FERTILIZATION OF NORTHERN HARDWOODS

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and
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Abstract.--Northern hardwoods grow. over a considerable range of climatic and edaphic conditions and exhibit a wide range in productivity. Many northern hardwood forests are capable of high production relative to other forest types, but are often slow to reach maximum productivity because of low nutrient availability. Altering the patterns of biomass accumulation so that managers can maximize productivity over shorter rotations may be accomplished with fertilization. The success of forest fertilization to accomplish this goal is dependent upon our understanding of the factors governing the availability of nutrients at metabolically active sites. Toward this end, the future of forest fertilization research should be directed away from field trials toward studying factors such as nutrient uptake, redistribution of nutrients among ecosystem components, internal nutrient cycling, and soil processes. Without such basic information, our field trials will remain inconclusive and full of uncertainties.

INTRODUCTION

Fertilization of northern hardwoods may be undertaken to accomplish numerous objectives. It may, for example, be employed to detect nutrient deficiencies, calibrate foliar to soil nutrient levels, restore canopy vigor on degraded sites, screen various fertilizer formulations, speed natural regeneration or growth of crop trees, accelerate biomass production for short rotations or recycle industrial and municipal wastewater and sludge. Because of the multi-purpose nature of fertilization programs in the northern hardwood forest, it is difficult to aggregate the results of many separate trials conducted over broad geographic areas of high floristic diversity.

Variation in field fertilizer trial results not only depends on the afore mentioned objectives but also on the spatial interaction of the fertilizer subsidies with the biotic and abiotic characteristics of the soil. The success of forest fertilization in achieving higher rates of productivity is dependent upon an understanding of the factors governing the availability of nutrients at absorption sites. Consideration needs also be given the response variables because they vary by objective and need to be carefully considered prior to experimentation.

The objective of this paper is to summarize recent achievements in fertilization of northern hardwoods for several major objectives and

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briefly discuss the economic considerations of implementing a fertilization program.

STAND DEVELOPMENT AND CROP TREE GROWTH IMPROVEMENT

Fertilizers have been employed to promote advanced reproduction in northern hardwoods by stimulating adequate seed supplies. Good seed years are difficult to predict and regeneration cuts cannot be scheduled only when seed production appears adequate. Bjorkbom (1979) and coworkers (1979) examined the influence of fertilizers on seed production in mixed Allegheny hardwoods as well as individual black cherry (Prunus serotina) trees. Fertilization rates of 333 $kgNha^{-1}$ from urea and 95 $kgPha^{-1}$ from triple superphosphate with or without 90 $kgKha^{-1}$ as potassium chloride promoted seed production in Allegheny hardwood stands, but more importantly, provided significantly greater numbers of seedlings than unfertilized stands. The greater likelihood of poor seed years plus poor establishment of advanced regeneration on low fertility sites makes fertilization an option for ensuring a relatively stable supply of seeds and seedlings.

Fertilizers have also been used to accelerate stand development from the seedling through sapling stages. Probably the most notable success of accelerating natural regeneration growth through the use of fertilizers has been achieved by Auchmoody (1982) in work conducted on black cherry stands of the Allegheny Plateau. Nitrogen alone or in combination with P produced significantly greater height, diameter and basal area growth. Growth responses were found to peak two years following treatment and foliar responses returned to control levels by year four. In all cases N was determined the primary growth limiting nutrient for the Allegheny soils supporting hardwoods. Recommended rates ranged between 120 and 220 $kgNha^{-1}$ with 50 $kgPha^{-1}$.

Another use of fertilizers has been in combination with silvicultural systems to accelerate growth of early to mid-rotation Populus crop trees (Doucet and Veilleux 1978). Nitrogen fertilization on trembling aspen (P. tremuloides) and balsam poplar (P. balsamifera) in Quebec produced 15 to 30% increases in diameter growth on thinned trees over controls. Maximum growth response was recorded in the third year following treatment. In a similar study (Czapowskyj and Safford 1979), a to-year old aspen-birch-maple (Populus-Betula-Acer) stand in Maine was fertilized with various combinations of N, P, and lime (448-112-4480 $kgha^{-1}$). The greatest responses following thinning were found on the N treatment plots where respective increases in height and volume of 79% and 69% over controls were measured at year three. The most responsive species to fertilization were big tooth aspen (P. grandidentata) and paper birch (B. papyrifera). Trembling aspen and red maple (A. rubrum) responded least, suggesting that fertilization may be impractical for stands where these species dominate. The general response of these mixed stands to fertilizer indicates a potential for shortening rotation lengths by a single application of growth limiting nutrients.

The use of fertilizers for accelerating crop tree development following commercial thinning has proven to be not as predictable in birch-maple forest types as the aspen-birch types. In one report (Hannah 1985), small yellow birch (*B. alleghaniensis*) and sugar maple (*A. saccharum*) poles in Vermont did not significantly respond to N, P, K, applications of up to 275 $kgha^{-1}$ per element. Over the 14 year study period several fertilizer trials failed to produce additional growth responses over the thinning treatment alone. Hannah concluded that the relatively fertile soils (schists and limestones) in Vermont contain adequate amounts of essential elements so that fertilizers do not result in growth responses. In contrast, maple-birch stands on acid crystalline rocks (quartz) in New Hampshire and New York increased growth following fertilization (Safford 1973; Hoyle 1970). In the Adirondack Mountains, a 15 percent basal area growth response over a 100 percent thinning response was measured two years following application of 275 $kgNha^{-1}$ to a 70 year old thinned maple-birch-beech (*Fagus gradifolia*) stand (Lea et al. 1979).

In a southern Ontario field trial, an individual crop-tree release and fertilization program in a late rotation hardwood stand of sugar maple-black cherry-white ash (*Fraxinus americana*) failed to provide any response for N and P rates up to 590 $kgha^{-1}$ and 454 $kgha^{-1}$, respectively (Ellis 1979). Although foliar levels of applied nutrients were significantly elevated, growth responses were not recorded for the three species. A partial explanation for this lack of fertilizer response is the medium fertility of the stoney calcareous till deposits in southern Ontario plus the lack of precision by which a tree's rooting zone can be estimated for individual tree fertilizer placement. Stone (1982) also failed to obtain responses for individually fertilized hardwood in Michigan using a balanced application of N-P-K fertilizer.

For northern hardwood stands late in the rotation, fertilization may provide only a small incremental response. However, if the site is already of sufficiently high fertility to grow quality hardwoods in the first place, thinning rather than fertilization is more likely to result in the greatest economical gain in growth. One possible exception is in the production of log quality black walnut (*Juglans nigra*). Fertilization responses in black walnut have been successfully demonstrated for seedlings and young plantations (Ponder 1980; Braun and Byrnes 1982: Pope et al. 1982) as well as for crop trees following a release thinning in natural stands (Stringer and Wittewer 1985). The potential for combining fertilization with other cultural practices in plantations and for capitalizing on the high rate of return expected from individual high value logs in natural stands makes black walnut a viable candidate for fertilization.

BIOMASS PRODUCTION

To more precisely evaluate the potential of northern hardwoods for biomass production many experiments have been run throughout Europe, Canada and the United States utilizing optimum fertilization and, in some cases, irrigation. Even in harsh northern climates, fertilization has provided biomass yields several times greater than control stands and greater than agricultural crops. In regions where N is the principally limiting element, fertilization is the only means of obtaining acceptable biomass yields, as well as minimizing nutrient losses where whole tree complete harvests deplete natural soil fertility.

As rotation lengths shorten and management intensifies, forest biomass plantations are increasingly similar to conventional agronomic systems (Hansen et al. 1983). In effect, short rotation intensively cultured biomass plantations are established following clear cultivation, N fertilizer and weed control. When irrigation is considered, yields of hybrid poplar plantations can be increased up to 77% (Hansen 1983; McLaughlin et al. 1985).

There are many studies which have assessed the productivity of biomass plantations (Sajdak et al. 1981). In Vermont, hybrid poplar clones produced up to 16 Mg ha^{-1} yr^{-1} during the first rotation when irrigated and fertilized. In Quebec, a balanced NPK fertilizer treatment applied to a hybrid poplar plantation at planting produced a four year height growth response of 72% and a total diameter response of 69% (Sheedy, 1982). Krause and workers (1982) reported a doubling of growth for trembling aspen within 5 years following N-P-K fertilization in the mixed wood section of Saskatchewan.

Although many of the intensive culture biomass plantations provide high biologic response to fertilization and other intensive practices, economic analyses have shown that such culture may not necessarily yield high monetary returns (Rose et al. 1981). Reasons for a lower return include the high costs associated with transportation, site preparation, fertilization, irrigation-and suceptibility to pests and frost injury (Ranney et al. 1982). Consequently, less intensive management techniques have been investigated by Mroz and coworkers (1985) by fertilizing coppice regrowth of natural northern- hardwood stands for biomass production. Such research is justified because of the evidence that fertilization has been found to be necessary to offset soil nutrients lost as a result of the frequent biomass removals from short rotation plantations (Blake and Raitanen 1981). Even in longer rotations (10-20 years) of natural coppice stands in northern Europe, fertilizers have been required to optimize stocking and growth rates of coppice (Paavilainen 1981). Consequently, when naturally regenerated maple coppice systems were examined by Mroz and coworkers (1985) it was not surprising to find biomass per stump and on an area basis was increased with NPK fertilization on mesic sites. On dryer sites, fertilizers failed to provide significant responses because of moisture stress. Fourth year periodic biomass production on fertilized pole size origin coppice yielded a maximum of 48 Mg ha^{-1} yr^{-1} on good sites.

RECLAMATION

Large scale perturbations such-as coal, gravel and ore mining cause drastic surface effects on the landscape as well as environmental damage. The primary objective of reclamation is to establish a vegetative cover, to build soil and regenerate soil organisms which provide a buffer against further site and water quality degradation. At the same time, establishment of vegetation improves the visual qualities of the landscape and enhances long-range land use opportunities.

Fertilization is essential to establish the initial vegetative cover, Mine soils are almost always deficient in nitrogen and phosphorus. Because there is usually no reservoir of organic matter in the soil, fertilizer may be required in subsequent years to meet the nutrient demands and sustain the growth of established vegetation. In many cases fertilization can overcome the initial limitations caused by mine soil bulk density which limits root exploration. Fertilization may also provide nutrients which encourage repopulation of the site by important bacteria, mycorrhizae and soil macro-fauna which accelerate nutrient cycling and rejuventate of soil physical properties (Vogel 1981).

Fertilization requirements vary by cover crop and species. For forage crops, fertilizer applications will exceed those common for standard agricultural production. For reforestation and wildlife habitat, fertilization is necessary for initial establishment and early maintenance of phytomass vigor. After a decade or less, natural processes should be sufficient for the continued maintenance and development of plant communities.

FERTILIZATION WITH WASTEWATER SLUDGE

Implementation of secondary treatment standards for wastewater discharge in the United States, as required by the Federal Water Pollution Control Act Ammendments (PL 92-500) of 1972, has resulted in the increased production of nutrient-rich wastewater sludges which may serve as inexpensive fertilizer materials when applied in forest ecosystems (Smith and Evans 1977). National sludge production is approaching 5 million Mg and will obviously increase as the U. S. population approaches 300 million. While most land applications of sludge currently occur on farmland, the potential for increased sludge use on forest land is substantial (Brockway and Nguyen 1986).

Extensive research in northern hardwood forests has indicated that wastewater sludge application produces multiple benefits (Sopper and Kerr 1979; Koterba et al, 1979: Brockway, 1983, Urie et al. 1984). Increases in soil nutrient levels, understory vegetation production, overstory tree growth and the nutritive quality of wildlife foods are nearly universal results. When rates are balanced with the assimilative capacity of the ecosystem the benefits can be realized with little measurable environmental degradation (Riekerk 1981; 1982; Brockway and Urie 1983; Urie et al. 1986)

While sludges are highly variable in composition (Table 1), nutrients of major concern in forest ecosystems are usually present in good supply. Site applications with- a typical sludge of LO $Mgha^{-1}$ provide nitrogen and phosphorus loadings exceeding 700 $kgha^{-1}$ each, Trace metals can in some instances be a concern, but levels in most waste streams are decreasing over time as pretreatment programs become implemented at wastewater facilities.

Table 1. Nutrient composition of wastewater sludges applied to forest land.

	Seattle, WA	Cadillac, MI	Rogers City, MI	Augusta, GA
		%		
Nitrogen	4.3	6.0	8.6	7.2
Phosphorus	1.5	7.8	4.2	1.6
Potassium	.16	1.54	.13	.27
Calcium	.4	1.4	5.6	1.5

Growth responses to sludge additions are reportedly of greater magnitude and larger duration than the average response obtained from applications of commercial fertilizer (Zasoski et al. 1983). In northern Michigan, basal area growth rates increased as much as 56% on a 50 year-old stand of northern hardwoods fertilized with 9 Mg ha^{-1} of sludge (Hart and Nguyen 1986). Volume yield increases of 1.0 m^3 $ha^{-1}yr^{-1}$ of merchantable wood per 10 Mg ha^{-1} of sludge (365 kg N ha^{-1}) have been recorded (Lutrick et al., 19861.

In the long term, repeated sludge applications should provide cumulative positive effects upon site quality. Although speculative at this time, one would anticipate a continued build up of site nutrient capital and development of a rich forest humus, resulting in a greatly ameliorated environment for plant growth. This process of accelerated site aggradation could lead to permanent increases in forest production, as long as sludges employed in application programs are low in levels of potential toxicants. Forest fertilization with wastewater sludge has been developed through research into an attractive silvicultural opportunity especially when one recognizes that this by-product "resource" is most often furnished without charge to the land manager.

CALIBRATION OF BIOASSAYS

Foliar bioassay is a method often used to assist diagnosis of mineral deficiencies in forestry. However, its application is severely limited by the genetic variability of natural hardwood stands and lack of homogeneity among forest soils and sites, age structure and stocking. Obviously, foliar analysis has proven most useful where stand growth has been precluded by an extreme deficiency or where single species plantations are established at uniform stocking on uniform sites.

The interpretation of mixed northern hardwoods response to fertilizer through the use of foliar analysis can prove very difficult depending on the stage of stand development and species composition. Research has almost always demonstrated elevated foliar nutrients following fertilization (Lea et al. 1979 ab; Hansen and Tolsted 1985), but often the growth response proves non-significant (Ellis, 1979: Stone

1980: Lea et al. 1980; Stanturf and Stone 1985). Wide variations in the pre-treatment stand conditions often mask a statistical response to treatment(Auchmoody, 1982: Salonius et al. 1982).

There are several techniques that have been employed to calibrate bioassay analysis with field fertilization results. One method that proved quite successful was described by Safford (1982). Bulk soils from adjacent areas to field fertilizer trials were treated with equivalent field rates of fertilizers and paper birch seedlings were grown from seed and bioassayed for correlation to three year volume growth of saplings. This technique proved valuable in that correlation coefficients were 0.88 for height growth and 0.91 for dry weight growth on one site and 0.72 and 0.63 on the other, respectively. With further refinement, this technique will have potential for estimating field responses of young paper birch to fertilizer and ranking soils in need of fertilizers.

Another sucessful calibration technique of bioassay to crop response is described by Leech and Kim (1981) for high nutrient demanding hybrid poplars. Their technique refined Beaufils' (1956) "Diagnosis and Recommendation Integrated System" (DRIS) model to determine when to fertilize, what fertilizer to use, how much to use and how to assess crop response (Leech and Kim 1979). The DRIS technique utilizes greenhouse calibration by comparing foliar composition of healthy growing trees with that of slow growing trees. In the field, the average ratio of foliar nutrient concentration of rapidly growing trees becomes a field standard by which growth performance of plantations is judged. The DRIS formula is then employed to target nutrients that are limiting to the entire plantation. Rapidly growing trees may require proportionately greater levels of fertilization to obtain a balance and the slow growing trees lesser applications of limiting nutrients.

After the foliage of the plantation has reached a balance of nutrients, it is desirable to elevate the foliar concentrations to optimize growth. For this purpose the greenhouse bioassay standard is employed so that DRIS indicies can be applied forelevating, optimizing and stabilizing the nutrition of plantation poplars.

Bioassay in an artificial environment can never account for all the interacting influences in the field such as moisture availability, soil temperature, light quality, soil microbiology and competition. Their greatest applicability comes from the control they provide so that mechanistic studies can be made for understanding growth dynamics under rapidly changing physiological and nutritional relationships.

ECONOMICS OF FERTILIZATION

The most important financial return to forest fertilization is the increase in the net value of the forest crop. The increased yields of merchantable volume resulting from fertilization lead to higher gross financial yields per acre. In addition, lower harvesting costs per unit volume result from increased tree size and greater volumes per acre at rotation age. By increasing the growth rate of the forest crop a shorter financial rotation also results which accrues economic rent and becomes imputed as an additional return.

Lamson and McCoy **(1982)** provided calculations to determine whether fertilization pays for the landowner. Their assessment includes the following equations:

1. Rate of return on the investment is the traditional method, where

$$(1 + i)^n = \frac{\text{value increase due to fertilizing}}{\text{cost of fertilizing}}$$

n = number of years for calculation

i = interest rate

2. Calculating the volume increase needed, where

$$\text{Volume increase needed} = \frac{\text{End value of timber costs}}{\text{timber value}}$$

3. Calculating the timber value needed, where

$$\text{Timber value needed} = \frac{\text{End value of fertilization Costs}}{\text{Expected volume increase}}$$

4. Calculating **fertilization** costs, where

Fertilization costs needed = Discount to present (Timber value x Expected volume increase)

where: end value of fertilization costs = **present** fertilization costs multiplied by $(1 + i)^n$ and **discount** to present = future value divided by $(1 + i)^n$.

If the landowner knows any two of three values, **(1)** fertilization costs, **(2)** volume growth or **(3)** value of timber, then the third can be calculated. The calculated value will indicate what change is needed for fertilization to pay. If one can attain the expected value, then the decision to fertilize will be profitable.

Fertilization costs have to be carried at compound interest to the end of the rotation before any returns on the investment are realized. It is obvious that the greatest returns are from these treatments which obtain volume responses at the end of the rotation, or where the establishment of a crop without fertilization would be impossible.

CONCLUSIONS

Field fertilization trials over the broad range of sites occupied by northern hardwood forests have demonstrated the wide applicability of adding nutrients for **enhancment** of growth or stand development. However, one must remember that there have been many field trials which were installed with little knowledge of soil processes or native fertility of the ecosystem. If one was lucky, a significant growth response was realized, if not, the investigator was left with a wealth of definitive experience.

What is sorely lacking in fertilization technology is the knowledge of the biological aspects of fertilizing forests. We presumably know something about the stands and the sites supporting these stands. Most managers understand which types of stands to fertilize, but there is little help in defining what kinds of soils to fertilize. The soil is where the treatment originates, and it is with the soil that the effectiveness of the treatment will be manifested. The future of forest fertilization rests not with stand, soil, or foliar analysis, but with an integrated knowledge of the biology of the soil system and its calibration to species assemblages, stand conditions and landscape features.

More emphasis needs to be placed on studying the processes involved in nutrient supply to actively absorbing roots, rather than **installing** wide ranging field trials over uncontrollable conditions. After we establish the functional basis of response to fertilizers, standard diagnostic techniques such as soil or foliar analysis should be employed to confirm our expectations for an economic response. With an appreciation for soil limiting processes, the manager will be primarily gambling on stand rather than site conditions for initiating a fertilizer program.

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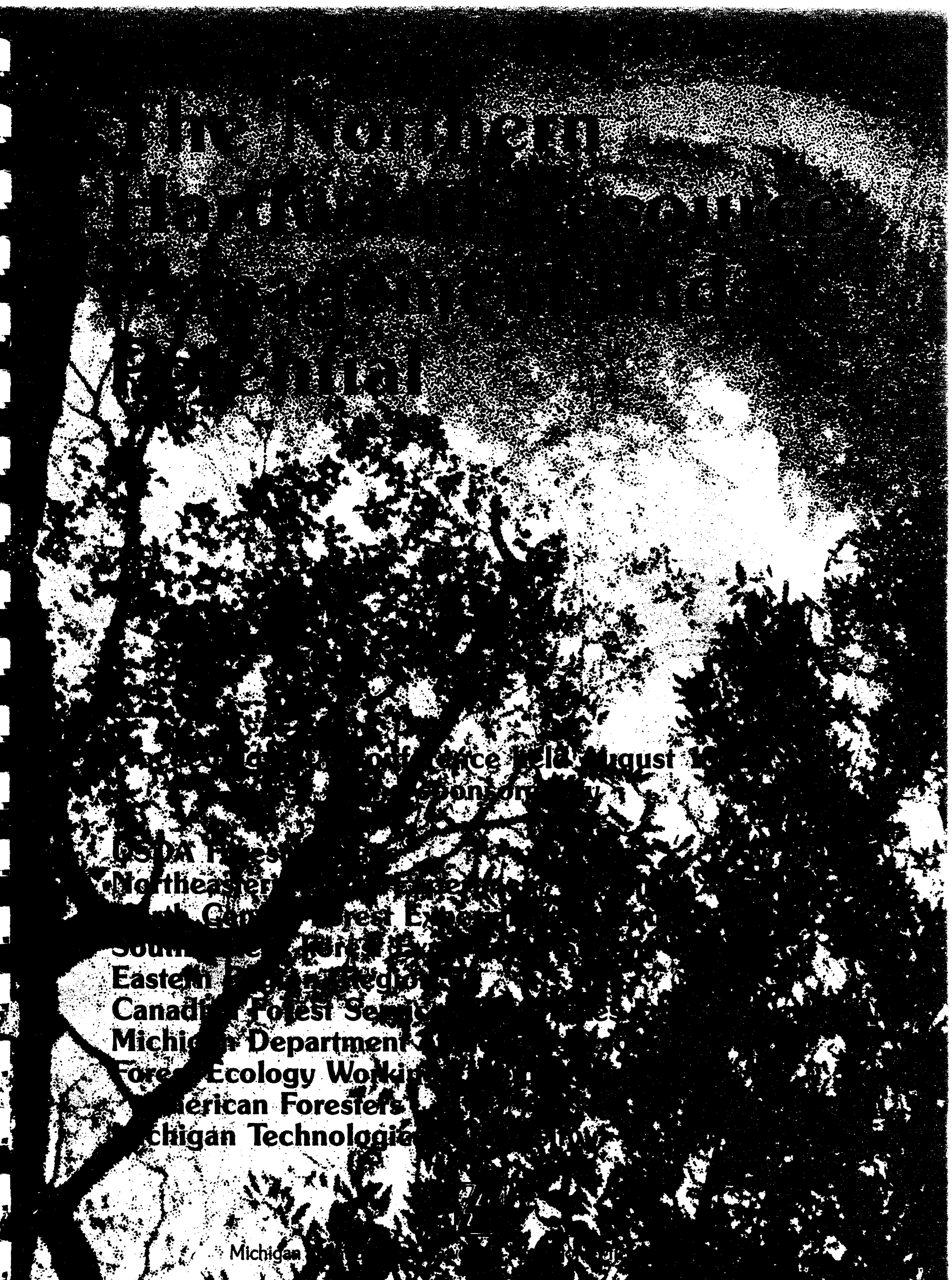
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