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NUTRIENT CYCLING IN UPLAND BLACK SPRUCE

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INTRODUCTION

Successful management of upland black spruce (*Picea mariana* [Mill.] B.S.P.) forests, including stand reestablishment, requires manipulating the humus layers to create physical and nutritional conditions favorable for tree growth. As for other tree species, the limiting factors that can affect the growth of black spruce can be related to light, heat, moisture, or nutrients. The slow release of nutrients from humus that accumulates beneath forest canopies in mature spruce forests has been considered to limit nutrient uptake and thereby contribute to declining productivity or even site degradation (Roberge et al. 1968, Pastor et al. 1987). However, nitrogen (N), phosphorus (P), and potassium (K) fertilizers have frequently failed to stimulate growth of mature spruce. This suggests that nutrients may not be as universally limiting to black spruce productivity as previously thought. The availability of growth-limiting factors to stands will vary with tree stocking and site conditions, including macro- and microclimatic variables.

The objective of this note is to report on estimates of the nutritional requirements of late-rotation black spruce by examining ecosystem nutrient contents and cycling (Fig. 1). A more detailed account of the nutrient status of the site, including estimates of projected nutrient removals associated with different intensities of harvesting, is contained in Foster and Morrison (1987). The 1987 work was carried out cooperatively by the Canadian Forest Service; Domtar Inc.; and the Ontario Ministry of Natural Resources, Nipigon District.

APPROACH

The study focused upon a 110-year-old black spruce stand growing on shallow (30 cm), stony, silty, morainal till over compacted, sandy, basal till and/or granitic bedrock near Lake Nipigon. The mean height, basal area, stocking, and effective rooting depth of the trees were recorded as 19.6 m, 23 m^2/ha, 1,200 stems/ha, and 19 cm, respectively.

The diameter at breast height (DBH) of all trees, and samples of foliage, branches, stems, and roots from 88 trees were obtained from twelve 0.01-ha plots. Stand contents for N, P, K, calcium (Ca), and magnesium (Mg) were calculated on a plot-by-plot basis using mean concentrations and tree component dry weights per area. The humus layers and the litterfall (leaves, needles, twigs, bark, and cones) were quantitatively assessed using eighty 0.02-m^2 plots and twenty 0.25-m^2 traps, respectively. Their nutrient concentrations were also determined.

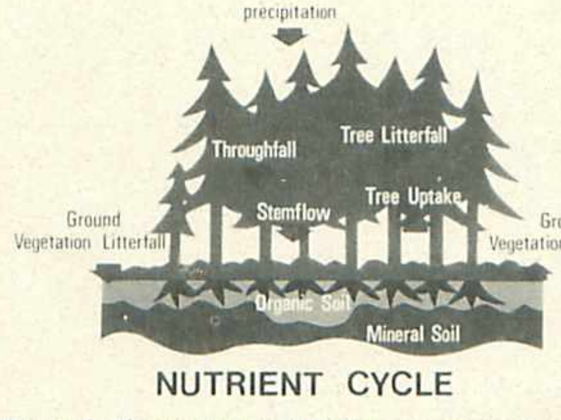

Figure 1. The nutrient cycle in forest ecosystems.

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Uptake of nutrients by the trees (U) was calculated by the equation $U = A - P + T + S + L$, where A, P, T, S, and L represent the amount of nutrients annually accumulated in perennial tree organs, precipitation, throughfall (precipitation reaching the forest floor), stemflow, and litterfall, respectively. The nutritional requirement of the trees was calculated as the sum of annual nutrient accumulation in perennial tissues, plus nutrients in current foliage. Translocation was identified as the difference between requirement and uptake.

STUDY FINDINGS

This medium texture till site supported a very productive, but considerably understocked, black spruce stand (Fig. 2). Forest vegetation accounted for 7% of total N on the site and 3% of total P (Table 1). General nutrient contents in this stand, with the exception of P, were near median values reported for black spruce (Fig. 3). There were more K and Ca immobilized in the vegetation than remained on the exchange sites in the soil.

Spruce stands are quite variable in their nutrient content, which is related to differences in stand productivity. In turn, this is determined by stand age, environmental factors such as site fertility, and genetic variation within populations. In part, the nutrient content in the trees reflects the low density of the stand and, particularly, a very low foliar mass (9,100 kg/ha) that is well below that recorded in many other stands.

From a nutritional point of view, it is the nutrient content of the humus and surface mineral horizons that is critical for black spruce growth because the fine feeder roots are often most abundant there. In some cases they are restricted largely to these horizons. In this stand, sinker roots with many branches and fine roots (<l mm) were also present in abundance throughout the upper till (upper B horizon.).

Forest floor horizons in these shallow soils contained a large proportion (N=59%, Ca=68%, P=23%, K=72%, and Mg=5%) of the readily accessible nutrient capital of the soil (Table 1).

Figure 2. View of the black spruce stand under study.

NUTRIENT CYCLING

Estimated nutrient uptake was generally equal to or greater than nutrient requirement, except for N (Table 2). Most of the nutrient requirement for current tree growth, therefore, is derived from uptake from the soil. Translocation of nutrients from foliage prior to abscission appears to play a minor role in satisfying current nutrient demand. For some nutrients, such as Ca, uptake greatly exceeds requirement and the trees exhibit luxury consumption. Soil reserves are sustained by

Table 1. Distribution of organic matter and nutrients in a 110-year-old black spruce ecosystem.

	Nutrient distribution (kg/ha)					
Ecosystem component	Organic matter	N	Ca	P	K	Mg
Trees	185,000	256	410	21	136	50
Ground vegetation	300	2.7	1.9	0.2	1.5	0.8
Moss	1,600	15.9	6.6	1.6	5.8	1.3
Forest floor	120,000	1,790	206[a]	100	75[a]	36[a]
Ablation till	144,000	1,240	97[a]	335	29[a]	34[a]
Basal till	11,500	349	70[a]	319	10[a]	20[a]
Total	463,000	3,660	792	777	257	142

[a] Based on exchangeable NH_4OAc at pH 7 in the forest floor and till.

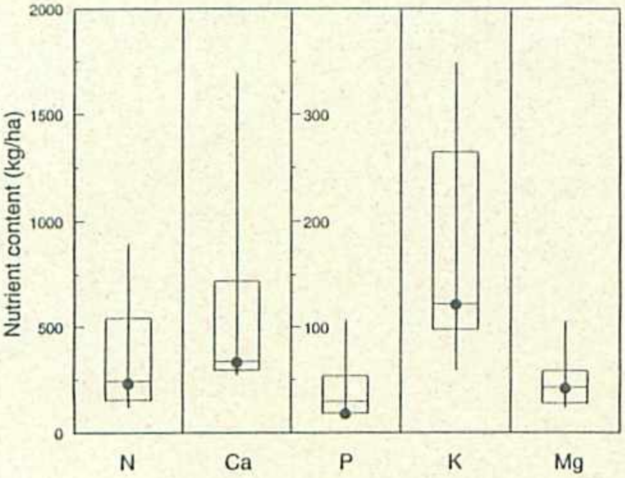

*Figure 3. Box plots of N, Ca, P, K, and Mg content in the aboveground tree phytomass for black spruce forests (*for literature citations see *Foster and Morrison 1989). In each box, the central bar is the median and the lower and upper limits are the first and third quartiles, respectively. The lines extending vertically from the box indicate the spread of the distribution.*

Table 2. Indices of nutrient cycling in black spruce stands.

Nutrient	Uptake kg/ha per yr	Requirement kg/ha per yr	Translocation kg/ha per yr
Nitrogen	6.3	13.6	6.7[*]
Calcium	22.0	5.6	-16.4
Phosphorus	1.2	1.3	0.1
Potassium	11.1	7.5	-3.6
Magnesium	2.6	1.8	-0.7

[*] Includes 3.5 kg/ha per yr of foliar absorption from precipitation.

annual litterfall, which contains (kg/ha) 15.0 N, 15.5 Ca, 1.4 P, 2.7 K, 1.8 Mg, and annual throughfall with 3.5 N, 7.8 Ca, 1.4 P, 8.6 K, and 1.0 Mg.

For N, there were sufficient reserves in the soil but insufficient turnover to meet the nutrient requirements of this black spruce stand. In fact, the spruce trees appeared sufficiently N-limited that 3.5 kg/ha per year of N was absorbed from precipitation and 3.2 kg/ha per year was retranslocated from older foliage to new growth. Potential N turnover in soil, as NH_4-N, was estimated using biological availability tests to approach 40 kg/ha per year, but actual N turnover was obviously much lower. Severe temperature and/or moisture constraints on decomposition are suggested, otherwise more of the N required by vegetation would be derived from the soil. Where low air and soil temperatures control black spruce productivity, the moss layer alone can act to retard N cycling (Weber and Van Cleve 1981). In fact, N accumulated in the humus layers of the Nipigon stand faster than did carbon and many other nutrients.

MANAGEMENT IMPLICATIONS

There appeared to be sufficient nutrient reserves and cycling at this site to sustain spruce trees to maturity, despite the restricted rooting depth and volume. With the exception of N, current nutrient requirements were met largely by uptake from the soil. Soil reserves were replenished by cycling between the trees and the soil.

Strictly speaking, the results from this study apply only to a limited but very representative area of shallow, podzolic soils that support upland black spruce stands near Nipigon, Ontario. Large site-to-site variability in stand, humus layer, and mineral soil nutrient content has been reported for black spruce stands. The high degree of uncertainty in predicting site nutrient reserves reflects the difficulties in generalizing about potential impacts of management on the nutrition of black spruce. On specific sites, various physical conditions, such as a rise in the water table following clear-cutting, can play a role in limiting nutrient availability. The occurrence of especially warm summers can positively affect nutrient cycling by accelerating bacterial activity in the soil.

Postharvest treatments designed to encourage regeneration, but which may result in the removal of the nutrient capital of the humus layers (e.g., deep scarification), should be avoided on shallow till soils. Nutrients in the humus layers should be conserved if a substantial proportion of the nutrient reserves on a site are contained in these materials. Site preparation methods that retain organic matter and nutrients on site (e.g., disc trenching, patch scarification, chemical site preparation) are much less drastic than are blading and piling. Retention of organic matter, in fact, makes soils less susceptible to compaction by logging and site preparation equipment (Sands et al. 1979).

Nitrogen uptake appears to be limited by the accumulation and slow release of N from humus layers. Satisfactory early growth of a regenerating black spruce stand may not be possible without N supplements if the release of nutrients from deep humus layers is not stimulated by harvesting and site preparation. Regeneration will benefit from the nutrient reserves in the humus layers, particularly if nutrient turnover is accelerated by mixing and incorporation of organic matter into the mineral soil by appropriate mechanical site preparation.

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