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# Response of Young Black Spruce (*Picea mariana* (Mill.) B.S.P.) to a Mixture of Wood Ash and Secondary Papermill Sludge

Robert K. Shepard
*Professor*
*Department of Forest Management*
*College of Natural Sciences, Forestry and Agriculture*
*University of Maine*
*Orono, Maine 04469-5755*

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## INTRODUCTION

A study to examine the effects of a combination of wood ash and secondary papermill sludge applied to a clearcut planted to black spruce was initiated in 1987 with the cooperation of Great Northern Paper. Objectives of the study were to assess the effects of the residuals on (1) seedling growth, (2) seedling foliar element concentrations, and (3) chemical properties of the forest floor and mineral soil. This report emphasizes growth results for 1991 through 1995 and foliar element results through 1994. However, some results obtained prior to 1991 are presented, primarily as background information. Some information on soil pH is presented in the discussion of foliar element concentrations, due to the importance of pH in regulating element availability and uptake. For those not requiring the degree of detail included in this report, a summary is presented at the end.

## PROCEDURES

The study was established in a clearcut planted to 1-0 black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings in the spring of 1986. The seedlings were grown in paper containers by Great Northern Paper. Prior to harvest, the site was occupied by a mixed hardwood stand, with white birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), bigtooth aspen (*Populus grandidentata* Michx.), and red maple (*Acer rubrum* L.) being the dominant species. There were occasional red spruce (*Picea rubens* Sarg.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.) scattered throughout the stand. The soil is a Hermon very stony, sandy loam. This soil is coarse textured, ranges from well drained to somewhat excessively drained, and tends to be "droughty" at times during the growing season. The clearcut was treated with an aerial application of herbicide in late August 1987 to control hardwood sprouts and herbaceous vegetation. Decomposition of the forest floor occurred after the stand was harvested, and when the study was established, the thickness of the forest floor had diminished considerably.

One-hundred-eight square plots, 26 ft on a side, were established after the 1987 growing season. Seedlings were numbered using aluminum tags, and the root collar diameter and height of each seedling were measured. The residual mixture was applied to the plots at (1) rates of 0 and approximately 2.4, 4.8 and 9.6 dry tons per acre (subsequently referred to as rates 0, 1, 2 and 3), (2) in either late May, late July, or late September, and (3) for one, two, or three years in succession.

The mixture was 25% sludge and 75% ash on a dry weight basis. The ash was generated by the biomass boiler at the Great Northern mill in East Millinocket, and the sludge was obtained from the wastewater treatment plant serving the same mill.

The first set of treatments was applied in late May 1988 and the last in late September 1990. The mixture contained most of the elements required for tree growth. The most notable characteristics of the mixture were a calcium carbonate equivalent of 30%, a nitrogen concentration of 1.1%, a calcium concentration of 15%, and a pH of 10. Portions of the clearcut, including all of the plots, were treated with a second application of herbicide in late August 1989.

Root collar diameter was measured after the conclusion of each growing season, from 1987 through 1991. Root collar diameter measurements were discontinued after the 1991 growing season, and stem diameter measurements were made at a height of 1 ft after the 1991 and 1994 growing seasons. After the 1994 and 1995 growing seasons, stem diameter measurements were made at breast height. Future diameter measurements at breast height will continue. Seedling height was measured after the 1987 growing season, and height growth was measured after the 1988, 1989, 1990, and 1991 growing seasons. Height growth measurements were discontinued after the 1991 growing season.

Samples of current year foliage were taken from seedlings in all plots beginning after the 1988 growing season and in each succeeding year through 1991. Foliage samples were also collected after the 1994 and 1995 growing seasons. The foliage from individual seedlings was combined to form a composite sample for each plot. Foliage samples were oven dried at 65°C for 24 hours and ground in a Wiley Mill to pass through a 20-mesh sieve. The samples were analyzed for the following elements: nitrogen, phosphorus, calcium, potassium, magnesium, boron, iron, copper, zinc, aluminum, and manganese. Analyses were performed in the Analytical Laboratory of the Department of Applied Ecology and Environmental Sciences, University of Maine, Orono. Nitrogen, phosphorus, potassium, calcium, and magnesium are required by plants in relatively large amounts. The remainder, except for aluminum, are required in much smaller amounts. Aluminum is not known to be required for plant growth (Kramer and Kozlowski 1979), but changes in foliar aluminum concentrations are frequently indicative of changes in soil pH.

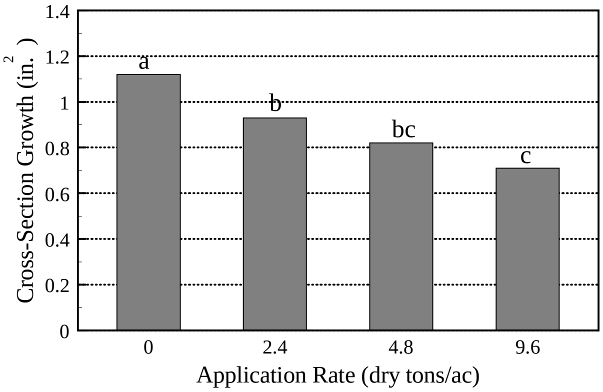


*Figure 1. 1991 root collar cross-section growth of black spruce seedlings treated with a mixture of wood ash and secondary papermill sludge at four rates. Means with the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

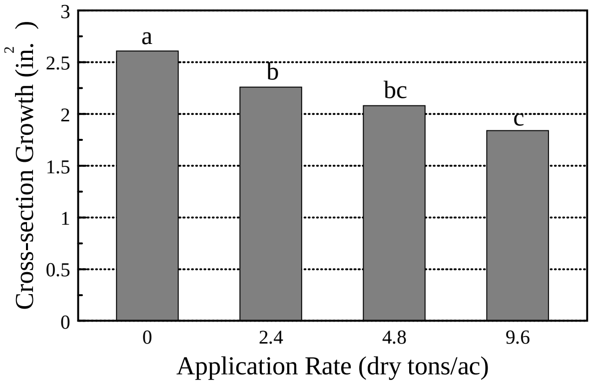


*Figure 2. Four-year (1988 through 1991) root collar cross-section growth of black spruce seedlings treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

The data were analyzed using analysis of variance to test for the significance of treatment effects. When the analysis showed a significant effect, Tukey's Studentized Range Test at P = 0.05 was used to ascertain which treatments were significantly different. Significant, as used in this report, indicates a statistically significant difference at P = 0.05.

## RESULTS AND DISCUSSION

### Seedling Growth

#### Stem cross-section and diameter growth

A marked difference in root collar cross-section growth among application rates was observed after the 1989 growing season, but the effect was not significant until the conclusion of the 1990 growing season. The effect was also significant for growth during the 1991 growing season (Fig. 1) and for the four-year period, 1988 through 1991 (Fig. 2). During that four-year period, growth of the controls was 41% greater than growth of seedlings in the rate 3 plots. The trend at each measurement period beginning in 1989 was one of decreasing cross-section growth with increasing application rate. In all figures, the overall mean for a given rate is based on the means of all plots that received that rate, irrespective of number of applications or time of application.

The number of applications did not influence root collar cross-section growth significantly until the 1991 growing season, but the effect of number of applications was much less than the effect of application rate. Growth was greatest in plots treated once and least in plots treated twice. The difference between plots treated two or three times was not significant. For the four-year period 1988 through 1991, the number of applications resulted in no significant differences, although the same trend existed as during the 1991 growing season.

The reduction in growth with successive increases in application rate is attributed primarily to competition from herbaceous vegetation, the growth of which was stimulated markedly by application of the residual. No reduction in the concentration of any foliar element included in the analyses appeared to be large enough to account for the growth decline. As explained below, both aluminum and manganese showed reduced concentrations beginning in 1989. How-

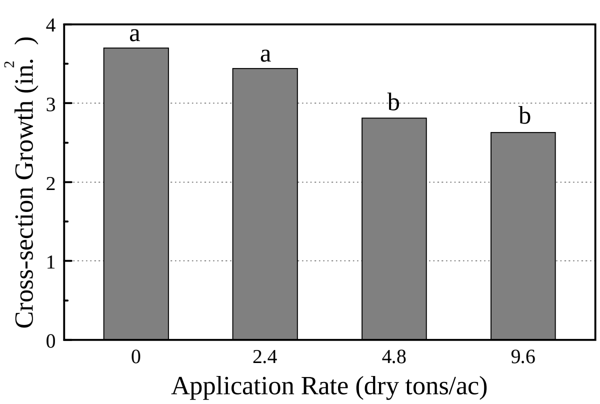


*Figure 3. Three-year (1992 through 1994) cross-section growth at a stem height of 1 ft of black spruce treated with a mixture of wood ash and secondary papermill sludge. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

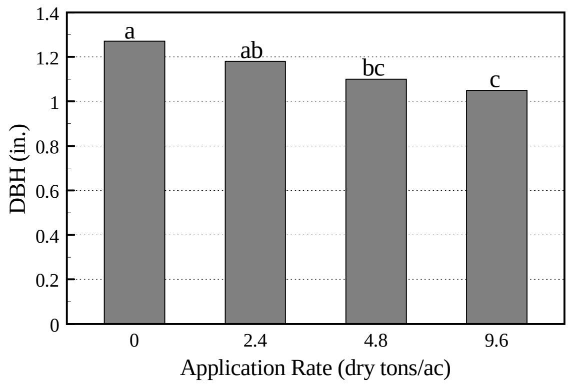


*Figure 4. 1994 dbh of black spruce treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

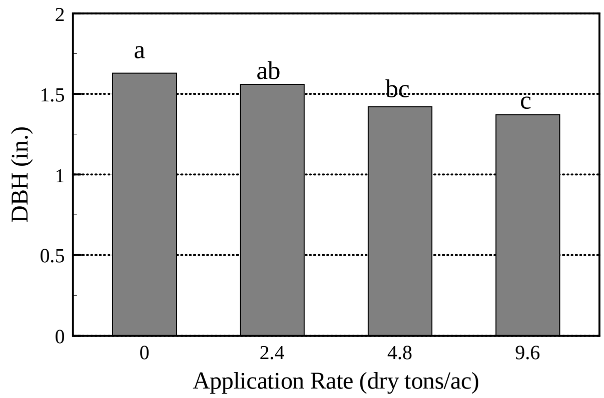


*Figure 5. 1995 dbh of black spruce treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

ever, aluminum is not required for plant growth and manganese is only required in small amounts.

The same general growth trend as described above continued at the 1-ft stem height during the three-year period 1992 through 1994 (Fig. 3). During this time, growth of the control trees was 38% greater than growth of the rate 3 trees. Although growth continued to decrease successively with increasing application rate, the difference between rates 0 and 1 was not significant nor was the difference between rates 2 and 3. Three-year growth at rate 1 was 22% greater than at rate 2.

The application rate effect on cross-section growth that occurred at and near the stem base was evident at breast height after both the 1994 (Fig. 4) and 1995 (Fig. 5) growing seasons. The overall effect on dbh was significant. In both years the rate 0 trees had the largest dbh and the rate 3 trees had the smallest dbh. After the 1994 growing season, the absolute difference was small, being only 0.23 in., but the relative difference was 22%. After the 1995 growing season the absolute difference between the same treatments was 0.26 in., and the relative difference was 19%. It thus appears that eight years after the first treatments were applied, the effect of application rate, exerted primarily through effects on competition, may have leveled off. The number of applications did not affect dbh after either the 1994 or 1995 growing seasons.

## Height growth

Height growth exhibited the same trend over time as cross-section growth, decreasing in each growing season after the first, as application rate increased. However, the effect of application rate was not statistically significant in any individual year. The effect of application rate on height growth was significant, however, for the entire four-year period (Fig. 6). Seedlings in the control plots outgrew seedlings in plots that received the maximum rate by 5 in. After the 1991 growing season, seedlings in the control plots averaged 58 in. tall, and seedlings in the rate 3 plots averaged 53 in. tall. There was no effect of number of applications on height growth, although there was a very weak trend of decreasing height growth with increasing number of applications. Time of application was not significant, nor were any of the interactions. Height growth measurements were stopped after the 1991 growing season because of the limited treatment effect and because some of the trees were more than 7 ft tall, making measurements accurate enough to detect small treatment effects very difficult and time consuming.

The relatively greater effect of application rate on root collar cross-section growth than on height growth is evident in the percentage differences between seedlings from the control plots and seedlings from the rate 3 plots. In 1990, cross-section growth of the controls was 45% greater than the rate 3 plots, and in 1991 it was 57% greater. In contrast, height growth of the controls was 21% greater in 1990 than in the rate 3 plots and 15% greater in 1991. For the four-year period, cross-section growth of the controls was 41 % greater than for the rate 3 seedlings, whereas height growth was only 14% greater.

Table 1. Level of significance (n.s. = not significant) and direction (increase [+] or decrease [-]) of treatment effects on elemental concentrations of black spruce foliage.

| | Growing Season and Treatment[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1988 | | 1989 | | 1990 | | 1991 | | 1994 | |
| Element | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Nitrogen | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | 0.001- | n.s. | n.s. | n.s. |
| Phosphorus n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | 0.001+ | n.s. | |
| Calcium | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Potassium | n.s. | n.s. | 0.001+ | n.s. | 0.001+ | n.s. | 0.001+ | n.s. | 0.001+ | n.s. |
| Magnesium | n.s. | n.s. | 0.001+ | n.s. | 0.001+ | n.s. | 0.001+ | n.s. | 0.001+ | n.s. |
| Iron | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | 0.001- | n.s. | n.s | n.s. |
| Boron | 0.001+ | n.s. | 0.001+ | 0.001+ | 0.001+ | 0.001+ | 0.001+ | 0.001+ | 0.001+ | 0.005+ |
| Manganese | n.s. | n.s. | 0.001- | n.s. | 0.001- | n.s. | 0.001- | 0.001- | 0.001- | 0.001- |
| Aluminum | n.s. | n.s. | 0.001- | n.s. | 0.001- | 0.001- | 0.001- | 0.001- | 0.001- | 0.001- |
| Copper | n.s. | n.s. | n.s. | n.s. | 0.001- | n.s. | 0.001- | n.s. | n.s. | n.s. |

[a]1 = application rate - 0, 2.4, 4.8, 9.6 dry tons/ac; plots were pooled by rate irrespective of number of applications or time of application
2 = number of applications - 1, 2, or 3; plots were pooled by number of applications irrespective of rate or time of application

## Foliar element concentrations

The effects of both application rate and number of applications increased through the 1991 growing season and were still readily apparent at the conclusion of the 1994 growing season (Table 1). Time of application and the various interactions were not significant, with several exceptions.

All three possible trends in element concentrations occurred with increasing application rate—either an increase or a decrease or no change. All elements included in the foliage analyses were present to varying degrees in the ash and sludge mixture, and an increase in foliar concentrations of at least some elements might be expected simply because they were added to the soil. In addition, the availability of some elements increases as soil pH increases (acidity decreases). Included among these elements are nitrogen, phosphorus, calcium, potassium, and magnesium (Brady 1974; Pritchett and Fisher 1987). The availability of other elements decreases as soil pH increases. Included among these elements are iron, boron, copper, manganese, aluminum, and zinc (Brady 1974; Pritchett and Fisher 1987). Results for foliar element concentrations are presented for the period 1988 through 1990, and for 1991 and 1994.

## Foliar element concentrations—1988 through 1990

Boron was the only element significantly affected by treatment in 1988, increasing as application rate increased. This runs counter to the reported trend of decreasing boron concentration with increasing pH (Tisdale and Nelson 1975; Fisher and Pritchett 1987). Boron concentrations in 1988 were also related to time of application. Concentrations in the foliage of seedlings treated in both late May and late July were virtually identical, 28.4 and 28.1 mg/kg, respectively. Concentration in the foliage of seedlings treated in late September was 21.2 mg/kg. This was the only instance in any year in which time of application was significant for any element.

Nitrogen concentrations in 1988 foliage averaged 1.95%. This is above the concentration required for good to very good growth of black spruce (Swan 1970) and suggests that growth would not have been increased by the nitrogen added to the site in the sludge-ash mixture.

In samples taken after the 1989 growing season, magnesium and boron were significantly higher at one or more non-zero rates, and manganese and aluminum concentrations were significantly lower (Table 1). Boron concentrations were also significantly increased by the number of applications, being higher in plots treated twice than in plots treated only once.

In the 1990 growing season potassium and copper concentrations were also significantly affected by application rate, with potassium being higher and copper lower at one or more non-zero rates (Table 1). Both boron and aluminum concentrations were significantly affected by number of applications (Table 1). Boron concentrations increased successively as the number of applications increased, and aluminum concentrations were lower in plots treated three times than in plots treated either once or twice.

## Foliar element concentrations--1991

The maximum effect on foliar element concentrations observed at any time occurred in foli-

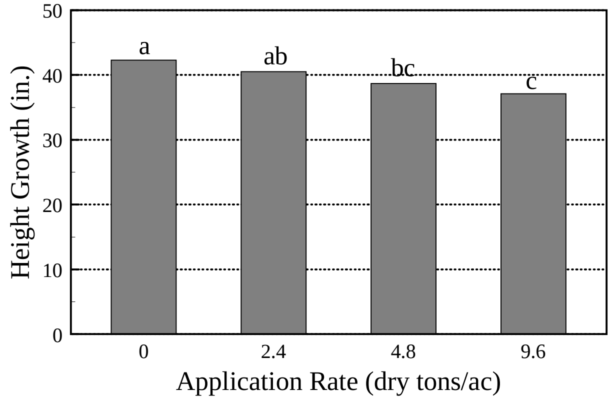


*Figure 6. Four-year (1988 through 1991) height growth of black spruce seedlings treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

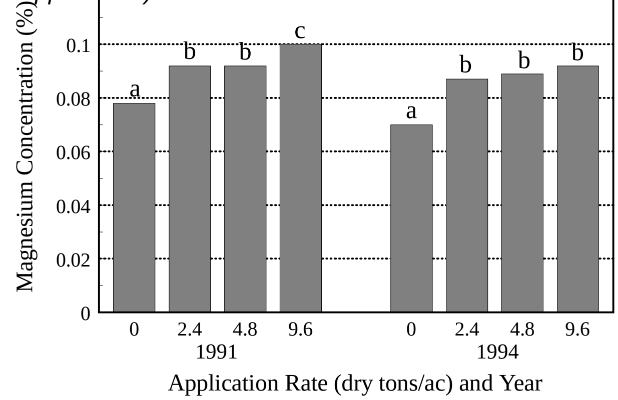


*Figure 7. Magnesium concentrations in 1991 and 1994 foliage of black spruce treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

age sampled after the 1991 growing season, when seven elements displayed either increased or decreased concentrations at one or more non-zero rates (Table 1). Concentrations of potassium, magnesium (Fig. 7), and boron were significantly higher at some rates, and concentrations of nitrogen (Fig. 8), aluminum (Fig. 9), manganese, and copper were significantly lower. There was also a distinct trend of lower iron concentrations with increasing application rate, but differences among rates were not significant. The reduction in nitrogen concentrations is attributed to some uptake of that element by the dense, herbaceous vegetation in the treated plots. The difference between the control and maximum application rate plots was small, however, being only 0.12%.

Aluminum concentrations in control plots were approximately 50% greater than in the rate 3 plots, and manganese concentrations were more than twice as great in control plots as in the rate 3 plots. Reductions in aluminum, manganese, and copper are presumed to be due at least partly to an increase in soil pH, which reduces the availability of those elements for plant uptake. The reductions in both aluminum and magnesium are quite large, however, relative to the magnitude of the pH changes.

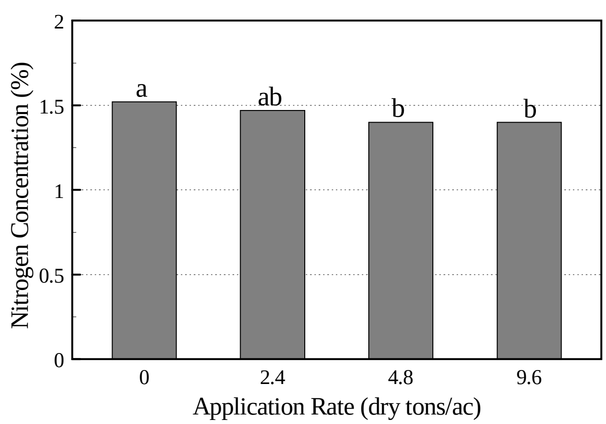


*Figure 8. Nitrogen concentrations in 1991 foliage of black spruce treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

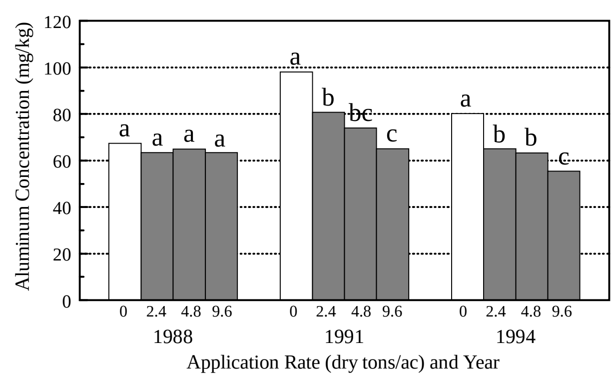


*Figure 9. Aluminum concentrations in 1988, 1991, and 1994 foliage of black spruce treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

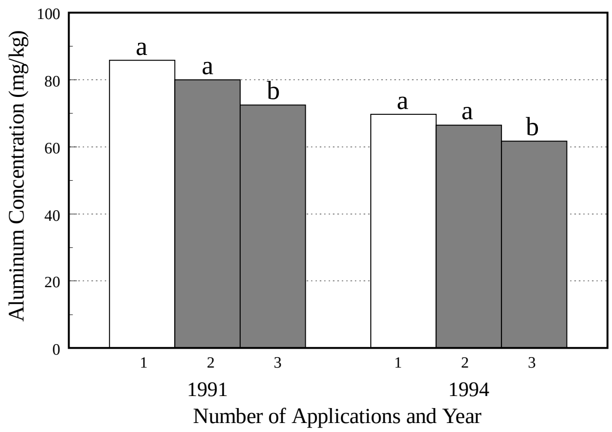


*Figure 10. Aluminum concentrations in 1991 and 1994 foliage of black spruce treated with a mixture of wood ash and secondary papermill sludge for one, two, or three years in succession. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by number of applications irrespective of rate or time of application.)*

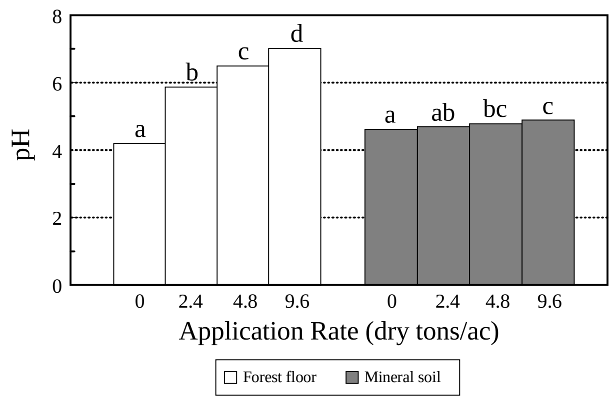


*Figure 11. 1991 pH of the forest floor and mineral soil treated with a mixture of wood ash and secondary papermill sludge at four rates. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by rate irrespective of number of applications or time of application.)*

The number of applications of the mixture significantly affected concentrations of boron, manganese, and aluminum (Table 1). Boron concentrations increased as number of applications increased, and aluminum (Fig. 10) and manganese concentrations decreased as number of applications increased. The increase in boron probably occurred because more was applied as the number of applications increased. Reductions in aluminum and manganese likely resulted partly from a higher soil pH that occurred with two or three applications.

Increases in pH of both the forest floor and mineral soil, but especially of the forest floor, occurred after the treatments were applied. pH of the forest floor probably increased (acidity decreased) almost immediately after treatment, because the mixture became a part of the forest floor very quickly. Analysis of forest floor samples collected in May 1989, approximately one year after the first treatments were applied, showed a significant effect on forest floor pH, with a difference of 2.39 pH units between untreated plots and rate 3 plots. It should be emphasized that considerable decomposition of the forest floor had occurred by the time that the first set of treatments was applied, and the buffering effect of the forest floor was probably reduced. The 1988 treatments caused no effect on pH of the mineral soil.

After the third year of treatments (1990 growing season--samples taken in May 1991), the same trend in forest floor pH persisted among application rates as after years 1 and 2 (Fig. 11). The difference between pH of the highest rate and the control was 2.82 units. The effect on pH of the mineral soil, which was first detected to be significant in samples taken in May 1990 was also significant in the 1991 samples. For mineral soil the difference between pH of the highest rate and the control was 0.27 units. This was a larger difference than the 0.15 units observed after the second growing season, but it appears to be too small to have had a major effect on nutrient availability.

After the 1990 growing season (samples taken in May, 1991), there was a significant effect of number of applications on forest floor pH but not on mineral soil pH (Fig. 12). pH increased successively as number of applications increased. Although the difference in pH of 0.25 units between two and three applications was not statistically significant, it probably was due to the effect of number of applications.

There are several points to consider regarding the observed decreases in foliar nutrient concentrations. One is the degree to which changes in pH of the mineral soil that occurred at some distance from the trees was representative of the changes that occurred adjacent to, and possibly within, the paper containers in which the seedlings were planted. It is likely that during the first year or two of the study the root systems were still largely confined to the containers and the adjacent soil. Movement of infiltrating water, which probably contained some of the sludge and ash mixture, along the boundary between the containers and the soil, and possibly through the containers, may have affected pH and therefore, the uptake of

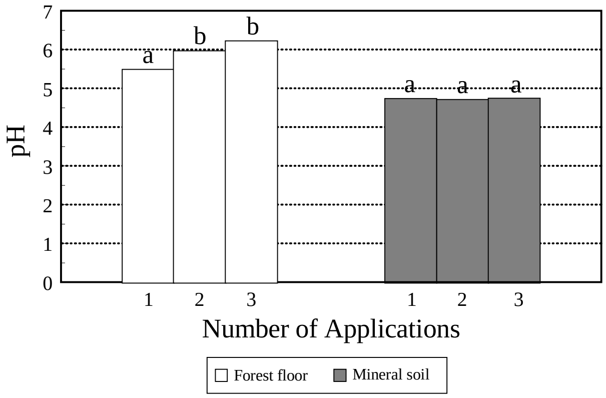


*Figure 12. 1991 pH of the forest floor and mineral soil treated with a mixture of wood ash and secondary papermill sludge for one, two, or three years in succession. The first treatments were in May 1988. Means having the same lower case letter are not significantly different (P = 0.05). (Plot means were pooled by number of applications irrespective of rate or time of application.)*

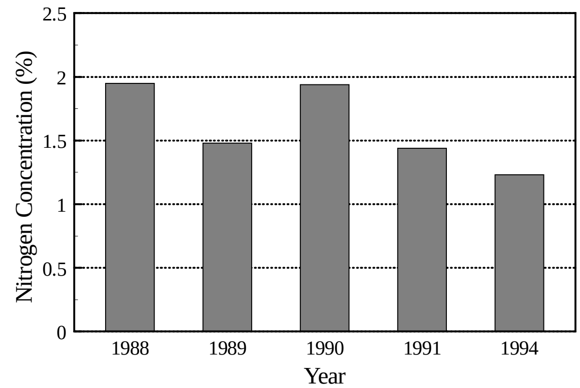


*Figure 13. Trend over time of nitrogen concentrations in current-year foliage of black spruce treated with a mixture of wood ash and secondary papermill sludge. Yearly means were calculated from the means of all plots, including the controls.*

elements whose availability is a function of pH, more than was the case in the soil overall. Although this may have been a factor early in the study, by the 1991 growing season, the fourth of the study and the sixth since the seedlings were planted, and especially by the 1994 growing season, expansion of the root systems into the surrounding soil should have minimized any large pH effects that may have occurred in and adjacent to the paper containers during the early stages of the study.

Another point relates to the distribution of the seedling roots in the mineral soil and the change in soil pH with depth. If many fine feeder roots are located in the upper portion of the mineral soil immediately below the forest floor, and if the pH of this soil is higher than the overall average for the top 4 in. of the B horizon, then pH effects on element availability may be greater than would be expected based only on the average pH of the upper 4 in. of the B horizon.

## Foliar element concentrations—1994

After the 1994 growing season (seventh growing season after the first application), treatment effects on foliar element concentrations were still evident, but there were some differences from 1991 (Table 1). Nitrogen and copper concentrations were no longer significantly affected by application rate. There was still a weak trend of decreasing iron concentrations with increasing application rate. No such trend was evident for either nitrogen or copper. Magnesium (Fig. 7), boron, potassium, and phosphorus concentrations were all significantly increased by application rate. Neither phosphorus nor potassium showed treatment effects at any sampling time prior to 1994.

The long-term effect of application rate on foliar element concentrations is evident in the analyses on foliage of trees from plots treated only in 1988. In 1994, concentrations of five elements—magnesium, phosphorus, boron, aluminum, and manganese—were all significantly related to application rate. Magnesium, phosphorus, and boron all increased at one or more non-zero rates, and aluminum (Fig. 9) and manganese decreased. Concentrations of potassium increased with increasing application rate, although the effect of rate was not significant.

Concentrations of potassium, boron, aluminum, and manganese were all related to number of applications (Table 1). Potassium and boron increased significantly as number of applications increased, and concentrations of aluminum (Fig. 10) and manganese decreased significantly as number of applications increased. Concentrations of potassium and boron were highest in plots treated three times and lowest in plots treated once. However, the differences among number of applications were small and probably of no practical importance.

Concentrations of both aluminum and manganese decreased with increasing number of applications. Aluminum concentrations were about 10% lower in plots treated three times than in plots treated only once, and manganese concentrations were nearly 20% lower. For both elements the effect of number of applications was less pronounced after the 1994 growing season than after the 1991 growing season. The 1994 growing season was the fourth after the last set of treatments was applied, and it is reasonable that during that time, some treatment effects would have diminished.

## ADDITIONAL ASPECTS

### Nutrient Concentrations

The yearly fluctuations in foliar nitrogen concentrations that occurred from 1988 through 1994 are noteworthy; the mean nitrogen concentration for trees from all plots had dropped to 1.2% in 1994 from a high of 1.9% after the 1988 growing season (Fig. 13). There were large changes in nitrogen concentrations during the first three years of the study. The high concentration in 1988 may have been due to a combination of a residual effect from fertilizer remaining in the containers, release of nitrogen from forest floor decomposition, and uptake of applied nitrogen. The drop of nearly 0.5% from 1988 to 1989 may have resulted from a decrease in the effect of the fertilizer in the containers and a large increase in the uptake of nutrients by the herbaceous vegetation, which was extremely dense during the middle and late portions of that growing season. The rise in 1990 may have been due to the uptake of nitrogen released by decomposition of herbaceous vegetation killed by the August 1989 herbicide application. Reductions in nitrogen concentrations since 1990 are probably due to regrowth of herbaceous vegetation and increased black spruce foliage mass. It should be stated, however, that by 1995 the black spruce had increased to a sufficient size and the stand to a sufficient density in many places so as to substantially reduce the growth of herbaceous vegetation.

Nitrogen concentrations above 1.6% are considered adequate for good to very good growth of spruce (Swan 1970). A concentration of 1.2% is considered not sufficient for good growth. The lower nitrogen concentrations observed in 1991, and especially in 1994, suggest that the stand may either have entered, or will soon enter, a stage of development in which growth may be limited by insufficient nitrogen. Low nitrogen concentrations frequently limit the growth of spruce and fir on many sites in Maine.

Concentrations of all other macronutrients (calcium, potassium, phosphorus, and magnesium) were generally sufficient for good to very good growth during the entire period, based on criteria established in greenhouse studies (Swan 1970). Magnesium was the exception, being present in foliage of trees from control plots at concentrations suggesting a slight deficiency at all sampling times. This slight deficiency was alleviated by application of the residual. It is not possible to comment on the sufficiency of other elements relative to the concentrations in which they are required because criteria for those elements are not available. It should be emphasized that seven elements—sulfur, molybdenum, chlorine, sodium, cobalt, vanadium, and silicon—all of which have been found to be essential to the growth of some plants (Tisdale and Nelson 1975), were not included in the foliar analyses of this study.

### Appropriate Time for Application of Sludge and/or Ash

The reduction in growth that occurred in this young black spruce plantation following application of the sludge and ash mixture raises the question as to the stage of development during which a stand may benefit most from an application of sludge and/or wood ash. From the standpoint of ease of application, treatment of a stand within several years of establishment is desirable. However, it is unlikely that a very young conifer stand will show increased growth to an application at that time for several reasons. One is related to the fact that planted seedlings may have been germinated and raised in containers to which fertilizer was added. There could be a carryover effect of this fertilizer after the seedlings were planted, which might reduce or eliminate possible growth benefits from the residual. Another reason is that the rate of decomposition of the forest floor increases following removal of the overstory. This means that nutrients may become available to seedlings in a recently planted clearcut at a rate equal to, or greater than, that required by the seedlings.

A third consideration is the nutrient requirements of conifers compared to those of competing hardwoods and herbaceous vegetation. The competing vegetation has higher nutrient requirements than the young conifers and is, therefore, more likely to benefit from added nutrients. Stimulation of competing vegetation may cause reduced growth of conifers and could necessitate additional vegetation control efforts. In addition, where the growth of conifers is limited by a nutrient deficiency, nitrogen is usually the nutrient that is deficient. There is little or no nitrogen in wood ash. Secondary sludge, which is relatively high in nitrogen, would have to be added in order to satisfy a nitrogen deficiency. In short, there appears to be little reason to expect that the growth of newly established conifer stands will be increased by the addition of nutrients.

The application of nutrients at, or shortly before, crown closure presents a greater opportunity to increase growth. At about the time of crown closure, individual trees are producing new foliage at a rapid rate. If nutrients do not become available rapidly enough to satisfy the needs of the trees, some loss of growth may occur. Therefore, addition of sludge and/or ash at this time may be beneficial to growth. Sludge, and especially ash, have a high pH, which is likely to cause increased decomposition of the forest floor which would furnish an additional supply of nutrients. However, corridors would have to be cut through the stand to provide access for the spreading equipment.

The other stage of stand development during which application of sludge and/or ash might increase growth is the mature stage that occurs a number of years after crown closure. Over time the weight of the forest floor increases, and as this occurs the amount of nutrients "tied up" in the forest floor increases. This is especially true of nitrogen, insufficient amounts of which limit the growth of older conifer stands in Maine. Application of a high nitrogen sludge with a low carbon:nitrogen ratio should lead to improved growth. Application of a sludge low in nitrogen and with a high carbon:nitrogen ratio may have the opposite effect. Application of wood ash might also increase growth, because the high pH of the ash will increase the mineralization rate of the forest floor and the release of nitrogen. As previously stated, access corridors would have to be cut for the spreading equipment.

A number of concerns arise with application of sludge or ash at this stage of stand development. These include a limited spreading distance due to the high stand basal area, possible abrasion or other damage to the bark of some trees, root damage to the trees along the corridors, and windthrow along the corridors.

## SUMMARY AND CONCLUSIONS

A mixture of wood ash and secondary papermill sludge was applied at rates of 0 and approximately 2.4, 4.8, and 9.6 dry tons/ac to plots in a clearcut planted to black spruce two years before the first treatments were applied. The mixture was applied at three different times during the growing season and for one, two, or three years in succession.

The sludge and ash mixture significantly reduced stem cross-section growth of the planted black spruce. The reduction in growth became more pronounced as application rate increased. During the period 1988 through 1991, trees that were not treated grew 41% more than trees that received the maximum rate. The same trend existed from 1992 through 1994, with controls surpassing the rate 3 trees by 38%. The effect of the treatments was plainly evident in dbh measurements made after the 1994 growing season. Trees in control plots had a dbh that was 0.22 in. greater than the rate 3 trees. Slower growth in the treated plots was probably due to competition from vegetation that was stimulated by the mixture.

The effect on height growth was much smaller than the effect on stem cross-section growth. From 1988 through 1991, height growth of the control trees exceeded that of the rate 3 trees by only 5 in., which was less than 10%.

The effect of the treatments on foliar element concentrations was highly variable: some concentrations increased, some decreased, and some remained unchanged. Boron concentrations increased during the first year of the study, and magnesium concentrations increased and aluminum and manganese concentrations decreased during the second year.

The maximum effect on foliar element concentrations occurred during the fourth year when potassium, magnesium, and boron increased, and nitrogen, aluminum, manganese, and copper decreased. The reduction in nitrogen is attributed to uptake by the dense, herbaceous vegetation in the treated plots. However, the difference between the maximum rate and the control was only 0.12% (1.40% vs. 1.52%). Reductions in aluminum, manganese, and copper were probably due at least partly to increased forest floor and mineral soil pH, which reduced the availability of those elements for plant uptake. After the seventh growing season following the first application magnesium, boron, potassium, and phosphorus concentrations increased with increasing rate, and concentrations of aluminum and manganese decreased. Relative decreases in aluminum and manganese were much larger than relative increases in the other elements.

An important finding was the gradual decrease in nitrogen concentrations over time. After the first growing season, the average nitrogen concentration for all plots was approximately 1.9%. After the seventh growing season the average nitrogen concentration was approximately 1.2%. This is well below the concentration required for good growth of black spruce, based on Swan's (1970) criteria. This suggests that the plantation has entered a developmental stage in which growth may be limited by insufficient nitrogen. Concentrations of other elements were generally sufficient for good growth.

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