NUTRITION AND FERTILIZATION OF LODGEPOL

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ABSTRACT

Lodgepole pine is not considered to be a nutrient demanding species. It grows well on nutrient poor soils. A review of the relatively few fertilization trials in North America is presented. Fertilizer work in both jack pine and lodgepole pine suggests a close similarity in response between the species, which actually interbreed. Lodgepole pine appears to be particularly responsive to nitrogen additions; phosphorus deficiencies may be induced by nitrogen additions. Responses as high as 50% in volume increment over a 10-year period have been found with applications of nitrogen over 150 kg/ha. Some case study data are presented.

In North America most fertilization studies have been conducted in naturally regenerated stands on upland sites, often following spacing. Boron and copper micronutrient deficiencies have been identified on some soils. In Europe, particularly in Ireland, phosphorus and nitrogen are required in the extensive use of coastal lodgepole pine in peatland afforestation.

INTRODUCTION

Our understanding of lodgepole pine nutrition and fertilization is much better than is indicated by the sparse North American literature. This is because:

1. Lodgepole pine as a hard, two-needle pioneer pine species is apparently very similar in its nutritional requirements to other pines of this type, notably jack pine (*P. banksiana*)—with which it interbreeds naturally in Alberta—and to Scots pine (*P. sylvestris*). There is evidence to suggest that lodgepole pine will respond in the same way as these two species with regard to soil nutrient additions as fertilizer (especially nitrogen (N)) and to soil nutrient deficiencies.
2. Much work has been done in Britain, Ireland and Scandinavia on lodgepole pine nutrition and fertilization.

This paper reviews some of our understanding on these species, outlines some current studies, and presents some recent fertilization response data. Nursery nutrition of lodgepole pine will not be covered.

The species is famed for its extraordinarily wide ecological amplitude and low competitive ability. Outside of its altitudinally defined interior North American range (spp. *latifolia*), where it forms vast forests, *Pinus contorta* is "forced off" the richer sites by more competitive species and occurs on extreme sites (muskegs, dunes, rocky sites, and serpentine soils) as spp. *contorta*. In an extreme case (spp. *bolanderi*) it occurs as dwarf trees on very nutrient poor acid podzols (Critchfield 1978, 1980). Its ability to tolerate and successfully grow in extremely nutrient poor sites is borne out by mineral nutrition studies. Swan (1972a,b) found its nutritional requirements similar to Scots and slash pine (*P. elliottii*). Table 1 presents foliar nutrient concentration standards from three sources. Morrison (1974) reviewed literature on the interpretation of foliar nutrient status data. A micro-computer program using published data to provide interpretation of the nutritional status of foliage samples for macro- and microelelments has recently been developed (Ballard and Carter 1983). Color photographs of visual deficiencies in lodgepole pine are presented (Binns *et al.* 1980).

Table 1.—Published interpretations of foliar macronutrient concentrations for lodgepole pine.

	Foliar concentrations, % dry mass				
Nutrient Element	Very severely Deficient[a]	Severely Deficient	Slight to Moderate Deficiency[b]	Adequate	Source[e]
N	0.00-1.05	1.05-1.20	1.20-1.55	>1.55	I
	–[c]	–	≤1.20[d]	≥1.70[d]	II
	–	–	<1.10	≤1.40	III
P	–	0.00-0.09	0.09-0.15	>0.15	I
	–	–	≤0.07[d]	>0.17[d]	II
	–	–	<0.12	≥0.14	III
K	0.00-0.35	0.35-0.40	0.40-0.55	>0.55	I
	–	–	≤0.30[d]	≥0.60[d]	II
	–	–	<0.30	≥0.50	III
Ca	–	0.00-0.05	0.05-0.10	>0.10	I
	–	–	≤0.06[d]	≥0.10[d]	II
Mg	–	0.00-0.06	0.06-0.10	>0.10	I
	–	–	≤0.07[d]	≥0.09[d]	II
	–	–	(<0.03	>0.05)[f]	III

Notes:

(a) Categories are a modified version of those of Ballard and Carter (1983); data from other sources were fitted into this on the basis of associated equivalences according to the qualitative terms used by authors.

(b) For sources other than Ballard and Carter (1983), values given may also include more severe deficiencies than indicated by this category.

(c) Dash implies no explicit statement possible for the relevant categories. Please see note (b) also.

(d) Values are lower and upper limits respectively, of Swan's (1972a and b) "transition zone from deficiency to sufficiency"; includes shore pine data.

(e) Sources are as follows: I = Ballard and Carter (1983); II = Swan (1972a and b); III = Binns *et al.* 1980).

(f) Bracketed values are tentative only.

Work on nutrient cycling in the last decade has recognized two phases in stand development (Miller 1981, Royal Society 1982).

Phase I Prior to Canopy Closure

At this phase, the trees are very dependent on soil supplies and almost any nutrient may be limiting, especially when lodgepole pine is planted or occurs on extreme sites or soils. Precise and early diagnosis is clearly desirable. Lodgepole pine planted on acid impoverished mineral and organic soils in Britain and Ireland can grow with low levels of available N and potassium (K) if phosphorus (P) is applied. This characteristic of lodgepole pine has permitted the establishment of very extensive stands on oligotrophic peats in Britain and Ireland. Lodgepole pine planted on peats on the coastal belt of Norway have shown frost damage and shoot dieback due to low foliar boron concentrations (less than 3 ppm); a situation readily alleviated by borax additions to bring the concentrations up to 10 ppm. "Elimination" fertilizer trials to identify the nutrient needs of lodgepole pine planted on ombrogenous and soligenous peats have successfully yielded the appropriate fertilizer prescription, usually involving N, P, and K plus perhaps some micronutrient addition (Braekke 1977a,b). Such studies in the U.K. and Scandinavia have demonstrated dramatic growth rates for fertilized lodgepole pine with balanced nutrition. Mean annual increments of 12-15 m^3/ha/yr are attainable – values reflected in the U.K. Forestry Commission yield tables for lodgepole pine growing on good sites.

Similar dramatic response for lodgepole pine with balanced nutrition is no doubt attainable in North America, particularly for shore pine in the coastal environment. In Europe lodgepole pine is the basis for major planting programs on the poor soils made available for forestry.

Not only does lodgepole pine respond dramatically to balanced nutrition, but Scandinavian experience has shown that for unfertilized soils, it grows much faster than Scots pine. For the same level of nutrition it is apparently photosynthetically more efficient than Scots pine. Massive use has been made of lodgepole pine in Swedish planting programs (see Hagner's paper in this proceedings).

Whether or not N fertilizer will improve growth rates prior to canopy closure depends on the rates of N mineralization on the site. For peatlands, the rates are often too low to satisfy modest demands of planted trees. The plantations themselves may result in improved N-mineralization rates of peats (William *et al.* 1979). The form of added nitrogen appears to make little difference based on studies in Scotland (MacIntosh 1982) and British Columbia (B.C.). In North America, N may be limiting before canopy closure on many fire origin stands and cutover, particularly if organic matter reserves or cation exchange capacities are low in mineral soils. A key feature may be the length of the period of the flush of increased nutrient availability following fire or cutting (Assart effect). Capture of this flush by trees often occurs rapidly in fire regenerated stands with serotinous cones, but may be missed on cutovers with delayed site preparation and regeneration.

Literature on nutritional studies of this species before canopy closure is limited. A 1981 test of 17 stands of young, precommercially thinned lodgepole pine stands in the interior of B.C. used first year needle weight and graphical diagnosis of foliar analysis to screen for response to a factorial test of levels of N fertilization with and without P and K (Weetman and Four-

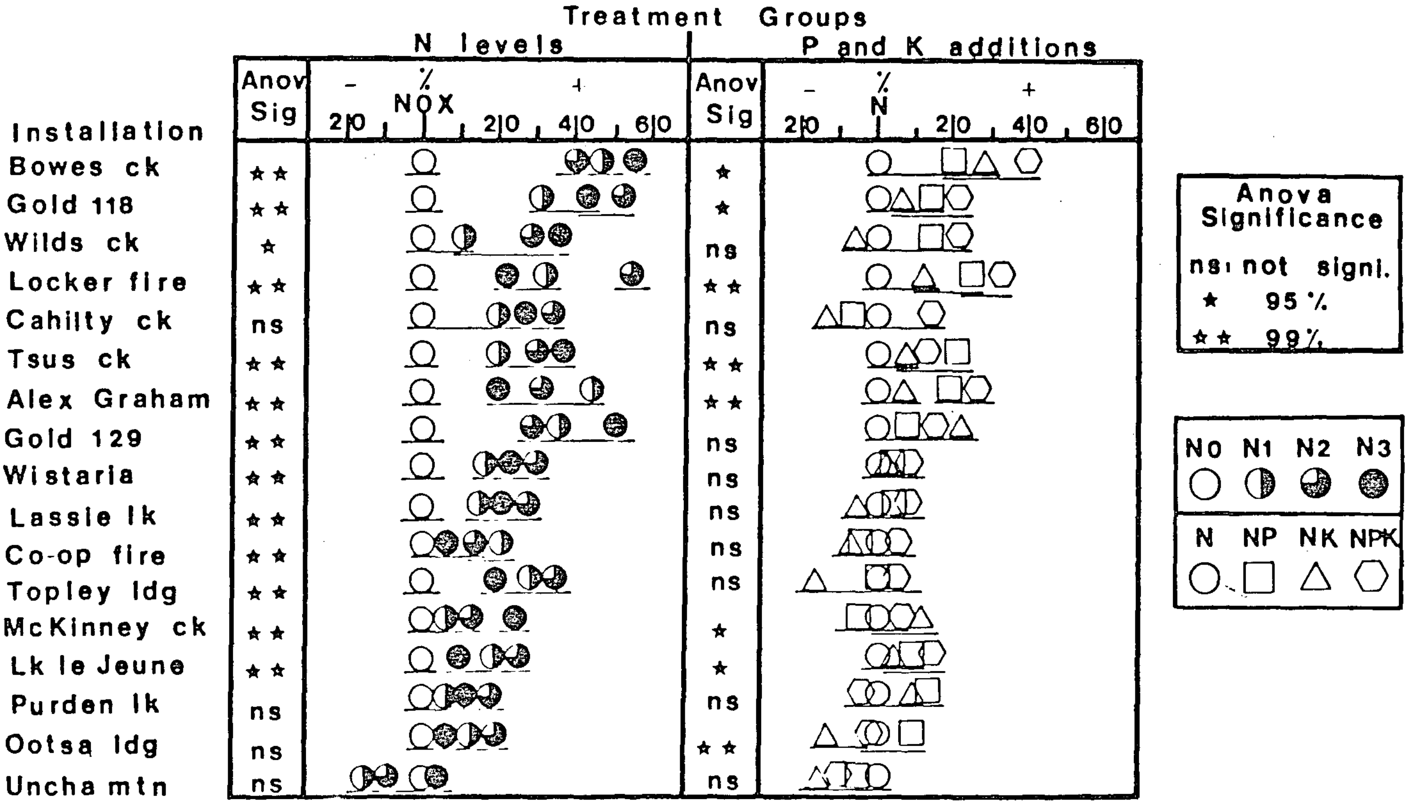

Figure 1. – Relative first year needle weights by treatment groups, statistical significance of two-way analysis of variance, and Student-Newman-Keuls multirange tests for 17 lodgepole pine fertilizer screening trials in British Columbia.

nier 1982). Over half the stands were strongly responsive, with 20% plus increases in unit foliage needle weight (Figure 1). Work with other species, notably jack pine (Weetman and Algar 1974, Camire and Bernier 1981, Timmer and Morrow 1984), has shown first year needle weight response to be highly correlated with subsequent volume response. A systematic series of 11 fertilizer trials in young lodgepole pine stands has been established by the B.C. Ministry of Forests in the interior of B.C. (Brockley 1980, 1983; see also Brockley and Barker poster session abstract). There is some evidence that N fertilization of young spaced lodgepole pine attracts more girdling by snowshoe hares and squirrels.

It may be that many young lodgepole pine stands suffer from nutrient deficiencies. Since lodgepole pine grows on such an enormous variety of sites, it is probable that on many the trees may be deficient in nutrients, almost certainly on organic soils, and probably on soils of unusual chemical composition. Nitrogen may be suspect as limiting on soils of low organic matter content. Since precommercial thinning is expensive, but often required to produce sawlog sized trees, systematic testing by foliar analysis, screening trials and conventional fertilizer trials may be warranted on stands not yet closed.

Phase II After Canopy Closure

Although before canopy closure there is a shift of nutrients from soil to tree, once the canopy is closed, the tree's demands on the soil rapidly reduces, because the cycles within the tree and through the tree-litter system are now fully charged. The cycle within the tree is based on the recovery and reuse of nutrients prior to the death of old tissues, including those of the leaf before abscission, and can be up to 85% efficient. What is discarded, except that left in heartwood, is, to a greater or lesser extent, available to roots and mycorrhizal fungi from the litter layer.

These cycles may be very tight and, when supplemented by inputs from the atmosphere in rain or from other sources, may, for elements such as K and Mg (magnesium), enable the tree to become virtually independent of soil sources of supply. For other elements, however, notably N and, to lesser extent, P, rather slow release from the decomposing litter means the tree may have to continually recharge the cycle from native soil sources. For N this immobilization in humus can lead to the development of late rotation N deficiency, a phenomenon that, because it has attracted a lot of research attention, has led to the belief that deficiency of N is the major nutritional problem in forests (Miller 1982).

This belief has been supported by the few reported fertilizer trials in closed stands, recently reviewed by Brockley (1983). These include one trial reported from Oregon (Cochran 1975, 1979), one study from B.C. (Boyd and Strand 1975), an exploratory study (Bella 1978) and a full fledged fertilization experiment in 30- and 70-year-old stands on two soil types in Alberta (Yang 1984a,b) which is presented as a case study below.

In Oregon, a single, mixed NPS treatment (N 672, P 336 and S 101 kg/ha) was compared to an unfertilized control in a thinned, 40-year-old pole-sized PL stand growing on pumice soil. Four-year and eight-year growth response was reported by Cochran (1975, 1979). Eight-year volume response averaged 18.8 m^3/ha (+79%).

Another Oregon study was established by Weyerhaeuser Co., again on volcanic soils. Treatments consisted of (1) control, (2) N at 207 kg/ha, (3) N at 414 kg/ha, and (4) N at 414, P 90, K 98 and S 78 kg/ha. The experiment was conducted on both ash and pumice soil types. Three-year volume responses as large as 12.0 m^3/ha (+87%) were reported by Cochran (1979).

In the sparse North American literature, sulfur nutrition has received notable attention. Because soils in central Oregon, the Cascade Mountains and western Alberta are reportedly low in S (Will and Youngberg 1978, Rennie 1974), S has often been added in fertilization trials of lodgepole pine (Cochran 1975, Bella 1978, Yang 1984a,b). The mechanism of S nutrition in lodgepole pine growth is not clear, although it is found that a constant ratio of 0.030 has been maintained between organic S and total N in coniferous needles (Turner 1979). Further investigations on interactions of S and N in lodgepole pine stands are needed.

The lone B.C. study was undertaken by Crown Zellerbach Corporation on TFL 9, near Kelowa. The research consisted of two parts: (1) an initial screening trial which indicated that N was the only nutrient limiting growth on the study site (Boyd *et al.* 1975, Strand and Lin 1969), and (2) a study to test the effect of N fertilization, chemical thinning, and fertilization + thinning on the growth of 40- and 80-year-old stands (Boyd and Strand 1975). N at rates of 0, 112, and 224 kg/ha as urea was applied to thinned and unthinned research plots. Thinning with MSMA was conducted at the time of fertilization. Four-year basal area growth response averaged 0.88 m^2 (+32%) and 0.28 m^2/ha (=19%) for the 40- and 80-year-old stands, respectively. Four-year volume growth response averaged 4.06 m^3/ha.

An exploratory study in Alberta (Bella 1978) in which a 70-year-old, medium site lodgepole pine stand was thinned for fence posts and then fertilized with NPS (N 112 and 673 as urea=ammonium; P 56 and 168; S 28 and 84 kg/ha) resulted in about 7 m^3/ha (30%) gain in merchantable volume over 7 years due only to N (P and S were not significant).

Closed jack pine stands have also shown a consistent response to N applications. The addition of urea (225 kg N/ha) to natural stands produced on average 8.5 m^3/ha over 5 years (Foster and Morrison 1983). It is reasonable to expect similar response in lodgepole pine. Whether or not moisture or N is the first limiting to growth in closed stands is probably a site specific phenomenon. Moisture is not a major limiting factor in most jack pine stands, but it may be in many lodgepole pine stands.

The problem of identifying and predicting response of closed stands to fertilizer additions still requires field trials; there is no sure way to identify responsive stands with confidence solely by soil analysis (such as N-mineralization rate) or foliar analysis. Screening trials using single tree fertilizer additions and foliar analysis offer a fast, inexpensive way to identify potentially reponsive stands in one growing season (Weetman and Fournier 1982). Provided lodgepole pine is rooted in mineral soil, it is probable that P and K are unlikely major limiting elements in any soil types (Bella 1978, Yang 1984a,b).

The upper limits of lodgepole pine productivity should be explored by various fertilization strategies (Axelssen 1983). There is every reason to expect that, as with Scots pine, stand productivity is directly related to N availability which in turn is controlled by N-mineralization and fertilization rates. Lodgepole pine grown close to optimum nutrition conditions should display a change in carbon allocation with increased bolewood efficiency and improved photosynthetic rate. All this suggests that the potential for growth improvement by better nutrition is obviously very great in lodgepole pine.

Case Study: Response of Lodgepole Pine to N, P, and S Fertilization in Alberta

The study areas were located southeast of Hinton, Alberta (53°25'N, 117°34'W) on the lease area of St. Regis (Alberta) Ltd. Forests here are within the Lower Foothills Section of the Boreal Forest Region (Rowe 1972). The area has a typical continental climate, characterized by long, cold winters and cool summers. The mean annual temperature is 1°C and the average frost free period is 60-65 days. Approximately 50% of the annual precipitation (530 mm) comes as snow.

Four lodgepole pine stands of age class 30 and 70 were chosen on two important soil types: Coalspur (Orthic Gray Luvisol) and Mercoal (Podzolic Gray Luvisol). Stands on these two soils were most likely to benefit from fertilization. Each study area was divided into three blocks containing 24 circular plots (0.02 ha in 70-year-old and 0.004 ha in 30-year-old stands). Nitrogen (0, 76, 188, 300, and 377 kg/ha), phosphorus (0, 38, 94, 150, and 188 kg/ha), and sulfur (0, 23, 56, 90, and 113 kg/ha) were used in a factorial experiment augmented with star design to form a second-order central composite design (Cochran and Cox 1957). Nutrients were applied in forms of urea, ammonium phosphate, triple phosphate, and elemental sulfur. Fertilizers were broadcast by using cyclone seeders in mid-May, 1972.

All plots were remeasured in early summer, 1981. In addition to plot tally of surviving trees, three dominant or codominant trees on each plot were felled and stem analysis disks were taken for assessing fertilizer effects on tree growth.

Foliar analysis of N, P, and S contents of these stands prior to fertilization is shown in Table 2. This table suggests lodgepole pine on both Coalspur and Mercoal soils were severely deficient in N, and possibly deficient in P (Table 1). Foliar S was low in comparison with those reported by Beaton *et al.* (1965) for lodgepole pine in B.C., although some of this discrepancy could be due to analytical procedures. Sulfur content in biological materials is prone to vary by the technique used.

Table 2.—Foliar N, P, and S contents prior to fertilization

	Coalspur		Mercoal	
	70-yr	30-yr	70-yr	30-yr
N%	1.10	1.07	1.09	1.15
P%	0.11	0.10	0.11	0.12
S ppm	406	452	373	439

Factorial analysis of 10-year volume increments of dominant and codominant lodgepole pine showed different response on these two soils to N, P, and S fertilization. On Coalspur soils, tree volume growth showed response only to N additions of at least 188 kg/ha (Figure 2). Phosphorus and sulfur had little effects on growth on Coalspur soils. These response patterns were observed in both the young and mature stand.

Lodgepole pine on Mercoal soils, in addition to responding to N, an addition of 56 kg/ha S also improved tree volume growth. A combination of 188 kg/ha N and 56 kg/ha S gave consistently the highest improvements in volume increments in 30- and 70-year-old stands (Figures 3 and 4). The effect of P on volume growth was not statistically significant.

Soils in western Alberta are reportedly low in S. Here, tree growth response to S occurred only on Mercoal at 56 kg/ha S level. Further studies on physiological and soil response to S application are needed to explain this phenomenon.

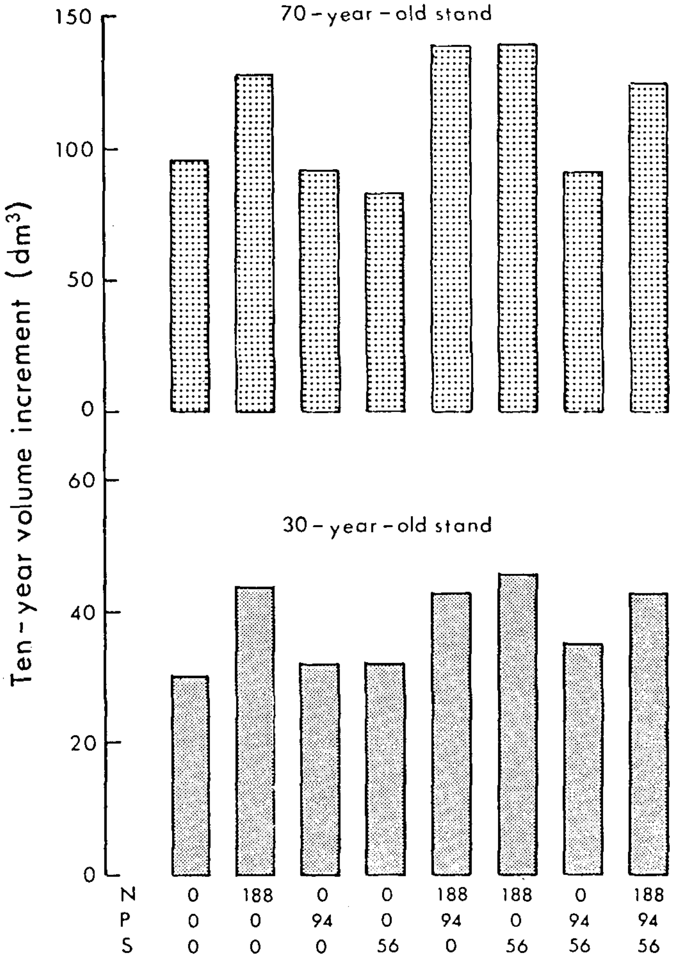

Figure 2.—Volume increments of dominant/codominant trees on Coalspur soils in response to N, P, and S fertilization.

Despite the consistent tree volume growth responses to N, P, and S application (Figures 2 and 3), net stand volume increments after fertilization were less consistent (Table 3) because of mortality. In 70-year-old stands, mortality, in number of

Table 3. Stand volume increments (m^3/ha) in 70- and 30-year-old lodgepole pine stands 10 years after fertilization.

	Coalspur			Mercoal			Coalspur		Mercoal	
Fertilizer	Initial Volume	Total Volume Incre.	Merch. Volume Incre.	Initial Volume	Total Volume Incre.	Merch. Volume Incre.	Initial Volume	Total Volume Incre.	Initial Volume	Total Volume Incre.
	70-year-old						30-year-old			
Control	246.8	65.0	68.7	304.1	55.1	58.2	123.7	38.7	116.1	45.6
N188	312.9	72.5	72.5	297.6	65.5	65.6	89.5	45.5	122.0	73.6b
P 94	251.4	68.2	72.5	279.4	53.0	52.1	97.2	31.0	110.0	53.6
S 56	292.0	58.3	60.7	237.3	64.6	62.6	97.8	30.9	122.4	56.8
N188 P 94	267.3	94.7b	92.6b	273.1	63.5	62.4	91.9	42.6	156.3	56.9
N188 S 56	259.0	64.0	65.8	232.3	62.1	58.6	83.4	44.0	89.8	47.2
P 94 S 56	284.3	71.4	70.8	273.4	65.3	67.0	100.2	49.1	104.0	38.2
N188 P 94 S 56a	273.8	81.0	82.9	275.6	70.5	70.1	93.8	48.3	101.3	58.9
N 76 P 38 S 23	287.8	58.9	60.2	240.8	70.3	70.2	79.6	37.1	99.7	61.5
N300 P 38 S 23	250.1	95.2b	96.2b	291.9	66.0	67.3	100.4	49.2	111.4	56.0
N 76 P150 S 23	279.6	68.7	72.0	298.0	71.7	75.5	93.7	39.1	83.5	42.0
N300 P150 S 23	280.7	75.8	78.6	306.2	78.0	81.7	70.7	59.2b	126.3	61.5
N 76 P 38 S 90	245.7	66.2	68.4	300.5	64.4	65.4	83.8	32.7	130.0	63.0
N300 P 38 S 90	250.3	88.9b	88.6b	271.9	66.6	65.3	85.0	47.3	112.2	72.0b
N 76 P150 S 90	202.2	78.3	82.9	286.5	61.1	59.5	98.5	51.1b	107.2	68.5
N300 P150 S 90	242.5	81.9	83.6	305.5	86.6b	85.8b	99.4	52.7b	90.8	52.6
N377 P150 S 90	281.2	99.1b	101.8b	250.0	76.2	74.6	83.7	38.2	128.9	81.9b
N300 P150 S 90	276.3	77.8	79.7	299.8	69.4	72.4	86.3	41.7	117.6	45.3
N300 P150 S113	259.8	71.4	76.7	275.0	85.2b	86.2b	71.3	28.4	91.6	43.4

a: Treatment repeated 6 times as required by the experiment design.

b: Mean significantly differs from that of the control at the 5% level.

stems per hectare, ranged from negligible (0 to 6.7%) on Coalspur to moderate (0 to 16.7%) in Mercoal stand. In 30-year-old stands, it was excessive on both soil types (Coalspur 37 to 51%; and Mercoal 32 to 48%).

In spite of mortality, in 70-year-old stands, four fertilizer combinations on the Coalspur and two on the Mercoal soils resulted in significant improvement in total as well as merchantable volume. Fertilization improved average stand productivity as much as 31 to 34 m^3/ha in total and 38 to 31 m^3/ha in merchantable volume over a 10-year period (Table 3). This means up to 50% improvement in periodic volume increment. Extrapolating stern analysis results from the 70-year-old stand showed also a volume increment of 30 m^3/ha assuming 700 dominant and codominant stems per hectare.

Although N on Coalspur soils, and N and S combinations on Mercoal soils showed significant improvement in volume increments of dominant and codominant trees in 30-year-old stands, net stand volume increments, with few exceptions, showed no significant improvement because of mortality. This suggests that in young, dense stands, thinning should precede fertilization.

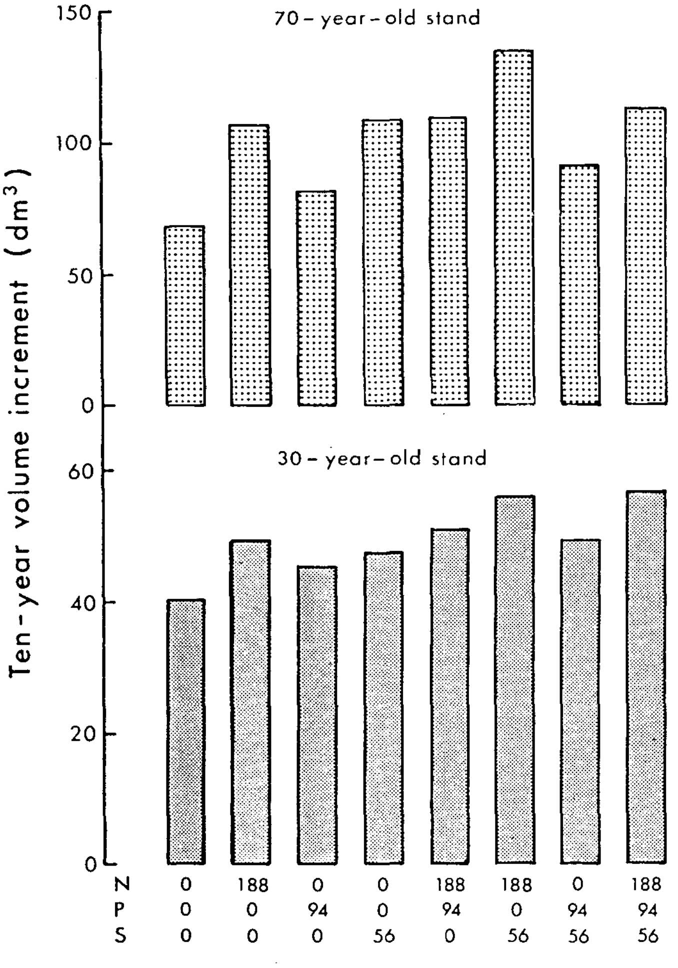

Figure 3.—Volume increments of dominant/codominant trees on Mercoal soils in response to N, P, and S fertilization.

To illustrate the potential impact of fertilization in an operational setting, we chose the McLeod Working Circle of St. Regis (Alberta) Ltd. at Hinton. This Working Circle contains 163,300 ha productive forest land just south of the mill; 48% is in the lodgepole pine cover type. Coalspur and Mercoal soils make up about 29% of the productive land area; of which about 1680 ha is in the 70-year age class of lodgepole pine. An application of N300, P150 and S90 kg/ha over this 1680 ha area could yield 36,000 m^3 merchantable volume, assuming average stand conditions on this area would be similar to those found in the study areas.

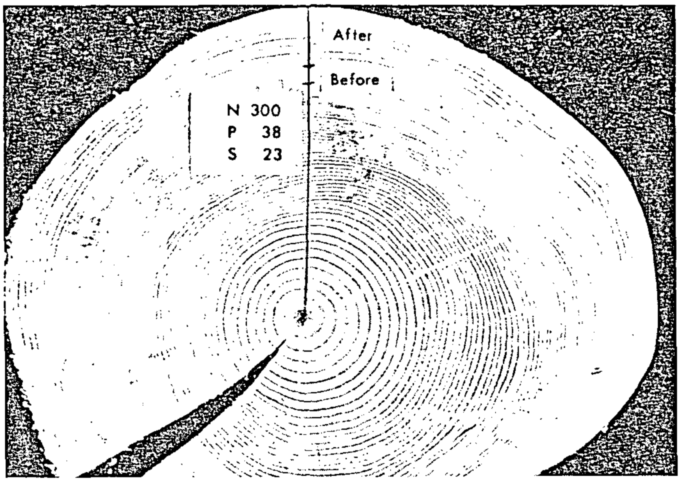

Figure 4.—Stem section showing the effect of fertilization (N300, P38, S23 kg/ha) on Dbh increment of 70-year-old lodgepole pine.

Practical Questions

1. Will nutrient removals in whole tree harvesting reduce soil fertility?
   This may occur in poor sites; particularly those low in organic matter. It is less probable on rich sites if it occurs once per long rotation.
2. Will slash burning result in fertility losses?
   There appear to be no long term nutrient balance studies on the species. Avoid organic matter loss on poor sites.
3. How should stands be tested for fertilizer response?
   There are many ways ranging from screening trials to formal factorial fertilizer/thinning experimental designs. Obtain good advice and replicate. The 1979 Forest Fertilization Conference (Gessel, Kenady and Atkinson 1979) is helpful.
4. Should lodgepole pine be fertilized at the time of planting?
   Broadcast fertilization may result in increased vegetative competition, particularly grass, for the planted trees. It may not be necessary on fresh cutovers and fires with high levels of nutrient availability. On old cuts and burns, and on poor sites low in organic matter, it may be helpful.
   Nutrient demands of planted trees are low, but nutrient supply is very dependent on the soil type. Very few trials have been done in North America.
5. Should fertilization immediately follow precommercial thinning (PCT) or be done later?
   Some current studies suggest that fertilization should follow PCT to build tree crowns.

6. Will fertilization improve insect or disease resistance?
   There is some evidence that it does. Waring and Pitman (1983) found significant resistance to mountain pine beetle when canopy density was reduced and nitrogen nutrition improved. In jack pine resistance to sawfly defoliation has been found.
7. What is the best time of the year to fertilize?
   The conventional time is before bud flush in the spring.
8. What is the current status of lodgepole pine fertilization?
   It is entirely experimental with most of the current trials in Canada.
9. What additional studies are needed?
   More cooperative screening trials and formal testing of the closed stands for response to nitrogen; identification of limiting nutrients in young stands; generation of fertilization and thinning growth response data.

CONCLUSIONS

1. Lodgepole pine can grow on sites with extremely low nutrient availability. The species has very modest nutrient demands, but responds dramatically to improved nutrient status.
2. It can be successfully established and, by use of customized fertilizer additions to achieve balanced nutrition, made to grow very quickly on poor sites, until some other factor becomes limiting.
3. The nutritional requirements and foliar analysis diagnosis values are well established.
4. Stands before crown closure, relying primarily on soil nutrition, may show deficiencies in many elements, depending on the soil type.
5. After stand closure, nitrogen deficiency can usually be suspect. Response to nitrogen additions as high as 50% in stand volume increment over a 10-year period have been found with applications of N over 150 kg/ha.

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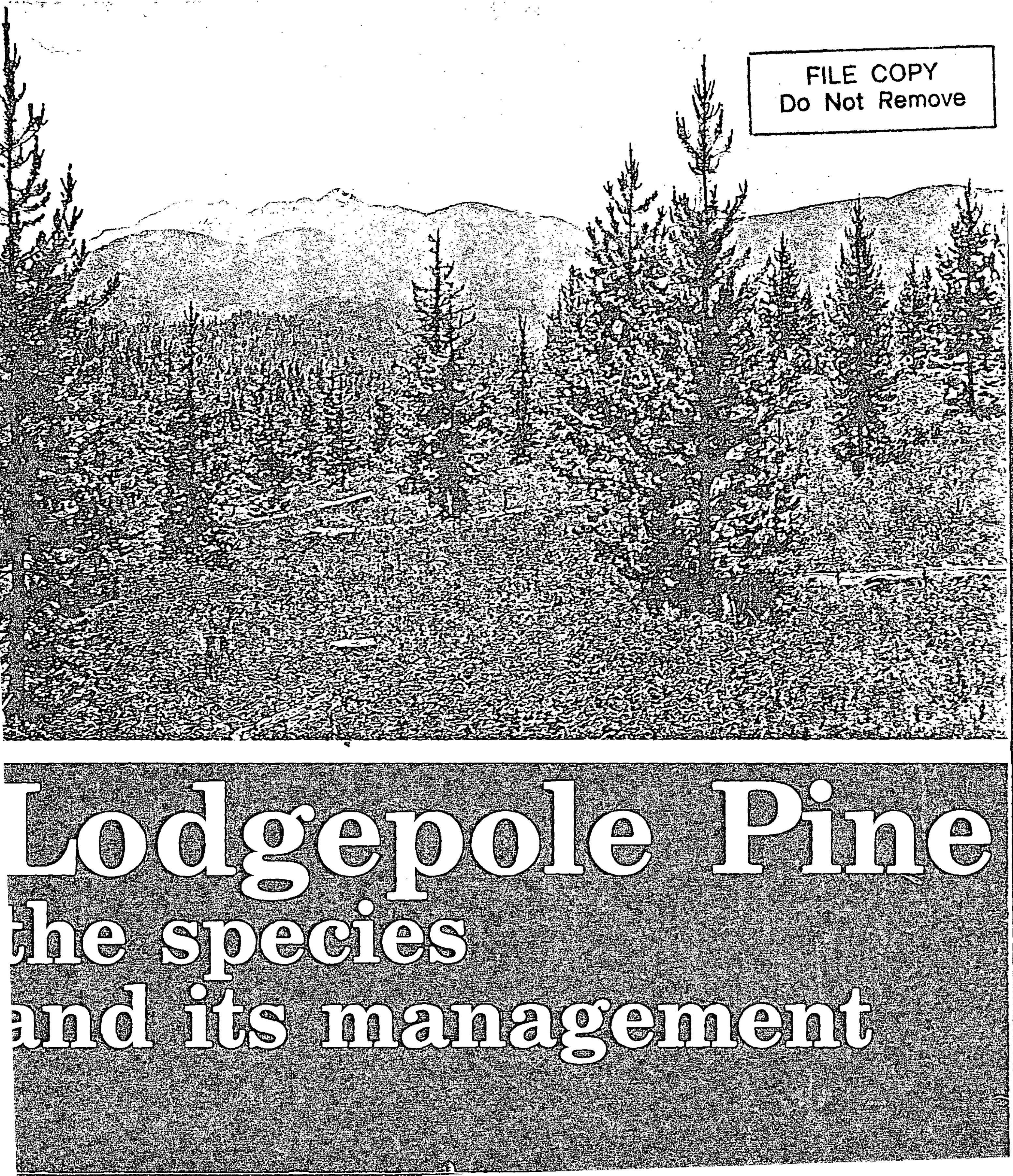

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on an 18 year old clearcut,
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