analyses

All statistical analyses were performed with StatView SE© (BrainPower, Inc.).

RESULTS

Mineralization Patterns

Soils at the Monument Canyon Research Natural Area had highly variable nitrogen mineralization potentials with both low and very high rates. In addition, the soils showed a wide range in their mineralization patterns (Fig. 4). All sites along the A transect (A2, A3, A4, A5) and site G1 showed typical patterns of nitrogen mineralization with only an increase in ammonium during incubation and low or no nitrate production. Of these samples, A4 and G1 also had typically low rates of ammonium production (below 30 mg/kg NH₄-N); however, the other sites (A2, A3, A5) had very high rates of ammonium production, up to 130 mg/kg NH₄-N! Sites D1, E1, and F1 had high rates of nitrification during incubation, responses that are more typical of higher productivity forests. Site E1 and F1 showed patterns typical of very high

productivity sites with ammonium gradually declining and nitrate immediately increasing through the incubation.

DISCUSSION

The reason for choosing this site in part was to test the prediction that the site should demonstrate the pattern of low mineralization and inhibition of nitrification. This pattern was seen at other sites in the Jemez Mountains that have a long period since fire. The mechanism behind the proposed pattern was the accumulation of monoterpene-rich litter, which also contained specific monoterpenes that inhibit nitrification and net mineralization. Since Monument Canyon is very dense with small dbh trees and the area has not had a fire of significant proportions for approximately 90 years, it was predicted that monoterpenes should have accumulated to a sufficient magnitude to produce the predicted response. It should be noted that monoterpene content was never directly measured.

The N mineralization patterns were not as expected (Fig. 4). Only sites A4 and G1 had the expected low rates of net N mineralization and little or no nitrate produced over the incubation period. There were two ways in which the other sites differed from this predicted pattern. First, although some sites showed little or no nitrification (as predicted), the rate of ammonium production was much greater than expected. Second, two sites (E1, D1) show mineralization patterns similar to higher productivity sites with no apparent lag in nitrification (nitrate rose at the beginning of the incubation).

The two mineralization/nitrification patterns different from the predicted could have multiple causes. The greater than expected production of ammonium could occur if monoterpenes were low enough to allow net mineralization to occur without the stimulation of net immobilization (or low mineralization) that most carbon-rich compounds would be expected to produce. Lower than expected monoterpene concentrations could result from lower than expected concentrations of monoterpenes in the needles and thus the forest floor, or from

higher than expected rates of breakdown or consumption of needle monoterpenes.

The high rates of nitrification in sites E1, F1, and D1 could result from two factors. First, the total amount of monoterpenes in the forest floor and soil could be low because of low rates of input and/or high rates of consumption. This factor could be supported by an inverse relationship between rates of nitrification and forest floor mass, which represents the potential source of monoterpenes. Such a relationship was shown (Fig. 5), but it was very weak. Also, there is a very distinct mass of forest floor above which little or nitrification occurred (approximately 50 g per 200 cm²). Such a dramatic effect on nitrification with such a slight increase in forest floor mass seems unlikely. Second, high rates of nitrification could occur if the composition of monoterpenes changed along the approximate east-west sample line that includes D1, E1, F1, and G1. Such a change in composition could result from genetic differences in the dominant trees and their off-spring, which is expressed in different monoterpene composition and concentrations. A change in monoterpene composition coupled with declining concentrations could cause such abrupt changes in soil nitrification rates. This later explanation could be easily tested with collection and analysis of needles for monoterpene composition and concentration.

CONCLUSIONS

Although soils collected at some sites showed the expected pattern of low net nitrogen mineralization and nitrification rates, many soils showed different patterns. Part of the reason for these changes may be different monoterpenes produced by trees that differ genetically. The presence of such different patterns in such a relatively close position in the field may be useful in future investigations to identify the degree of control that plant genetics (as expressed by differing monoterpene composition and concentrations for genetically different trees) plays in ecosystem-level nutrient cycling. Future research on comparative monoterpene composition and their persistence in the field is strongly recommended at this site.

With respect to fire management, potential productivity at this site is already high. Given enough water (which would limit decomposition and production) and enough other resources (light, or another nutrient could become limiting) productivity at this site could be very high. This may be the case (high productivity), but the productivity is distributed among a high number of individuals. As recognized by Peterson and Rasmussen (1986), this high stocking also is very hazardous from a fire prevention and protection perspective. The fire hazard represents a greater threat to the site than potential nitrogen limitation, which does not appear limiting based on results of this study.

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List of Figures.

Figure 1. Responses of soil ammonium, soil nitrate, and lysimeter nitrate concentrations in laboratory incubations following soil collection in a hypothetical ecosystem. The phases of the response are given above that portion of the graph. Refer to the text for the meaning of lines A and B. (Redrawn from Vitousek et al. 1979, with permission)

Figure 2. Potential patterns for ammonium and nitrate concentrations in a soil following disturbance or during laboratory incubations for determination of mineralization and nitrification potentials. Patterns range from rapid (A), through intermediate (B), to slow (C).

Figure 3. Changes in inorganic nitrogen (ammonium open squares, nitrate closed circles) during laboratory incubation of mineral soil samples from Monument Canyon Research Natural Area

Figure 4. Patterns for extractable ammonium (open squares) and nitrate (closed circles) concentrations during laboratory incubations of soils collected at Monument Canyon. The samples shown in descending order lay in the same order an approximate north-south transect (Line A) in the field, while the samples shown along the diagonal lay in the order shown along an approximate west-east line extending to the east from line A.

Figure 5. The relationship between the amount of nitrate produced during 10-week incubation of 8 soil samples and their respective mass of forest floor (ash-free weight). Note the abrupt change in nitrate concentrations above about 50 g forest floor mass.

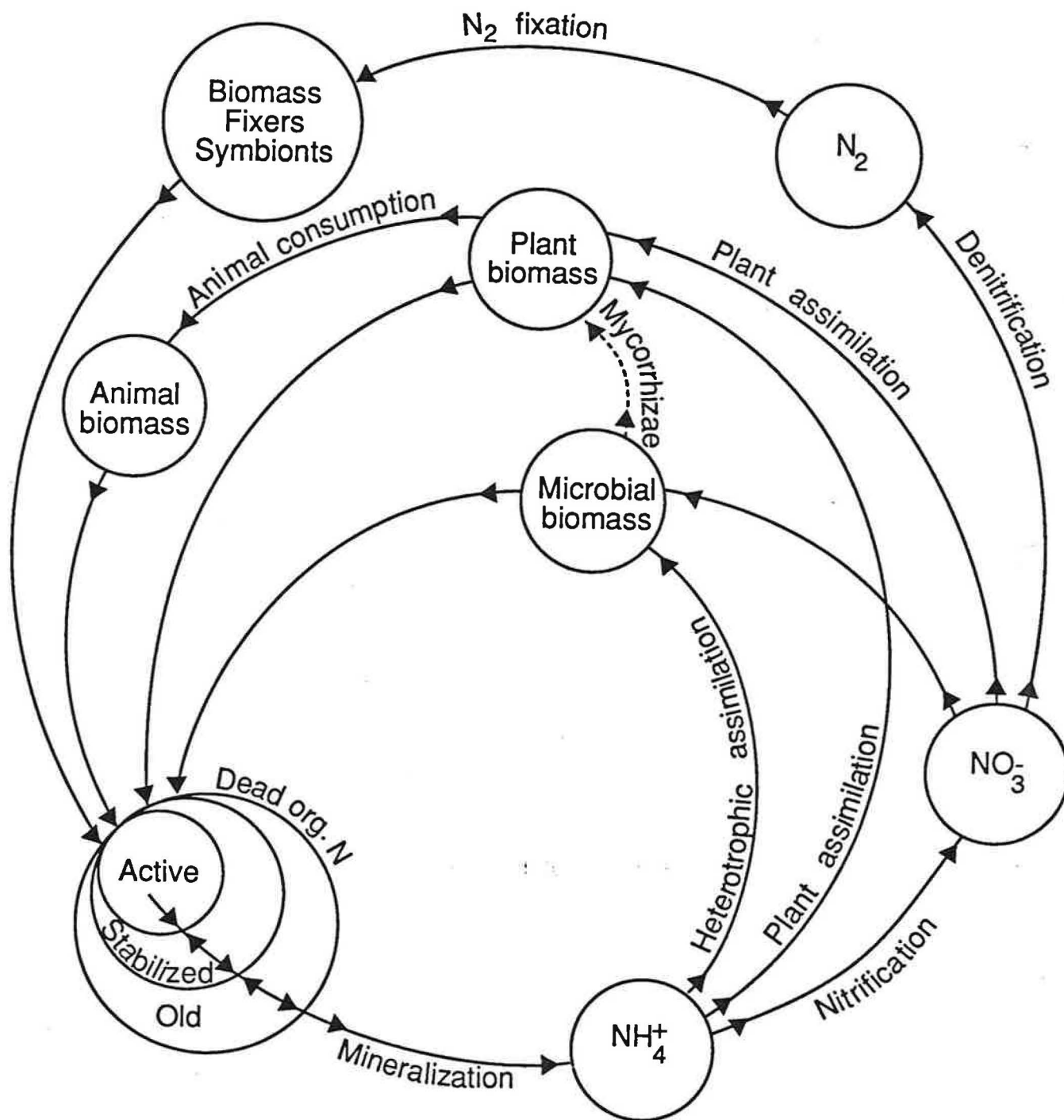


Figure 1

Nitrogen Mineralization Pattern

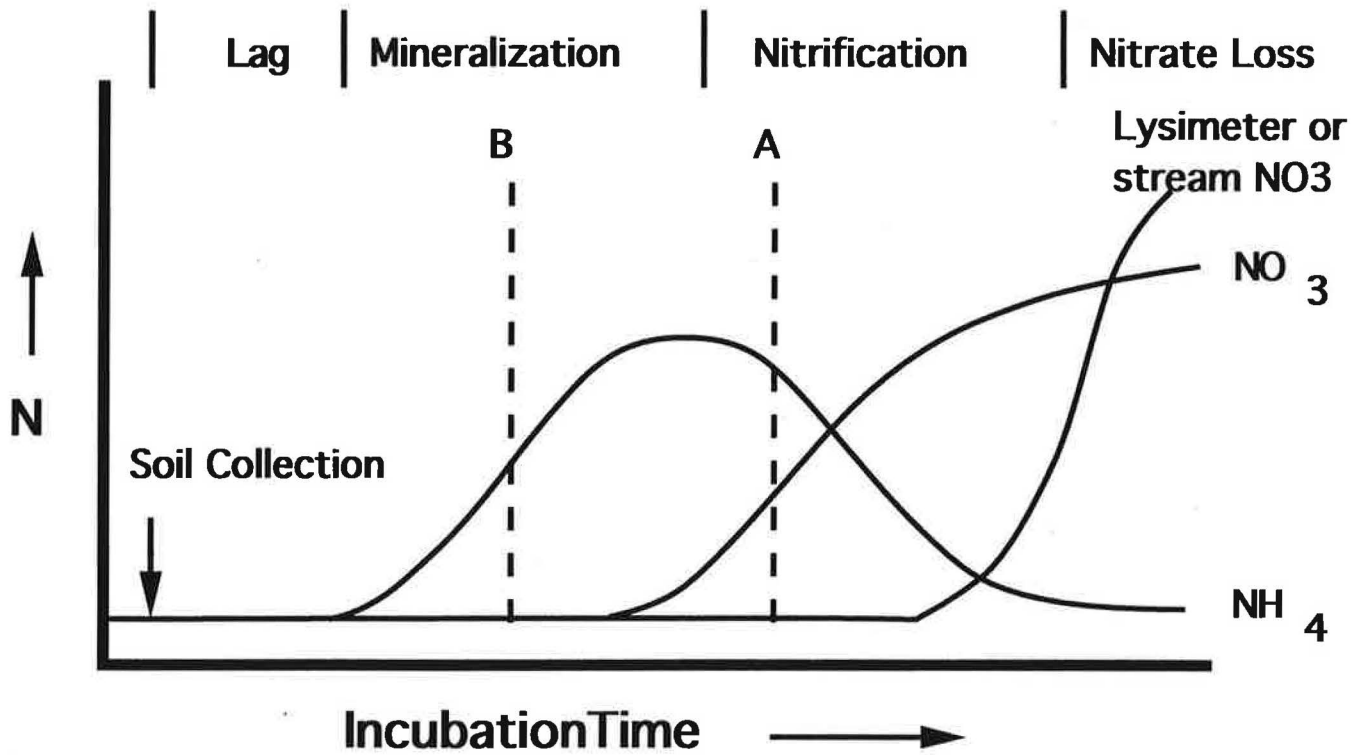


Figure 2

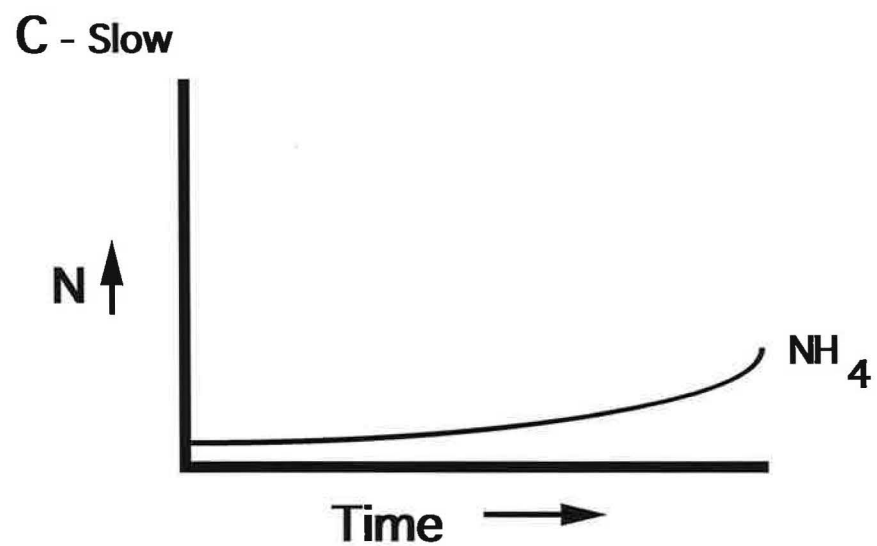
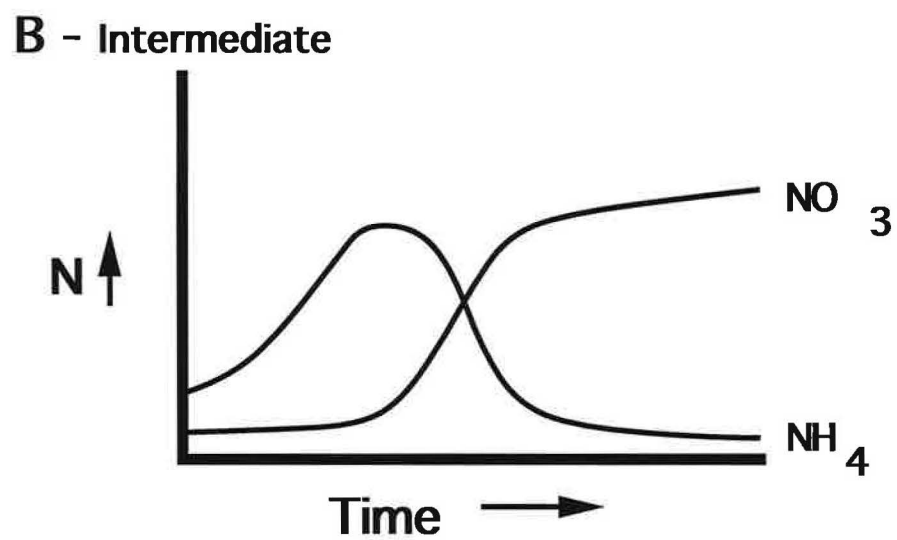
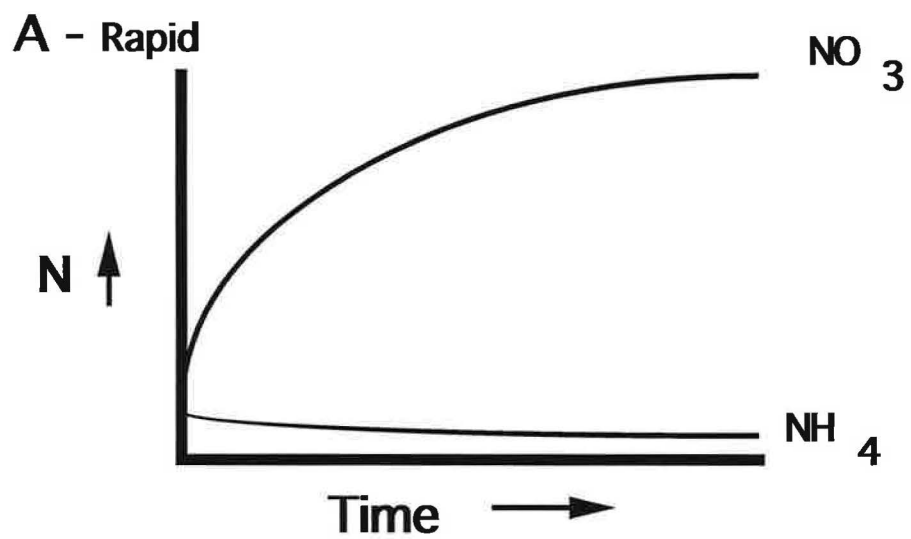


Figure 3

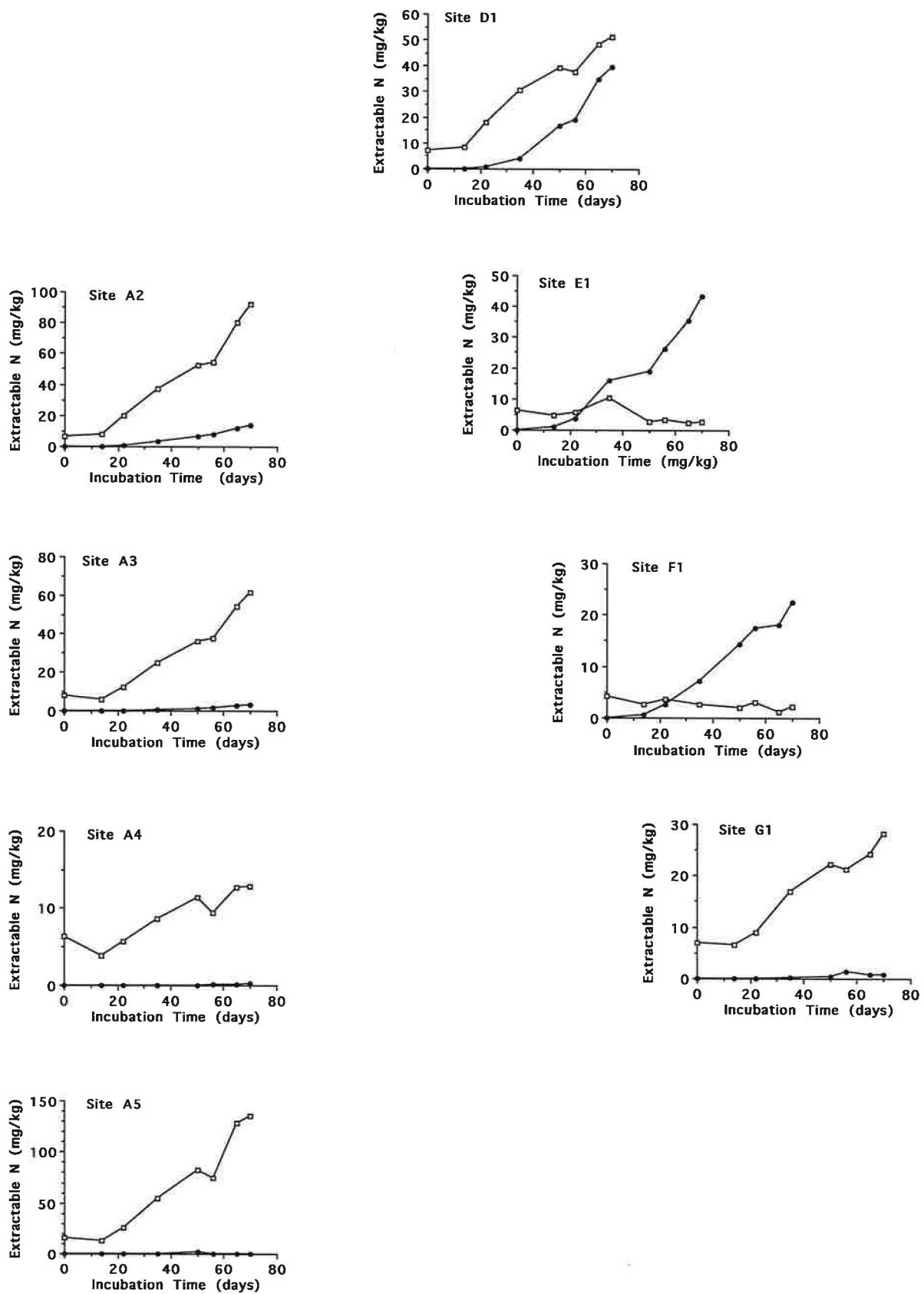


Figure 4

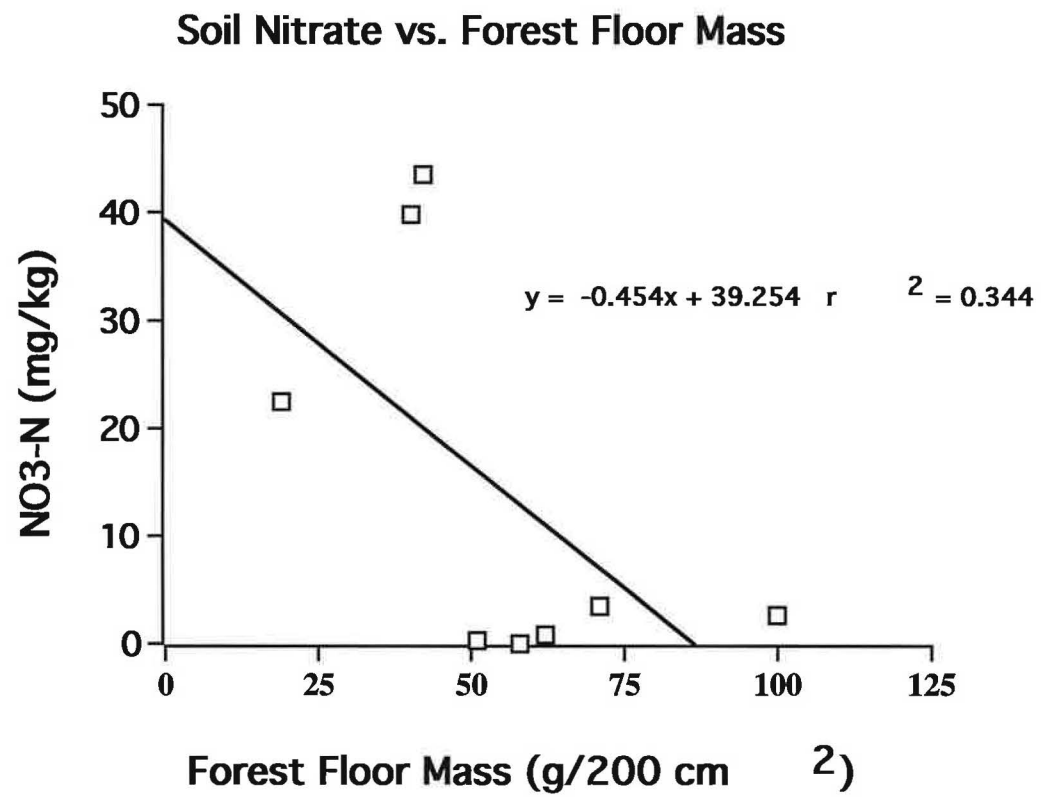


Figure 5