Forest Sciences

Prince Rupert Forest Region

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Soil Nitrogen and Lodgepole Pine Seedling Responses to Five Years of Legume Cover

Research Issue Groups:

- Forest Biology
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- **Soils**
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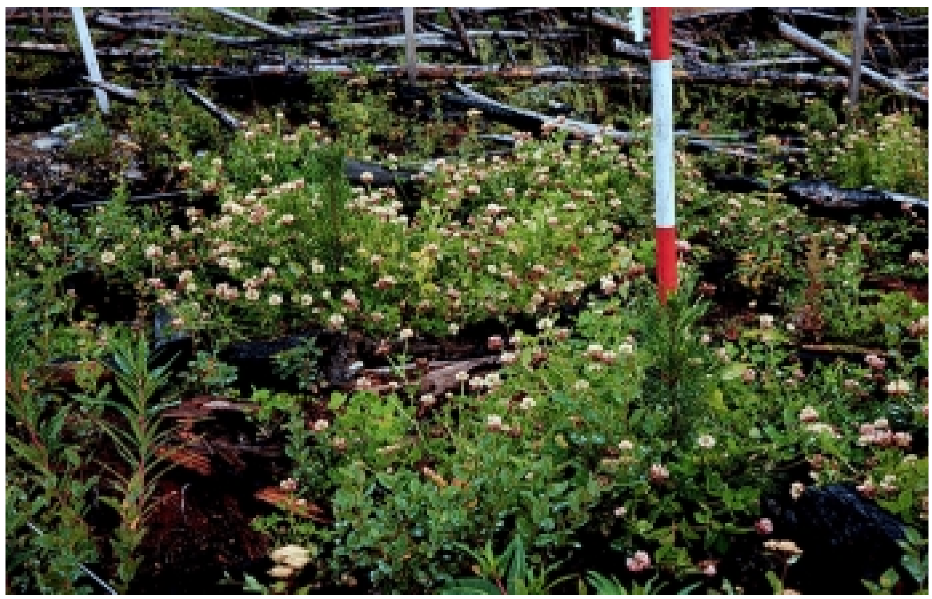

Figure 1. Nitrogen-fixing Alsike clover growing with lodgepole pine seedlings.

Nitrogen is often considered the nutrient most limiting to tree growth in coniferous forests, and nitrogen-fixing plants have been advocated as a beneficial component for forest stands. Lodgepole pine stands in the central interior of British Columbia often have low nitrogen status and have responded to nitrogen fertilizer applications. Managing nitrogen-fixing plants during reforestation could be an economically and environmentally attractive substitute for synthetic fertilizers, for mitigating the nitrogen limitations of these soils.

Agronomic legume plants (pea family) have been used as a silvicultural tool in this regard. The legumes and rhizobium bacterial inoculants are commercially available and many species grow well in forest soil environments. Other potential benefits include forage for animals, a reduction in competing native plants, and the establishment of a more suitable microclimate for tree survival and growth. Experiments in west-central British Columbia were established in 1987 to examine the response of lodgepole pine and alsike clover grown together. Early results looked promising and a second experiment was established to examine other legume species along with the tree and soil responses on other sites. In this note we summarize the five- year results of the legume treatment on soil nitrogen and lodgepole pine growth from both experiments.

Study description

The three experimental sites are located in the Bulkley and Lakes Districts, in the Sub-boreal Spruce Zone (SBS). The alsike clover seeding density experiment (Experiment 1) took place at Richardson Lake, where alsike clover was seeded at 0, 10, 20 and 30 kg/ha. The multiple species study (Experiment 2), replicated at the Tintagel and Fulton sites, tested alsike clover, birdsfoot trefoil, and white clover. All the plots had been broadcast burned and planted to lodgepole pine. The clover seed had been inoculated with *Rhizobium*, the symbiotic bacteria required for nitrogen-fixation.

Results

Accretion of biologically fixed-nitrogen in above-ground legume biomass

In 1990, we determined biologically fixed-nitrogen inputs at Experiment 1 to be 0.7 kg/ha/yr of nitrogen added to the site for every 1% cover of alsike clover (Table 1). The relationship between % cover and nitrogen inputs was not strong (r^2=39%), probably because visual estimates of % cover are imprecise. Nitrogen inputs of 38 kg N/ha concur with reported results of 25-44 kg N/ha for alsike clover and 32-48 kg N/ha for trefoil. We periodically tested root nodules on the legume species from both experiments for the presence of leghemoglobin (indicated by a bright pink colour within the nodule). The active nodules indirectly confirm that biological nitrogen-fixation is occuring with the legumes. Based on the results from 1990, we estimated nitrogen inputs for the other treatments and legume species (Table 2). These estimates are very approximate, because legume mass and foliar N were not

Table 1. Measured nitrogen inputs from clover biomass (mean ± standard deviation)

Treatment	Cover %	Mass kg/ha	foliar N %	N Kg/ha	kg N/ha per % cover	% cover vs kg N	
						p	r^2
Experiment 1 alsike clover (1990, n=23)	56 (± 19)	1907.3 (± 928)	2.06 (± 0.26)	37.9 (± 16)	0.70 (± 0.3)	0.002	0.39

Table 2. Estimated nitrogen inputs after 5 years of clover growth

Treatment	% cover					Est. N input (kg/ha) after 5 years cover
	year 1	year 2	year 3	year 4	year 5	
Experiment 1						
10 kg/ha	0.2	24	73	51	32	126
20 kg/ha	0.8	41	72	61	36	148
30 kg/ha	1.0	42	72	56	21	134
*Experiment 2**						
Alsike	n/a	69	90	n/a	74	221
Trefoil		28	54		36	114
White		42	63		12	109

** nitrogen estimates assume no cover at year 1 and % cover at year 4 midway between years 3 and 5* determined each year, but the estimate (of 100 kg N/ha or more accreted over 5 years) gives an indication of the possible treatment effect.

Effects on soil nitrogen and carbon

In Experiment 1, establishment of alsike clover over five years resulted in relatively greater biomass accumulation as detritus in the forest floor (detected as 'total carbon'), and greater levels of mineralizable and total nitrogen compared to control plots (Table 3). In Experiment 2, significant increases were observed only for forest floor mineralizable nitrogen. The additional nitrogen and carbon from the legumes did not affect the C:N ratio of the forest floor, which in both studies was considered high enough (>25) to immobilize nitrogen.

We detected no effects of the legume treatments on mineral soil nitrogen and carbon in either study. Apparently, newly accreted nitrogen was partly recycled into microbial biomass of the forest floor (as indicated by mineralizable nitrogen) but little was translocated into the upper mineral soil (0-20 cm). Any translocation of nitrogen into the subsoil (>20 cm) would not have been detected in these studies.

Effects on lodgepole pine seedlings

The legume treatments did not affect mortality of the pine seedlings in either study (Table 4). Tree heights and diameters after six growing seasons were not significantly different between the controls and the legume treatments in either study.

After six years of growth, seedling foliar nitrogen and needle mass were not enhanced by the legume treatment, and were slightly reduced in Experiment 1 (Table 5). These results conflict with the fourth-year results reported previously (Trowbridge and Holl 1992), so we decided to collect foliage again at the end of the seventh growing season on this site alone. The trend reversed again (Figure 2), suggesting that other climatic events or site factors could be limiting the uptake of N by the seedlings.

Nitrogen status of the soils was apparently poor regardless of treatment because foliar N is at concentrations considered deficient for lodgepole pine (Table 5). The legume treatment resulted in lower levels of foliar boron, perhaps low enough to cause boron deficiency, and suggests that legumes compete with lodgepole pine for boron. The only other deficient nutrient observed was sulphur, which was below 0.10 % across treatments at all three sites.

Discussion

Yearly input of nitrogen through the legume biomass is a small percentage of the soil's total nitrogen budget. However, this organic nitrogen should be more available for plant uptake compared to the recalcitrant nitrogen in humified organic matter. Lodgepole pine did not respond to the legume treatments despite the deficiencies in foliar nitrogen and the increases in forest floor mineralizable nitrogen.

Table 3. Nutrient mass of forest floors and mineral soils after 5 years

Treatment	Mineralizable N			Total nitrogen			Total carbon			C:N ratio	
	min.	f.f.	total	min.	f.f.	total	min.	f.f.	total	min.	f.f.
		kg/ha			kg/ha			kg/ha			
Experiment 1											
Control	22	1.5c[1]	23.8a	972	74a	1046	18024	3358c	21382a	18.5	46.5
10 kg/ha	26	5.5b	31.5ab	900	137b	1037	16524	6017b	22541ab	18.6	45.0
20 kg/ha	27	8.2a	35.0ab	1068	158b	1226	18000	6094b	24094ab	17.0	39.6
30 kg/ha	35	7.5ab	42.9b	918	191c	1109	18360	8821a	27054b	20.4	46.8
Experiment 2											
Control	31	5.5b	36.6b	1324	255	1580	26844	8631	35475	20.6	34.9
Alsike	38	9.7a	47.7a	1327	285	1612	25037	9481	34518	19.5	33.3
Trefoil	31	7.1ab	37.8ab	1075	253	1328	22045	9098	31143	20.6	36.5
White	35	8.0ab	42.7ab	1281	282	1563	25031	9339	34370	20.0	33.8

[1] *significantly different values between columns within each experiment are distinguished by different letters (p<0.05)*

Table 4. Lodgepole pine response after 6 years

Treatment	Survival (%)	Tree ht (cm)	Tree dia (mm)
Experiment 1			
Control	75	111	25
10 kg/ha	78	112	25
20 kg/ha	77	104	24
30 kg/ha	74	115	26
Experiment 2			
Control	95	188	45
Alsike	95	180	42
Trefoil	97	197	49
White	95	192	47

Table 5. Lodgepole pine foliar concentrations, year 6

Treatment	N (%)	B (ppm)	S (%)	needle. mass (g/100 needles)
Experiment 1				
Control	1.13a[1]	9.6a	0.092	1.61a
10 kg/ha	1.09ab	6.4b	0.085	1.37b
20 kg/ha	1.07b	5.8b	0.085	1.39b
30 kg/ha	1.07b	5.4b	0.084	1.39b
Experiment 2				
Control	1.04	10.5a	0.065	2.08
Alsike	1.03	7.3b	0.063	2.17
Trefoil	0.97	7.7b	0.061	2.16
White	1.02	8.1b	0.064	2.23
deficient <*:	1.20	10	0.10	--

[1] significantly different values between columns within each experiment are distinguished by different letters ($p<0.05$)
** concentration below which deficiencies occur for lodgepole pine*

Mineralizable nitrogen has been linked to tree productivity, so we expected legume treatment to improve tree growth on these sites. Other studies have found increased tree growth with legume treatments. The lack of a tree response to the increased nitrogen levels suggests that other growth limitations exist or that fixed nitrogen is unavailable for tree uptake.

The lack of a growth response by the trees to the increased nitrogen availability might be partly explained by other nutrient limitations. Sulphur limitations are common in the British Columbia interior, and fertilization trials have shown that sulphur included with nitrogen fertilizers improves tree response. Boron is also a recommended addition to nitrogen fertilization because of inherently low levels in many interior soils of British Columbia. Foliar boron was reduced by the legume treatment to levels considered deficient, although we saw no signs of boron deficiency. Usually nutrient limitations become more apparent when induced by increased nitrogen uptake, but there were no changes in foliar nitrogen concentrations from the legume treatment. Low levels of sulphur and boron could reduce growth response to added nitrogen, but we would not expect these possible nutrient limitations to have prevented nitrogen uptake.

Most of the planted pine roots are in mineral soil because forest floors on these sites are thin (0.5 to 2 cm), often patchy and dry in the summer. Nitrogen accumulation in the mineral soil was not observed, so fixed nitrogen from forest floors would have to be mineralized and leached through the soil profile for uptake by tree roots. We also showed that C:N ratios of forest floors were not reduced by nitrogen inputs and presumably are high enough to immobilize nitrogen. It is not clear how much, or when, fixed nitrogen would translocate through the mineral soil, but evidently this nitrogen cycle does not correspond well with periods of tree uptake and growth. The root distribution seems the most likely explanation for lack of nitrogen uptake, but the year-to-year variation in foliar nitrogen emphasizes the complexity of nitrogen cycling. Other factors such as competition for available moisture could relate to differences in treatment response between years.

The Experiment 1 site is mostly flat, and very slow to drain in the spring. This could explain the poorer tree growth and lower survival compared to trees from Experiment 2. The

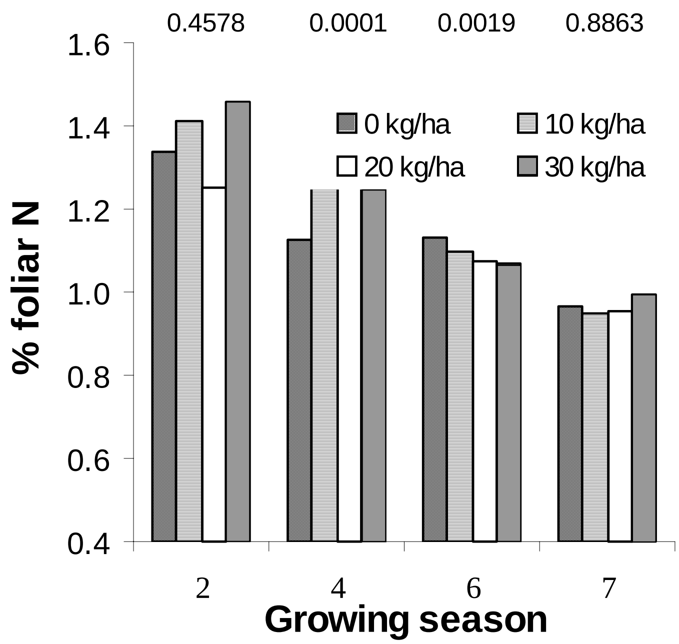

Figure 2. Foliar nitrogen concentrations at Experiment 1 over seven growing seasons. Control vs clover-seeded comparison results (p>F) are placed above the growing season year.

cold, wet conditions could also be a factor in the different rates of nitrogen accumulation between experiments. Alsike clover grew well in Experiment 2, but increases in forest floor nitrogen were only demonstrated in Experiment 1. If the legume litter decomposed rapidly then fixed nitrogen might be susceptible to losses from leaching or denitrification, especially if tree uptake of nitrogen is hampered. Perhaps the better drained sites had higher rates of decomposition and subsequently lower forest floor and nitrogen accretion. Another difference between the two studies was the planting density of lodgepole pine: 1 x 1 m spacing for Experiment 1 and 2.5 x 2.5 m spacing for Experiment 2. It is, however, difficult to imagine a large effect of tree spacing on microclimate and litter decomposition because of the small tree size (just over 1 m). At this point we are unsure as to why nitrogen accumulations are insignificant in some of the legume trials, but will continue to monitor these treatments for further changes over time.

Conclusions

After five years of legume litter contribution, the treatments were ineffective in increasing stand productivity and inconsistent in increasing soil nitrogen. Nitrogen uptake could increase over time as pine roots exploit more of the soil and forest floor. Other possible nutrient limitations to lodgepole pine need to be tested to determine if legume treatments can be made more effective. Overall, the fifth year results suggest that caution should be exercised in prescribing legumes as a silviculture treatment specifically to reduce nitrogen-derived growth limitations in the interior of British Columbia.

For more information, please contact: **Marty Kranabetter**, Soil Scientist

Suggested reading (available from the Forest Sciences section, Smithers)

Brockley, R.P., R.L. Trowbridge, T.M. Ballard and A.M. Macadam. Nutrient management in interior forest types. *in* Forest fertilization: sustaining and improving nutrition and growth of western forests. *Eds.* H.N. Chappell, G.F. Weetman, and R.E. Miller. Institute of Forest Resources, No. 73, pp. 43-63.

Trowbridge, R. and F.B. Holl. 1992. Early growth of lodgepole pine after establishment of alsike clover-Rhizobium nitrogen-fixing symbiosis. Can J. For. Res. 22:8(1089-1093).

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Yole, D., R. Carter and R. Trowbridge. 1991. Evaluation of five single tree fertilizer trials in thinned lodgepole pine stands in the Prince Rupert forest region. B.C. Min. For. Research Report 91002-PR. 19 p.