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# Foliar Nutrient Status of Young Red Spruce and Balsam Fir in a Fertilized Stand

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## Abstract

Average dry weight and nutrient levels in current foliage from red spruce and balsam fir seedlings and saplings in the understory of a 25-year old aspen and birch stand were observed 3 years after N, P, and lime treatments were applied. Elemental concentrations were plotted as a function of needle weight and quantity of element per needle. This allows interpretation of treatment effect on overall nutrient levels for both concentration and quantity of each element in the foliage. In balsam fir, dry weight per needle was significantly increased by N fertilizer. Nitrogen also significantly affected levels of ash, N, P, K, Ca, Fe, Mn, Zn, and Na in balsam fir foliage. In red spruce, dry weight per needle, N, and Fe levels all responded to N fertilizer; P fertilizer affected P foliar concentration and lime significantly affected Mn levels. In both species there were significant interactions among the N, P, and lime treatments, indicating that response to one element varied according to the other elements added simultaneously. Balsam fir needles were heavier and contained higher levels of nutrients than red spruce needles. The magnitude of changes in elemental levels was generally greater for balsam fir than for red spruce.

# INTRODUCTION

THERE IS INCREASING CONCERN that site productivity of spruce-fir forests in Maine may be diminished by complete-tree utilization. Current interest in forest fertilization, and current research on nutritive values of spruce and fir foliage for the spruce budworm population dynamics, have intensified the need for more accurate estimates of tree responses to fertilizer application.

Foliage analysis is a sensitive and accepted method of assessing the ability of soils to supply nutrients for adequate tree growth. In 1974 we established a study to determine if a stand with an aspen-birch-maple overstory and a scattered spruce and fir understory would respond to treatments with lime, nitrogen, and phosphorus applied singly and in combination following a precommercial thinning. The responses of the overstory hardwoods to fertilizer and lime were documented earlier (Czapowskyj and Safford 1979, Schmitt et al. 1979).

In this paper we report the concentration and content of nutrients in the current-year foliage of red spruce and balsam fir as related to fertilizer treatments applied three growing seasons earlier.

# STUDY

The study was established in Washington County, Maine, on land owned by Georgia Pacific Corporation. The stand originated following a wildfire in 1952. The overstory consists primarily of aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.), 78 percent of the basal area, and paper birch (*Betula papyrifera* Marsh.), 14 percent of the basal area. The soils are well- and moderately well-drained Haplorthods. For a more detailed description of the study area, the origin and composition of the forest overstory, and soil characteristics see Czapowskyj and Safford (1979). In the present study we observed the effects of lime and fertilizer and the foliage of the understory stand consisting of red spruce (*Picea rubens* Sarg.), white spruce (P. glauca (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill.) (Table 1).

Twenty-four 20- by 20-m plots with 7-m wide isolation strips were laid out. Because of the nature of the landscape, some plots were on well-drained soils, some on moderately well-drained soils, and some plots had both. Lime and fertilizer treatments were assigned randomly among plots as follows:

- Control (C)
- Lime (L): 4,480 kg/ha; 100 percent $CaCO_3$ equivalent as ground limestone providing 1,749 kg Ca and 27 kg Mg/ha.
- Nitrogen (N): 448 kg/ha of elemental N, as 46-0-0 urea.
- Phosphorus (P): 112 kg/ha of elemental P as 0-45-0 triple superphosphate. In addition to P, the fertilizer contained 12 percent Ca (±30 kg/ha).
- All combinations—NL, PL, NP, NPL—for a total of eight treatments replicated three times.

Lime was broadcast by hand on the soil surface in the fall of 1974. Phosphorus and one-half of the nitrogen were broadcast in June 1975; the remaining nitrogen was added in August 1975.

## Foliage sampling and analysis

The samples of red spruce and balsam fir foliage were collected in early September 1977—three growing seasons after the stand was fertilized.

*Sampling*. Three trees of each species were selected randomly to represent each treatment and replication. The trees were less than 1.37 m tall and were free of any damage caused by spruce budworm (*Choristoneura fumiferana* (Clem.)) infestation. Twigs with

**Table 1.—Characteristics of a 15-year-old aspen-birch spruce-fir stand before fertilization (average of three replications)**

| Species | | Stand characteristics | | | | | |
|---|---|---|---|---|---|---|---|
| | | Trees/ha | | Height | Dbh | Basal area/ha | |
| | | *Number* | *Percent* | *m* | *cm* | $m^2$ | *Percent* |
| Overstory | | | | | | | |
| Aspen, birch, other hardwoods | | 1512 | 74 | 6.7 | 6.4 | 4.9 | 98 |
| Understory | | | | | | | |
| Red spruce | $\geqslant$ 1.37m | 67 | 3 | 2.34 | 1.80 | 0.04 | 0.7 |
| | $<$ 1.37m | 135 | 7 | .75 | — | — | — |
| Balsam fir | $\geqslant$ 1.37m | 60 | 3 | 2.75 | 2.65 | 0.05 | 0.9 |
| | $<$ 1.37m | 139 | 7 | .67 | — | — | — |
| Other softwoods | $\geqslant$ 1.37m | 10 | 1 | 2.45 | 2.17 | 0.02 | 0.4 |
| | $<$ 1.37m | 100 | 5 | .74 | — | — | — |
| Total or average of softwoods | | 511 | 26 | $\geqslant 1.37\ \overline{x} = 2.53$<br>$< 1.37\ \overline{x} = 0.72$ | $\overline{x} = 2.20$ | 0.11 | 2 |

current-year needles were collected from upper crown portions. Equal quantities of foliage of each of the three trees per species were combined for a total of 24 composite samples of red spruce and 23 of balsam fir (one plot had no balsam fir). Samples were dried at 65°C to constant weight, ground to pass a 20-mesh screen, and prepared in duplicate for chemical analysis.

*Chemical analysis.* The samples were dry ashed at 500°C; the ash content was determined gravimetrically. The ash was taken up in dilute HC1 and calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), manganese (Mn), zinc (Zn), and iron (Fe) were determined by atomic absorption. Nitrogen (N) and total phosphorus (P) were determined in Kjeldahl digests with an auto analyzer.

All analyses were performed on the oven-dry (65°C) samples. Foliar nutrients are expressed both in concentration (percent or ppm) and actual content (mg per 1,000 needles).

## Statistical analysis

For each species, ash, oven-dry weight, nutrient concentration, and content were analyzed as dependent variables by analysis of variance. The experimental design was a complete factorial with three fertilizer treatments: lime, nitrogen, and phosphorus. Each factor had two levels: absent and present. Each treatment was replicated three times except for balsam fir which had only two replicates for the lime treatment.

Because main effect factors have only two levels, mean separation techniques were not necessary. Factorial analysis of variance and the F test were used to determine significance of the main effects of each nutrient treatment as well as interaction among nutrient elements (Mendenhall 1968).

## RESULTS

Mean needle weight and nutrient levels in the foliage of these understory red spruce trees (Tables 2 and 3) are generally consistent with findings of Schomaker (1973) and Safford et al. (1977) in overstory dominant and codominant red spruce. Average needle weight, nitrogen concentration, and potassium concentration of control foliage differed the most. In this study, needles from control trees weighed 1.72 mg per needle compared with 2.5 mg per needle reported by Safford et al. (1977); N concentration in this study was 0.82 percent while Schomaker (1973) and Safford et al. (1977) reported 1.03 percent. Potassium concentration of foliage from this study averaged 0.49 percent compared with 0.92 percent reported by Schomaker (1973) and 0.98 percent reported by Safford et al. (1977).

Mean needle weight and nutrient levels in the balsam fir trees in this study (Tables 4 and 5) are very close to those reported for similar-size trees by Timmer and Stone (1978) and Czapowskyj (1979); N concentration at 0.95 percent in this study was somewhat lower than that reported by either Timmer and Stone (1978) at 1.5 percent or Czapowskyj (1979) at 1.4 percent.

**Table 2.—Sample means and standard deviations of red spruce foliar ash and nutrient concentrations three growing seasons after fertilization.**

| Treatment | Ovendry weight of 1,000 needles | Ash | Nutrient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | P | Ca | K | Mg | Mn | Na | Fe | Zn |
| | *gm* | *Percent* | | | | | | | *ppm* | | |
| Control | 1.72<br>(0.43)[a] | 2.37<br>(0.60) | 0.82<br>(0.08) | 0.16<br>(0.02) | 0.31<br>(0.13) | 0.49<br>(0.13) | 0.07<br>(0.04) | 0.16<br>(0.10) | 282<br>( 99) | 42<br>(19) | 56<br>(52) |
| N only | 1.74<br>(0.22) | 2.22<br>(0.16) | 1.00<br>(0.18) | 0.14<br>(0.02) | 0.27<br>(0.07) | 0.50<br>(0.09) | 0.05<br>(0.02) | 0.13<br>(0.01) | 252<br>( 75) | 66<br>(24) | 35<br>(26) |
| P only | 1.62<br>(0.26) | 2.33<br>(0.30) | 0.75<br>(0.12) | 0.18<br>(0.02) | 0.28<br>(0.03) | 0.61<br>(0.06) | 0.06<br>(0.02) | 0.14<br>(0.02) | 271<br>( 12) | 45<br>(21) | 32<br>( 9) |
| Lime only | 1.33<br>(0.13) | 2.42<br>(0.14) | 0.78<br>(0.05) | 0.16<br>(0.01) | 0.30<br>(0.10) | 0.53<br>(0.08) | 0.06<br>(0.02) | 0.11<br>(0.01) | 239<br>(103) | 46<br>(15) | 66<br>(58) |
| N+P | 1.89<br>(0.21) | 2.24<br>(0.60) | 1.18<br>(0.16) | 0.16<br>(0.02) | 0.26<br>(0.07) | 0.46<br>(0.12) | 0.05<br>(0.02) | 0.09<br>(0.02) | 247<br>( 50) | 46<br>(13) | 50<br>(45) |
| Lime + N | 2.19<br>(0.27) | 2.52<br>(0.22) | 1.05<br>(0.08) | 0.15<br>(0.01) | 0.25<br>(0.01) | 0.62<br>(0.04) | 0.05<br>(0.02) | 0.08<br>(0.01) | 339<br>(144) | 40<br>( 3) | 32<br>(13) |
| Lime + P | 1.60<br>(0.20) | 2.53<br>(0.20) | 0.70<br>(0.04) | 0.18<br>(0.02) | 0.29<br>(0.02) | 0.56<br>(0.02) | 0.07<br>(0.01) | 0.10<br>(0.01) | 201<br>( 91) | 33<br>(11) | 63<br>(77) |
| Lime + N+P | 1.78<br>(0.24) | 1.99<br>(0.49) | 1.07<br>(0.10) | 0.16<br>(0.02) | 0.33<br>(0.03) | 0.45<br>(0.02) | 0.06<br>(0.01) | 0.06<br>(0.01) | 229<br>( 78) | 58<br>(23) | 19<br>( 4) |

[a]Standard deviation in parenthesis.

**Table 3.—Sample means and standard deviations of ash and nutrient contents for red spruce foliage three growing seasons after treatment.**

| Treatment | Ash | Nutrient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | Ca | K | Mg | Mn | Na | Fe | Zn |
| | *mg/1000 needles* | | | | | | | | | |
| Control | 42.0 (19.7)[a] | 14.1 ( 4.2) | 2.8 (0.9) | 5.7 (3.8) | 8.2 ( 1.7) | 1.4 (1.1) | 2.4 (1.2) | 0.47 (0.11) | 0.08 (0.05) | 0.11 (0.13) |
| N only | 38.8 ( 7.5) | 17.3 ( 3.6) | 2.5 (0.5) | 4.7 (1.2) | 8.7 ( 2.1) | 0.8 (0.2) | 2.3 (0.5) | 0.43 (0.08) | 0.11 (0.05) | 0.06 (0.04) |
| P only | 38.0 ( 9.4) | 12.3 ( 3.9) | 3.0 (0.7) | 4.6 (0.8) | 9.9 ( 2.4) | 1.0 (0.4) | 2.3 (0.7) | 0.44 (0.07) | 0.08 (0.04) | 0.05 (0.02) |
| Lime only | 32.1 ( 1.8) | 10.3 ( 0.4) | 2.1 (0.3) | 3.9 (0.9) | 7.0 ( 0.7) | 0.8 (0.2) | 1.5 (0.2) | 0.32 (0.15) | 0.06 (0.02) | 0.09 (0.08) |
| N+P | 42.8 (14.3) | 22.0 ( 0.7) | 2.9 (0.4) | 5.0 (1.8) | 8.6 ( 1.7) | 1.0 (0.4) | 1.7 (0.5) | 0.47 (0.13) | 0.08 (0.02) | 0.10 (0.09) |
| Lime + N | 54.9 ( 2.1) | 23.0 ( 1.8) | 3.2 (0.3) | 5.5 (0.7) | 13.6 ( 0.8) | 1.0 (0.4) | 1.8 (0.2) | 0.73 (0.26) | 0.09 (0.02) | 0.07 (0.03) |
| Lime + P | 40.6 ( 6.4) | 11.2 ( 1.3) | 2.8 (0.2) | 4.7 (0.3) | 9.0 ( 1.3) | 1.1 (0.3) | 1.6 (0.3) | 0.33 (0.19) | 0.05 (0.02) | 0.11 (0.15) |
| Lime + N+P | 34.7 ( 6.1) | 19.2 ( 4.4) | 2.8 (0.2) | 5.8 (0.8) | 8.1 ( 1.0) | 1.1 (0.2) | 1.1 (0.2) | 0.41 (0.14) | 0.11 (0.06) | 0.03 (0.01) |

[a] Standard deviation in parenthesis.

**Table 4.—Sample means and standard deviations of balsam fir foliar ash and nutrient concentrations three growing seasons after fertilizing.**

| Treatment | Ovendry weight of 1,000 needles | Ash | Nutrient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | P | Ca | K | Mg | Mn | Na | Fe | Zn |
| | *gm* | *Percent* | | | | | | | *ppm* | | |
| Control | 3.45 (0.59)[a] | 3.32 (0.18) | 0.95 (0.13) | 0.19 (0.03) | 0.51 (0.02) | 0.61 (0.06) | 0.08 (0.02) | 0.16 (0.02) | 174 ( 60) | 35 ( 4) | 48 ( 4) |
| N only | 4.74 (0.53) | 2.86 (0.50) | 1.22 (0.10) | 0.16 (0.01) | 0.57 (0.16) | 0.45 (0.21) | 0.09 (0.03) | 0.07 (<0.01) | 262 ( 98) | 50 ( 4) | 58 (25) |
| P only | 3.62 (0.59) | 3.04 (0.41) | 0.86 (0.08) | 0.23 (0.06) | 0.56 (0.10) | 0.42 (0.03) | 0.06 (0.01) | 0.13 (0.01) | 142 ( 54) | 47 ( 6) | 43 ( 5) |
| Lime only | 3.30 (0.40) | 2.90 (0.04) | 0.91 (0.06) | 0.18 (0.01) | 0.58 (0.16) | 0.50 (0.02) | 0.06 (0.02) | 0.07 (<0.01) | 154 ( 69) | 42 ( 3) | 37 (13) |
| N+P | 4.95 (0.49) | 3.14 (0.32) | 1.40 (0.14) | 0.24 (0.04) | 0.55 (0.16) | 0.57 (0.11) | 0.09 (0.01) | 0.09 (0.03) | 216 ( 27) | 51 ( 9) | 48 ( 6) |
| Lime + N | 4.38 (0.73) | 3.15 (0.50) | 1.26 (0.05) | 0.18 (0.01) | 0.54 (0.03) | 0.60 (0.03) | 0.08 (0.02) | 0.07 (0.02) | 227 ( 59) | 54 ( 7) | 60 (19) |
| Lime + P | 3.16 (0.40) | 3.30 (0.20) | 0.87 (0.08) | 0.20 (0.03) | 0.54 (0.06) | 0.52 (0.08) | 0.08 (0.03) | 0.09 (0.01) | 200 ( 54) | 45 (14) | 50 ( 5) |
| Lime + N+P | 4.03 (0.58) | 3.09 (0.23) | 1.22 (0.11) | 0.20 (0.04) | 0.46 (0.14) | 0.68 (0.02) | 0.07 (0.04) | 0.05 (0.01) | 221 ( 58) | 44 ( 9) | 46 (13) |

[a] Standard deviation in parenthesis.

**Table 5.—Means and standard deviations of ash and nutrient contents for balsam fir foliage three growing seasons after treatment.**

| Treatment | Ash | Nutrient | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | Ca | K | Mg | Mn | Na | Fe | Zn |
| | *mg/1000 needles* | | | | | | | | | | |
| Control | 114.5 (16.9)[a] | 32.4 ( 3.0) | 6.3 ( 0.6) | 17.7 ( 3.1) | 20.9 ( 2.1) | 2.9 (0.9) | 5.3 (0.4) | 0.58 (0.14) | 0.12 (0.02) | 0.17 (0.04) |
| N only | 136.9 (38.4) | 57.7 ( 1.6) | 7.6 ( 0.8) | 27.4 (10.7) | 21.1 ( 9.4) | 4.5 (1.9) | 3.5 (0.3) | 1.28 (0.61) | 0.24 (0.04) | 0.28 (0.15) |
| P only | 108.4 ( 4.7) | 31.3 ( 8.0) | 8.1 ( 1.6) | 20.4 ( 5.3) | 15.3 ( 3.4) | 2.2 (0.7) | 4.5 (0.4) | 0.53 (0.29) | 0.17 (0.02) | 0.16 (0.04) |
| Lime only | 95.4 (10.2) | 30.4 ( 5.6) | 5.9 ( 0.9) | 18.8 ( 2.9) | 16.3 ( 1.2) | 2.1 (0.8) | 2.2 (0.3) | 0.52 (0.29) | 0.14 (0.03) | 0.12 (0.06) |
| N+P | 155.8 (22.0) | 69.1 ( 3.0) | 11.8 ( 3.1) | 27.5 ( 8.0) | 28.1 ( 6.0) | 4.5 (0.5) | 4.4 (1.4) | 1.07 (0.22) | 0.26 (0.06) | 0.24 (0.05) |
| Lime + N | 140.7 (46.8) | 55.5 (11.4) | 7.8 ( 1.5) | 23.9 ( 4.2) | 26.3 ( 5.8) | 3.5 (0.6) | 3.0 (0.9) | 0.97 (0.17) | 0.24 (0.07) | 0.26 (0.08) |
| Lime + P | 104.8 (19.6) | 27.7 ( 6.3) | 6.4 ( 1.6) | 17.3 ( 3.9) | 16.5 ( 4.5) | 2.5 (1.4) | 2.9 (0.3) | 0.62 (0.10) | 0.15 (0.06) | 0.16 (0.04) |
| Lime + N+P | 125.0 (26.3) | 48.6 ( 5.8) | 8.2 ( 1.7) | 18.7 ( 7.2) | 27.5 ( 3.1) | 2.9 (2.0) | 2.0 (0.5) | 0.90 (0.35) | 0.18 (0.05) | 0.18 (0.08) |

[a]Standard deviation in parenthesis.

The fertilizer treatments significantly affected dry weight and levels of ash, N, P, K, and Mn in both species. Levels of Ca, Fe, Zn, and Na in balsam fir foliage also differed significantly with N fertilizer. Magnesium was the only element not significantly affected by the fertilizer treatments (Table 6).

## Needle weight

Nitrogen significantly increased needle dry weight for both species (Table 6). Needles from each N treatment were heavier than the comparable non-N treatment for both species. Balsam fir needles were heavier than red spruce needles and they increased more than red spruce needles did for each treatment ( Fig. 1). The addition of P tended to increase balsam fir needle weight above comparable treatments without P. Lime tended to decrease needle weight below each equivalent treatment without lime.

The three-way NP lime interaction was significant for red spruce needle weight (Table 6). We interpret this to mean that both P and lime affected the way red spruce needle weight responded to N. When either P or lime was added in combination with N, needle weight significantly increased above control and N alone. But, when both P and lime were added with N, needle weight was only slightly greater than for N alone. Although the main effect of neither P nor lime was significant, each tended to have a negative effect on needle weight and thus contributed to the significant NP lime interaction (Fig. 1).

**Table 6.—Summary of analysis of variance showing significant effects for foliar nutrient levels of balsam fir and red spruce in soils fertilized with N, P, and lime.**

| Source of variation | | Dry weight | Ash | N | P | K | Ca | Mg | Fe | Mn | Zn | Na |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | BALSAM FIR | | | | | | | | |
| N | Concentration[a] | ** | | ** | | | | | * | ** | | |
| | Content[b] | | ** | ** | ** | ** | * | | ** | | ** | ** |
| P | Concentration | | | | ** | | | | | | | |
| | Content | | | | * | | | | | | | |
| Lime | Concentration | | | | | | | | | ** | | |
| | Content | | | * | | | | | | ** | | |
| NP | Concentration | | | | | * | | | | | | |
| | Content | | | | | | | | | | | |
| Lime + N | Concentration | | | | | | | | | * | | |
| | Content | | | | | | | | | | | |
| Lime + NP | Concentration | | | | | | | | | * | | |
| | Content | | | | | | | | | * | | |
| | | | | RED SPRUCE | | | | | | | | |
| N | Concentration | ** | | ** | | | | | | * | | |
| | Content | | | ** | | | | | | | | |
| P | Concentration | | | | * | | | | | | | |
| | Content | | | | | | | | | | | |
| Lime | Concentration | | | | | | | | | * | | |
| | Content | | | | | | | | | * | | |
| NP | Concentration | | | | | * | | | | | | |
| | Content | | | | | * | | | | | | |
| Lime + N | Concentration | | | | | | | | | | | |
| | Content | | | | | * | | | | | | |
| Lime + NP | Concentration | * | | | | | | | | | | |
| | Content | | * | * | | * | | | | | | |

[a]Foliar concentration is percent or ppm
[b]Content per needle.
*significant at 5% level.
**significant at 1% level.

## Ash

Ash content ($\mu g$/needle) of both species followed the response pattern of needle dry weight discussed previously. The ash content of balsam fir foliage was significantly increased by N fertilizer. The ash content of red spruce foliage was influenced primarily by N but the P and lime treatments had significantly different impacts on the response to N as indicated by the significant NP lime interaction (Table 6). Ash components varied in proportion to overall weight increases, keeping concentrations relatively constant at around 3 percent in balsam fir foliage and 2.5 percent in red spruce (Fig. 2).

## Nitrogen

Nitrogen fertilizer stimulated the uptake of N in both balsam fir and red spruce foliage. The main effect of N was highly significant for both concentration and content of N in both species (Table 6). Foliage from red spruce trees treated with N averaged 1.08 percent and 20 $\mu g$ per needle compared with 0.76 percent and 12 $\mu g$ for foliage from trees not treated with N. The N levels for balsam fir foliage averaged 1.28 percent and 58 $\mu g$ per needle for trees treated with N compared with 0.90 percent and 30 $\mu g$ per needle for non-N treatments. The NP lime interaction term was significant for N content of red

Figure 1.—Effect of N, P, and lime treatments on average dry weight of red spruce and balsam fir needles.

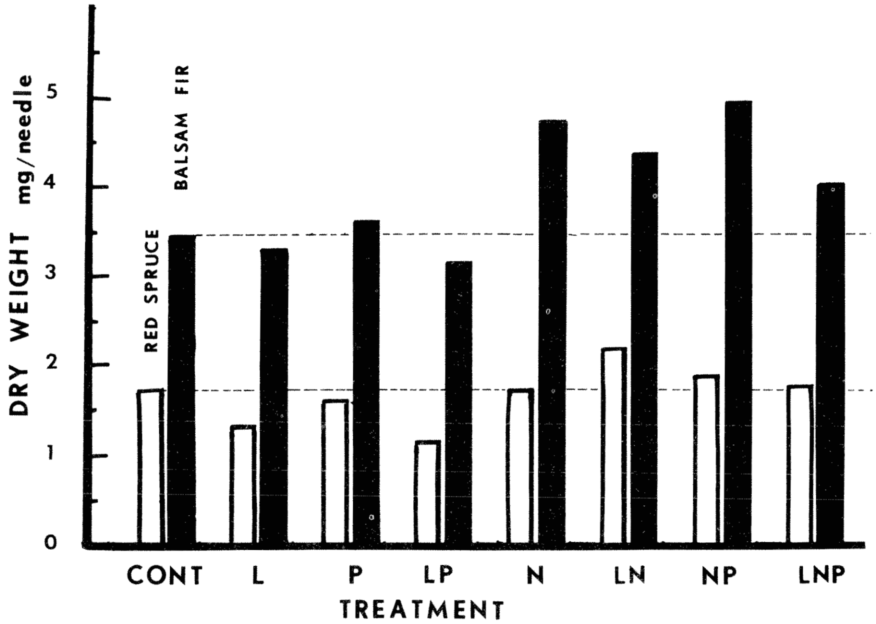



Figure 2.—Average ash levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.

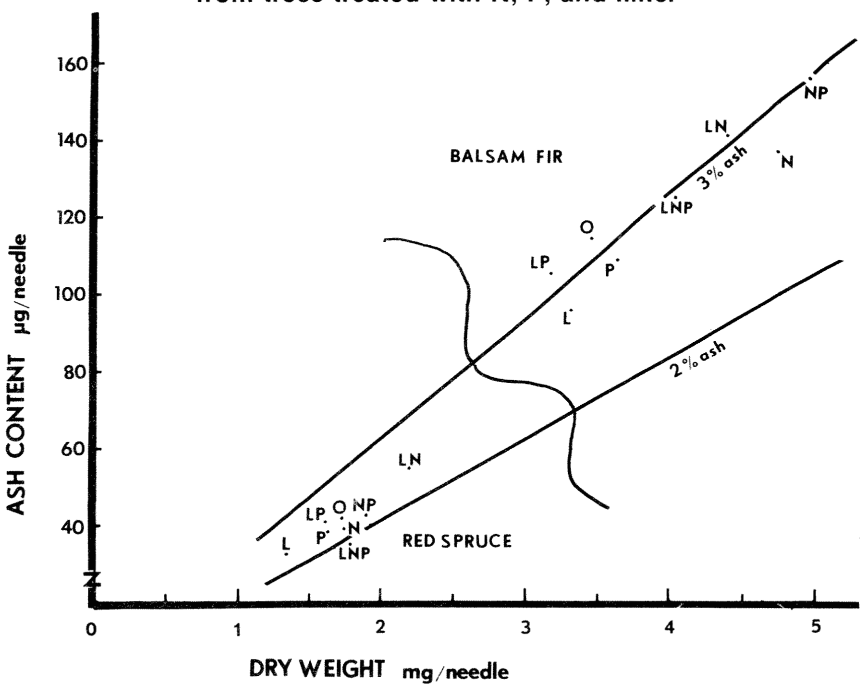
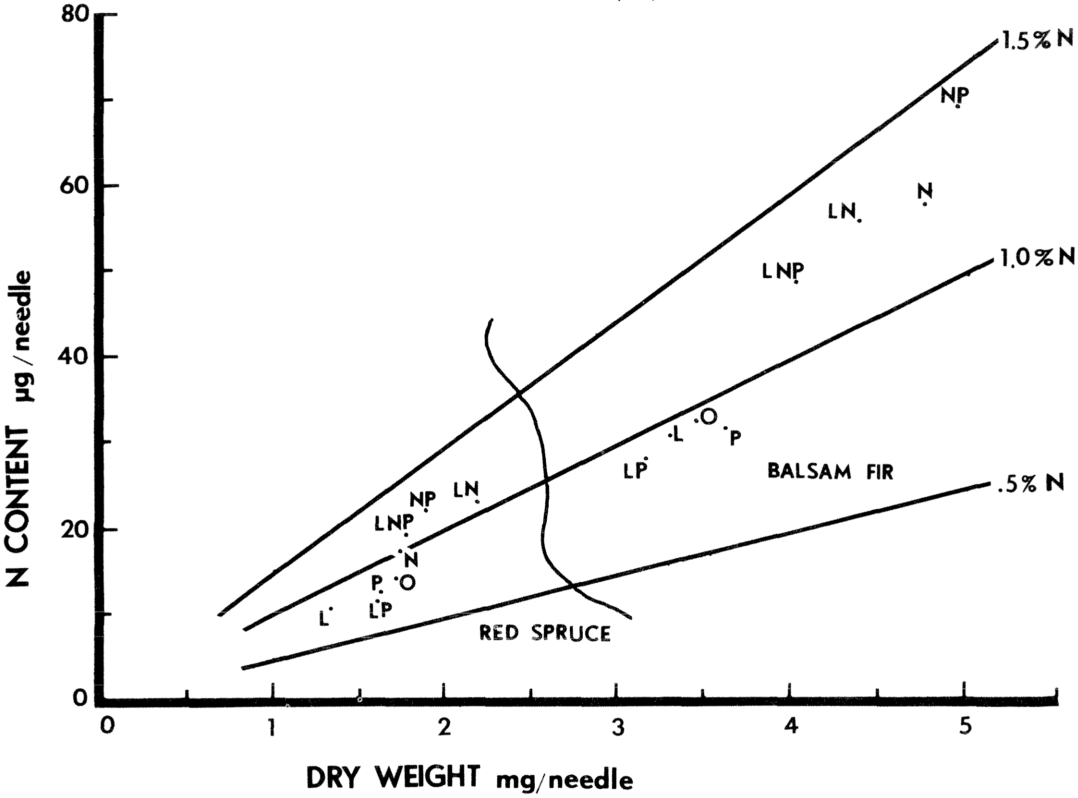


Figure 3.—Average N levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.




spruce foliage. When either P or lime was added in combination with N, the N content of red spruce needles increased above that for trees treated with N alone. But when P and lime were added together with N, the N content decreased to the N only level (Fig. 3). This corresponds to the significant NP lime interaction on needle weight already discussed. We interpret this to mean that the needle components that constituted the increased dry weight contained N and that the N concentration in these components was about the same as that in the untreated needles.

Nitrogen content of balsam fir needles was significantly decreased by lime (Table 6). Foliage from balsam fir trees treated with lime ranged from 2 to 20 $\mu g$ N per needle less than each treatment without lime (Fig. 3). These lower contents resulted from the trend of decreased weight per needle for lime as well as a trend of decreased concentration in some treatments (Table 4). The greatest difference was between the NP and NP lime treatments. Apparently, this difference was not so much a reduction of N uptake as it was a suppression of response to the NP fertilizer combination. That is, the NP treatment produced the heaviest needles (4.95 mg) with the greatest N content (69 $\mu g$). In the NP lime treatments, the needles were still heavier than control (4.03 versus 3.45 mg) and had a greater N content (49 versus 32 $\mu g$).

## Phosphorus

Phosphorus fertilizer significantly increased concentration and content of P in balsam fir foliage and P concentration only in red spruce foliage. None of the interaction terms was significant (Table 6). All treatments with P averaged 0.22 percent and 8.6 $\mu$g per needle P in balsam fir needles compared with 0.18 percent and 7.0 $\mu$g for non-P treatments. In red spruce foliage from trees treated with P, the P concentration was 0.17 percent and that of non-P treatments was 0.15 percent (Fig. 4).

## Potassium

The K content of balsam fir foliage was significantly affected by N, and the K concentration was significantly affected by the NP interaction term (Table 6). In red spruce foliage, the NP interaction term was significant for both K concentration and content. The K content was also significantly affected by the N lime and NP lime interaction (Table 6).

In foliage of balsam fir trees treated with N, the content of K averaged 25.7 $\mu$g per needle whereas needles from trees not treated with N contained 17.3 $\mu$g of K. This difference resulted from the increase in dry weight per needle caused by the N treatments in combination with a tendency for N-treated trees to have higher concentrations of K, 0.58 percent compared with non-N treatments, 0.51 percent. We interpret the significant NP interaction term as follows:

Figure 4.—Average P levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.

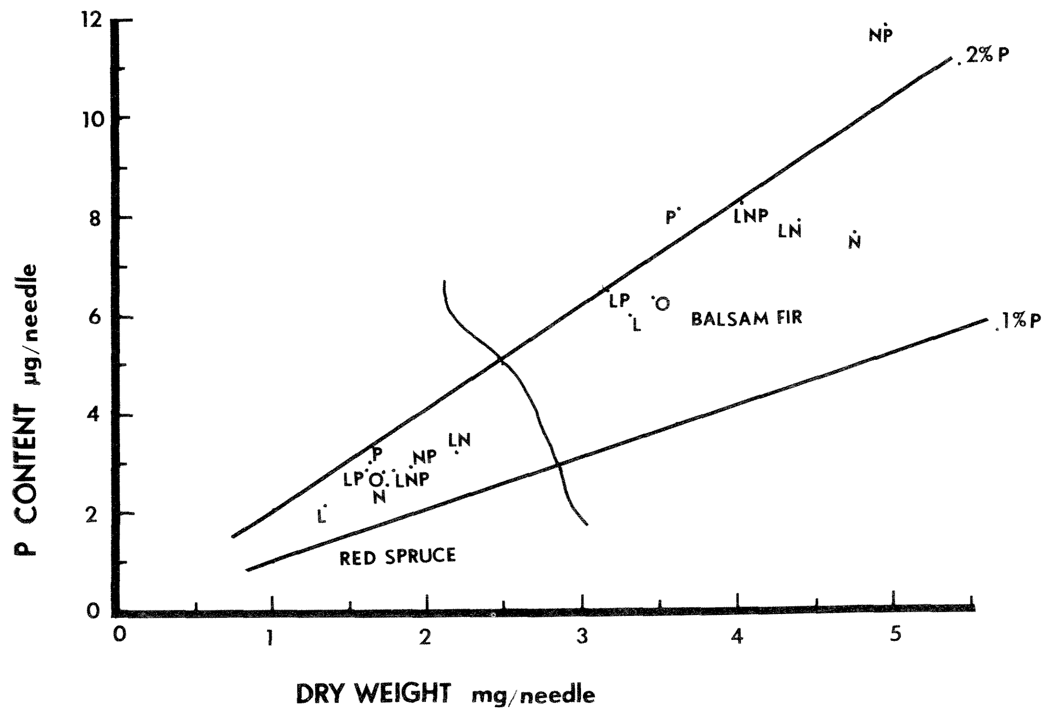
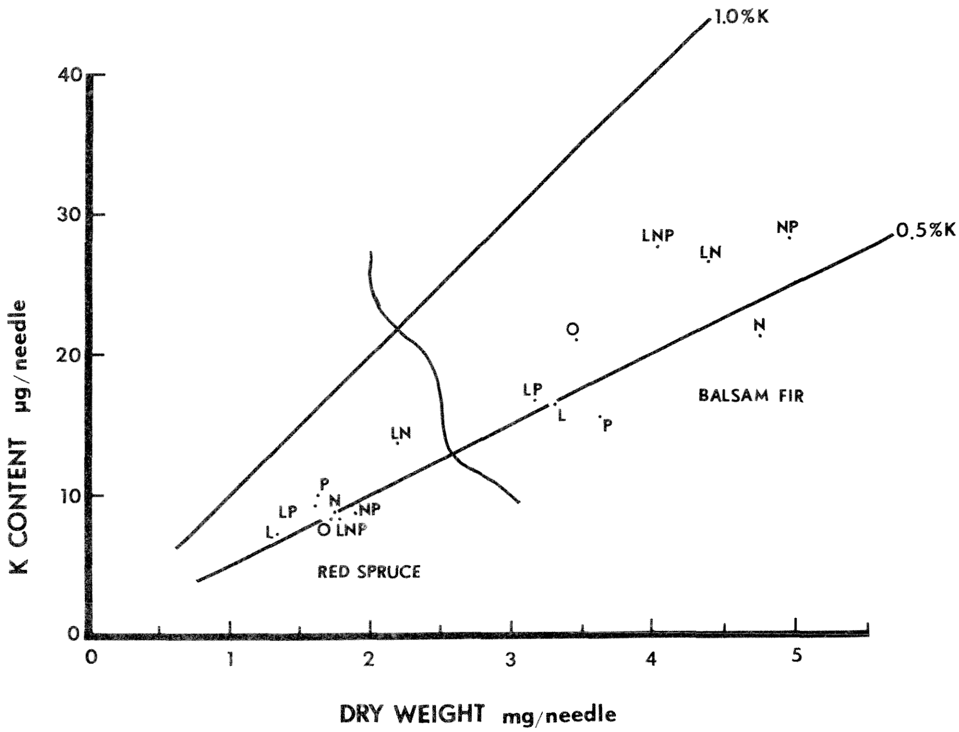


Figure 5.—Average K levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.




In the absence of N, the foliage of balsam fir treated with P contained 0.47 percent K, but in the presence of N, the concentration of K was increased to 0.62 percent by the addition of P (Fig. 5).

The K content of red spruce needles was significantly affected by the NP, N lime, and NP lime interaction terms. Concentration of K in the foliage was significantly affected only by the NP interaction (Table 6). The effect of the NP interaction on red spruce foliar K was the reverse of that on balsam fir. Potassium concentration was increased by P in the absence of N to 0.58 percent and depressed in the presence of N to 0.45 percent (Fig. 5).

It is difficult to interpret the simultaneous significance of these interaction terms—NP, N lime, and NP lime—on K content of red spruce foliage. Lime by itself depressed K content below control (7.0 vs. 8.2 µg/needle). However, lime substantially increased K content in combination with N (13.5 vs. 8.7 µg/needle). The effect of NP interaction on K content was the same as on K concentration already discussed. The NP lime interaction can be interpreted as paralleling the significant interaction on needle dry weight already discussed.

## Calcium

The Ca content of balsam fir needles was significantly increased by N fertilizer (Table 6), averaging 24 $\mu g$ per needle versus 18 $\mu g$ per needle for non-N treatments. This increase results from the increased needle weight from N treatments (Fig. 6). No other treatments or interactions were significant for Ca in balsam fir or red spruce foliage.

Calcium concentration in balsam fir foliage (0.54 percent) was about double that of red spruce foliage (0.29 percent). This could indicate that either the fir has a higher Ca requirement or a greater ability to extract Ca from the soil than red spruce (Fig. 6).

## Iron

The iron concentration and content of balsam fir foliage were both significantly increased by N treatments (Table 6). Foliage from balsam fir trees treated with N averaged 50 ppm and 23 $\mu g$ per needle versus 43 ppm and 14 $\mu g$ per needle for treatments without N. There was a trend for each of the lime and fertilizer treatments to increase Fe levels in balsam fir foliage (Fig. 7). Red spruce foliar Fe was unaffected.

## Manganese

The concentration of Mn in balsam fir foliage responded significantly to N, lime, and N lime and NP lime interactions; Mn content was significantly affected by lime and the NP lime interaction. In red spruce foliage, Mn concentration was significantly changed by N and lime, and the Mn content by lime only (Table 6).

All fertilizer treatments tended to decrease

**Figure 6.—Average Ca levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.**

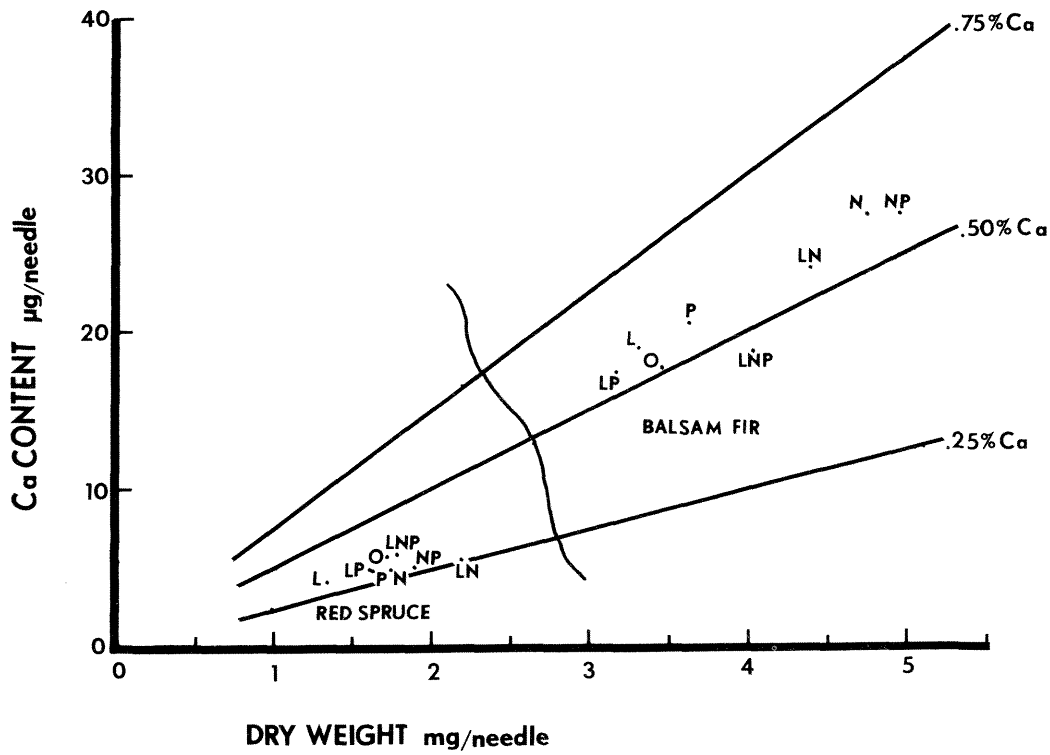
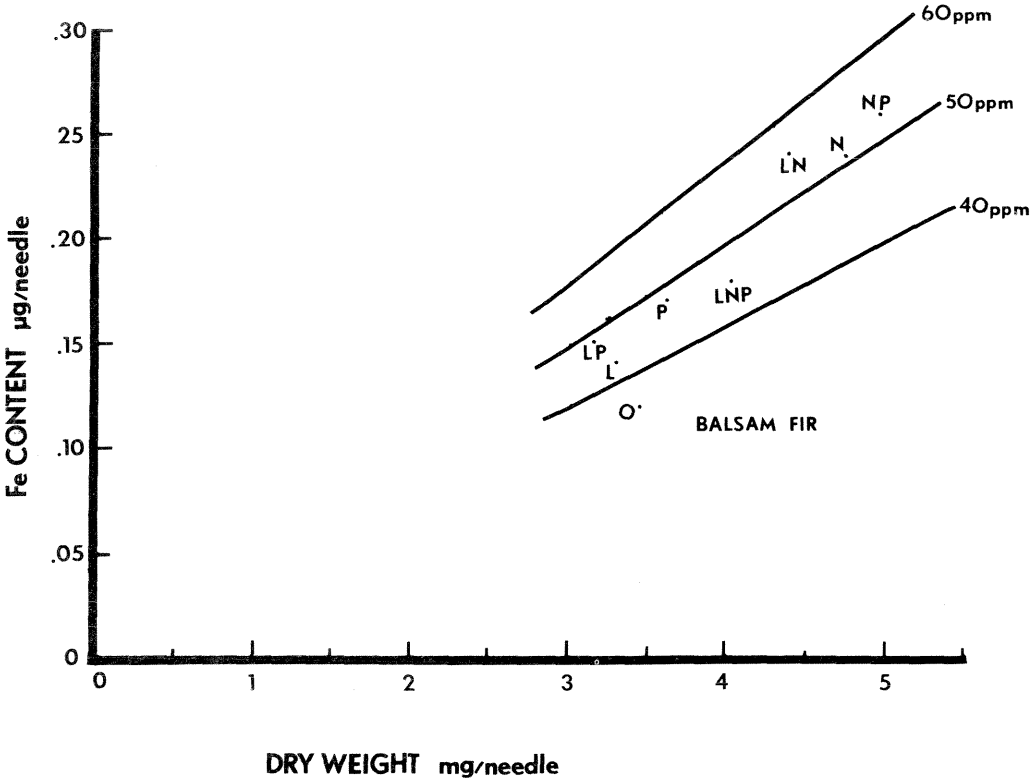


Figure 7.—Average Fe levels in balsam fir foliage from trees treated with N, P, and lime.




Mn levels—both concentration and content—in the foliage of both species (Fig. 8). In balsam fir foliage, treatments that included N averaged 0.07 percent Mn; those without N averaged 0.11 percent Mn. This is a dilution effect created by the gain in needle weight in response to N fertilizer. Lime decreased both average concentration and content of Mn from 0.11 percent and 4.4 $\mu g$ per needle to 0.07 percent and 2.6 $\mu g$ per needle. These decreases resulted from reduced uptake of Mn of balsam fir trees from plots treated with lime. The significant N lime interaction resulted from a greater reduction of Mn concentration by N in the absence of lime—0.14 to 0.08 percent—than in the presence of lime—0.08 to 0.06 percent. The significant NP lime interaction resulted from an increase or no change in Mn levels when N or P was combined with lime only; whereas, NP plus lime resulted in the greatest reduction of Mn of all treatments (Fig. 8).

In red spruce foliage from trees treated with N, concentration of Mn averaged 0.09 percent versus 0.18 percent for non-N treatments. This decrease is partially a dilution effect and partly decreased uptake in the NP and NP lime treatments (Fig. 8); Mn concentration in foliage from red spruce trees treated with lime decreased from 0.13 percent to 0.08 percent, and Mn content decreased from 2.2 to 1.5 $\mu g$ per needle. This decline results primarily from decreased uptake of Mn (Fig. 8).

## Zinc

The Zn content of balsam fir foliage was significantly increased by N fertilizer. None of the treatments significantly affected the Zn levels in red spruce foliage (Table 6). The Zn content of balsam fir foliage averaged 0.24 $\mu g$ per needle compared with 0.15 $\mu g$ for non-N treatments. This significant increase in Zn content reflects the increase in total needle weight caused by N treatment and a trend toward greater Zn uptake in the N and N lime treatments (Fig. 9).

## Sodium

The Na content of balsam fir foliage was significantly increased by N fertilizer. None of the treatments affected Na levels in red spruce foliage (Table 6). The Na content averaged 1.06 $\mu g$ per needle for treatments with N compared with 0.56 $\mu g$ per needle for non-N treatments. This significant increase in Na level reflects the increase in total needle weight caused by N treatments plus a trend of greater uptake of Na in the N treatments, which averaged 231 ppm Na versus 169 ppm for the non-N treatments (Fig. 10).

**Figure 8.—Average Mn levels in red spruce and balsam fir foliage from trees treated with N, P, and lime.**

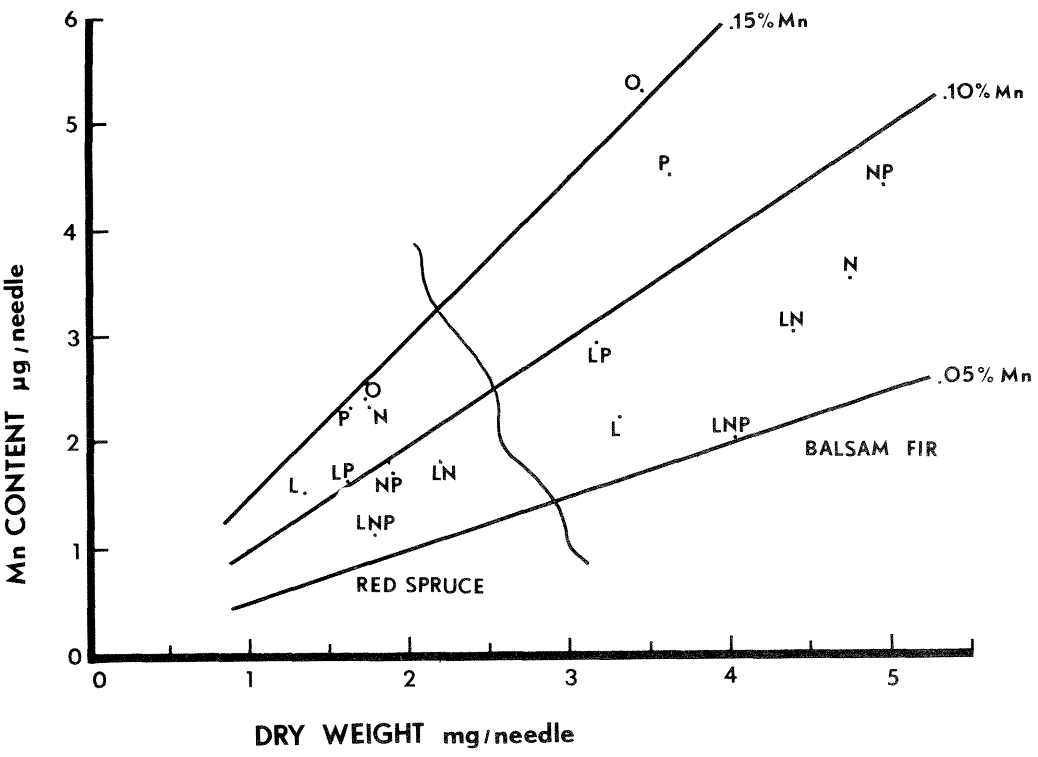


Figure 9.—Average Zn levels in balsam fir foliage from trees treated with N, P, and lime.

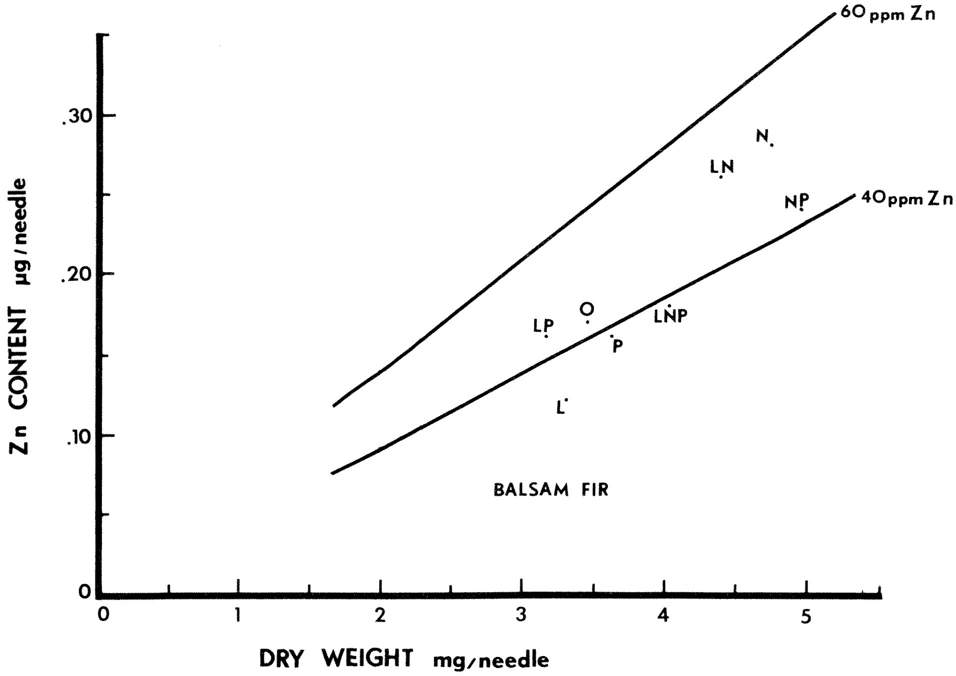
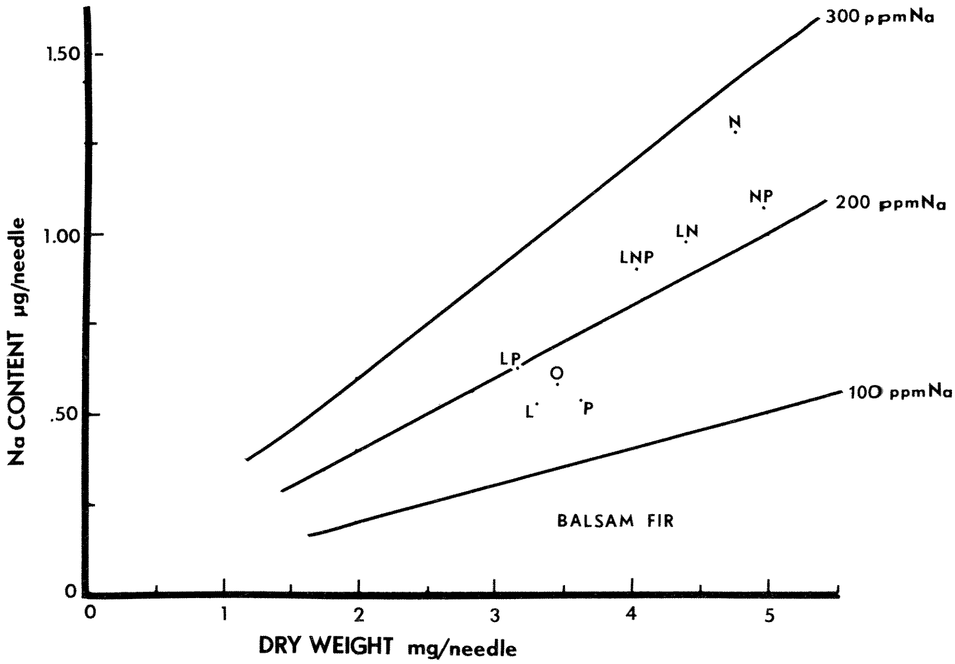



Figure 10.—Average Na levels in balsam fir foliage from trees treated with N, P, and lime.



# DISCUSSION

Three years after treatment, weight of current-year needles, both balsam fir and red spruce, increased in response to nitrogen fertilizer. This fact implicates nitrogen as being a growth limiting nutrient on the site.

Foliar nutrient levels in balsam fir needles appear to have responded more to fertilization than those of red spruce. Every foliar nutrient (except Mg) changed significantly in response to N fertilization. In red spruce, N was the only element that increased significantly in response to N fertilizer. Also, needle mean dry weight for balsam fir increased by 34 percent compared with a 21 percent increase for red spruce in response to N fertilization.

Although not greatly different, average concentrations of ash and each element except Fe, Mn, and Na were higher in balsam fir than in red spruce. And, because of the greater weight per needle, the content of every element was greater in balsam fir. The substantially higher concentration (0.54 vs. 0.25 percent) and content (18 vs. 6 $\mu g$ per needle) of Ca in balsam fir may indicate a fundamental difference in Ca requirements or in capacity of the two species to absorb and translocate Ca. The addition of lime had no direct effect on either Ca or Mg levels in either species. Apparently, the surface application of ground limestone was less available to the understory stand than to the overstory hardwoods, which increased uptake of both Ca and Mg (Czapowskyj and Safford 1979; Schmitt et al. 1979). Another possibility for this lack of response is that the conifer's requirements may have been satisfied by the quantities of Ca and Mg available in the untreated soil.

Nutrient concentration is a function of needle dry weight and nutrient content. Therefore, significant changes in nutrient concentration reflect changes in dry weight or nutrient content, or both. When significant increases in nutrient content are not accompanied by a significant increase in concentration, the logical hypothesis is that increases in dry weight are responsible for the observed increases in nutrient content. In the case of balsam fir, contents of ash, Ca, K, Fe, Zn, and Na contributed to increased needle weight. That is, the content of these elements increased at a rate in proportion to the dry weight increase of the needles. The contents of N, P, and Fe increased at a greater rate than dry weight; therefore, concentrations of N, P, and Fe were higher. But the content of Mn diminished even though dry weight was greater; there was a reduction of Mn concentration. These relationships are easily observed in Figures 2-10, where elemental content is plotted as a function of needle weight by the concept described by Safford (1978) as an alternative to that suggested by Timmer and Stone (1978) based on earlier references. The use of this method allows a new interpretation of the response to each of the treatments.

# CONCLUSIONS

On the basis of the results of this study, we draw the following conclusions about the response of understory red spruce and balsam fir to fertilizer and lime treatments.

1. Dry weight and levels of ash, N, P, K, Ca, Fe, Mn, Zn, and Na were significantly affected by fertilizer treatments, especially by N alone and in combination with P and lime. The significance of several interaction terms indicated that response to a given element or elements may depend on the status of other elements.

2. Balsam fir needles were heavier and had generally higher levels of nutrient elements than red spruce needles, especially Ca concentration and content.
3. Balsam fir foliage exhibited a greater response to fertilizer treatments, both in the number of elements significantly changed and in the magnitude of the changes.

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