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Eight-year Growth Response and Recovery of ^{15}N -Fertilizer Applied to Lodgepole Pine near Spillimacheen, B.C.

The application of nitrogen fertilizer to young conifer crop trees to increase growth is a common silvicultural technique. The high cost of this application, however, dictates that the treatment be applied in the most efficient way possible.

One way to ensure fertilization is efficient is to measure how much nitrogen is taken up by trees. Previous forestry studies with ^{15}N -fertilizer (Hulm and Killham 1990; Preston *et al.* 1990) indicate that uptake by crop trees in one growing season is often a small percentage (5–15%) of the N fertilizer applied. Up to 70% may remain in the soil, with some 10–50% being lost to processes such as denitrification (conversion of nitrates and nitrites into nitrogen gas), leaching, or volatilization of ammonia.

It is well known from agricultural research that the availability of N fertilizer to plants is low once it is immobilized in the soil in organic forms (Preston 1982), but there is little information on the long-term fate and subsequent uptake of residual N fertilizer in forestry situations.

A field study on ^{15}N uptake, originally established in 1981 (Preston *et al.* 1990) to evaluate the efficacy of applying N fertilizers on snow, provided a unique opportunity to investigate the above questions. Nitrogen-15 is a heavy isotope of nitrogen occurring at a natural abundance of 0.4%, with ^{14}N making up the other 99.6%. It can be used as a stable, non-radioactive "tag" to track the movement and uptake of ^{15}N -enriched fertilizer applied to trees. The study was established near Spillimacheen, B.C., in the Interior Douglas-fir biogeoclimatic zone, in a lodgepole pine plantation (*Pinus contorta* Dougl. var. *latifolia* Engelm) and had four replicates of four different treatments (no fertilizer, ^{15}N -urea, $^{15}\text{NH}_4\text{NO}_3$, and $\text{NH}_4^{15}\text{NO}_3$). Fertilizer was applied on snow in January 1981, and eight of the single tree microplots were destructively sampled in October 1981 (for results see Preston *et al.* 1990). The remaining two replicates (eight plots) were revisited in August 1988 for a field sampling to obtain information on long-term N uptake, growth response, and distribution of ^{15}N -fertilizer in plant and soil components.

SITE DESCRIPTION

The site is located about 32 km west of Spillimacheen (50° 53' N, 116° 51' W) (Figure 1), on a level to moderately sloped kame terrace with humps and depressions of about 10 m. The terrace has a northeast to southeast aspect and a mean elevation of 1370 m. The soil, derived from till of shale, conglomerates and granites, is 25–50 cm deep with a gravelly

clay loam texture. The site receives 400–560 mm precipitation per year and is located in an area described as having 60–140 frost-free days annually.

A fire in 1967 resulted in dense regeneration of lodgepole pine, which was thinned in 1976 to a spacing of 3.6 × 3.6 m. In 1979, the average age of trees was 9 years and the average height was 3.6 m. The sparse understory vegetation on the site consists of willows (*Salix* sp.), birch-leaved spirea (*Spiraea betulifolia* Pall.), Sitka alder (*Alnus sinuata* (Reg.) Rydb.), and bunchberry (*Cornus canadensis* L.).

FERTILIZATION AND FIELD SAMPLING

In January 1981, single tree plots of lodgepole pine 2 m in radius were fertilized on snow. Nitrogen-15 fertilizer was applied at 100 kg/ha. In October 1981, after one growing season, eight of the plots were destructively sampled to measure ^{15}N in the trees, understory and soil. Uptake by plot trees was low, ranging from 1.9 to 10.1% of applied fertilizer (Preston *et al.* 1990).

The 8-year field sampling was carried out in August 1988 through the destructive sampling of the remaining two replicates. Included in the analysis were the whole tree, all understory and litter within the plot, some tree roots and three pits for soil sampling. In addition, soil, tree and understory samples were analyzed from areas surrounding the plots.

The main objectives for the 1988 field sampling were: 1) to determine growth response (volume inside stem) from 1976 to 1988; and 2) to determine the distribution (recovery) of ^{15}N in trees, understory and soil, both inside and outside the plots.

Procedures for laboratory analysis of the samples were similar to those described in Preston *et al.* (1990). Tree and soil samples were analyzed for total N and ^{15}N enrichment above natural levels. Once researchers knew the amount of extra ^{15}N present, they evaluated how fertilizer had been distributed.

GROWTH RESPONSE AND DISTRIBUTION OF ^{15}N IN PLANT BIOMASS AND SOIL

Figure 2 shows individual tree growth response (volume inside bark) to 100 kg N/ha. The response to fertilization was statistically significant, showing a 34% increase in growth over the control after 8 years. There was no difference between urea and ammonium nitrate treatments.

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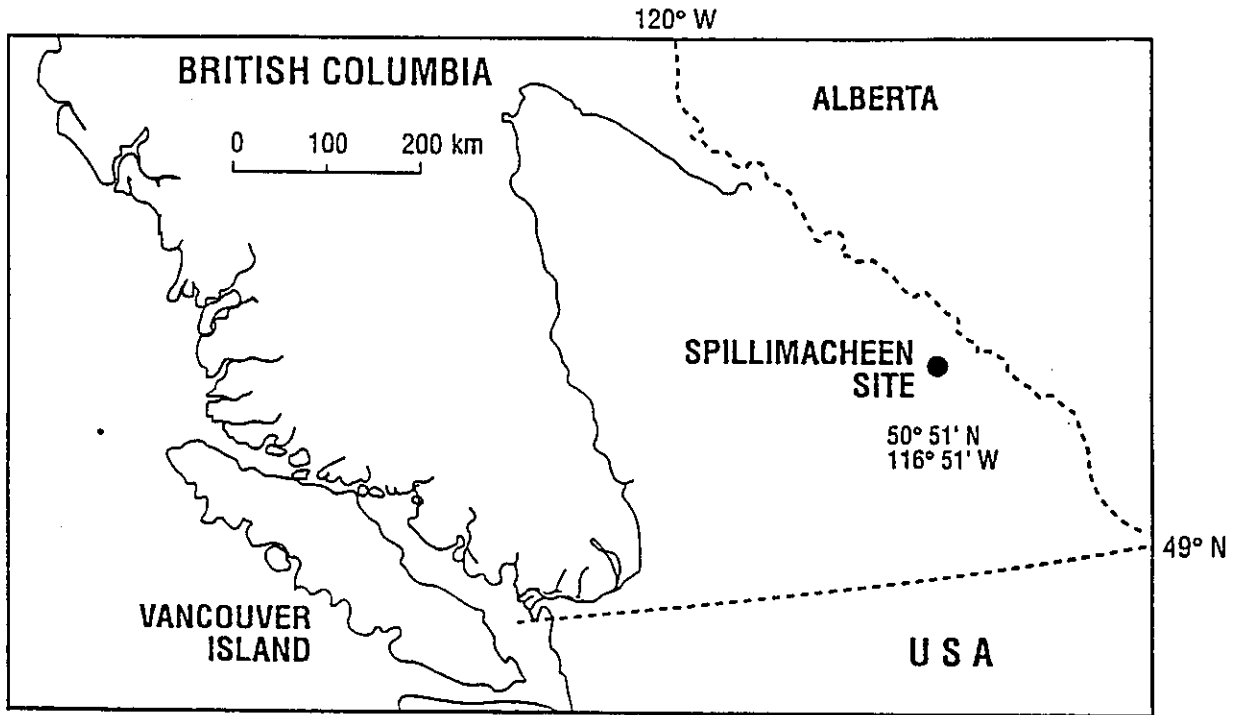


FIGURE 1. Location map for the Spillimacheen site.

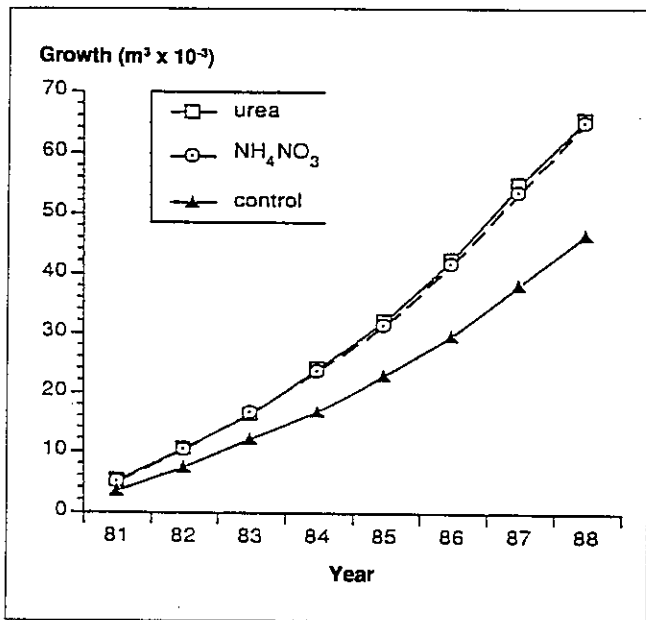


FIGURE 2. Growth response determined on the 8 individual trees.

The total amount of ¹⁵N (as % of total ¹⁵N applied) found in the ecosystem after 8 years — including inside- and outside-plot recoveries — was 61.7% for ¹⁵N-urea, 60.8% for ¹⁵NH₄NO₃, and 28.4% for NH₄¹⁵NO₃ (Table 1). This represents about two-thirds of the amount recovered in 1981. In a comparison of the 1- and 8-year recoveries within plots, there was little change

TABLE 1. Comparison of total site ¹⁵N recoveries in 1981 and 1988 and estimation of mineralization rate of within-plot soil organic ¹⁵N

| | ¹⁵ N-urea | ¹⁵ N ₄ NO ₃ | NH ₄ ¹⁵ NO ₃ |
|---|----------------------|--|---|
| Total recoveries as % of ¹⁵N applied | | | |
| 1981 | 93.3 | 95.5 | 44.4 |
| 1988 | 61.7 | 60.8 | 28.4 |
| Total 1988 recovery as % of total 1981 recovery | | | |
| | 66.1 | 63.7 | 64.0 |
| Soil organic ¹⁵N (within plot only) as kg/ha⁻¹ | | | |
| 1981 | 63.5 | 73.2 | 30.6 |
| 1988 | 27.2 | 29.5 | 14.1 |
| Change | -36.3 | -43.7 | -16.5 |
| Average annual loss | | | |
| As kg/ha ⁻¹ | 5.2 | 6.2 | 2.4 |
| As % of 1981 amounts | 8.2 | 8.5 | 7.7 |

in the ¹⁵N recovered in plot trees, indicating no significant additional ¹⁵N uptake over the 8 years. The slight increase in ¹⁵N recovered in the understory vegetation and litter suggests some continuing uptake during the intervening years.

For all three fertilizer forms, the recovery of ¹⁵N as organic N in plot soil in 1988 was approximately half that recovered in 1981. All soil ¹⁵N was in organic (i.e., immobilized) form in 1988, as compared to 1981 when some ¹⁵N was recovered in an inorganic form (ammonium or nitrate). The analysis of variance of the 1981 and 1988 tree uptake data showed that uptake in the NH₄¹⁵NO₃ treatment was significantly lower

($p=0.0004$) than in the $^{15}\text{NH}_4\text{NO}_3$ or ^{15}N -urea treatments. The lower recovery in both trees and soil was probably due to losses of nitrate by denitrification to N_2 or by leaching during snowmelt. Nitrate is more susceptible to leaching and denitrification than ammonium (NH_4) which has to be nitrified (converted by nitrifying bacteria to nitrates) before it is lost by these processes. In the 1981 study, there was little indication of movement of ^{15}N outside plot boundaries. By contrast, in 1988 about one-fifth of the ^{15}N recovered in plant biomass and soil was found outside the plot boundaries for all three forms.

The rate of loss of residual soil ^{15}N , expressed as a percentage of that immobilized in organic forms in the soil in 1981, averaged 8% annually. Generally, 2–6% of native soil N is mineralized each year in temperate agricultural soils. The rate of mineralization for residual fertilizer N is initially higher, but declines exponentially to approach that of native soil N as the N becomes incorporated into more complex, highly condensed macromolecules and organomineral complexes (Smith and Power 1985; Webster and Dowdell 1985; Kelley and Stevenson 1987). Recent work in agricultural soils has indicated that N may be mineralized and nitrified during the winter, then lost by denitrification in the spring before significant plant uptake can occur (Mahli and Nyborg 1986; Heaney and Nyborg 1988). It is possible the same process is taking place in forest soils. Relevant N transformations appear to continue even when the soil is frozen (Heaney and Nyborg 1988).

Residual soil ^{15}N behaves similarly regardless of its original form. Although large differences in the behaviour of the three forms of N were noted in the first season after application, once immobilized in the soil in organic form they lost similar proportions of ^{15}N over time. The distribution of ^{15}N inside and outside plots was also similar after 8 years. These results agree with processes long recognized in agricultural soils. After N has been processed through the microbial pathways, the resulting soil organic matter shows little variation in chemical structure regardless of the chemical form of fertilizer applied (Oades *et al.* 1988).

CONCLUSIONS

This study indicated that uptake of fertilizer N by crop trees was largely complete after 1 year. Interpretation of the data indicates that residual ^{15}N in the soil continued to be mineralized, although the amounts taken up by trees were too small to have any significant effect on growth. The results of this long-term study suggest that tree response to fertilization is largely the result of the increase in photosynthetic capacity generated by the first year of uptake. Once immobilized in the soil, fertilizer N has low availability to crop trees and becomes subject to losses, presumably through leaching and denitrification. This is true regardless of the original chemical form of the fertilizer. The overall losses measured in 1988 amounted to one-third of the ^{15}N found in October 1981.

The results from this site clearly indicate the importance of maximizing uptake of N fertilizer during the first growing season to avoid losses from leaching, denitrification and volatilization of ammonia. Although factors controlling initial fertilizer loss by these processes are generally understood, low utilization of fertilizer N by conifer plantations continues to be a widespread phenomenon.

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