

STATUS OF FERTILIZATION AND NUTRITION RESEARCH IN NORTHERN FOREST TYPES

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Abstract

Forest fertilization is a useful tool that, when combined with other silvicultural practices, results in increased forest growth. Many experiments have demonstrated that both hardwoods and conifers of the northern forest respond to the addition of one or more nutrients. Examples of pitfalls and successes are given. Present status of research and future research needs are discussed.

GREATER DRAIN on the northern forest is expected in the not-distant future. Obviously more raw material will have to be grown and harvested at shorter rotations and on less land.

Liming and fertilization are useful tools which, when combined with other ameliorative site treatments and silvicultural practices, result in increased forest growth.

In this paper I present a digest of available information and summarize the status of research in progress on forest fertilization in northern forest types, with emphasis on the work being done in New England and the Maritime Provinces of Canada.

This paper does not contain all details and does not pretend to be complete. The area is large, the forest conditions are diverse, and the research activities are complex. Attempt is made to point out the examples of pitfalls as well as successes in forest-fertilization efforts in northern forests.

AVAILABLE GUIDELINES

At the outset, something has to be said about the knowledge available worldwide. During the last quarter century, intensive research activities in forestry and

forestry-related disciplines such as soil science, tree physiology, and biochemistry have formed a basis for forest tree nutrition as an area of study in many schools and experiment stations in Europe, Canada, and the United States. Thus there is a considerable body of literature on both basic and applied aspects of forest fertilization, published worldwide.

Knowledge accumulated in recent years made possible four symposia, three international and one regional in scope, plus a workshop held recently in Canada. Two international symposia were held in 1967, one at the University of Florida; the second, organized by the International Potash Institute, was held in Finland. The third symposium, sponsored by FAO/IUFRO, was held in Paris, France, in 1973.

In recent years forest fertilization received considerable attention in northern forest types. The current knowledge on activities taking place in the northeastern United States and Eastern Canada were discussed at the symposium held in Warrensburg, N. Y. (Northeastern Forest Experiment Station 1973); at the Fourth North American Forest Soil Conference held in Quebec, Canada (Armson *et al.* 1975); and at the recently held workshop in Ontario (Environment Canada 1974).

In addition to the most recent research findings, the participants presented a digest of existing literature. If it were not for these proceedings, the researcher would be forever looking to article sources or collecting scattered papers of diverse research published in many journals and languages.

EFFECTS OF WHOLE-TREE HARVESTING

The changes in the management practices from uneven-age to even-age silviculture is a common occurrence. In certain instances this involves complete stand removal. Previously unusable species, sizes, and qualities are now marketable. Significant acreage of spruce-fir forest is being salvaged to minimize the losses caused by spruce budworm.

Changes of this kind, which result in more biomass removed from the forest, are causing concern about depletion of soil nutrients and possible site degradation. We are very short of detailed information on this subject for New England conditions, but some valuable data are available from other regions, and an attempt to obtain additional information is in progress.

The effects of wood harvesting on the nutrient status of spruce-pulpwood stands in Quebec were discussed by Weetman and Webber (1972). They concluded that "it is unlikely that the full tree logging will result in any reduction in growth, due to nutrients removed, during the second rotation of trees. However, there is a possibility full-tree harvesting on sites of marginal fertility and low in organic matter may eventually require an addition of Ca, K, and N."

Recently, changes in nutrient status were assessed on spruce-fir sites harvested by strip-clearcutting in which slash was left in place, removed, or burned. Eight years after harvest, the clearcut areas showed an increase in both pH and percent base saturation, but concentrations of N and P were comparable to those found in the residual forest. There was no evidence of site degradation from strip-clearcutting (Czapowskyj et al. 1976).

Young and Guinn (1966), and Young and Carpenter (1967), in the context of complete-tree utilization concept, provided data on chemical elements in the wood, bark, and leaves of the major species of different ages. The data provide a basis for calculating nutrient budget and estimating nutrient losses due to timber harvesting in Maine.

NUTRIENT AVAILABILITY AND DEFICIENCY

Forest fertilization is a supplement of essential nutrient elements that are lacking in a soil or are not available in adequate quantities for optimum tree growth. Thus a knowledge of soil fertility, the establishing of tree needs, and the identification of deficient elements are essential to a meaningful fertilization program.

Nutrient deficiencies have been observed in coniferous plantations established nearly 50 years ago on abandoned agricultural land in the State of New York (Heiberg and Leaf 1960). Diagnostic techniques of determining soil-nutrient deficiencies--mainly K--were studied; and the responses to fertilization were documented (Heiberg and White 1949 and 1951). The pioneer work by Mitchell and Chandler (1939) clearly identified lack of available N as a critical factor in the growth of many hardwood species on many sites in the United States Northeast.

Foliar analysis seems to provide a valuable tool for diagnosing nutrient deficiencies and relationships in tree-growth parameters. However, it does not tell enough about the soil fertility.

Valuable information on foliar nutrient contents for major species growing in Maine was provided by Young and Guinn (1966). Swan (1966 and 1971) provided basic information for evaluating the results of foliar analysis and suggested critical levels of deficiency, sufficiency, and luxury consumption for major Canadian species.

Schomaker (1973a) studied foliar nutrient concentrations of fertilized mature red spruce (Picea rubens Sarg.) in Maine and compared his data with those reported by Young and Guinn, and with the critical levels suggested by Swan. From these comparisons, Schomaker concluded that the foliar N levels of red spruce stands growing in Maine were within the deficiency range, whereas P, K, Ca, and Mg were sufficient for good growth; and some of them were even approaching the luxury-consumption levels.

Assuming that Swan's critical values could be extrapolated to New England conditions and to all age classes, one might expect a marked response by red spruce to N applications. However in assigning the critical values based on foliar analysis alone for any element and for any of the species, extreme care must be taken. Time and method of sampling are of great importance. Nutrient levels in the foliage vary with the season. In red spruce, for example, nutrient levels vary among different soils and locations within the same soil series (Safford and Young 1968), as well as with the location of the foliage in the crown (Young et al. 1967), and with the foliage age (Safford 1970).

Hoyle and Mader (1964) reported that different growth parameters related differently to tree nutrition. Height growth correlated better with Ca levels, and basal-area growth with K; and the volume growth was related to available soil moisture.

RESPONSE TO FERTILIZATION

Northern Hardwoods

In their summary paper on fertilizing eastern hardwood species, Auchmoody and Filip (1973) emphasized

the following points:

1. Some hardwood species have potential for greater response to improved fertility.
2. N is the primary growth-limiting element on many sites, but response to P and other elements can be expected on some sites when used with N.
3. Response to N is rapid and easily observed in sums of tree growth and foliage color and size, but duration of response is not yet known.

Since the Auchmoody-Filip paper, some additional studies have been reported.

Bjorkbom (1973) tested the effects of N, P, and K on the growth of paper birch (Betula papyrifera Marsh.) in sand culture and found that seedling growth improved with increasing supply of N. Three to 4 percent N in the foliage seems to be adequate for seedling growth. There was no response to P and K applications. But response by yellow birch (Betula alleghaniensis Britton) to P had been demonstrated in a pot-culture experiment with a Vermont soil (Hannah 1973). This confirms earlier work by Hoyle (1965, 1969, 1970, 1971) in New Hampshire.

Field trials of lime plus N-P-K to a 90-year-old stand resulted in increased biomass of fine absorbing roots throughout a podzol soil profile (Safford 1974). Nutrient content of these roots was elevated above those of the control, providing a source of enrichment to the deeper soil horizons as a result of surface application of fertilizers. Diameter growth of these mature trees was also substantially increased: sugar maple (Acer saccharum Marsh.) 158 percent greater than control, paper birch 69 percent, yellow birch 51 percent and beech (Fagus grandifolia Ehrh.) 20 percent (Safford 1973b).

An application of N-P-K fertilizer plus lime to the soil after clearcutting and site scarification increased biomass after 4 years by 300 percent over the control. Unfortunately pin cherry (Prunus pensylvanica) responded so strongly that the growth of birch and other desired species was hindered (Safford and Filip 1974). On another site that was heavily scarified and deep-limed, planted yellow and paper birch responded dramatically to control of competition and N-P-K

fertilizer. Fertilized and released yellow birch were 20 percent taller and 120 percent greater in basal area; paper birch were 50 percent taller and over 400 percent greater in basal area than the control or trees released only (Hoyle 1975).

Not all hardwood plantations have shown positive response to fertilizers. In southern Ontario, von Althen (1973) reported little or no response to added nutrients by hardwood seedlings. This lack of response is probably due to having fertile planting sites and good site preparation. Von Althen (1973) concluded that "if hardwood planting is restricted to good planting sites with deep, moist, but well-drained soils, there is little need for fertilization... However...hardwoods are often planted on sites that do not meet the foregoing criteria. Fertilization may be necessary on these marginal sites."

Stone and Christenson (1974) reported no diameter-growth response to N, P, or K treatments in factorial combinations in a pole stand of sugar maple in Michigan. Release increased growth over controls by about 80 percent. Foliar N of controls was close to satisfactory levels (2 percent) given by Mitchell and Chandler (1939) and Mader *et al.* (1969). Concentration of nutrients in foliage of released trees decreased despite the growth response. Stone and Christenson attributed this decrease to a dilution effect and suggest that some site factor other than nutrition might be limiting growth in this Michigan stand (Stone and Christenson 1975).

A combination thinning-and-fertilizer study with 25-year-old paper birch in Maine also showed greatest growth response to thinning, 100 percent over controls; but fertilizer treatments stimulated growth by an additional 30 percent. Foliage nutrient levels in released-only trees increased over controls; and each element--N, P, K, and Ca·Mg (in lime)--when added, increased nutrient levels above that of released-only trees (Safford, L.O.: unpublished data on file at U.S. Forest Service Forestry Sciences Laboratory, Durham, N.H.).

These conflicting results point to a need for caution when extrapolating data from one location or species to another. They also suggest that standardized research methods and analysis would benefit evaluation of results of fertilizer studies.

Conifers

Forest fertilization activities in coniferous forests of the eastern United States have been summarized by Safford (1973a), and in eastern Canada by Krause (1973). However, the most relevant facts will also be repeated briefly in this section.

Long- and short-term studies have been conducted in the Adirondack mountains in New York State. The summary of results have been given by Heiberg et al. (1959 and 1964) and Leaf et al. (1970 and 1975). Information has been used to improve productivity of soil deficient in K through application of potash to red pine (Pinus resinosa Ait.) plantations.

I do full justice to the researchers of SUNY for their manifold contributions to red pine and potash fertilization relationships in this brief review. Those interested in specifics are referred to the more detailed accounts: (Fornes et al. 1970; Kawana et al. 1969; Madgwick et al. 1970; White 1954 and 1956; Wittwer et al. 1975).

Information on white pine (Pinus strobus L.) is limited. Studies conducted in Pack Forest, New York, showed a response of a young plantation on a coarse sandy glacial outwash soil to the addition of logging slash, K, and complete fertilizer. The responses were immediate and lasting. No response to N was observed (Heiberg and Leaf 1960). The growth response of white pine plantations on coarse-textured droughty soil in Maine to N (urea), K, and N-P-K, were studied by Stratton and others (1968). The response in terms of basal-area growth were similar to those obtained on the Pack Forest. The stand responded to K and N-P-K application, but not to N alone. On the other hand, Schomaker (1973a) reported that the 10-year radial growth of a medium-aged white pine stand in southern Maine correlated positively to foliar N and negatively to P. Correlations between foliar K and diameter growth were weak.

Spruce-Fir

An extensive research program is under way in the northeastern United States and eastern Canada. Forest industries in Maine in cooperation with the School of Forest Resources, University of Maine, are currently conducting a series of field studies.

Experimental plots in nearly-mature spruce-fir stands were fertilized with 10-10-10, equivalent to 150 pounds per acre (168 kg/ha), each of N, K₂O, and P₂O₅ singly and in combination, and urea equivalent to 150 pounds per acre of elemental N. The preliminary results indicated that, after three growing seasons, only one stand responded significantly in basal-area growth. Increased growth was due to N-P-K treatments and due to N alone in urea form (Schomaker et al. 1973). The follow-up remeasurements will yield additional information in respect to response duration and the explanation as to why two other stands did not respond.

Our Northeastern Forest Experiment Station Unit in Orono, in cooperation with Georgia-Pacific, has recently established a study to determine how a young stand with pioneer northern hardwoods in the overstory, and a spruce-fir understory, will respond to thinning plus lime and fertilizer treatments. The question asked is if the hardwoods will respond so that a merchantable product can be harvested at a shortened rotation and if the spruce-fir in the understory will benefit from lime, N, and P fertilization.

In another study, the effects of site preparation, lime, and N-P-K, fertilizer treatments and control of competition on growth of black and white spruce (Picea mariana [Mill.] B.S.P. and Picea glauca [Moench] Voss) planted on a chip-harvester clearcut are presently being tested.

In the early 1960s an extensive research program had been initiated in the Maritime Provinces and in Quebec. Numerous tests and long-term studies had been established by the Pulp and Paper Institute of Canada, Canadian Forestry Service, provincial governments, and universities. It was soon recognized that N was deficient in the vast areas of northern coniferous boreal forests (Weetman 1962) and that northern coniferous forests will respond to N applications.

Available reports (Weetman 1968, 1971, 1975; Weetman et al. 1974) revealed strong responses of black spruce to N fertilization. The responses were manifested in height, diameter, and volume growth.

Stand thinning and fertilization relationships were demonstrated. a 65-year-old stand was thinned by 25 and 50 percent and fertilized with urea at the rates of 100 and 400 pounds per acre (112 and 448 kg/ha).

The stand responded to the N treatment after 1 year and to thinning only after 7 years. The basal-area growth was not increased by 25-percent thinning, but was increased by 50-percent thinning; however, it always was increased by the addition of N. The 10-year growth increases over control were: 130 to 290 ft³ (9.1 to 20.3 m³) for 100 pounds (112 kg) N and 238 to 297 ft³ (16.6 to 20.8 m³) for 400 pounds (448 kg) of N per acre (hectare).

Preliminary results from fertilization data obtained in New Brunswick (Krause 1973) are encouraging. Krause stated "that N shortage is commonly limiting growth in pole-size and maturing conifer stands and that substantial growth increases can be obtained with addition of fertilizer N. Under certain site conditions, tree growth may also be improved by the addition of K and P".

The growth response of a 35-year-old white spruce plantation due to K treatments was reported from Quebec. Applications of 84 lbs/acre (94 kg/ha) K alone or in combination with 102 lbs/acre (114 kg/ha) N produced during a period of 10 years 4.0 and 3.8 cunits (11.3 and 10.8 m³) respectively of extra wood (Gagnon et al. 1976). Response was due to K only. On the other hand, Timmer (1976) reports that in Nova Scotia neither young balsam fir (Abies balsamea (L.) Mill.) fertilized with 400 lbs/acre (448 kg/ha) of urea N, or semimature white spruce stands fertilized with 100 and 200 pounds of urea N per acre (112 and 224 kg/ha), resulted in increased basal-area increment 5 years after fertilization.

A recent unpublished report on a Canadian Inter-provincial Forest Fertilization Program (Weetman et al. 1976) provides an analysis of 5-year growth responses of major coniferous species in eastern Canada. It was evident that the responses of the spruce-fir stands to N fertilization were significant, but maximum gains were obtained from combined high N and P or high N and K, or high N and PK treatments. The effects of P and K were less important. White spruce stands in New Brunswick that were also affected by spruce budworm either did not respond to fertilizer treatments, or the results were inconclusive.

The growth responses of jack pine (Pinus banksiana Lamb.) to fertilization were observed in a few instances in Canada. The young stands growing in well-drained soils were fertilized with N (urea) and super-

phosphate. The treatments increased the needle weight of the foliage, but not height growth (Calvert and Armson 1975). The authors concluded that fertilization of young jack pine growing under conditions as in the study is not necessary.

In another study a 40-year-old stand responded to N fertilization, and the ammonium nitrate was found to be superior to the urea form of N. The growth responses were associated with increased needle weights and increased foliar N concentration (Weetman and Algar 1974).

FOREST FERTILIZATION IN PRACTICE

In Maine, a spruce-fir forest was limed and fertilized at several locations with the objective of demonstrating increased growth due to fertilization. One such demonstration area was established at the Penobscot Experiment Station in 1970. Lime was applied at the rate of 2 tons per acre (4.5 metric tons/ha), and fertilizer, N-P-K 15-15-15, at the rate of 120 pounds per acre (134 kg/ha). Fertilizer was applied on both limed and unlimed plots. Band dendrometers were installed and periodic observations have been made. At the present time the data are being analyzed.

Maine forest industries are conducting some fertilization experiments on their own.

Scott Paper Company has fertilized in 1967 about 300 acres (121 hectares) of mature and regenerated spruce-fir stands. Ammonium nitrate at rates of 100, 150, and 200 pounds of N per acre (112, 168, and 224 kg/ha) was applied. Preliminary data showed that overall the stands responded positively to fertilization. Balsam fir responded better than spruce. However there was no consistency as to the rates of fertilizer applied. In certain instances the volume growth of spruce actually decreased.

Great Northern Paper Company fertilized experimentally clearcut areas and second growth spruce-fir stands in 1968. On the clearcut areas 0.75 tons/acre (1.68 metric tons/ha) of lime and 600 pounds per acre (673 kg/ha) of 10-10-10 N-P-K was applied. Seven years later the area was heavily overgrown with raspberries with a few stems of softwood or hardwoods remaining. In mature spruce-fir stands urea or N-P-K (10-10-10) was applied at the rates 100, 150, and 200 pounds per acre (112, 168, 224 kg/ha) of each element. Seven years later responses were observed as increased height

growth and dbh, but there was no certainty that the fertilized plots showed superior growth or that the control plots exhibited marginal growth.

The Dead River Company has fertilized over 300 acres (121 hectares) of mature and second growth stands of spruce-fir, hemlock (Tsuga canadensis (L.) Carr.), mixed softwood and hardwood stands. The rates varied from 50 to 150 pounds of N urea per acre (56 to 168 kg/ha). Preliminary measurements indicate trends of increased growth. Another study involves ground application of NP and some minor elements in various combinations.

The Oxford Paper Company is also experimenting with lime and N-P-K fertilization. Data are being collected and evaluation will be made.

Georgia-Pacific has fertilized small plots of Norway spruce (Picea abies (L.) Karst.) and Japanese larch (Larix leptolepis) plantations. Ammonium nitrate at the rate of 400 pounds per acre (448 kg/ha) was applied in 1971. Preliminary observations indicate an increase in height growth. The company is also experimenting with applications of lime. In 1975 lime at a rate of 2 tons per acre (4.5 metric tons/ha), was experimentally applied to about 60 acres (24 hectares) of pioneer northern hardwoods and softwood stands.

ONGOING RESEARCH

To assess the course of ongoing forest-fertilization research in northern forests, a questionnaire was mailed to the researchers engaged in this in the New England States and the Maritime Provinces. From the response to the questionnaire, it is estimated that at present there are approximately 70 studies about equally divided between the northeastern United States and eastern Canada. The species studied and their frequencies are given in table 1.

Conifers are the prime subject of investigation in Canada, whereas the hardwoods get most attention in New England. The objectives of the studies in descending order are: tree growth increase, stand establishment, and seed and sap production.

Table 1.--Frequency of ongoing fertilization research
in northern forest

Species	Northeastern U.S.	Eastern Canada	Total
CONIFERS			
1. Red spruce	4	8	12
2. Black spruce	1	9	10
3. White spruce	3	7	10
4. Balsam fir	3	7	10
5. Jack pine	-	5	5
6. Red pine	2	-	2
7. Eastern hemlock	1	-	1
Total	12	36	48
HARDWOODS			
1. Sugar maple	9	3	12
2. Yellow birch	4	-	4
3. Paper birch	3	-	3
4. Red maple	3	-	3
5. White ash	3	-	3
6. Black cherry	3	-	3
7. American beech	2	-	2
8. Pin cherry	1	-	1
9. Hybrid poplar	1	-	1
Total	29	3	32

The application of N in the form of urea and ammonium nitrate at rates from 50 to 400 pounds per acre (56 to 448 kg/ha) of elemental N are used. The application of P in the form of superphosphates range from 25 to 200 pounds per acre (28 to 224 kg/ha) of elemental P. K is used less frequently, and lime the least.

A few studies included micronutrients. In one instance the effects of the municipal sewage sludge are being investigated. There are no indications of use of legumes.

COMMENTS

After discussing the established facts of soil nutrient deficiencies, citing examples of responses obtained from fertilization, and summarizing the research in progress, I have to say something about future research needs.

- The importance of forest health cannot be overrated. Thus research is needed on the health of fertilized forests, including population dynamics of insects and the changes occurring in pathogenic organisms.
- There is an increased awareness of disposal of municipal sewage sludge and farm manure. The possibilities of disposing of it on the forest warrants consideration.
- Site preparation and fertilization of extremely marginal forest areas, including the mechanical drainage of swamps and bogs, should be studied and evaluated.
- Introduction of nitrogen-fixing legumes and micro-organisms, as an alternative for mineral fertilizer applications, would reduce the cost and energy needed in processing and applying fertilizers. This subject deserves adequate attention.
- Possibilities of using the coated slow-releasing fertilizers should be explored.
- Improved techniques of soil and foliar analyses and the calibration of results for estimating site productivity and fertilizer needs are desired.
- Future research on soil productivity, natural fertility, or stand responses to ameliorants and fertilizers should be correlated with a kind of soil series or soil association.

If the physiologically healthy forest is to be grown, cultured, protected, and harvested, the land manager has to be aware of the potentials offered by intensive silviculture, including fertilization for a

given site and conditions. At present information is still inadequate. Research is needed to produce answers.

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