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Nitrate and Ammonium Levels in Relation to Site Quality in Douglas-fir Soil and Litter

Abstract

Nitrate and ammonium levels in the L horizon and soil to a 5 cm depth were analyzed during the months of July and January in three different aged Douglas-fir (*Pseudotsuga menziessi* (Mirb.) Franco) Site Class II stands and four Site Class IV stands in western Washington. Litter and soil ammonium levels in the high site quality (II) stand were significantly different from those in the low site quality (IV) stands. In contrast, however, nitrate concentrations were significantly greater in the high site quality stands. Total N or C did not appear related to the net nirate differences observed between the high and low site quality stands.

Introduction

Douglas-fir response to nitrogen fertilization has been shown to be greater in low site quality stands than in high site quality stands (Gessel and Atkinson ,1979). The response is attributed to differences in levels of available soil N (ammonium and nitrate). Few studies, however, have been conducted to determine in situ levels in soils in the Douglas-fir region. Even fewer studies have reported inorganic N levels in the litter where much of the nutrient release through decomposition is occurring.

Johnson (1979) has examined seasonal changes of available soil nitrogen in low site quality Douglas-fir stands and found ammonium and nitrate concentrations to be low. In a laboratory study of incubated, nonfertilized Douglas-fir soils, Heilman (1974) also found nitrate production to be low (< 3 ppm). Highest levels, however, were from the more productive sites (Heilman, 1974). Vitousek *et al.* (1979) also detected greater nitrate losses from their higher site quality Douglas-fir stands. From these studies, there is the implication that nitrate levels may be related to the site quality of a forest stand. Thus, the estimation of nitrate production (and potential nitrogen loss) in a forested area containing different site classes may be misleading if derived from data obtained from small research plots of only one site class. With many forests mapped as to site class, the possible high correlation of site quality to nitrate levels could prove useful in more accurate estimations of nitrate levels in forested regions.

It was the intent of this study to determine if there are significant differences in ammonium and nitrate levels in litter and soil between high and low site quality closed-canopy Douglas-fir stands.

Methods and Materials

Plots (0.045 ha in area) were established in each of three site class II (high site quality, King, 1966) and four site class IV (low site quality) Douglas-fir stands. Site class II stands were aged 45, 75, and 175 years, and site class IV stands were aged 45, 75, 120, and 175 years. Six of the stands were located approximately 120 km south of Seattle, Washington, at the Charles Lathrop Pack Experimental Forest of the University of Washington. The site class II, 45-year-old stand was located on nearby Weyerhaeuser property.

The predominant tree species on all plots was Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Understory vegetation consisted of swordfern (*Polystichum munitum* (Kaulf.) Presl.), vine maple (*Acer circinatum* Pursch), Oregon grape (*Berberis nervosa* Pursh), and salal (*Gaultheria shallon* Pursh). In the site class II stands, swordfern was the dominant understory vegetation, whereas salal dominated in the site class IV stands.

Soils in the high site stands were of the Wilkeson Series (fine-loamy, mixed, Eutric Glossoboralfs). Litter ($O_1 + O_2$ horizon) depths in these stands averaged 2.2 ± 1.2 cm. Low site quality soils were fine-loamy mixed, mesic Typic Xerumbrepts of the Baumgard Series with litter depths averaging 3.4 ± 1.5 cm. Both soil types were deep, well-drained, residuum derived from Andesite with the litter classified as duff-mull according to Hoover and Lunt (1952). The climate at Pack Forest is moderate with a rainfall of approximately 100 cm/yr with a winter maximum and a dry summer. Mean annual air temperature is 9.6°C. The elevation of the stands ranged between 340 and 580 m.

Four litter and four soil (0-5 cm depth) samples were collected from randomly located points in each of the seven plots during July 1976 and January 1977. The four soil samples were obtained directly below the four litter samples. Samples were immediately transported to the laboratory and stored at −10°C until analyzed. All samples were randomly withdrawn from the freezer until they were all analyzed.

Using a dial thermometer (Taylor), litter and soil temperatures were recorded in each plot during each sampling period. Soil and litter moisture contents were determined gravimetrically (105°C and 75°C, respectively) on a wet weight basis. The glass electrode method (Peech, 1965) was used to determine pH with ratios of litter and soil to water of 1:10 (w/v) and 1:2 (w/v), respectively.

Litter and sieved soil (< 2 mm) samples were extracted with 2N KCl at 1:5 and 1:25 (w/v) litter and soil solution ratios, respectively. The samples were then shaken for three hours, filtered through GF/A filters, and analyzed for NH_4^+–N and $NO_3^- + NO_2$–N on a Technicon Auto Analyzer II. Hereafter, $NO_3^- + NO_2$–N will be referred to only as NO_3^-–N. This notation assumes that NO_2–N levels were minor compared to the NO_3^-–N levels.

Total nitrogen was determined only from the July samples. Soils were passed through a 2 mm sieve while the litter was ground and passed through a 40 mesh sieve. The samples were then digested using a wet oxidation technique (Parkinson and Allen, 1975) and analyzed on the Tecnicon Auto Analyzer II for NH_4^+–N as a technique for total nitrogen determination. Soil and litter bulk densities were determined in order to calculate nitrogen content (kg/ha). Total carbon was determined on the July samples using a Leco Carbon Analyzer. This includes charcoal carbon as well as the more available carbon.

Results

Temperature, Moisture, and pH

Generally, litter and soil (to a 5 cm depth) temperatures at the time of sampling were not significantly different at the 95 percent level. As expected, the temperatures were warmer in July (litter and soil means ranging from 12.8 to 14.4°C) than in January (5.3 to 8.9°C). No significant temperature differences were observed between site class II and IV except in January in the soil, where the site II stands averaged 8.1°C and site IV stands 5.3°C.

Litter and soil moisture contents (percent by wet weight) were always significantly different, ranging from 54.9 to 71.1 percent in the litter and 25.1 to 35.2 percent in the soil. However, the expected moisture differences between the normally drier July and the more moist January occurred only in the site class II litter (54.9 and 71.1 percent, respectively). Although the site class II soil was more moist in January (35.2 percent in January vs 27.9 percent in July), the difference was not significant. Significantly higher levels between January and July samples did not occur because the week preceding the July sampling period had higher than normal rainfall. Only during January in the soil was there a significant moisture content difference between the site class II (35.2 percent) and site class IV (25.1 percent) stands.

The pH values, ranging from 5.3 to 6.3, usually did not significantly change from July to January or show significant differences between litter and soil, or between site class II and IV stands (Table 1). There was one exception in the soil, of the site class II stands during July. The mean pH of 6.3 was statistically different from the litter above it (5.9), the January soil pH level (5.9), and site class IV pH mean in the soil during July (5.3).

TABLE 1. Litter and soil total N and C, NH_4^+-N, NO_3^--N, C/N ratio, and pH in site II and IV Douglas-fir stands in July 1976 and January 1977. Numbers in parentheses are standard errors. Statistical differences were determined using one-way analysis of variance.

	Sampling Period	LITTER Site Class II	LITTER Site Class IV	SOIL (0-5 cm) Site Class II	SOIL (0-5 cm) Site Class IV
NH_4^+-N (ppm)	July	72.1 (11.2)[bc]	110.4 (23.2)[bc]	21.8 (2.4)[b]	14.0 (3.8)[b]
	January	34.7 (6.1)[c]	44.1 (5.7)[c]	3.7 (0.3)	3.2 (0.4)
NO_3^--N (ppm)	July	4.1 (1.5)	1.0 (0.2)[bc]	3.1 (1.0)[ab]	1.0 (0.3)[b]
	January	4.5 (2.2)[ac]	0.5 (0.1)[c]	12.2 (2.9)[a]	0.2 (0.02)
Total N (%)	July	1.06 (0.04)[ac]	1.21 (0.05)[c]	0.3 (0.04)	0.23 (0.02)
Total N (kg/ha)	July	398 (92)[c]	476 (67)	975 (161)	654 (130)
Total C (%)	July	43.1 (0.9)[c]	44.3 (0.4)[c]	6.4 (0.8)	6.0 (0.6)
C/N[d]	July	41.2 (1.8)[c]	37.4 (1.4)[c]	21.7 (1.1)	25.8 (1.5)
pH	July	5.9 (0.1)[c]	5.5 (0.3)	6.3 (0.1)[ab]	5.3 (0.3)
	January	5.8 (0.1)	5.9 (0.2)	5.9 (0.1)	5.5 (0.2)

[a]Significant differences at 95 percent level existed between site classes II and IV within a similar substrate and sampling period.

[b]Significant differences at 95 percent level existed between July and January within a similar site class and substrate.

[c]Significant differences at 95 percent level existed between litter and soil within a similar site class and sampling period.

[d]C/N calculated for each sample then x ± S.E. calculated, rather than the total C mean divided by the total N mean.

Available N in Relation to Site Quality

Litter NH_4^+-N concentrations appeared higher in the site class IV (low site quality) stands than the site class II (high site quality) stands in both July and January (Table 1). The reverse situation occurred in the soil. However, these differences between site classes were not statistically significant in either the litter or in the soil. Ammonium levels in both litter and soil in both site qualities significantly decreased from July to January (Table 1). Extractable NH_4^+-N concentrations were greater in the litter than in the soil in all cases (Table 1).

Generally, NO_3^--N concentrations were significantly higher in site II than site IV stands ($p < .05$), except for the litter in July (Table 1). There was also a significant decrease in NO_3^--N from July to January in site IV litter and soil. However, in site II stands, NO_3^--N levels remained the same in litter but increased significantly in the soil from July to January. A consistent pattern, however, was not observed for NO_3^--N concentrations. In January, site IV stands showed significantly greater NO_3^--N concentrations in the litter (0.5 ppm) than in the soil (0.2 ppm), but this situation was reversed in the site II stands (4.5 vs 12.2 ppm, respectively). In July there were no significant NO_3^--N differences between the litter and soil in either site class.

Total Carbon and Nitrogen and C/N Ratios and Relationships to Available N

The total nitrogen concentration (percent) was three to five times greater in the litter than in the soil (Table 1). Total N concentraion of site IV litter (1.21 percent) was significantly higher than the litter in site II (1.06 percent). However, the reverse was true of the soil N, site II (0.30 percent) vs site IV (0.23 percent) (Table 1). Total N content was not significantly different between litter (476 kg/ha) and soil (to a 5 cm depth) (654 kg/ha) in the site IV stands, but there was a significant difference between the litter (398 kg/ha) and soil (to a 5 cm depth) (975 kg/ha) in the site II stands. No significant differences in total N content appeared between the site IV (654 kg/ha) and site II (975 kg/ha) stands.

Percent carbon was also greater in the litter than in the soil by about seven times (Table 1). There were no significant differences in carbon between site II and IV in either the litter (43.1 percent and 44.3 percent, respectively) or the soil (6.4 percent and 6.0 percent, respectively).

The C/N ratio was greater in the litter than in the soil (Table 1). In both the litter and soil, the mean C/N ratio was similar between site II (41.2 and 21.7, respectively) and IV (37.4 and 25.8, respectively). Relationships between total N and C/N ratios and available N were generally consistent. In the litter, higher total N values and lower C/N ratios were related to high NH_4^+-N but lower NO_3^--N levels. The situation was slightly different in the soil where the NO_3^--N values were higher with associated high total N, lower C/N, and high NH_4^+-N levels. Higher C values in the litter and soil also were related to higher total and available N.

Discussion

Site II Douglas-fir stands in western Washington have been shown to produce more wood volume than site IV stands (RFNRP, 1980). This difference is generally attributed to better moisture conditions and higher soil N levels. Inorganic NH_4^+-N constitutes, in general, less than 1 percent of the total soil N present, and NO_3^-–N an even lower percentage; however, these inorganic nitrogen species are the most important forms in which nitrogen becomes available to trees. Levels of NH_4^+–N and NO_3^-–N, however, are not constant in soils and fluctuate seasonally. For example, Ellis (1974) found that a spring increase in NH_4^+–N levels was followed by a mid-summer decline, an autumn peak, and finally a winter low in maple woodlot and an old field in Ontario. In low site quality Douglas-fir stands in Washington, Johnson (1979) found that mean NH_4^+–N concentrations ranged from approximately 1 ppm in March to a high of 5 ppm in October. Mean NH_4^+–N values obtained in this study for low site quality soils were slightly higher, ranging from 3.2 ppm in January to 14.0 ppm in July. However, the sampling depths in this study were 5 cm, whereas Johnson sampled to 15 cm. Assuming that microbial activity decreases with depth, a dilution effect could account for the lower concentrations observed by Johnson.

In this study there were no significant differences in NH_4^+–N concentrations between site II and Site IV stands in either litter or soil, although NH_4^+–N levels were consistently higher in the litter in site IV stands and generally higher in the soil in site II stands. Expected significant differences in NH_4^+–N concentrations between the high and low site quality stands were not observed. The higher productivity of the site II stands compared to the site IV stands may be explained by the slightly higher soil NH_4^+–N concentrations and total soil N (kg/ha) in the site II stands.

In contrast to both soil and litter NH_4^+–N concentrations, NO_3^-–N concentrations were significantly higher in site II stands than in site IV stands, except for the litter sampled in July. In the soil, NO_3^-–N concentrations ranged from 3.1 to 12.2 ppm in the site II stands but only from 0.2 to 1.0 ppm in the site IV stands. The slightly higher moisture, pH, and temperatures of the soils in site II stands may have enhanced nitrification. These factors are known to influence nitrification (Alexander, 1978). However, Heilman (1974) found that nitrate production in incubated Douglas-fir soils was unrelated to pH, poorly correlated with C/N ratios, but better related to soil organic C and total nitrogen. In this study, higher soil NH_4^+–N, total N, and carbon and pH were generally related to higher NO_3^-–N levels. These relationships seemed to be reversed in the litter.

Soil NO_3^-–N levels in the low site stands studied by Johnson (1979) did not exceed 0.3 ppm and were similar to those found in this study. Johnson also found no relationship between NH_4^+–N and NO_3^-–N concentrations and found higher soil NO_3^-–N during the winter months. In this study, the January levels of soil NO_3^-–N were greater than in July in the site II stands but not in the site IV stands. The increase in soil NO_3^-–N with increase in site quality found in this study was also observed by Heilman (1974). He found greater NO_3^-–N production in incubated high site Douglas-fir soils (2.8 ppm, site index 125) than in lower site soils (0 to 0.1 ppm, site index 94). These NO_3^-–N values, however, are somewhat lower than those observed in this field study. Vitousek *et al.* (1979) also presented evidence that NO_3^-–N production may be influenced by site quality. A study by Youngberg (1978) showed that litter and soil with highest sustained N mobilization rates come from the highest site quality Douglas-fir types.

The higher concentrations of NH_4^+–N in the litter in comparison to the soil in both site II and site IV stands probably reflects the higher mineralization rates in the litter. Van Praag and Weissen (1973) also reported that litter had higher NH_4^+–N concentrations than A horizon soil in beech stands in Belgium.

Higher concentrations of litter NH_4^+–N in the site IV than in site II stands may indicate a more active microbial immobilization of NH_4^+–N and/or greater tree uptake in the site II stands. The total N concentration (percent) in the litter of the site IV stands was significantly greater than that in the site II stands; however, the total N content (kg/ha) was not significantly different.

The following conclusions can be drawn from this study:

1. There was no significant difference between NH_4^+–N concentrations in litter and soil in high and low site quality stands. However, litter NH_4^+–N levels were always higher in site IV stands, whereas soil NH_4^+–N levels were always higher in site II stands.
2. Higher NH_4^+–N concentrations were observed in July than in January in both site II and site IV stands in both litter and soil.
3. Generally, significantly higher NO_3^-–N concentrations occurred in site II stands (3.1 to 12.2 ppm) than in site IV stands (0.2 to 1.0 ppm). Levels in high site stands are as high as those reported for eastern deciduous forests.
4. Highest NO_3^-–N concentrations were observed in January in the high site stands, but the reverse situation occurred in the low site stands.
5. There was little apparent relationship between net NH_4^+–N and NO_3^-–N concentrations.
6. Litter NH_4^+–N levels were higher than soil NH_4^+–N levels in all cases, but no consistent pattern existed for NO_3^-–N.
7. Higher levels of NH_4^+–N were related to lower C/N ratios and higher total N in litter and soil when comparing site II and IV stands. Higher values of NO_3^-–N were related to lower C/N ratios and higher total N only in soil when comparing site II and IV stands, whereas the reverse occurred in the litter.
8. Environmental variables (litter and soil moisture, temperature, and pH) were not very different between sites II and IV, although site II soils were slightly warmer, more moist, and had slightly higher pH values. These differences may have favored decomposition and NH_4^+–N and NO_3^-–N production.

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