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EFFECT OF SOIL AND UREA FERTILIZATION ON FOLIAR NUTRIENTS AND BASAL AREA GROWTH OF RED SPRUCE

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INTRODUCTION

Fertilization is a tool for intensive forest management. To use this tool successfully, a forester must know how a stand with a given set of characteristics will respond to the type of fertilizer and application rate that he plans to use. In Scandinavia and in the western United States, large areas have been treated with nitrogen fertilizers. Some areas have responded better than others; this variable response indicates that site characteristics such as the type of soil and the natural fertility of soil may influence the growth response by fertilized trees.

The forest manager also must consider the cost of buying and applying fertilizer. If he fertilizes trees that are nearly ready for harvesting, he will minimize the interest charges on these invested funds, and he will soon recover his investment. If the stand has been treated with proper silvicultural practices during its development, only high-quality trees will remain in the stand. So additional wood produced because of fertilization will have high quality and value. If the manager's objective is to produce pulpwood, all trees can be harvested, including those that might have died or have been lost by precommercial thinning.

In this experiment we studied the effect of nitrogen fertilizer and soil on the nutrient content of foliage and average basal area growth of red spruce (*Picea rubens* Sarg.) trees in stands that were approaching economic maturity. These trees were on three common soil series of eastern and central Maine. We conducted foliage analyses for 5 years after fertilization, and measured the basal area growth for 9 years after treatment.

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METHODS

The common soil series that we included in our study were: Plaisted, well-drained loamy spodosols developed on glacial till derived from fine-textured sedimentary rocks; Monarda/Burnham, an association of poorly and very poorly drained inceptisols developed on glacial till derived from fine-textured sedimentary rocks; and Hermon, well-drained to excessively drained sandy loam spodosols developed on glacial till derived from igneous rock, mostly granite.

We selected nine sample stands: three locations for each soil series. At each location, we selected four dominant or codominant red spruce trees for treatment. We applied urea fertilizer to an area around the bole of each tree that was equal to the area determined by the average crown diameter of that tree. The treatments were: control, 100, 200, or 400 pounds of nitrogen per acre.We sprinkled the urea from a coffee can "salt shaker" onto the soil surface in May, 1968.

We collected foliage samples in mid-October, 1967, before fertilization and each fall from 1968 to 1972, again in mid-October. We cut one or two branches from the base of the live crown on the south side of each tree. We plucked current twigs from these branches, placed them in paper bags, and dried them in a laboratory for several days at about 65°C. We separated the twigs from the needles with a 2-mm soil sieve. We determined the dry weight per needle by counting a sample of 1,000 whole sound needles from each tree, drying them at 70°C, and weighing them. We ground some of the needles twice through a 40-mesh sieve, placed them in glass jars, and dried them for 24 hours at 70°C. We sealed the jars and stored them for later analysis.

For nutrient analyses, conducted at the Maine Agricultural Experiment Station, use was made of the Kjeldahl method to measure the nitrogen content of the red spruce needles, and of a spectograph to determine the concentrations of 11 other elements (phosphorus, potassium, calcium, magnesium, manganese, aluminum, molybdenum, boron, zinc, copper, and iron). We report these concentrations in percentage or parts per million (ppm); we report the quantity per needle in milligrams ($mg = g \times 10^{-3}$); micrograms ($\mu g = g \times 10^{-6}$); or nanograms ($ng = g \times 10^{-9}$).

We designed the study as a randomized complete block. We analysed the variance of needle weight and the nutrient content of foliage by sample year, soil series, and treatment. We based this analysis on three observations per cell (soil location).

During each October from 1967 to 1976, we measured (with a steel tape) the diameter of trees at breast height, to the nearest .01 inch. We analysed the variance of basal area growth (square inches per tree) by soil series and treatment for that period. We based this analysis also on three observations per cell.

RESULTS AND DISCUSSION

Variation in Foliar Nutrient Content

Sample Year. The dry weight of needles and content of each element varied significantly ($P<.01$) among sample years on all soils. In some cases, the effect of sample year was significant because of year to year fluctuations in nutrient content (P, K, Fe, and Mo). Dry weight of needles and content of Zn, Mn, and Al, tended to increase during the sampling period; P content decreased during the same period. The N content of red spruce needles decreased for the first 3 or 4 sample years, but increased in the last sample year. This pattern was reversed for Ca, Mg, B, and Cu.

This high variability among sample years emphasizes the difficulty of using foliage data from a single year to evaluate nutrient status of individual trees or stands over a longer period. Schomaker (1973) found significant variation in foilage nutrient content for several elements over a 2-year sampling period. When he added data for a third year, the number of elements that showed variation and the significance of the differences among years (size of F value) increased. We found that the longer the sample period, the greater the variation for all variables. Presumably, a maximum range of natural fluctuation of foliage nutrient content exists. We need some method of estimating this range in order to interpret observations from a single year properly.

We can probably attribute some of this annual variation to experimental error. Though we followed standard procedures in obtaining and preparing needle samples for analysis, some variation could result from sample location within the trees, or sample date. For example, the calendar date on which we sampled may not be an equivalent physiological date from year to year—even though the trees were dormant when sampled. Within the laboratory, variation might result from the use of a nonrepresentative subsampling of ground needles, an accidental change in needle properties such as moisture content, or dust contamination during the analysis. The fact that annual variation differed among the elements in both magnitude and direction indicates that laboratory procedures did not cause the variation.

The magnitude of variability from these sources should be considered when sampling procedures are designed for similar studies.

Soil. The effect of soil on foliage nutrient content was significant for all elements but concentrations of N, Cu, Mg, Mo, and quantity of Fe (Tables 1, 2). This contrasts with an analysis before fertilization (Safford and Young, 1968) that showed that there were significant variations among soils only for concentrations of P, Zn, Mn, and B. Apparently, fluctuations in nutrient content by sample year differed among the soils be-

Table 1
Significance of nitrogen fertilizer, soil, and sample year on nutrient concentrations in red spruce needles, by analysis of variance.

Independent	Dependent variables											
variable	N	P	K	Ca	Mg	Mn	Fe	B	Zn	Cu	Mo	Al
Fertilizer (F)	**	**	NS[a]	NS	NS	NS	NS	NS	*	NS	NS	NS
Soil (S)	NS	**	*	NS	NS	**	**	**	**	**	NS	**
Year (Y)	**	**	**	**	**	**	**	**	**	**	**	**
F x S[b]	NS	**	**	*	NS	*	NS	NS	NS	NS	NS	*
S x Y	NS	NS	**	NS	NS	NS	**	**	NS	**	**	NS

**P < 0.01; *P < 0.05.
[a]Not significant.
[b]F x Y and F x S x Y not significant.

Table 2
Significance of nitrogen fertilizer, soil, and sample year on dry weight and amount of nutrients per red spruce needle, by analysis of variance.

Independent	Dependent variables												
variable	Weight	N	P	K	Ca	Mg	Mn	Fe	B	Zn	Cu	Mo	Al
Fertilizer (F)	NS[a]	NS	*	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Soil (S)	**	**	**	**	**	*	**	NS	**	**	**	**	**
Year (Y)	**	**	**	**	**	**	**	**	**	**	**	**	**
F x S[b]	NS	*	**	**	**	NS	**	NS	NS	NS	NS	NS	NS
S x Y	NS	NS	NS	*	NS	NS	NS	**	**	NS	**	**	NS

**P < 0.01; *P < 0.05.
[a]Not significant.
[b]F x Y and F x S x Y not significant.

cause the effect of the interaction of soil and year on variations in nutrient content was significant for K, Fe, B, Cu, and Mo.

Fertilizer. The effect of N fertilization on nutrient content was significant only for the content of P and Zn, and concentration of N (Tables 1, 2). The effect of the interaction of soil and fertilizer was significant for the content of P, K, Ca, and Mn; concentration of N; and quantity per needle of Al.

Needle Weight. Average needle weight fluctuated from year to year, with a trend of increased weight over the 6-year sampling period (Figure 1). Needles from trees on Hermon soils were consistently heavier (2.4 to 3.0 mg per needle) than those from trees on Monarda/Burnham or Plaisted soils (2.0 to 2.5 mg per needle). The effect of N fertilization on needle weight was not significant (Table 2), but on Monarda/Burnham and Plaisted soils, needle weight for fertilized trees averaged higher than it did for control trees during the first 2 years after fertilization (1968 and 1969) (Figure 1). In the first year after treatment, the weight of control needles declined from the previous year, while the needle weight for each N treatment increased. In the second year, all needles increased in weight, but needles from fertilized trees increased by larger amounts than those from control trees. Thus it seems that the effect of N fertilization on needle weight was not great. Normal variation from year to year obscured the slight effect of N fertilization on needle weight within 2 years.

Nitrogen. The N concentration in red spruce foliage increased in proportion to the amount of urea that was applied. The percentage of N in control foliage ranged from .94 to 1.13 percent during the sampling period; the percentage of N in needles from fertilized trees was highest at the end of the first growing season after treatment at 1.11, 1.22, and 1.30 percent for treatments of 100, 200, and 400 pounds of N per acre. Concentrations of N in foliage of fertilized trees declined to control levels after 2 years on the Plaisted and Hermon soils, and after 3 years on Monarda/Burnham soils. (Figure 2).

On Plaisted soils, fertilization had no apparent effect on the amount of N per needle (Figure 3). On the other soils, the amount of N per needle on fertilized trees increased in 1968 and in 1969, but dropped to control levels in 1970. The greatest differences in the amount of N per needle between fertilized and control trees ocurred on Hermon soils. These differences resulted from a strong decrease in values for control trees rather than from increases in fertilized trees.

Phosphorus. The effect of N fertilization on the percentage of P in red spruce needles varied among the soils. On Plaisted and Monarda/Burnham soils, P increased in foliage of control trees in 1968 and in 1969, but decreased during the last 3 sample years (Figure 4). From 1970 to 1972, the percentage of P in fertilized trees declined more sharply than it did in control trees. On Hermon soils, which had significantly lower initial concentrations of P (Safford and Young, 1968), fertilization had no apparent effect on the content of P; the percentage of P declined from an average of .19 percent in 1967 to .14 percent in 1972.

The amount of P per needle fluctuated among sample years but there was no general trend over the entire sampling period (Figure 5). This indicates that the decrease in the percentage of P over the entire sampling period resulted from the increase in needle weight during the same period; that is, needle components other than P increased from 1967 to 1972, while the amount of P per needle remained constant.

On Plaisted and Hermon soils, needles from trees treated with the largest amount of N generally contained less than those of the lower treatment and control. On Monarda/Burnham soils the opposite was true (Figure 5).

Potassium. The percentage of K fluctuated among sample years, and declined slightly from 1967 to 1972. Because K levels also differed by soil and by treatment, we could not determine the relationship between soil or fertilizer and the percentage of K in current red spruce needles. (Figure 6).

Needles from trees on Hermon soils had slightly higher amounts of K than those from trees on other soils. The amount of K in needles from trees on Hermon soils increased in 1969 and in 1971, while the amount in foliage from trees on other soils decreased, in 1970 and 1972, this pattern was reversed (Figure 7).

Calcium. Needles from trees on Monarda/Burnham soils had greater percentages of Ca than those from trees on Hermon soils. On soils of this series, Ca percentages decreased for all but the largest treatment (Figure 8); the same was true for the amount of Ca per needle (Figure 9).

Magnesium. The percentage of Mg in red spruce foliage increased from 1967 to 1970, but declined in 1971 and in 1972 (Figure 10); the amount of Mg per needle followed a similar pattern. Because the amount of Mg in needles from trees on Hermon soils was greater than it was in foliage from trees on other soils, the effect of soil on the amount of Mg was significant.

Minor Elements. Although the Zn content varied significantly among fertilizer treatments (Tables 1, 2), the relationship between treatments and Zn content is not clear. This is because the Zn content in needles for the largest and smallest treatments usually was lower than that for the other treatments—particularly on Hermon soils (Figures 11, 12). Despite the fluctuation in content between sample years, the Zn content generally increased over the entire sampling period. Red spruce needles from trees on Hermon soils contained consistently higher levels of Zn than did needles from trees on Monarda/Burnham or Plaisted soils.

Values for Mn and Al content of red spruce foliage fluctuated greatly from year to year. There was an overall increase in the foliage content of each of these elements during the 6-year sampling period (Figures 13-16). Foliage from trees on Hermon soils had consistently lower contents of Mn and higher contents of Al than the foliage from trees on other soils. These results confirm the trend that we noted before fertilization (Safford and Young, 1968). Foliage from trees on Monarda/Burnham soils had a consistently lower content of Al than the foliage from trees on other soils.

Of the remaining minor elements, Mo, B, Cu, and Fe, only B content maintained the same relative ranking among soils from year to year; but B content between any 2 sample years often varied—especially on Plaisted soils (Figures 17, 18).

Of these elements, only B showed significant variation among soils before fertilization; yet repeated sampling over a 6-year period showed significant variations in content among soils for all four elements. Except for B, however, the relative ranking of soils varied from year to year. These results emphasize the need for careful consideration in using foliage analyses to diagnose tree-soil nutrient status for minor elements.

Basal Area Growth

The average basal area growth per tree from 1967 to 1976 varied among soils but not among treatments (Table 3). The basal area growth of trees on Hermon soils was significantly greater than that of trees on Plaisted or Monarda/Burnham soils, and average growth did not differ between Plaisted and Monarda/Burnham soils (Table 4). This greater overall growth rate of trees on Hermon soil probably resulted from the lower stand density and the larger live crowns of trees on those soils rather than from greater productivity (Safford and Young, 1968).

The effect of fertilization on growth rate was not significant because of the small number of trees in the sample, and the high degree of variability among the fertilized trees for each combination of soil and treatment. On Plaisted and Hermon soils, the growth rate of control trees tended to be lower than that of fertilized trees, but there was no consistent trend by treatment (Figure 19). On Monarda/Burnham soils, the growth rate of fertilized trees tended to be lower than that of control trees. This apparent difference in response caused by soil drainage emphasizes a need for evaluation of interaction between soil properties and response to fertilizer treatments.

CONCLUSIONS

We concluded that:

1. The nutrient content of red spruce foliage varied greatly from year to year even though we sampled trees by standard procedures during the dormant season.

2. Soil series influenced natural foliage nutrient content, the effect of nitrogen fertilizer on foliage weight and nutrient content, and average basal area growth.

3. The effect of nitrogen fertilizer on foliage nutrient content, needle weight, and basal area growth was neither great nor long lived.

Table 3
Analysis of variance of average basal area growth of red spruce trees, by soil and nitrogen fertilizer.

Variable	Df	Sum of squares	Mean square	F
Soil (S)	2	143761.7	71880.9	16.00**
Fertilizer (F)	3	9716.0	3239.0	.72NS[a]
S x F	6	38305.8	6384.3	1.42NS
Error	24	107805.3	4491.9	____
Total	34	299588.8	____	____

**$P \leqslant 0.01$.
[a]Not significant.

Table 4
Average basal area growth of red spruce trees, 1967-1976 by soil series and nitrogen fertilizer treatment, in square inches per tree.

Soil series	Treatment (pounds of N per acre) 0	100	200	400	Mean
Plaisted	7.8	17.1	15.6	7.4	12.0
Monarda/Burnham	18.0	11.1	12.1	15.0	14.0
Hermon	21.1	26.8	31.3	26.0	26.3
Mean	15.7	18.3	19.7	16.1	17.1

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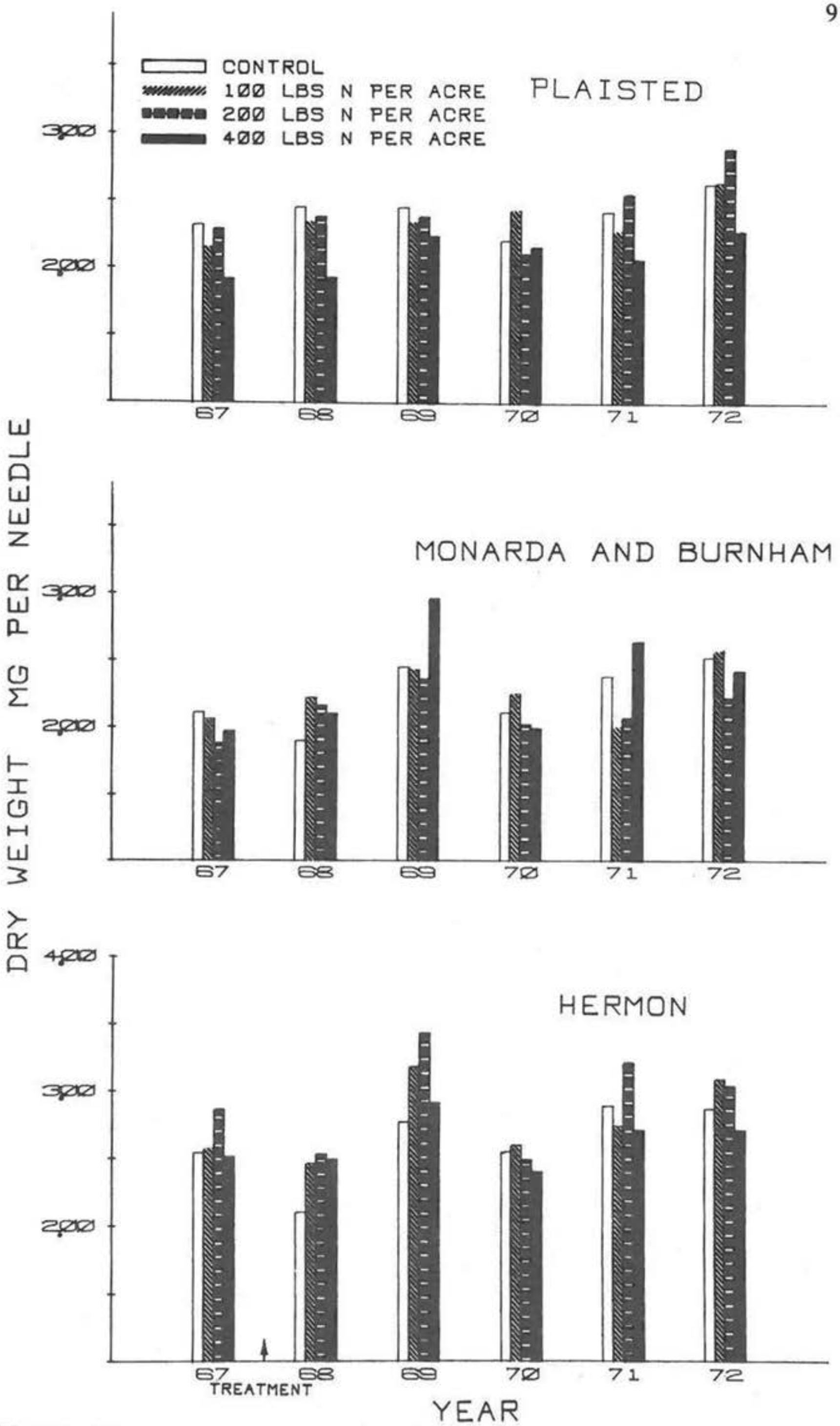

Figure 1. Annual variations in average dry weight per current year red spruce needle, by soil series and fertilizer treatment.

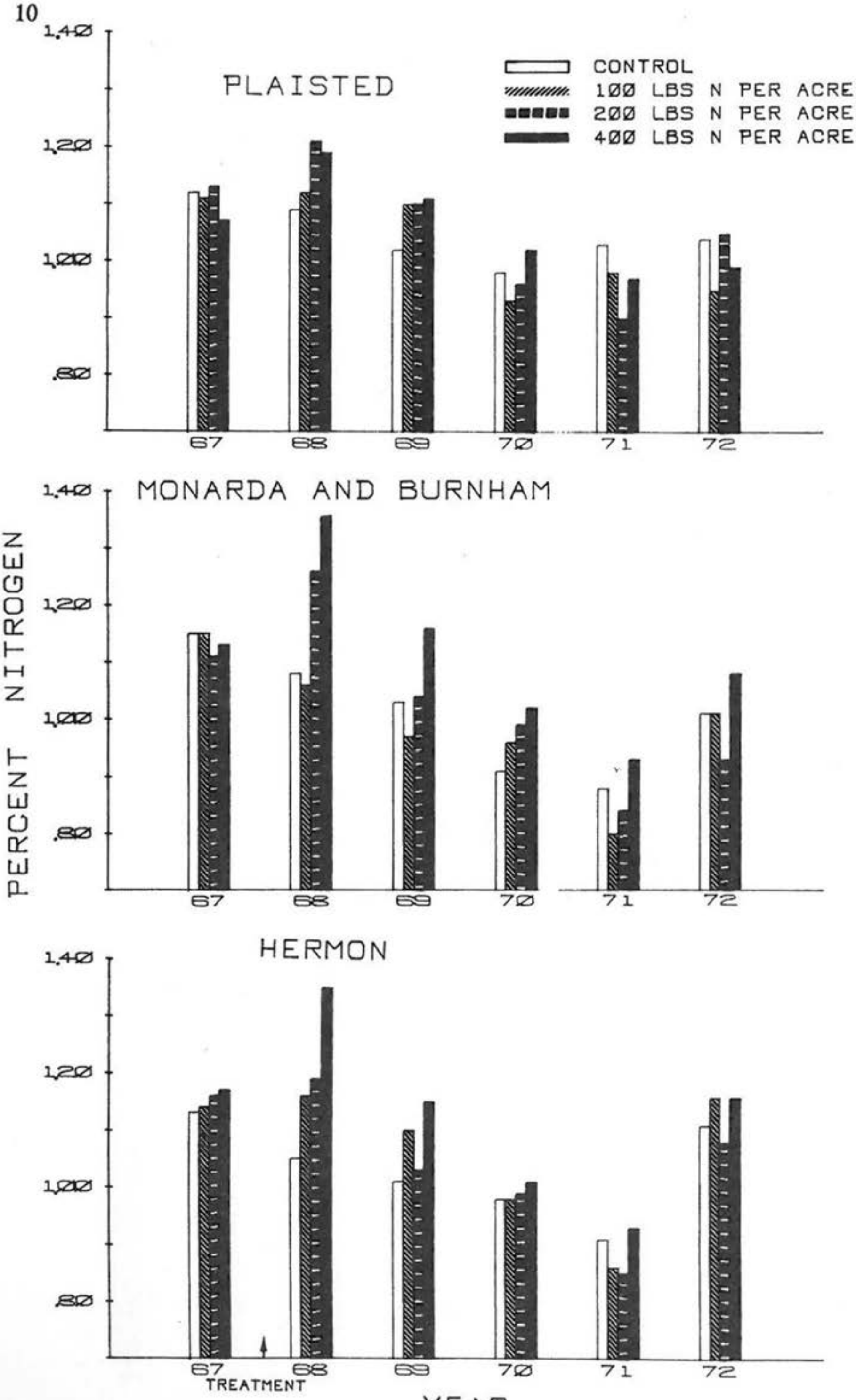

Figure 2. Annual variations in nitrogen concentration in current red spruce foilage, by soil series and fertilizer treatment.

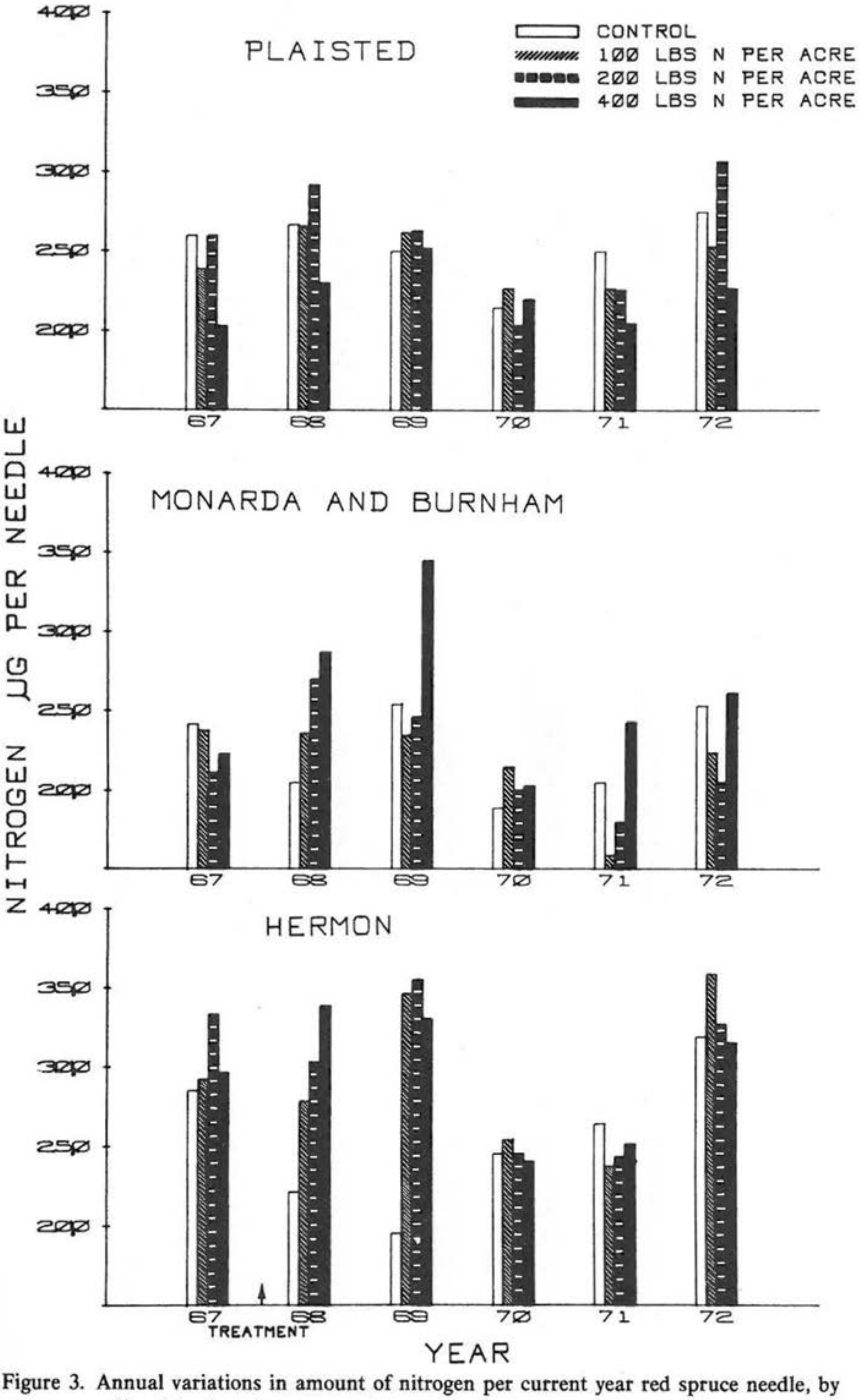

Figure 3. Annual variations in amount of nitrogen per current year red spruce needle, by soil and treatment.

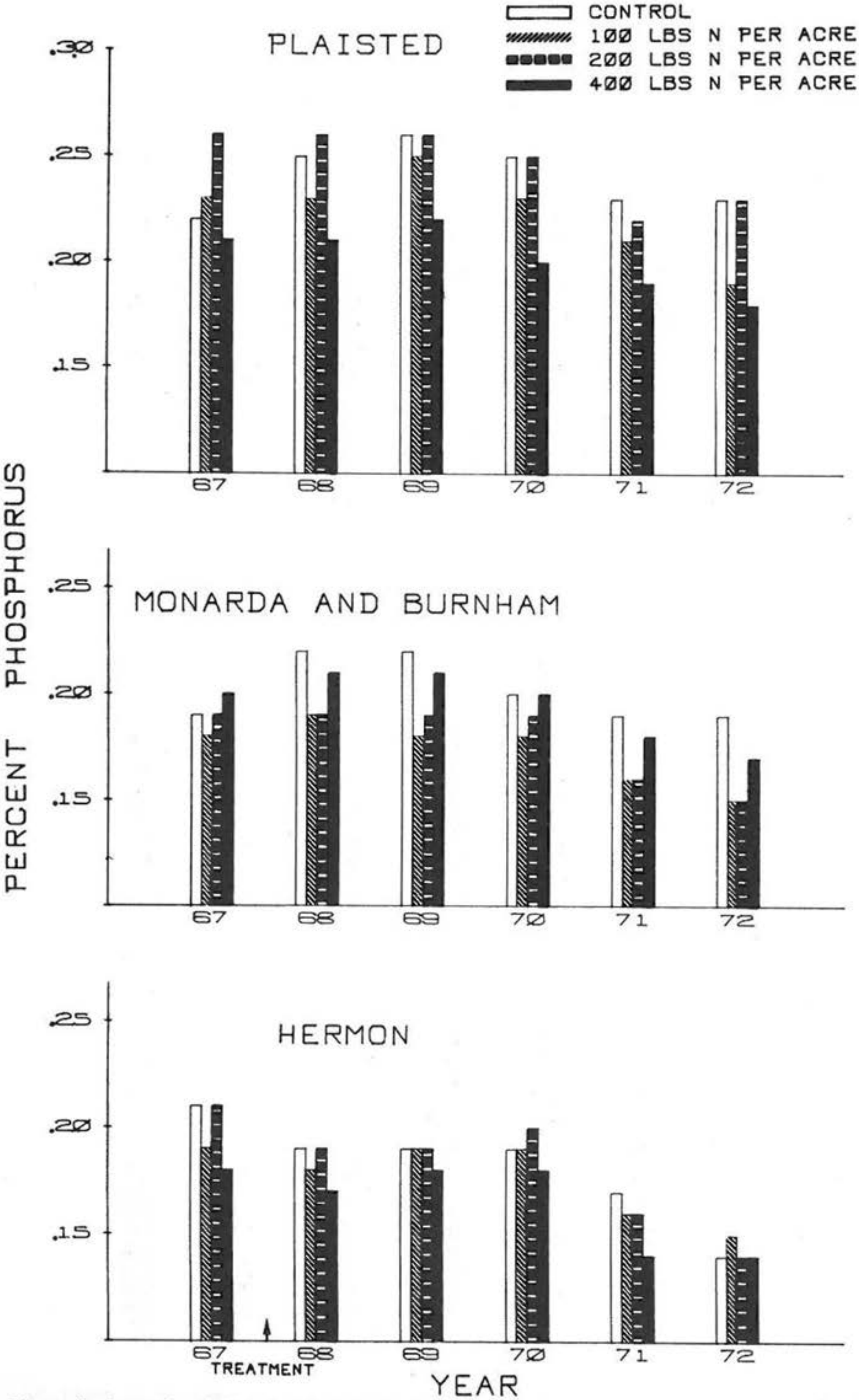

Figure 4. Annual variations in phosphorus concentration in current year red spruce foliage, by soil and treatment.

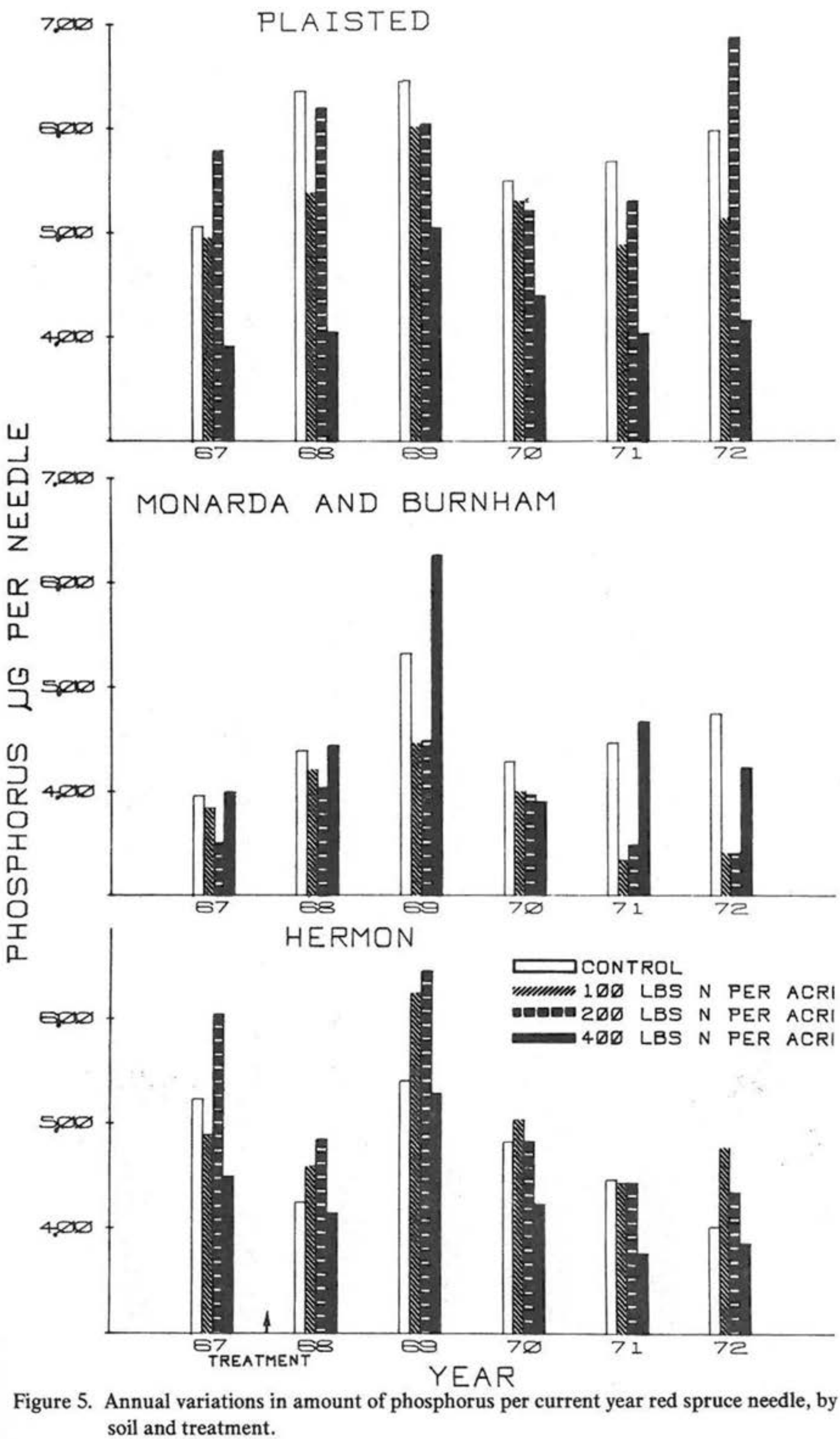

Figure 5. Annual variations in amount of phosphorus per current year red spruce needle, by soil and treatment.

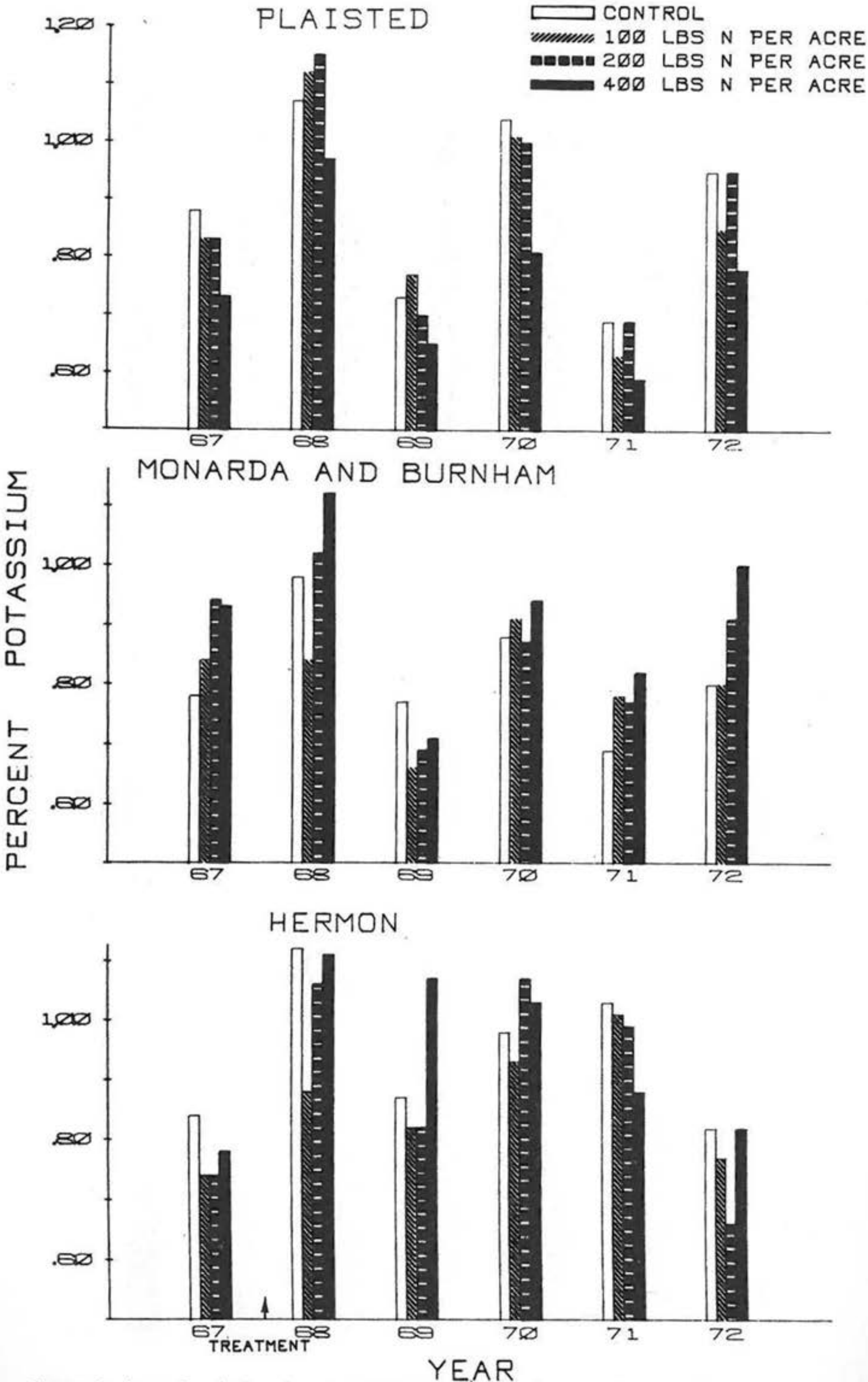

Figure 6. Annual variations in potassium concentration in current year red spruce foliage by soil and treatment.

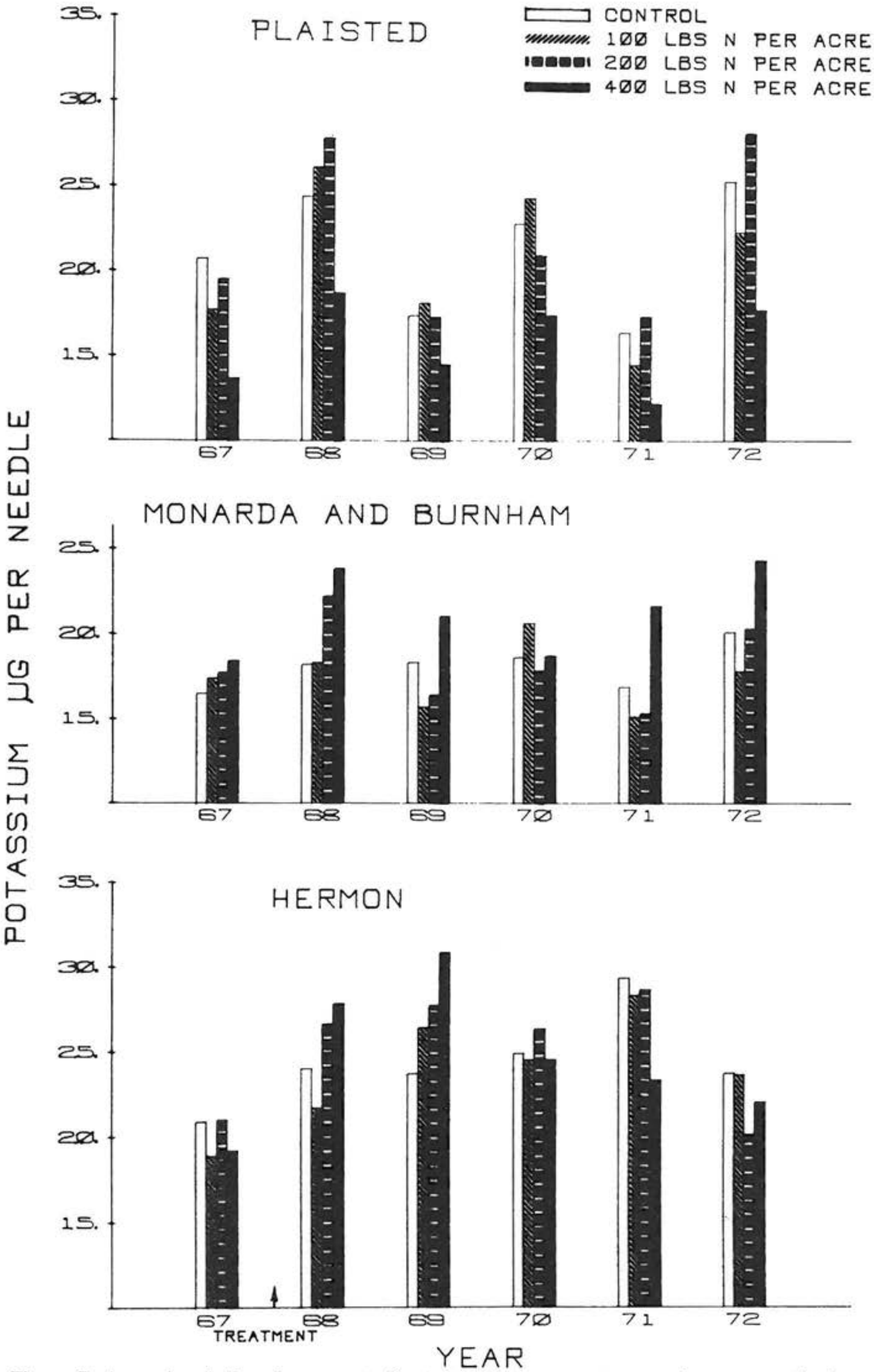

Figure 7. Annual variations in amount of potassium per current year red spruce needle, by soil and treatment.

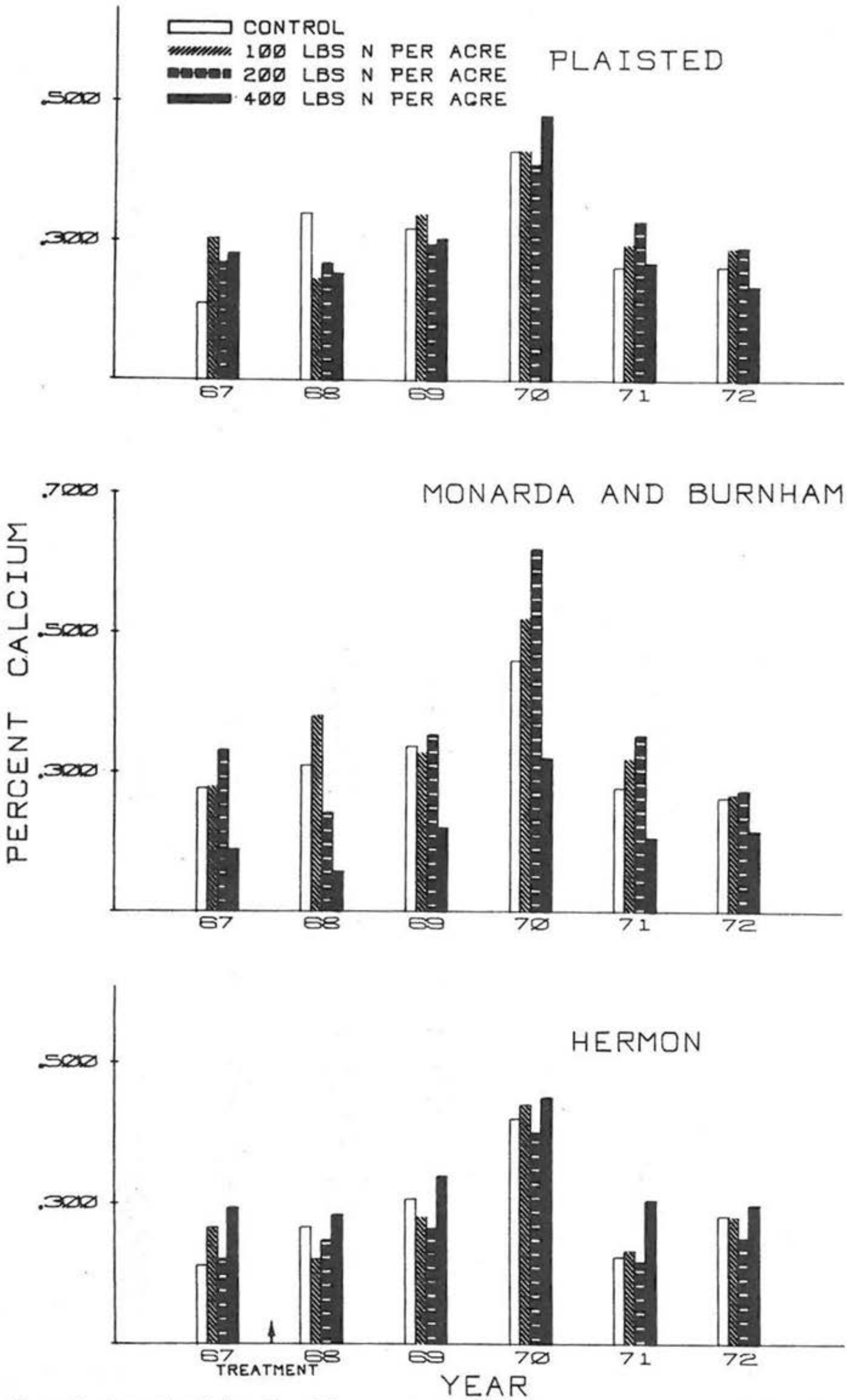

Figure 8. Annual variations in calcium concentration in current year red spruce foliage, by soil and treatment.

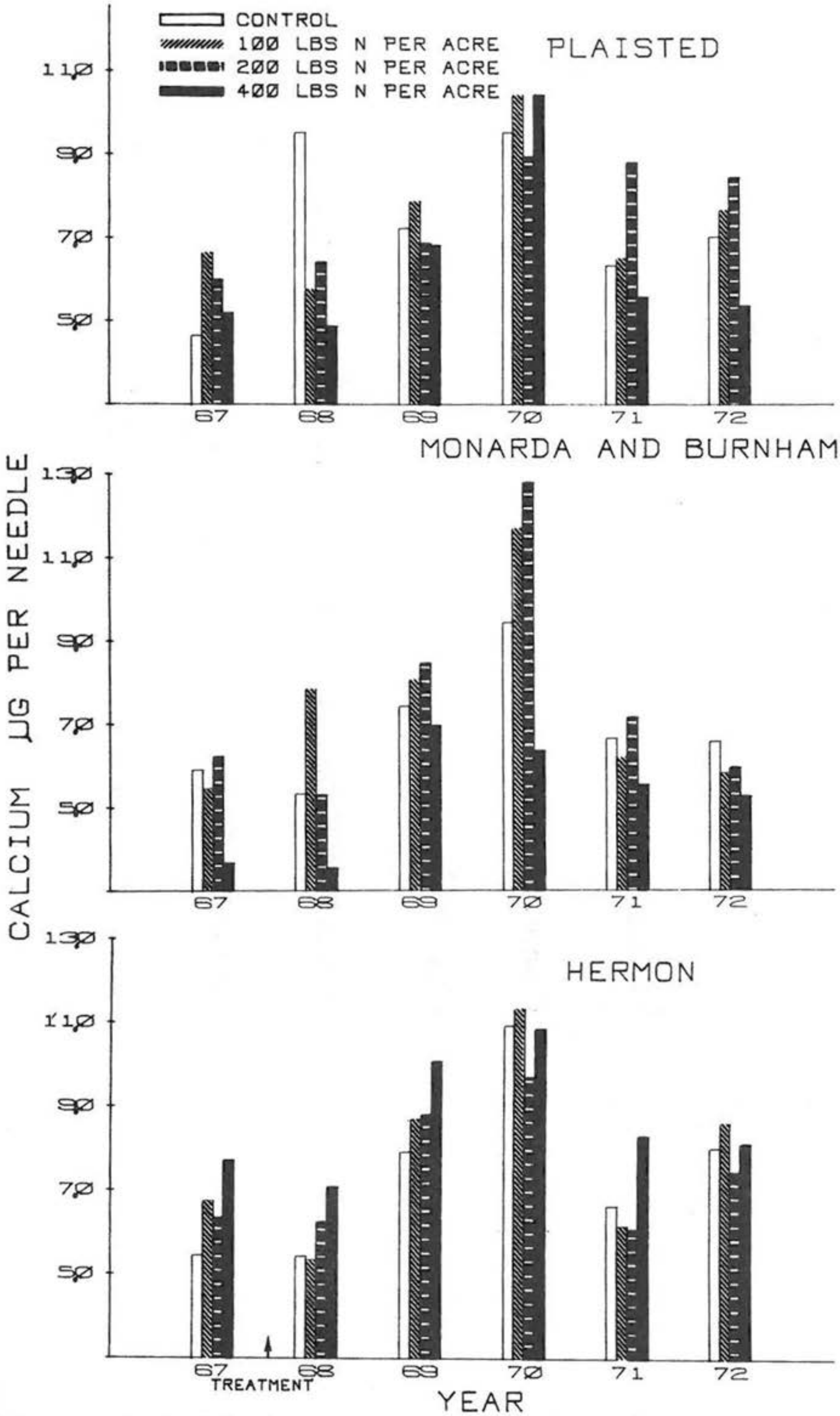

Figure 9. Annual variations in amount of calcium per current year red spruce needle, by soil and treatment.

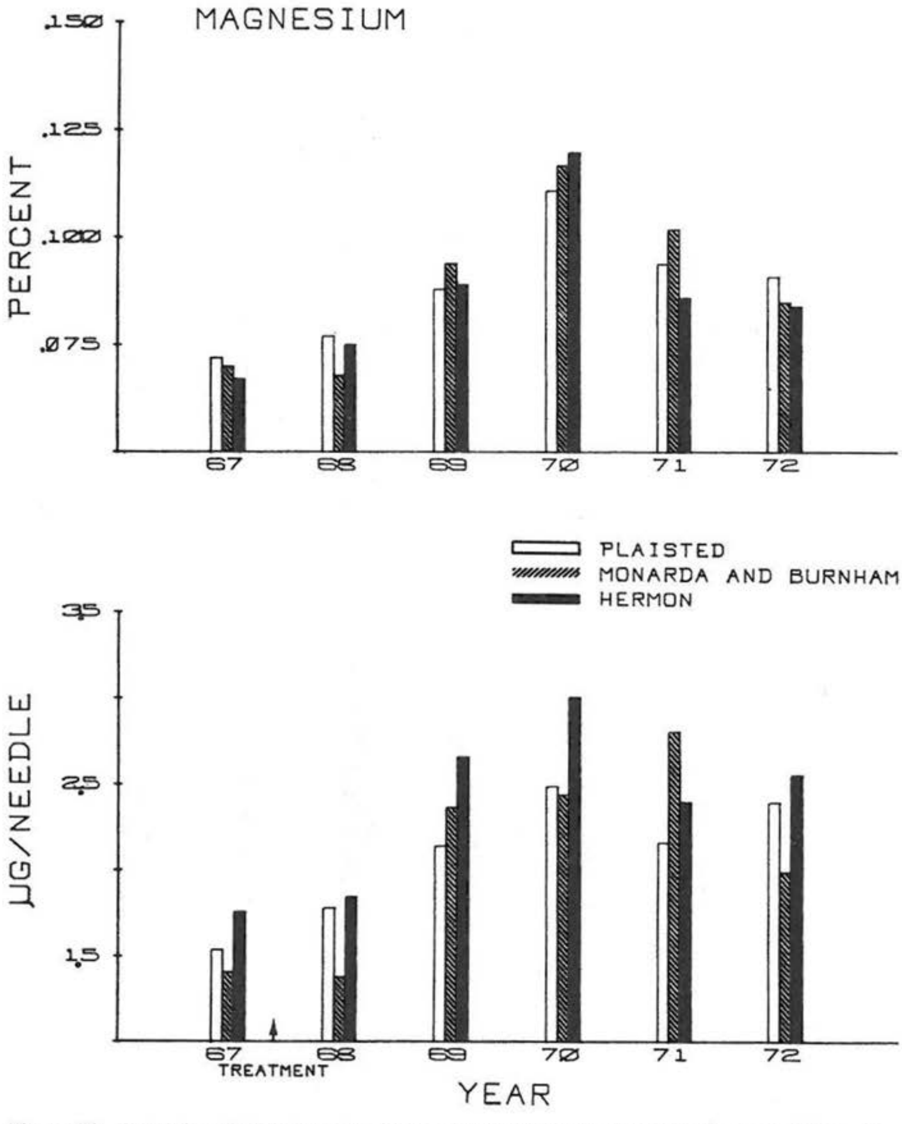

Figure 10. Annual variations in magnesium content of current year red spruce foliage, by soil series.

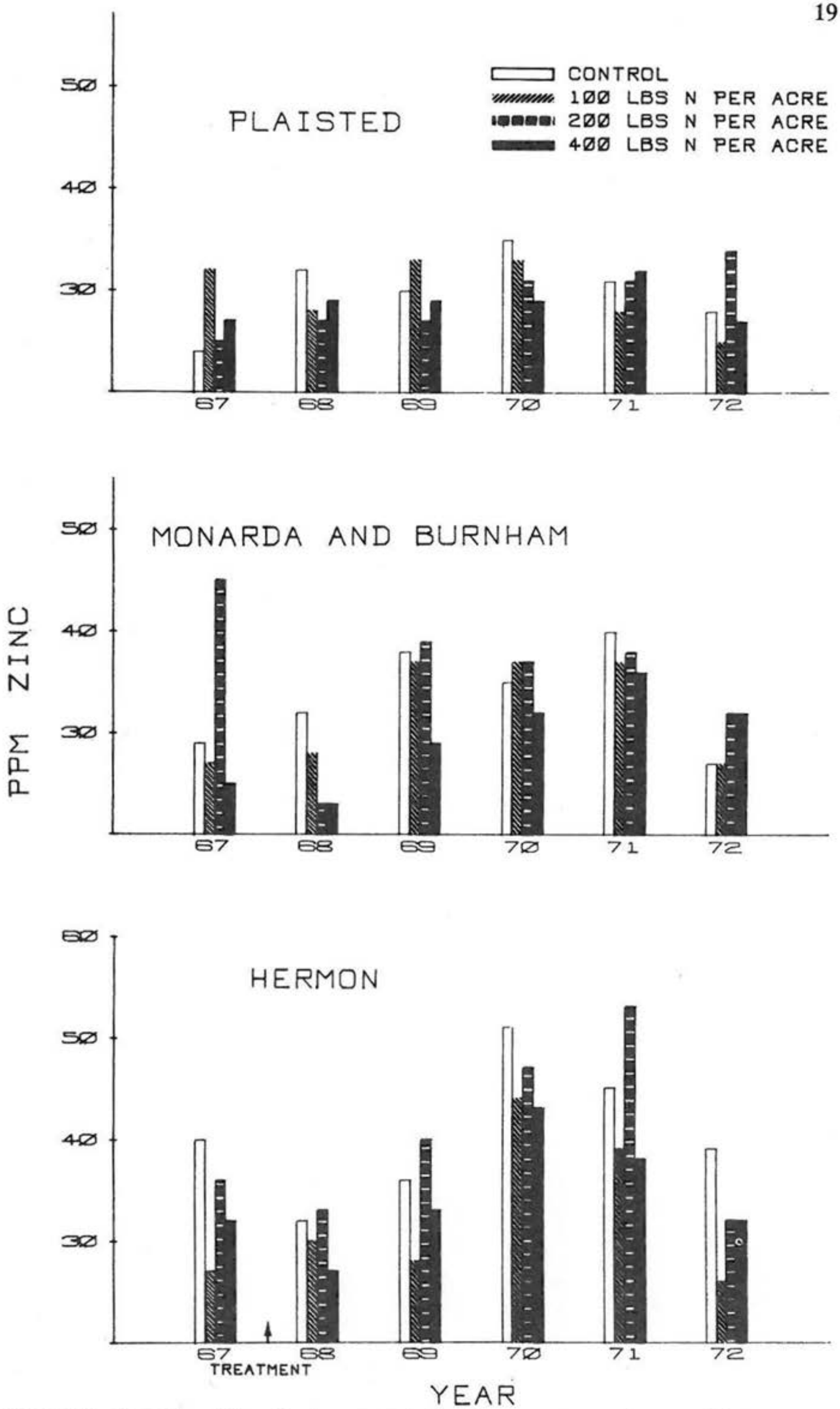

Figure 11. Annual variations in zinc concentration in current year red spruce foliage, by soil and treatment.

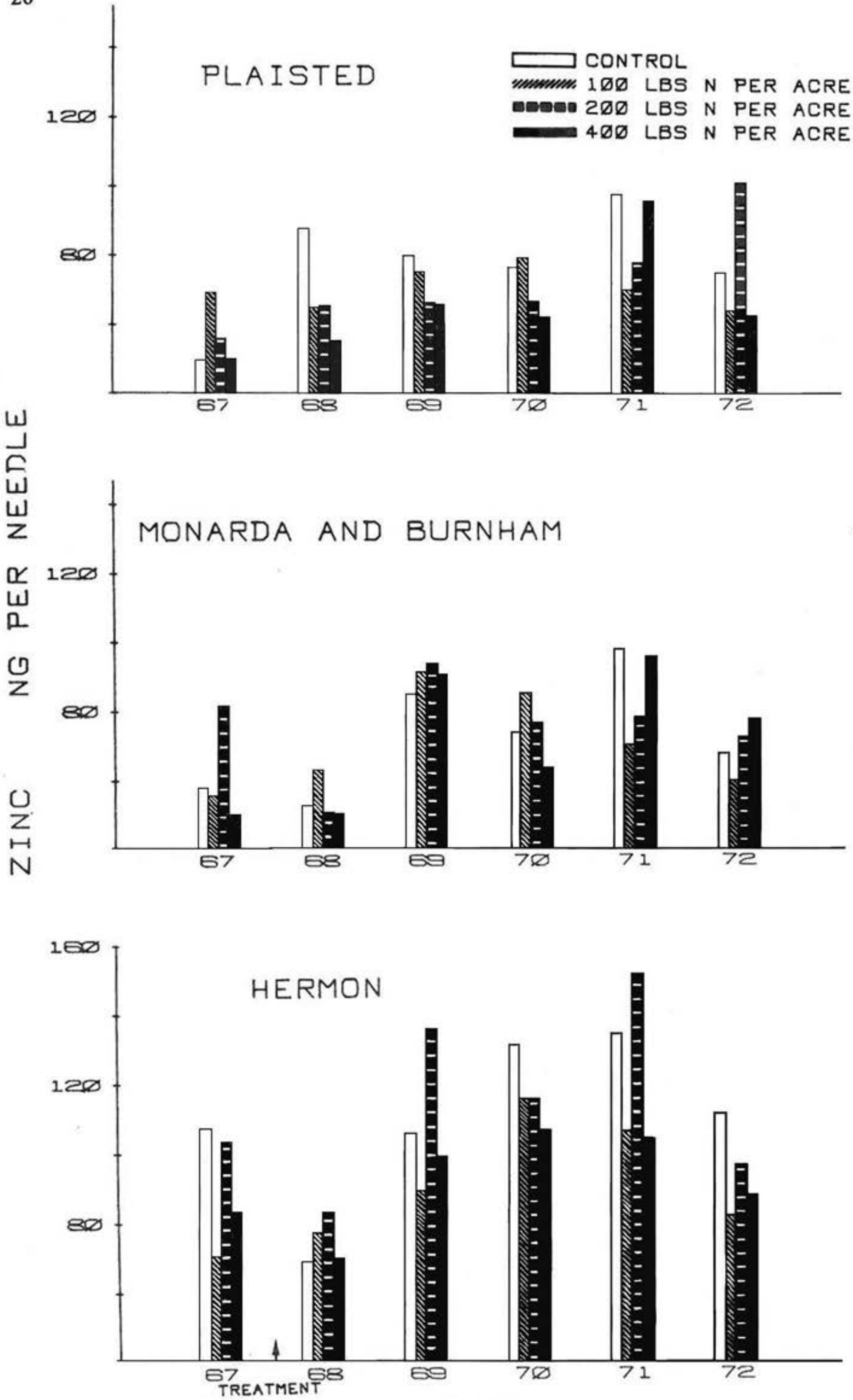

Figure 12. Annaul variations in amount of zinc per current year red spruce needle, by soil and treatment.

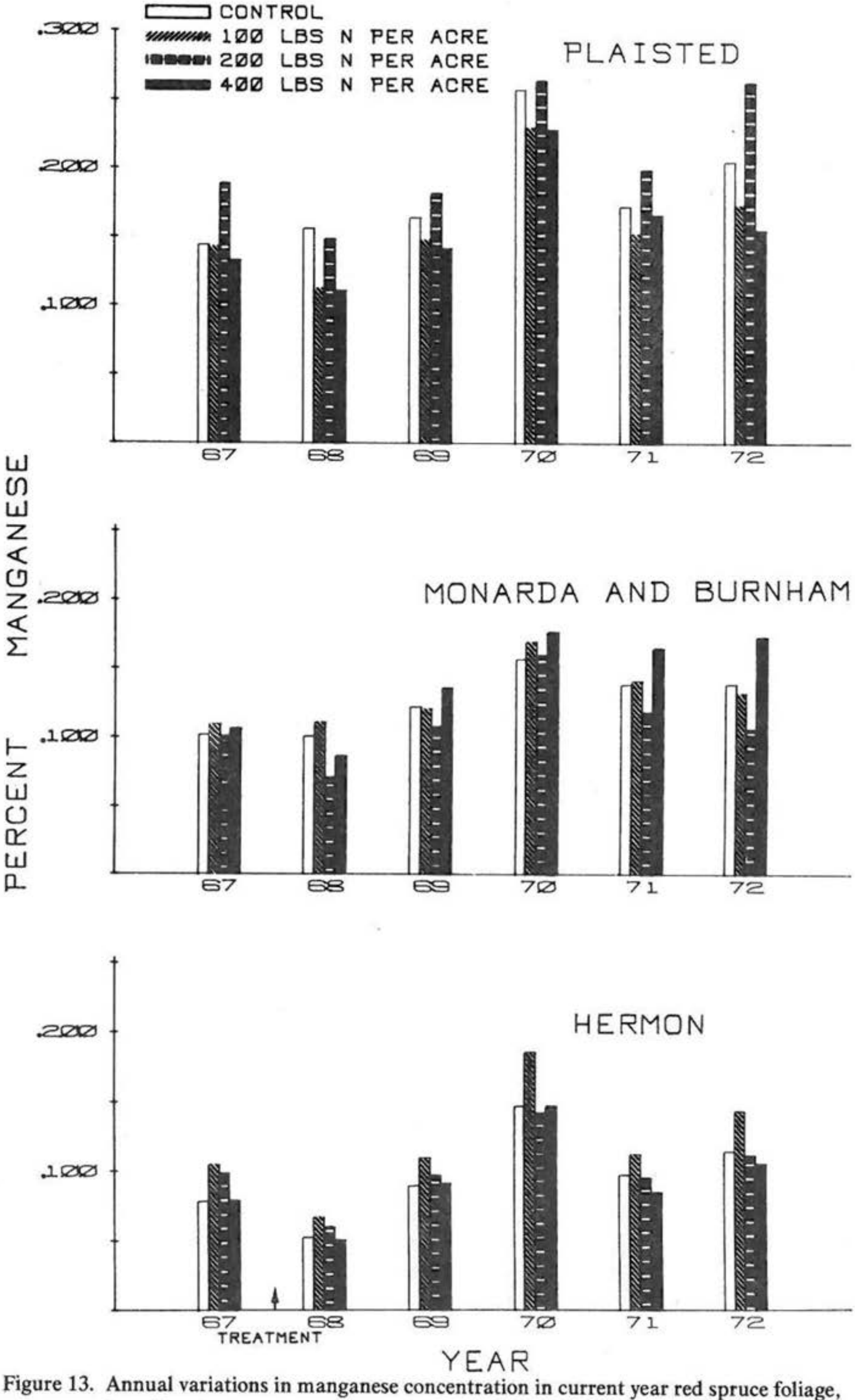

Figure 13. Annual variations in manganese concentration in current year red spruce foliage, by soil and treatment.

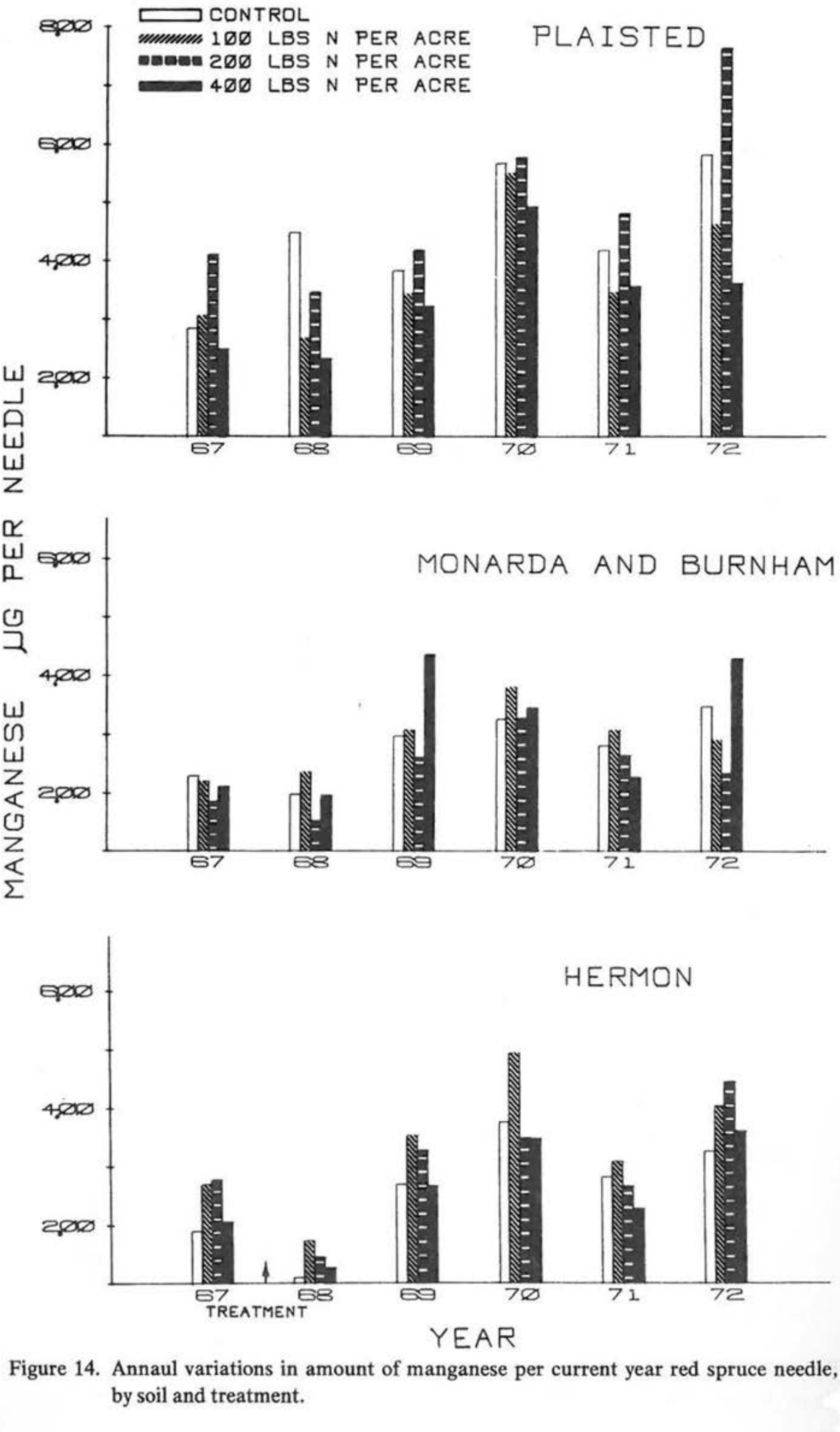

Figure 14. Annaul variations in amount of manganese per current year red spruce needle, by soil and treatment.

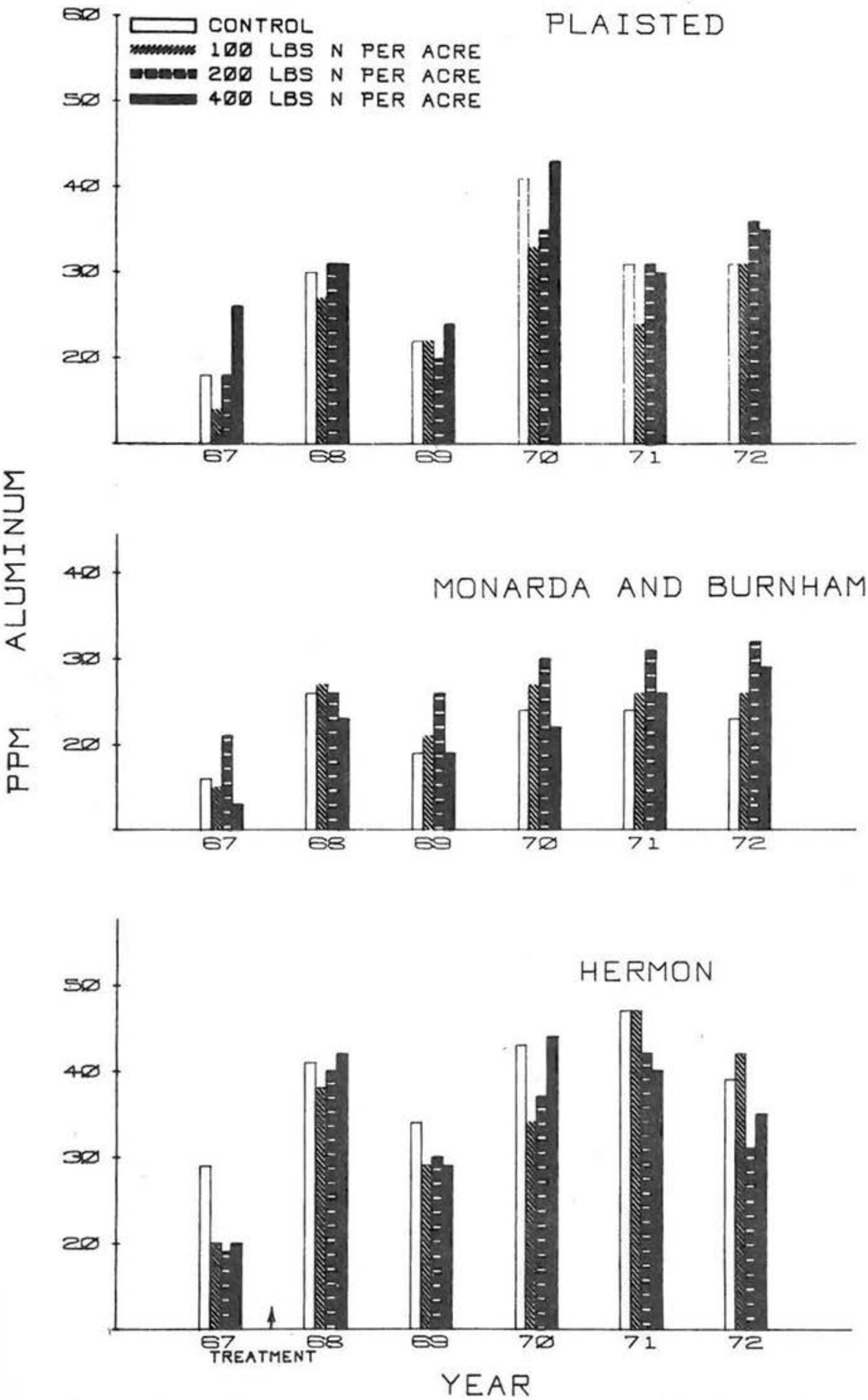

Figure 15. Annual variations in aluminum concentration in current year red spruce foliage, by soil and treatment.

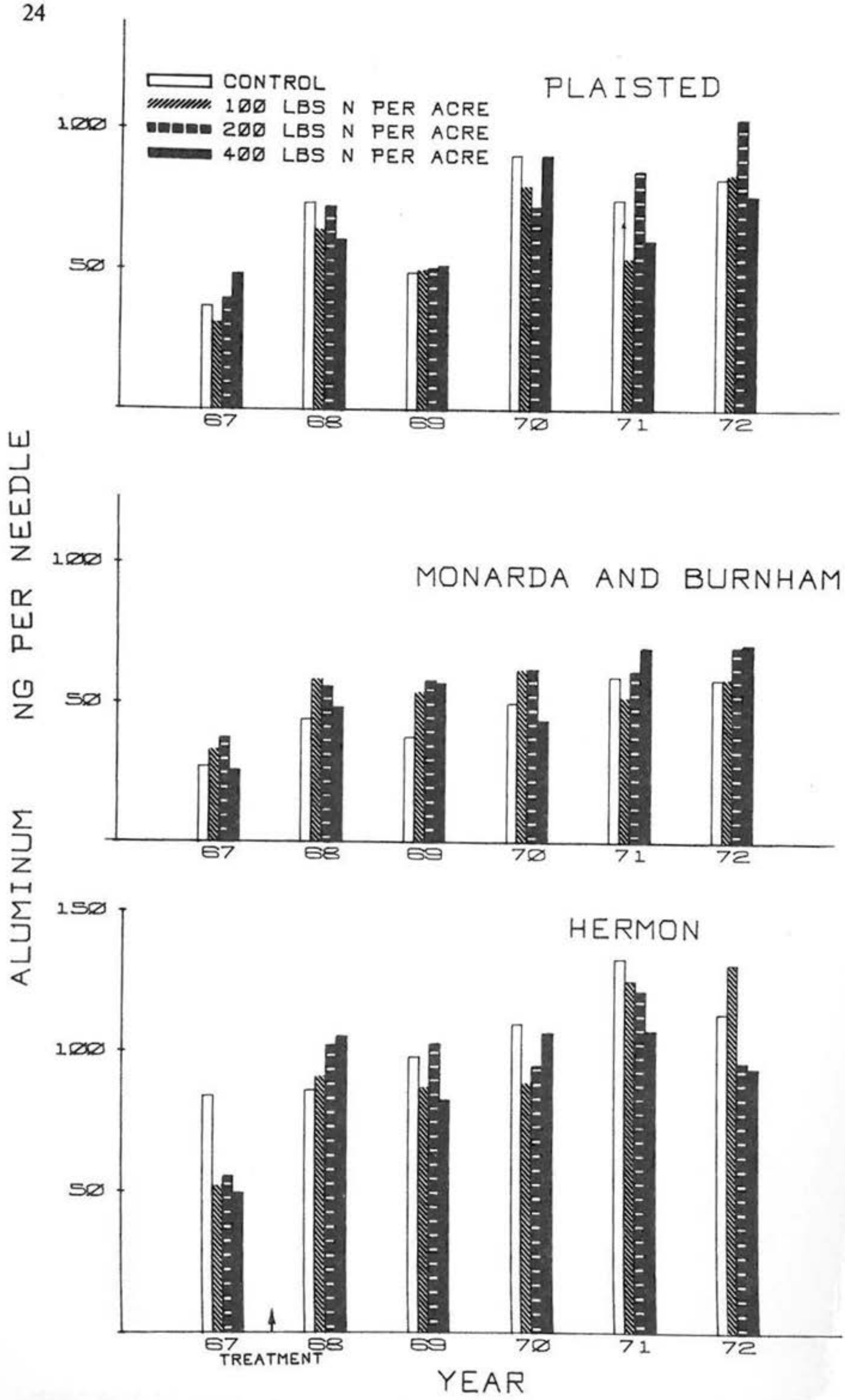

Figure 16. Annual variations in amount of aluminum per current year red spruce needle, by soil and treatment.

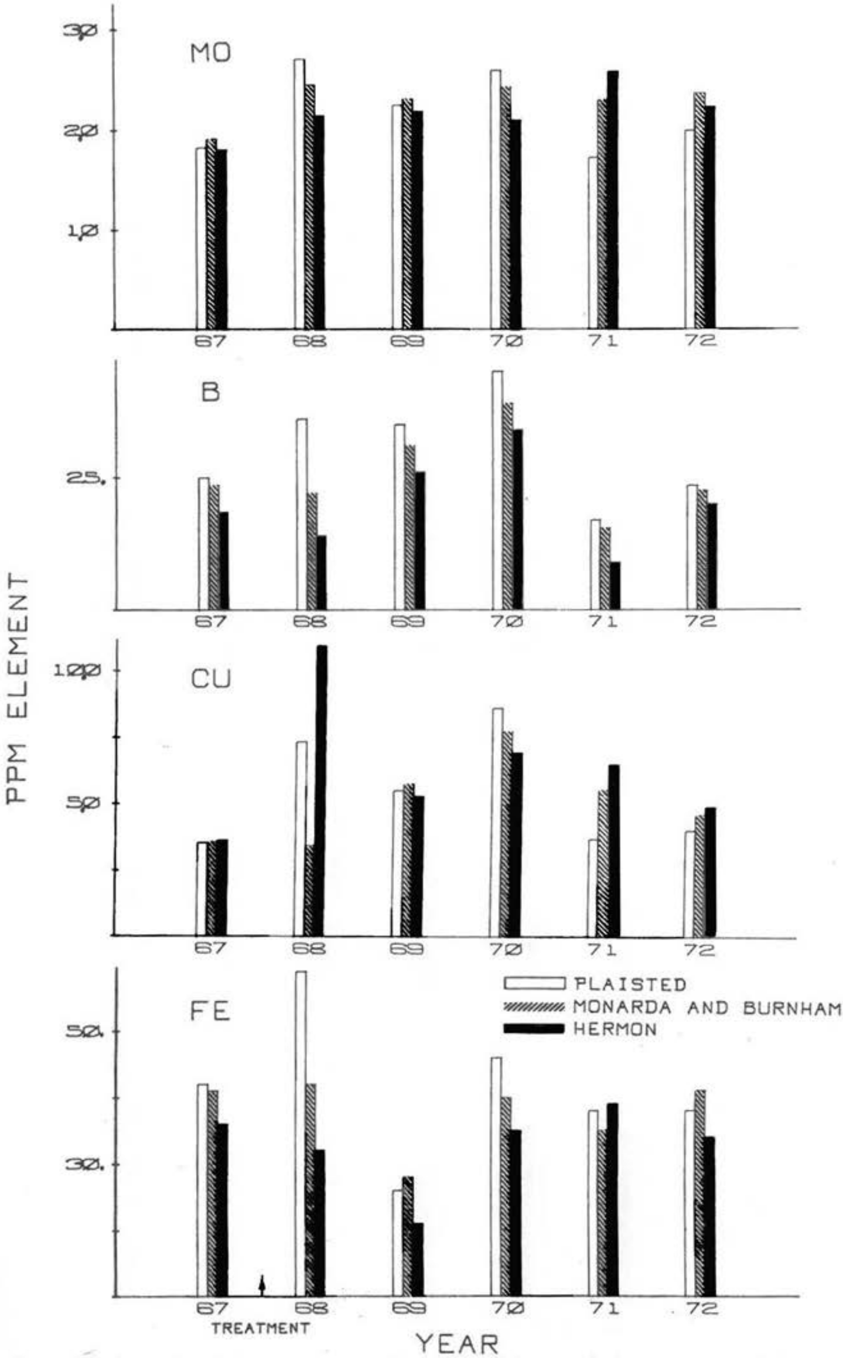

Figure 17. Annual variation in concentration of molybdenum, boron, copper, and iron in current year red spruce foliage, by soil.

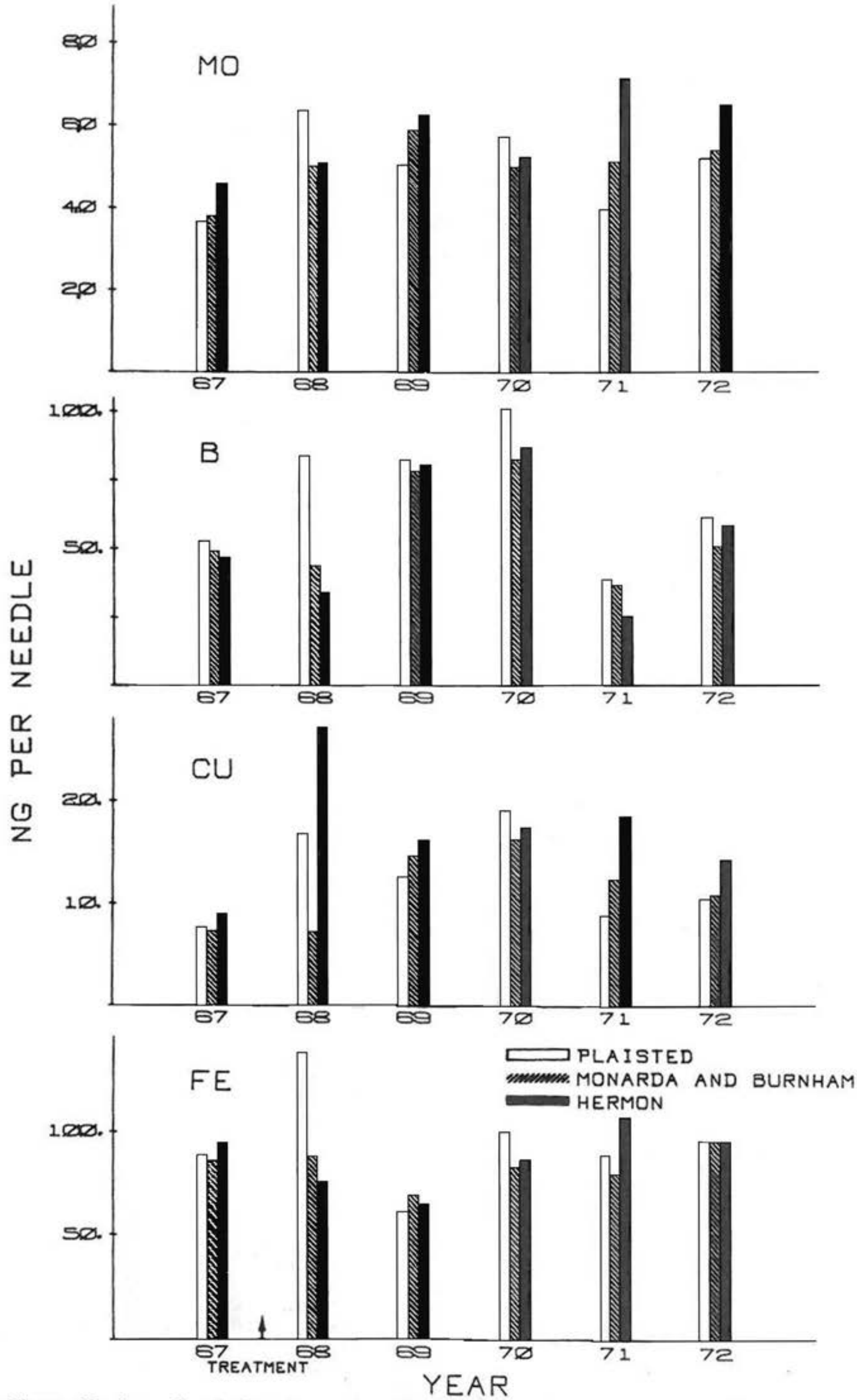

Figure 18. Annual variations in amount of molybdenum, boron, copper, and iron per current year red spruce needle, by soil.

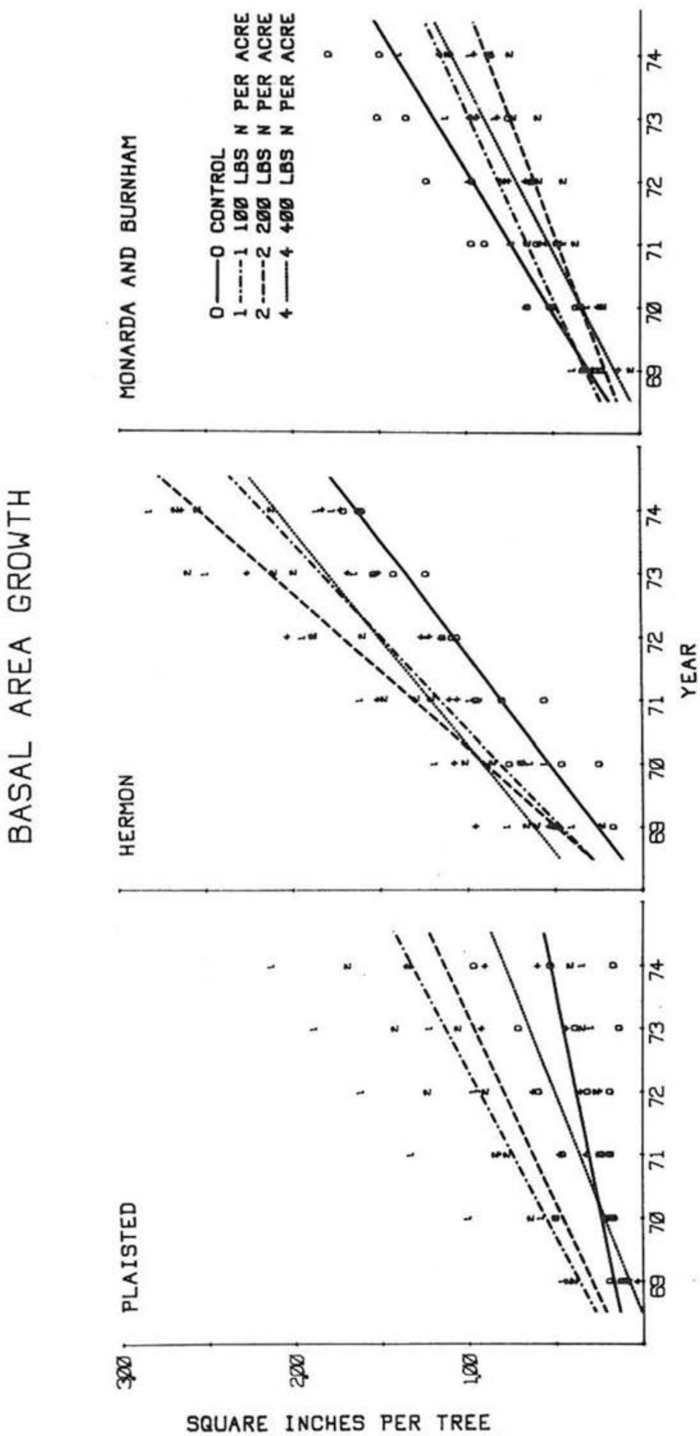

Figure 19. Basal area growth of red spruce sample trees (1967-1976), by soil and treatment.