Frontline
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Great Lakes Forestry Centre
Technical Note No. 96

CONSERVATION OF CARBON AND NITROGEN IS RECOMMENDED FOLLOWING 20 YEARS OF STUDY IN FERTILE AND INFERTILE JACK PINE STANDS

N.W. Foster[1], I.K. Morrison[1], P.W. Hazlett[1], G.D. Hogan[1], and M.I. Salerno[2]

CATEGORY: Forest environment
KEY WORDS: Nutrient cycling, forest floor, mineral soils, disturbance

INTRODUCTION

How can resource managers ensure that forests are managed in an ecologically acceptable manner and that the sustainability of future timber and non-timber resources is protected? To understand the potential impacts of forest management on ecosystem processes, information on the role of nutrient cycling on nutrient supply is needed at the different stages of stand development.

In closed-canopy maturing forests growing on infertile sites, wood production may be dependent more on nutrient cycling than on soil nutrient reserves (Miller et al. 1979). In fact, in some forests nearly all the nitrogen (N) uptake by the trees comes from the forest floor (Staff and Berg 1977, Cole 1981). In one study with jack pine (*Pinus banksiana* Lamb.), annual removal of the forest floor reduced N uptake and decreased tree radial growth by 30 percent (Weber et al. 1985). Still other researchers have concluded that tree nutrition may be adversely affected if nutrient cycling is slowed by an accumulation of nutrients in inactive organic layers (Williams 1972).

The objective of this study was to assess the development and function of natural stands by examining nutrient cycling and measuring changes in carbon (C) and N storage with stand age by sequentially sampling two jack pine ecosystems over a 20+ year period. This sequential approach is the best means of assuring that biomass and nutrient differences observed in the vegetation and soil are functions of age alone.

STUDY AREAS

The Dupuis study site (Lat. 47° 38'N, Long. 83° 15'W) is located on an outwash deposit consisting of 30 cm of silt loam over loamy sand or gravelly sand near Chapleau in the Sudbury District of Ontario. The Site Index 50 of the fire-origin jack pine forest is 16.5 m. Between the ages of 45 and 68 years, stand basal area and dry matter increased from 31 to 34 m^2/ha and from 127 to 167 tonnes (t)/ha, respectively, and density decreased from 2 926 to 1 478 trees/ha.

The Wells site (Lat. 46° 25'N, Long. 83° 23'W) is located on a deep outwash deposit of coarse to medium sand near Thessalon in the Algoma District of Ontario. The Site Index 50 of the fire-origin jack pine dominated forest, with a minor component of red pine (*Pinus resinosa* Ait.), is 19 m. Between the ages of 35 and 56 years, stand basal area and dry matter increased from 27 to 35 m^2/ha and from 117 to 175 t/ha, respectively, and density decreased from 1 952 to 1 174 trees/ha.

[1] Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario.
[2] Universidad Nacional de la Plata, La Plata, Republica Argentina.

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APPROACH

Stand biomass was estimated by applying age-adjusted regression equations, which related the tree dry weight to diameter measurement, to all the trees on four 0.04-ha permanent sample plots in 1972, 1982, and 1993 at Wells and five plots in 1970, 1975, 1980, 1985, and 1993 at Dupuis. Soil samples were obtained from six pits in each stand by volumetric extraction of all materials in 10-cm increments to a depth of 60 cm. Forest floor layers and litterfall were sampled and plant and soil samples were chemically analyzed according to procedures described in Foster and Morrison (1976).

ECOSYSTEM CARBON AND NITROGEN

Half of the ecosystem C at both sites was contained in the tree layer (Table 1). Between 60 to 66 percent of the total ecosystem C and 15–25 percent of the N was contained in the trees plus the forest floor. At a common age of 45 years, the Wells stand contained 15 percent more C and 60 percent more N than did the Dupuis forest. The Wells mineral soil contained twice as much N to a depth of 60 cm. Therefore, the loss of aboveground C and N by natural disturbances or by forest harvesting/site preparation would cause a lesser absolute impact on ecosystem C and N contents at Wells, but a greater impact at Dupuis. Fertilization trials have confirmed that jack pine growth at the age of 45 years was N-limited at Dupuis (Morrison and Foster 1990).

CARBON AND NITROGEN CHANGES WITH AGE

Nitrogen accumulated somewhat more rapidly than did C as both forests matured (Table 2). Increases in foliar N concentrations accounted for a significant proportion of the N accretion at Wells; but at Dupuis, N concentrations increased in stemwood. Approximately 200 kg of N was redistributed from mineral soil to tree and humus layers in 20–25 years in each stand (Tables 2 and 3). Removal of aboveground organic matter, therefore, would deplete more of the mineral soil nutrient reserves as these pine forests approached maturity.

In northern latitudes decomposition rates are slow and organic matter and nutrients accumulate in humus layers. In 1971 the forest floor depth and mass was 8 cm and 44 t/ha, respectively, with average C and N contents of 26 t/ha and 400 kg/ha in both midrotation jack pine stands. Nitrogen and C concentrations at both sites and the mass of the L and F layers at Wells were independent of age. However, the H-layer mass increased with age at both sites and, at the Dupuis site, the F-layer mass increased and then stabilized at the age of 53 (Table 3). Differences in mass, therefore, produced a net annual accumulation of forest floor N (5.8 kg/ha and 7 kg/ha) and C (0.2 t/ha and 0.8 t/ha) at Wells and Dupuis, respectively, over 21–23 years.

Table 1. Carbon and nitrogen contents in two 45-year-old jack pine ecosystems.

	Carbon (t/ha)		Nitrogen (kg/ha)	
Ecosystem component	Wells	Dupuis	Wells	Dupuis
Trees	71.1	61.4	329	207
Ground vegetation	0.2	0.5	6	9
Moss	0.6	0.5	19	13
Forest floor	21.8	20.6	404	404
Mineral soil	59.0	39.0	4 348	1 946
Total	152.7	122.0	5 106	2 579

Table 2. Carbon and nitrogen in two mid- to late-rotation jack pine stands in Ontario.

	Carbon (t/ha)				Nitrogen (kg/ha)			
	Wells		Dupuis		Wells		Dupuis	
	38 years	59 years	45 years	68 years	38 years	59 years	45 years	68 years
Foliage + fruit	3.5	5.1	3.0	3.9	73	121	62	93
Branches	7.3	10.7	6.7	8.5	44	123	53	70
Stem	37.2	54.7	43.5	55.9	80	98	77	129
Stump + roots	8.2	3.9	8.1	12.2	18	26	15	29
Total trees	56.2	84.1	61.4	80.5	214	369	207	322

Table 3. Age effects on the mass and N content of forest floor F layer under two jack pine stands. Corresponding letters indicate no significant (P=0.05) difference between values.

Dupuis			Wells		
Stand age (years)	Mass (kg/ha)	Nitrogen[1] (kg/ha)	Stand age (years)	Mass (kg/ha)	Nitrogen[1] (kg/ha)
46	14 440 a	285	38	16 470 a	288
47	19 120 ab	-	50	15 860 a	-
53	25 250 b	-	59	19 725 a	320
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[1] Includes L layer.

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NUTRIENT CYCLE CHANGES WITH AGE

Inputs from tree litterfall, mosses, and root detritus influence faunal and microfloral activity and determine C and N accumulation patterns in the forest floor. Annual litterfall of C (1.9 t/ha and 1.1 t/ha) and N (25 kg/ha and 15 kg/ha) inputs at Wells and Dupuis, respectively, did not vary systematically with increasing stand age and decreasing stand density. The mean residence time for N in the forest floor at the age of 45 years was longer at the Dupuis site (19 years) than at Wells (12 years). The authors estimated the residence time by dividing the L plus F pool size by the annual litter input. The mean residence time for N did not change between 35 and 47 years in the Wells forest floor.

At Wells, where the forest floor receives almost twice the N deposition in litterfall as Dupuis, shorter residence times would only be possible if decomposition rates were much higher. More N cycles between the soil and trees, but less N is incorporated into humus layers at the N-rich Wells site. Despite a lower N demand, the Dupuis jack pine forest must obtain more of its N needs, and as much N as Wells, from an N-impoverished mineral soil (Fig. 1). The release of N from decomposing organic layers could provide the majority of jack pine N uptake at the Wells, but not at the Dupuis, site (Fig. 1). Approximately 50 percent of the N uptake could be obtained directly from the forest floor at Wells; some of the N released from the forest floor leaches into the mineral soil as inorganic and organic N.

As the forest matures, less N will have to be supplied from the mineral soil because more N is supplied from the forest. The greatest mass of fine roots in each site was located in the upper 10 cm of mineral soil (Foster et al. 1995). The roots were positioned to take advantage of N leaching from the forest floor and the higher N concentrations in surface mineral soil horizons. As the two pine forests matured there was no slowdown in N cycling between vegetation and soil, and N uptake by the trees did not decline with age (Foster et al. 1995)

IMPLICATIONS FOR FOREST GROWTH

Nitrogen inputs to these two pine stands by precipitation were incorporated into a tight internal nutrient cycle (Fig. 1). If these inputs replace only the N that will be removed in harvesting, future forests will remain as N-limited and thus no more productive than the present forests. Jack pine forests are aggrading systems that accumulate N and C as long as they remain in a thrifty, productive state. In pine forests regenerated by natural or artificial seeding, N and C accumulation by the tree stand could be maximized if commercial thinning was avoided by controlling tree density using a precommercial thinning.

Infertile pine sites, like the Dupuis one, should be managed to conserve and enhance the C and N reserves of the ecosystem. Harvesting that leaves slash at the stump should be the preferred extraction method of mature stands, because less nutrients are removed than with full-tree harvesting. Retaining jack pine foliage and branches would be a benefit to the future productivity of these sites by building up soil C and N contents. If full-tree harvesting occurs on infertile soils, crown nutrients should be replaced by mineral fertilizers or by chipping tree tops and spreading the residue on the cutover.

Disturbances such as windrowing of slash, wildfires, and prescribed burning reduce forest floor N and C contents. These activities are likely to exacerbate N deficiencies in pine soils similar to the Dupuis site, and possibly induce them in more fertile sites like Wells. Retaining humus layer N on a site will minimize the requirement for second-growth forests to utilize reserves of N in the mineral soil. Mixing of forest floor layers with mineral soil may, in the short term, incorporate more nutrients into the seedling rooting zone. In the long term, mixing may contribute to the improvement of soil structure and increase nutrient and moisture retention in these dry, coarse-textured soils.

A Canadian Forest Service experiment has been established across a spectrum of jack pine productivity classes. This experiment will determine how soil disturbance and changes in site organic matter contents, related to harvesting and site preparation, affect the long-term sustainability of managed jack pine forests.

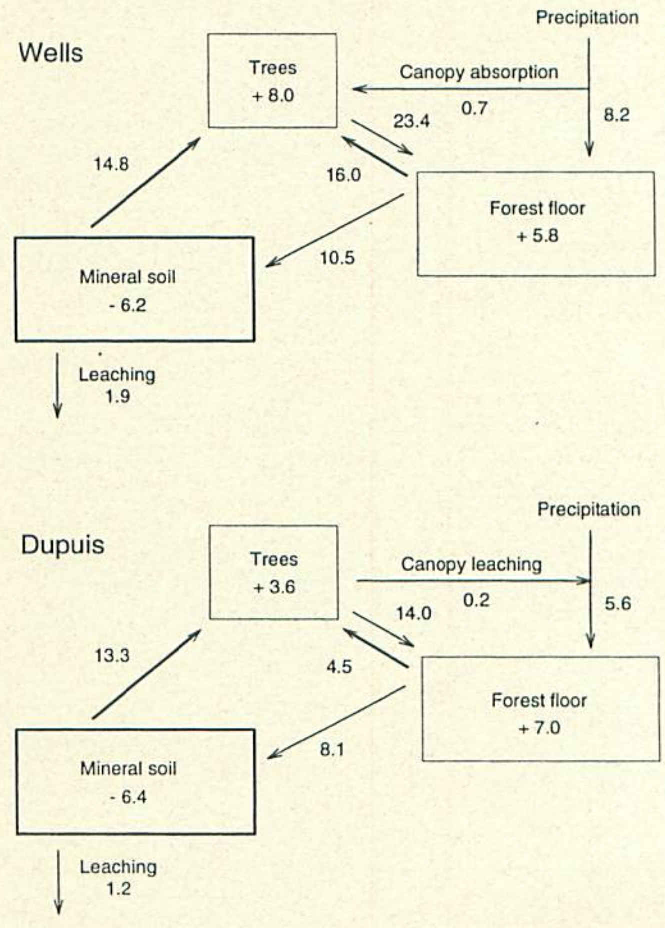

Figure 1. Annual fluxes and accumulation of nitrogen (kg/ha) as measured (—) or calculated (—) for two semimature jack pine stands.

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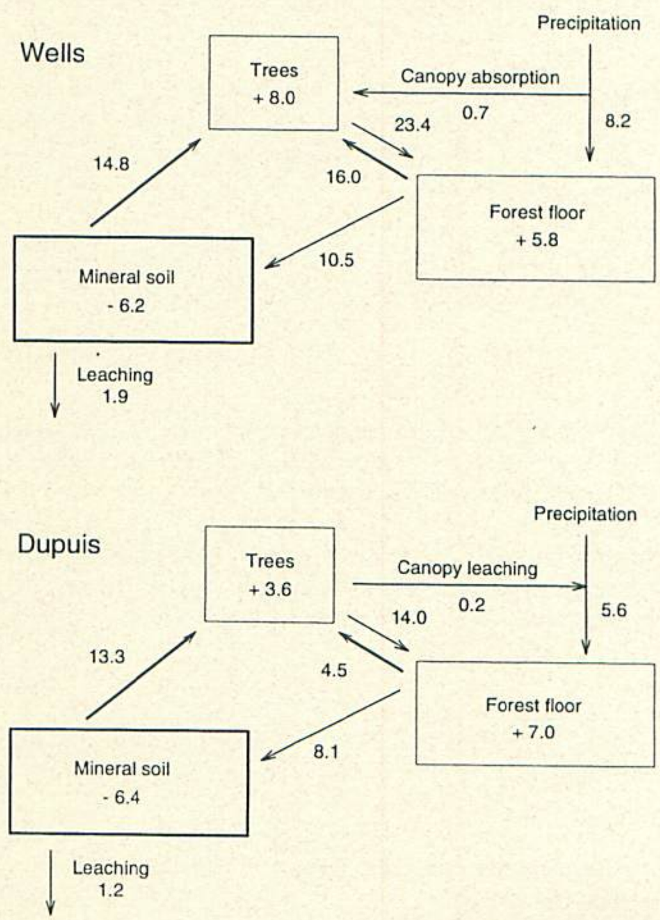

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