EFFECT OF CALCIUM AND MAGNESIUM, WITH AND WITHOUT NPK, ON GROWTH OF SEMIMATURE JACK PINE FOREST, CHAPLEAU, ONTARIO: FIFTH - YEAR RESULTS

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ABSTRACT

In May 1970, an experiment to test the effect on stand growth (mean DBH, BA, volume) of Ca and Mg was established in relatively thrifty (PAI = 6.7 m^3/ha) 45-year-old jack pine (*Pinus banksiana* Lamb.) forest of fire origin on a Site Class I sandy site near Chapleau, in north-central Ontario. The experiment consisted of all combinations of three levels of Ca (0, 224 and 448 kg Ca/ha) supplied as crushed calcic limestone and three levels of Mg (0, 28 and 56 kg Mg/ha) supplied as MgO, with and without a NPK mixture supplying 168 kg N, 56 kg P and 56 kg K/ha. Measurement plots were 0.02 ha in size, with two for each treatment. After five years the following response variables were estimated: mean DBH increment, BA increment, % BA growth, and total and merchantable volume increments. Analysis of variance indicated highly significant response to NPK in relation to all variables. In addition, the interaction of NPK with Ca and Mg was significant for BA and merchantable volume increment, and highly significant for total volume increment. Response to Ca and Mg was lacking in the absence of NPK, but with NPK several Ca and/or Mg treatments increased growth significantly over controls. Best responses were to NPK Ca 224 and NPK Mg 56, producing gains in PAI over controls of 2.8 and 2.3 m^3/ha/yr, respectively. The pattern of response with respect to volume growth was not consistent, and trends were therefore difficult to interpret. The pattern of response with respect to % BA growth, however, suggested that with NPK some additional response to Ca or Mg could be obtained.

RÉSUMÉ

En mai 1970, on a effectué une expérience pour vérifier l'influence du Ca et du Mg sur l'accroissement (DHP moyen, ST, volume) d'un peuplement relativement prospère (APA 6.7 m^3/ha) de Pin gris (*Pinus banksiana* Lamb.) âgé de 45 ans, issu d'un brûlis, sur une station sableuse de catégorie I, près de Chapleau, dans le centre-nord de l'Ontario. L'expérience a consisté à combiner trois concentrations de Ca (0, 224 et 448 kg Ca/éha) sous forme de chaux broyée, et trois concentrations de Mg (0, 28 et 56 kg/ha) sous forme de MgO, avec ou sans mélange NPK, procurant 168 kg N, 56 kg P et 56 kg K/ha. Les placettes contenaient 0.02 ha, et on en comptait deux par traitement. Après cinq ans, on évalua les résultats comme suit: accroissement moyen du DHP, accroissement de la ST, % d'accroissement de la ST, enfin, accroissement des volumes marchand et total. L'analyse des variances indiqua l'effet hautement significatif de NPK par rapport à toutes les variables. En plus, l'interaction de NPK avec Ca et Mg fut significative sur l'accroissement de la ST et du volume marchand et très significative quant à l'accroissement du volume total. L'effet du traitement Ca et Mg fut négatif à cause de l'absence de NPK, mais avec NPK en plusieurs traitements de Ca et/ou Mg, l'accroissement augmenta notablement, comparativement aux témoins. Les meilleurs résultats furent attribués au traitement NPK Ca 224 et NPK Mg 56, produisant un meilleur APA que chez les témoins, soit 2.8 et 2.3 m^3/ha/an respectivement. Cependant, le type de réponse quant à l'accroissement du volume ne fut pas constant et il fut donc difficile d'interpréter les tendances. Au sujet du % d'accroissement de la ST par suite de l'utilisation de NPK, on pourrait vraisemblablement obtenir quelque avantage additionnel avec le Ca ou le Mg.

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INTRODUCTION

The present study is one of a series of fertilizer experiments established in the spring of 1970 in semimature jack pine (*Pinus banksiana* Lamb.) forest in the vicinity of Chapleau, Ontario. The purpose of this experimental series was to examine further the possible role of mineral fertilizers in northern pulpwood silviculture.

It was well known, at the time these experiments were established, that plants (including forest trees) require for development and growth a number of soil-derived inorganic elements, and also that soils vary in their ability to supply these elements. It was also widely held that, on sandy sites in the boreal forest of Ontario, nitrogen (N) is the element whose deficiency most often limits the growth of conifers. This has been borne out by the results of various fertilizer experiments (Anon. 1974a, Morrison et al. 1976a,b). Nevertheless, there is also evidence that when N demand is met, another element such as phosphorus (P) could become limiting (Anon. 1974a). Therefore, in a second experiment to examine the possibility that P or potassium (K), in addition to or instead of N, could promote growth, all combinations of three levels of N, three of P and three of K were tested (Morrison et al. 1977b). In the present experiment, which represents the third in the series, two additional macronutrients, calcium (Ca) and magnesium (Mg), were also considered.

While Ca is an essential macronutrient element for all higher plants, with effects of its deficiency on coniferous seedlings and in particular on various species of pine seedlings having been amply demonstrated in culture (Pessin 1937, Mitchell 1939, Davis 1949, and others), its deficiency in field-grown trees is virtually unreported. Most soils, including largely granite- and diorite-derived low-base sands such as those in the area of the present study, appear capable of supplying sufficient of this element to meet direct nutritive needs. Even in agriculture, the common practice of liming (agricultural limes include a number of soil amendments, chiefly carbonates, hydroxides and oxides of Ca and Mg, variously processed and in varying degrees of purity) is more for the promotion of nitrification through the provision of exchangeable bases and for the chemical alteration of availability of various elements through its effect on soil pH, than it is for the direct meeting of Ca requirements. Similarly, for coniferous forest, the action of Ca is presumably through its stimulation of N mineralization; hence its effect on the availability of that element.

Whereas deficiency of Ca in trees is rare, and only indirectly affects growth through its influence on the availability of other elements, Mg supply has a somewhat more direct influence on growth. Deficiency of Mg, often in association with K deficiency, has long been recognized in Scots pine (*Pinus sylvestris* L.) and other species on nutrient-depleted sandy soils in western and central Europe (Becker-Dillingen 1937, 1940, Brüning 1962, Heinsdorf 1968, and others) where, in extreme cases, it results in stunted growth and characteristic yellow-tipping of foliage. In North America, Stone (1953) identified combined K–Mg deficiency in young planted red pine (*P. resinosa* Ait.), white pine (*P. strobus* L.), and jack pine on abandoned farmland on deep lacustrine sand derived from acid syenites and granites in upper New York State. Deficiencies of K and Mg have also been reported, chiefly in young planted red pine, on often excessively drained, coarse sandy alluvial or glaciofluvial deposits or old marine sands once used for agriculture in Quebec but now abandoned (Lafond 1958, Linteau 1962, Gagnon 1965). In both Europe and North America deficiencies were readily overcome by applications of suitable K and/or Mg manures.

In the fall of 1969, samples of current foliage were collected from the upper crowns of dominant and codominant jack pine trees in the experimental area, and analyzed for N, P, K, Ca and Mg. These results have been reported previously (Morrison et al. 1977b). Of direct relevance to the present experiment, however, is that foliar concentration of Ca was estimated at 0.16±.04%, thereby falling within Swan's (1970) "range of sufficiency for good to very good growth", whereas that of Mg was estimated at 0.08±.02%, falling within Swan's (ibid.) "transition zone from deficiency to sufficiency".

The present experiment was designed to test for response by jack pine to Ca and Mg singly and in combination, both with and without the application of N, P and K.

STUDY AREA

The stand in which this and other experiments were established is located at a point (lat. 47°38'N; long. 83°15'W) in Dupuis Twp (formerly Twp 12E) on the boundary of Nimitz Twp, Sudbury District, Ontario, some 25 km SSE of the town of Chapleau, astride the height-of-land separating the Arctic and Great Lakes watersheds. It is within the Missinaibi–Cabonga Section (B.7) of the Boreal Forest Region (Rowe 1972) and is on the common boundary of the Foleyet Site District of Site Region 3E and the Mississagi Site District of Site Region 4E (Hills 1955). Based on a 5.5°C index, the growing season, May through September inclusive, averages 161 days (Chapman and Thomas 1968). Annual mean total precipitation at the nearest weather station (Chapleau) is 810 mm, with approximately 53% of this falling during the growing season (Anon. 1973). Average annual potential evapotranspiration has been estimated at 480 mm. In profile the soil is a Mini Humo Ferric Podzol (Anon. 1974b) developed in silt loam over loamy sand, the latter commencing at a depth of approximately 30 cm below the mineral surface.

The stand at the beginning of the experiment was 45-year-old (stump age), uniform jack pine forest of fire origin. In the immediate vicinity of the present experiment, the total number of trees was 3141/ha, mean dominant height 17.1 m, mean diameter at breast height (DBH) 10.4 cm (range 3.0-31.0 cm), basal area (BA) 26.8 m^2/ha, total standing volume 173.4 m^3/ha, and merchantable standing volume 125.2 m^3/ha. The Site Class is I (Plonski 1974). The forest floor was occupied by a continuous moss layer, the predominating species being *Pleurozium schreberi* (BSG.) Mitt., with *Dicranum polysetum* SW and *Hypnum crista-castrensis* Hedw. in lesser abundance (Appendix). The most commonly occurring species in the herb and shrub layer included *Maianthemum canadense* Desf., *Anemone quinquefolia* L., *Cornus canadensis* L., *Vaccinium angustifolium* Ait., *Diervilla lonicera* Mill. and *Linnaea borealis* L. The grass, *Oryzopsis asperifolia* Michx., likewise occurred frequently.

METHODS

The experiment was set out in May, 1970 as a 3x3x2 completely randomized factorial, consisting of three levels of Ca (0, 224 and 448 kg Ca/ha) supplied as crushed calcic limestone ($CaCO_3$), three levels of Mg (0, 28 and 56 kg Mg/ha) supplied as fertilizer grade magnesium oxide (MgO) both with and without a fixed mixture of urea, triple superphosphate and muriate of potash, supplying 168 kg N/ha, 56 kg P/ha and 56 kg K/ha. There was one additional replication for a total of two plots per treatment and an overall total of 36 plots. Treatment plots were square, 0.08 ha in area with interior 0.02 ha measurement plots. The plots were arranged in a grid pattern with shared treatment plot boundaries. The portion of the treatment plots external to the measurement plots served as buffer zones between plots. Trees were labelled in the field with numbered metal tags. Fertilizers were hand-broadcast onto the soil surface in a two-or-more pass systematic pattern to attempt uniform coverage in late May, 1970. Initial DBH measurement of all trees, by steel diameter tape, was made and recorded at that time. Heights of one randomly selected tree per 2.5 cm diameter class per plot were also estimated. Remeasurement of DBH was made 5 years later, in late May, 1975. In accordance with standard practice, trees which died during the period 1970-1975 were removed from the tally. All measurements were in English units with subsequent conversion to SI units.

The following 5-year response variables were calculated: mean DBH increment, BA increment, % BA growth, total volume increment, and merchantable volume increment. Mean DBH and BA increment, and % BA growth, were calculated in the usual manner. The two volume increments were estimated as follows: a regression of height-on-diameter was derived from pooled measurements on the height-measured sample trees (supplemented by data from similarly selected trees in nearby experiments) and was used to approximate the height of each tree. Total and merchantable volumes, for both 1970 and 1975, were computed for each plot, on a tree-by-tree basis using these heights, measured DBH, and Honer's (1967) volume equations. Increments were calculated for each plot by subtracting 1970 from 1975 figures. Data were subjected to analysis of variance and Duncan's New Multiple Range Test for the detection of differences among means.

RESULTS

The analysis of variance (Table 1) indicated a highly significant (1%) across-the-board treatment effect, relative to all parameters, only for NPK. In addition the interaction of NPK with Ca and Mg together was significant (5%) for BA and merchantable volume increments and highly significant (1%) for total volume increment.

Table 1. Analysis of variance: summary of F-ratios

	Response variables				
Treatment	Mean DBH increment	Basal area increment	Basal area growth (%)	Total vol. increment	Merch. vol. increment
NPK	14.02**	45.87**	33.28**	53.99**	43.76**
Ca	.96	.05	.85	.13	.16
Mg	.58	.23	.68	.44	.40
Ca Mg	.63	2.08	1.00	2.90	2.30
NPK Ca	.61	.94	.04	.94	.70
NPK Mg	.14	.02	1.17	.01	.01
NPK Ca Mg	2.02	4.24*	1.37	5.13**	4.04*

* Statistically significant, P = .05

** Statistically significant, P = .01

Results of Duncan's New Multiple Range Test (Table 2) indicated that, without NPK, at no level or in no combination did either Ca or Mg produce any growth response significantly greater than that of the control; in fact, in several instances growth was less (not significantly) that that of the control. Whereas Duncan's test suggested that NPK alone produced only a minor response, several combinations of NPK with Ca and/or Mg resulted in growth responses significantly (1%) greater than those of the control. In general, with NPK, growth increased with Mg application rate whereas for Ca, response was greatest when Ca was supplied at 224 kg/ha. In terms of 5-year total or merchantable volume increment, the combination of Ca and Mg (with NPK) produced inconsistent results. With NPK, the combination of Ca and Mg produced a response surface (Fig. 1) in terms of % BA growth suggesting responses to Ca and Mg separately but antagonism between them in combination.

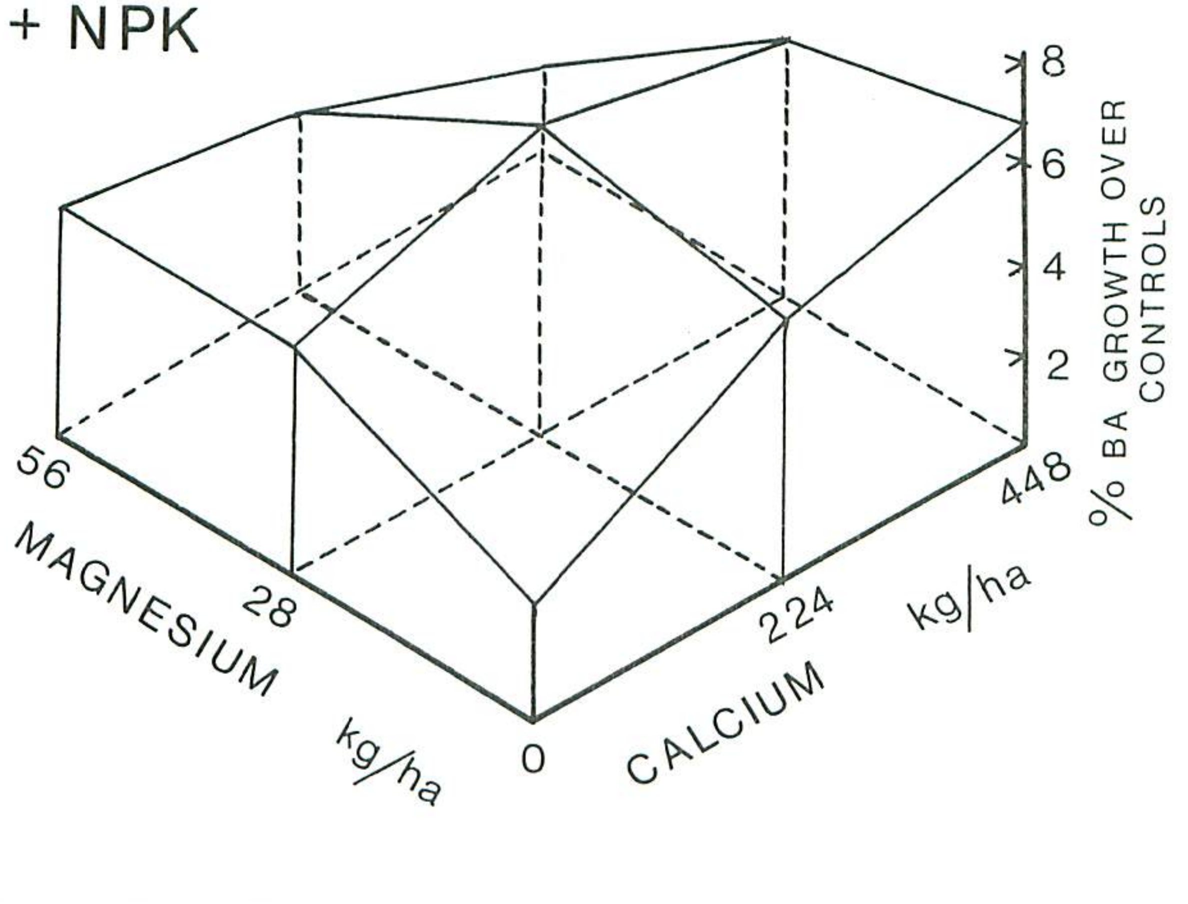

Fig. 1. Effect of calcium and magnesium with NPK on 5-year % basal area growth-over-control of 45-year-old jack pine.

Table 2. Five-year growth response of 45-year-old jack pine to calcium and magnesium with and without NPK

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Basal area growth (%)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
	Response variables				
Control	0.80	4.30	14.75	33.55	33.52
Mg 28	.80	4.18	15.35	32.39	32.63
Mg 56	.70	3.58	14.80	26.86	27.91
Ca 224	.80	3.86	14.30	29.52	29.47
Ca 224 Mg 28	.80	3.80	16.05	28.89	29.45
Ca 224 Mg 56	1.05	4.35	18.00	33.76	34.15
Ca 448	.70	4.17	14.30	30.42	29.84
Ca 448 Mg 28	.95	4.42	15.90	34.28	34.23
Ca 448 Mg 56	.70	4.17	14.50	31.26	31.97
NPK	.90	4.63	17.35	35.28	35.08
NPK Mg 28	1.00	5.15	19.60	39.72	39.91
NPK Mg 56	.95	5.97*	20.40*	45.15*	45.90*
NPK Ca 224	.95	6.24*	20.45*	47.75*	47.19*
NPK Ca 224 Mg 28	1.05	5.03	21.15*	38.31	38.61
NPK Ca 224 Mg 56	.95	4.92	18.50	37.95	38.83
NPK Ca 448	1.05	4.88	21.55*	36.07	36.03
NPK Ca 448 Mg 28	.95	5.82*	20.00*	44.62*	44.80*
NPK Ca 448 Mg 56	1.00	4.57	16.45	35.18	35.34

* Significantly different from control, P = .05, by Duncan's New Multiple Range Test.

Periodic annual total and merchantable volume increments over controls for the three treatments showing greatest responses are given in Table 3.

Table 3. Periodic annual increment over controls for treatments showing significant total and merchantable volume response

Treatment	PAI over control (m^3/ha/yr)	
	Total vol.	Merch. vol.
NPK Mg 56	2.32	2.48
NPK Ca 224	2.84	2.73
NPK Ca 448 Mg 28	2.14	2.26

DISCUSSION

Whereas most applications of Ca and Mg to pines have been with young plantations usually on soils depleted by previous cropping, in the present experiment Ca and Mg were applied to a semimature natural stand on a central northern Ontario low-base sand. The analysis of variance suggested an across-the-board response to NPK and an interaction of NPK with Ca and Mg. However, the two NPK-only plots fared poorly, their response not being significantly greater than that of the control when Duncan's New Multiple Range Test was used. Tests of significance of individual means indicated that certain combinations of Ca and/or Mg with NPK increased growth significantly over controls. In several instances the addition of Ca or Mg to NPK significantly increased growth over that promoted by NPK alone. The essential question therefore becomes: "Are the observed responses indicative of real deficiencies of these elements in this ecosystem?"

It is clear, from the lack of response to Ca and Mg in the absence of N, P and K, that deficiencies of Ca and Mg, if such exist, are at least not primary. Further, the poor response in this particular experiment to NPK alone perhaps unduly enhanced the apparent Ca-Mg effect. On the other hand, even when compared with the somewhat higher responses to similar N, P and K additions in another experiment conducted in the same stand (Morrison et al. 1977b), the addition of Ca and Mg over and above NPK seems to have had, at least in certain combinations, a growth promoting effect. Indeed, responses in this experiment to the better treatments, all of which included Ca and/or Mg, were of a considerably higher order than responses to the better treatments in experiments in the same jack pine stand with other mineral fertilizers. The increase in periodic annual increment (PAI) over controls (total volume basis) was as high as 2.8 m^3/ha for NPK Ca 224. It is in the interpretation of trends, particularly in relation to volume growth, that difficulties arise. While the data suggest that, when NPK demand is met, growth increases to the highest Mg level, or in the case of Ca peaks at the intermediate level, their various combinations produce inconsistent results. For example, NPK Ca 224 produces an additional 14 m^3/ha over 5 years and NPK Mg 56 produces 12, while their combination produces only 5; NPK Ca 448 produces 3 m^3/ha in 5 years, NPK Mg 28 produces 6, while their combination produces 11. Some reconciliation of trends can be observed in the % BA growth figures (Fig. 1), where effect of variation in plot initial standing BA is eliminated. Generally, with NPK, % BA growth increased with either Ca or Mg separately to the highest levels of application, but decreased when the two were combined.

The matter of forest liming might be considered further. As was stated earlier, Ca application is seen chiefly as a method promoting N availability. Whereas in Europe, liming of depleted soils is fairly common, particularly in relation to hardwood culture (Baule and Fricker 1970), in North America it has received relatively little attention. Weetman (1962) found hydrate of lime [$Ca(OH)_2$] ineffective in stimulating either growth or N uptake of 49-year-old black spruce (*Picea mariana* [Mill.] B.S.P.) in northeastern Ontario. More recently Morrison et al. (1977a) found no conclusive evidence that crushed limestone ($CaCO_3$) was beneficial over and above NPK when applied to 55-year-old jack pine in northwestern Ontario. Moreover, practical problems are seen in the application of Ca in lime form to semimature forest stands. The less reactive limes (calcic and dolomitic limestone, etc.), while relatively inexpensive, are generally applied in large dosages, and hence would be associated with high application costs. The more reactive oxides and hydrates of lime are sufficiently caustic (and thereby injurious to foliage) that they should not be applied aerially, although it is not inconceivable that in strip-thinned areas, lime (if it were to be proven beneficial) could be applied to leave-strips by blower from a hopper-equipped surface-vehicle.

Analysis of foliage, sampled prior to treatment, from trees in this stand revealed Mg concentrations within the upper portion of Swan's (1970) "transition zone from deficiency to sufficiency". The general validity of Swan's standard for Mg is seen in comparison of his transition zone from deficiency to sufficiency for red pine (Swan 1972). Truong dinh Phu (1975), in a region of demonstrated Mg deficiency, correlated growth with foliar Mg levels ranging from 0.03 to 0.09%.

On the one hand, as there was no response to Mg alone, no obvious Mg deficiency and no pronounced growth restriction--for indeed the stand was reasonably thrifty with an untreated PAI in excess of 6 m^3/ha--it would seem safe to suggest that the foliar concentration of Mg recorded for this stand, 0.08%, was probably closer to sufficiency than deficiency. It is likely, too, that there was an adequate supply of this element provided that growth was not increased by the melioration of some other factor. On the other hand, in this particular experiment it must be stressed that the principal across-the-board response was to NPK, although the prospect that additional response might be obtained to Ca or Mg once NPK demand is met cannot be ruled out.

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APPENDIX

APPENDIX

Occurrence of lesser plant species prior to treatment, expressed as a percentage of plots on which species occurred (based on a sample of two 1 m^2 subplots per plot).

Plant species	Occurrence (%)
LICHENS	
Cladonia mitis Sanst.	8
MOSSES	
Polytrichum spp.	6
Dicranum polysetum SW	36
Hypnum crista-castrensis Hedw.	17
Pleurozium schreberi (BSG.) Mitt.	100
HORSETAILS	
Equisetum sylvaticum L.	3
SEED PLANTS	
Picea mariana (Mill.) B.S.P.	28
Oryzopsis pungens (Torr.) Hitchc.	11
Oryzopsis asperifolia Michx.	78
Carex spp.	47
Clintonia borealis (Ait.) Raf.	14
Maianthemum canadense Desf.	100
Goodyera tesselata Lodd.	6
Salix spp.	42
Comptonia peregrina (L.) Coult.	31
Alnus crispa (Ait.) Pursh	6
Clematis verticillaris DC	3
Anemone quinquefolia L.	83
Coptis groenlandica (Oeder) Fern.	17
Sorbus decora (Sarg.) Schneid.	3
Amelanchier spp.	28
Rubus pubescens Raf.	17
Rubus strigosus Michx.	11
Rosa acicularis Lindl.	39
Prunus pensylvanica L.	3
Polygala paucifolia Willd.	61
Viola spp.	36
Epilobium angustifolium L.	6

(continued)

APPENDIX (concluded)

Occurrence of lesser plant species prior to treatment, expressed as a percentage of plots on which species occurred (based on a sample of two 1 m^2 subplots per plot).

Plant species	Occurrence (%)
SEED PLANTS (concl'd.)	
Aralia nudicaulis L.	8
Cornus canadensis L.	100
Pyrola secunda L.	3
Ledum groenlandicum Oeder	8
Epigaea repens L.	39
Gaultheria hispidula (L.) Bigel.	11
Vaccinium angustifolium Ait.	94
Vaccinium myrtilloides Michx.	75
Trientalis borealis Raf.	28
Melampyrum lineare Desr.	6
Galium spp.	3
Diervilla lonicera Mill.	86
Linnaea borealis L.	86
Solidago bicolor L.	58
Aster macrophyllus L.	19