NITROGEN-FIXING PLANTS TO REPLACE OR SUPPLEMENT SYNTHETIC NITROGEN FERTILIZERS

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ABSTRACT

Renewed interest in nitrogen-fixing plants in forestry is due in part to uncertainties about future cost and availability of energy-dependent nitrogen fertilizer. In addition, many attributes of nitrogen-fixing systems differ from those of fertilizer applications. We discuss the possible importance of such differences in nutrient management programs. We also describe characteristics of nitrogen-fixing plants desired for forestry applications and suggest some nitrogen-fixing plants in intensive forest management is promising. Moreover, sociopolitical and economic factors are changing in directions that favor use of nitrogen-fixing plants. Thus, forest scientists and managers should begin gathering knowledge and obtaining pilot-scale experience with nitrogen-fixing systems.

INTRODUCTION

Many papers presented in this volume have provided excellent reports regarding the state-of-the-art of forest fertilization in the Pacific Northwest. In most cases, good growth responses are obtained with N fertilizers; and in the case of Douglas-fir, fertilization can be a profitable investment. Yet, several reasons exist for considering use of N-fixing plants in managed forests.

Many foresters are concerned about the future cost and availability of N fertilizers. The future is uncertain because costs and availability of synthetic N fertilizers are closely linked to energy supplies and costs as well as to political decisions. Nitrogen-fixing plants may be viewed as a hedge against these uncertainties. There are other reasons, however, to consider N-fixing plants, even if synthetic N fertilizers remain available at present prices and in amounts sufficient to meet future forestry needs or desires.

One reason is that N added by N-fixing plants may be more effective—biologically and economically than synthetic N fertilizers in some forest situations. Another reason is that N-fixing plants do more than simply add N; they frequently provide other important benefits (e.g., control of soil-borne disease and increase in soil organic matter) which are the bases for much present as well as past use of these species in agriculture.

Interest in use of N-fixing plants is building throughout the world. For example, a major conference devoted primarily to forestry applications was recently held at Oregon State University, the proceedings of that meeting are now available (Gordon et al. 1979). The accelerating interest in use of N-fixing plants in forestry may be new, but the concept is not. Two of the pioneer forest soil scientists in this region suggested more than a decade ago that effective use can be made of native N-fixing plants in forest management (Tarrant 1961, Youngberg 1965). In recent years, many reviews have been made of this general topic (Tarrant and Trappe 1971; Silvester 1976, 1977; Haines 1978; Miller and Murray 1978, 1979; DeBell 1979; Haines and DeBell 1979).

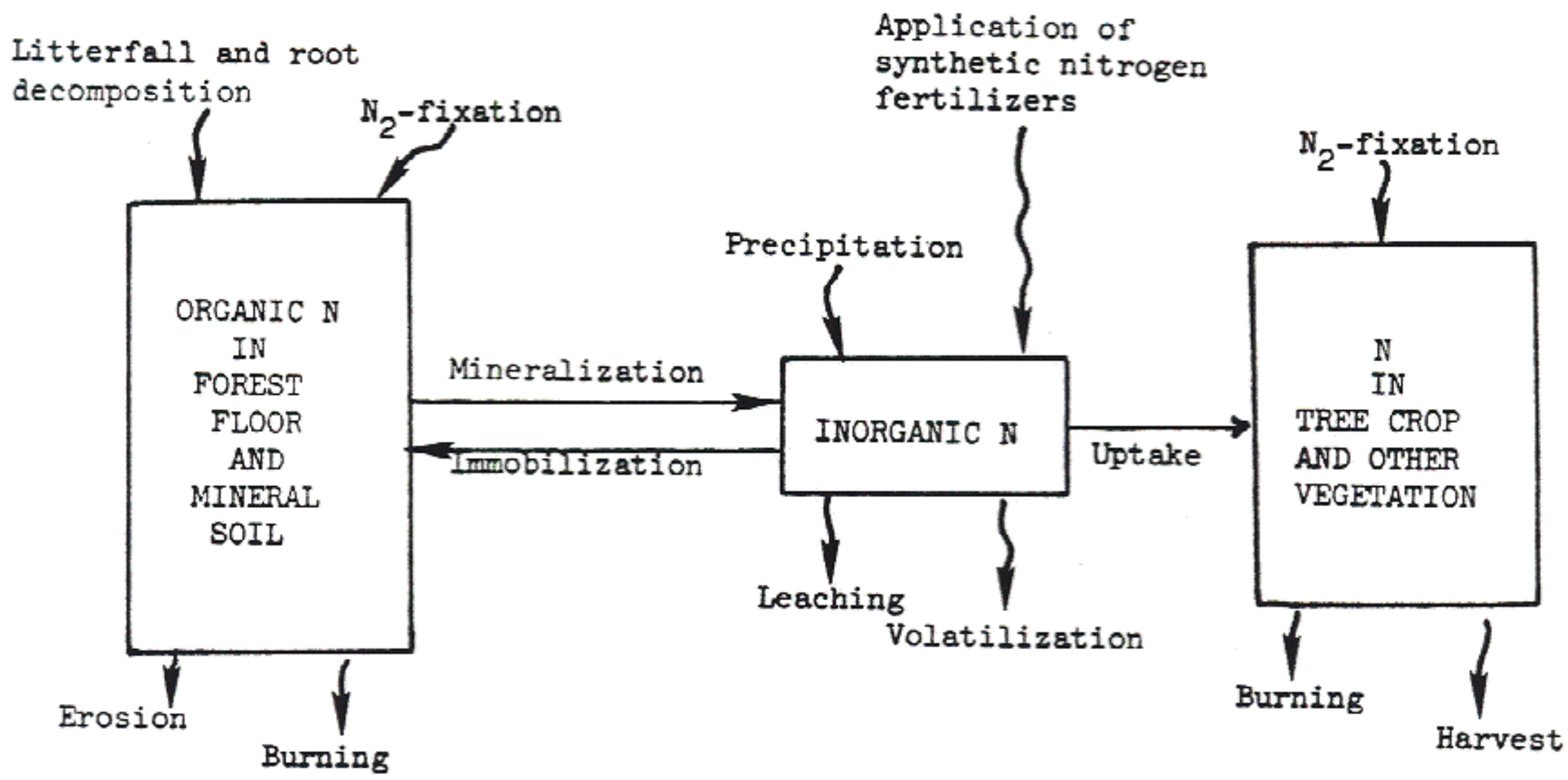
In this paper we will first review the forest's N supply system and compare some effects of N-fixing plants and synthetic N fertilizers. We will then describe characteristics desired in N-fixing plants for use in managed forests and examine possible management systems for using them. Finally, we will offer some recommendations and conclusions regarding their use in intensive forestry in the Pacific Northwest.

COMPARATIVE EFFECTS OF DINITROGEN-FIXING PLANTS AND SYNTHETIC NITROGEN FERTILIZERS

THE NITROGEN SUPPLY SYSTEM

A simplified description of the forest's N supply system (Figure 1) can provide perspective on some of the differences between N-fixing plants and synthetic N fertilizers. The purpose of any N-adding technique is to get the optimum amount of N into the tree crop and thereby optimize growth and yield for any given site and accompanying management conditions. The amounts of N assimilated by the stand or tree crop depends on: the total amount of N present (primarily as organic N) in the soil and forest floor; its rate of mineralization to inorganic

Figure 1. Major components of the nitrogen supply system in forests.



N; and the relative efficiency of tree roots, roots of competing vegetation, and soil microbes in absorbing the available inorganic N.

Conventional application of synthetic N fertilizer adds N directly to the inorganic N pool. This bypasses and supplements the mineralization process which usually is prerequisite to absorption of soil N by forest trees. This can be an important biological advantage provided the stand has developed to the point where it can absorb and utilize most of the inorganic N when it is applied. Otherwise, significant amounts of the added N can be immobilized in soil organic matter lost from this inorganic N pool via volatilization. Foliar application of N solutions may provide some direct input of N to the tree crop, but use to date in forestry has been very limited (Miller 1980).

Nitrogen-fixing plants can impact the N supply system in two ways. Such plants add organic N to the site when their tissues die and decompose; there may also be some root exudation, leafwash (throughfall), and stemflow of N compounds. Secondly, if a N-fixing plant is used as the crop species, fixation of atmospheric N by the root nodules provides direct input N to the tree crop. Most published reports for N accretion in soil beneath pure or mixed stands of red alder estimate annual accretion rates between 40 and 70 lb N/acre (Tarrant and Miller 1963, Franklin et al. 1968, Tarrant et al. 1969, Gessel and Turner 1974, Berg and Doerksen 1975, Cole et al. 1978, Atkinson et al. 1979).

OTHER FACTORS AFFECTING GROWTH

Many factors other than N influence forest productivity. Some of these factors may be affected by N-fixing plants—and synthetic N fertilizers—both favorably and unfavorably. Observed benefits of N-fixing plants include control of both weed competition (Haines et al. 1978) and soil-borne disease organisms (Fox 1965, Nelson et al. 1978), improved soil conditions such as organic matter and bulk density (Tarrant and Miller 1963), and perhaps production of stimulatory compounds.

Potential negative impacts of N-fixing plants are associated primarily with increased vegetative competition; however, N fertilizers may also stimulate increased competition during the early years of stand establishment. There have been consistent indications of increased soil acidity, particularly with *Alnus* species; in some cases, reduced amounts of "available" cations in upper horizons of mineral soils have been reported (Bollen et al. 1967, Crocker and Major 1955, Franklin et al. 1968, Mitchell 1968, Ugolini 1968, Yamaya 1968). The practical significance of such changes which can also occur with fertilizer application (Cole and Gessel 1965) is unknown. Other problems sometimes associated with improvement in N nutrition by both methods include increased incidence of damage by animals (e.g., bears, sapsuckers) and weather (e.g., freeze, ice, or snow damage). Allelopathic effects are another potential effect with some N-fixing species (Rice 1974).

CHOICE OF METHODS

If sufficient information were available for both methods, forest managers could take advantage of some of the differences between N fertilizers and N-fixing plants and use each method when and where it would be more effective. Current information provides a limited basis for speculation.

For example, application of synthetic fertilizer adds N directly to the available N pool and thus may be advantageous on sites where slow mineralization provides inadequate amounts of available N (e.g., high elevation sites, cold cli-

mates). This assumes that the stand can absorb and effectively utilize most of the fertilizer N at the time it is added. Thus, rapidly growing stands having canopies which are closed or about to close are in the best position to benefit, because the fertilizer is more likely to be absorbed by trees than competing vegetation. Fertilizer applications are especially attractive economically in older stands because they can also provide rapid growth increases in trees of merchantable size; in such situations, treatment costs can be quickly recovered by harvest in thinning or clearcut operations.

Although the current operations fertilizations in the northwestern United States apply only to N, this fertilizer prescription can be readily modified to include other elements that may limit stand growth. A major difference between the two options is that synthetic N fertilization is energy-intensive rather than labor-intensive and therefore may be a good or bad choice depending on whether energy or labor is more limiting and more costly.

Nitrogen-fixing plants may have advantages over chemical fertilizers on juvenile or severely disturbed soils where total N supplies and soil organic matter are low. Nitrogen-fixing plants improve soil conditions on such sites by: (1) increasing organic matter and N supplies rapidly and continually despite low levels of native soil N, and (2) enhancing the rate of humus formation via the addition of N-rich residues (Allison 1973). In contrast, fertilizers are probably less effective on such soils because opportunities for both absorption and adsorption are more limited; thus, applied nutrients are more likely to be leached through the soil profile.

Nitrogen-fixing plants can be used in newly established stands where they can offer possibilities for auxiliary benefits such as weed and disease control. Effects of N-fixing plants may persist long after the plants themselves disappear. Direct input of N to the tree crop is possible when the crop species is a commercially valuable N-fixing tree such as alder. Finally, N-fixing systems may be more labor-intensive and less energy-intensive than chemical fertilizer applications.

DINITROGEN-FIXING PLANTS FOR USE IN MANAGED FORESTS

DESIRED CHARACTERISTICS

Traits desired in N-fixing plants for use in managed forests include:

1. They must be capable of quick, uniform establishment, rapid growth, and high N fixation rates under conditions occurring in managed forests. The primary limitation on survival and growth is probably solar radiation, but fertility and moisture levels may also be important restrictive factors with some species and on some sites.

2. Their negative impacts on the associated crop species should be minimal.

3. Ideally, the N-fixing plant would also provide one or more other benefits such as improved wildlife habitat or aesthetics, control of weeds or soil-borne disease, or direct revenues.

A number of herbaceous shrub and tree species meet some or all of the above criteria. These generally fall into three categories: (1) Agricultural legumes (e.g., subterranean clover and alfalfa). (2) Native and naturalized legumes (e.g., black locust, scotch broom, and lupines). (3) Actinomycete-nodulated angiosperms (e.g., alders and *Ceanothus* species). Basic information on the more important genera and species in these categories has been summarized (Haines and DeBell 1979).

POSSIBLE MANAGEMENT SYSTEMS

Of numerous systems for using N-fixing plants in managed forests, six were recently described by Haines and DeBell (1979), including three mixed-species systems, two crop-rotation systems, and continuous cropping of N-fixing trees. In this paper we will consider only three of the systems—mixtures using N-fixing trees in the overstory, mixtures using N-fixing plants in the understory, and use of N-fixing trees as a pure overstory. For each system we will describe the components, given an example, and list some of its advantages and limitations.

Overstory Mixtures

Mixed overstory systems involve at least two commercial tree species. One species is a net "demander" and the other a net "fixer" from the standpoint of N supply; hereafter, the species will be referred to as N-demanders and N-fixers. In trials reported to date, the species have been planted with a ratio of one or more N-fixers for each N-demander (Tarrant 1961, Plass 1977, Miller and Murray 1978, DeBell and Radwan 1979). In some mixtures (e.g., red alder/Douglas-fir) the N-fixer has less economic value than the N-demander, and we would therefore like to keep the number of N-fixers to the minimum needed to provide the benefits we desire. Unfortunately, we do not yet know how many N-fixers we need for any given species combination and site condition.

A good example of the mixed overstory system is on the USDA Forest Service's Wind River Experimental Forest in southwest Washington. There, red alder was interplanted in a 4-yr-old Douglas-fir plantation. When the plantation was about 30 yr old, Douglas-fir growth (Tarrant 1961) and soil N and soil organic matter (Tarrant and Miller 1963) were greater in the mixed stand than in the remaining plantation retained as pure Douglas-fir. At age 48, the stands were remeasured and reevaluated (Miller and Murray 1978). The mixed stand had fewer Douglas-fir trees than in the surrounding pure stand, but they were larger and total volume of Douglas-fir per acre

exceeded that in the pure Douglas-fir stand. When the alder volume was added to that of the Douglas-fir wood production in the mixed stand was nearly twice that in the pure stand.

Advantages of mixed overstory systems may include a continuous input of N and the continuous presence of the principal crop on the site. Possible limitations include use of some of the site resources by a less valuable species. Moreover, competition between the height growth patterns of N-fixing trees and the higher value, principal crop may increase risk or management costs (e.g., early height growth of red alder exceeds that of Douglas-fir). This problem can be alleviated by planting the N-fixer a few years later than the principal crop or, perhaps, by planting or maintaining only as many N-fixers as necessary.

Understory Mixtures

Using N-fixing species in the understory is usually limited to the early years of stand development because most N-fixing species will be shaded out as the timber stands develop and crowns close. Understory mixtures are also possible in older stands if little shade is cast by the overstory (e.g., wide initial spacing or subsequent thinning) and/or the N-fixer is tolerant of shade.

Legumes (especially clovers) substantially increased growth of a young sycamore plantation in the southeastern United States (Haines et al. 1978). The use of autumn olive (a nonleguminous shrub) in black walnut plantings is now common practice in the Midwest. Recent experimental data show that walnut planted with olive was twice as tall as walnut planted alone (Funk et al. 1979); moreover, walnut growth was stimulated in many areas where N fertilizer had provided little or no growth benefits (Ponder 1976). Little definitive evidence exists about the influence of understory N-fixers on growth of young Douglas-fir stands. Substantial N accretion by snowbrush (*Ceanothus velutinus*) (Youngberg and Wollum 1976) and some evidence of early benefits to growth of young Douglas-fir plantations has been reported (Youngberg et al. 1979). Unpublished observations also suggest that scotch broom and certain clover species may prove useful in young managed forests of the Douglas-fir region.

Examples of understory mixtures in older stands include lupine with radiata pine in New Zealand (Gadgil 1977, Silvester et al. 1979) and with Scots pine and Norway spruce in Germany (Rehfuess 1979). There is also a report of increased soil N due to establishment of understory alder in a heavily thinned Douglas-fir (Berg and Doerksen 1975).

Potential advantages associated with the system involving understory N-fixers are that it can provide for current needs of a young stand for N. This system also builds soil N and soil organic matter for later use, and it does so while available resources (space, light, moisture, mineral nutrients) exceed the demand of the principal crop. Channeling these excess resources to a beneficial N-fixing plant may be a form of weed control because the established understory curtails invasion of the site by species which may compete more seriously with the crop species.

The primary disadvantage of this system is that timing of N input may not coincide with the period of maximum demand by the tree crop. Thus, subsequent benefits depend on high initial N input, retention of N at the site, and its release and availability to meet later stand needs. If insufficiencies develop later in the life of a stand, however, land managers could apply supplemental N fertilizers.

Cropping of Nitrogen-fixing Trees

Commercially valuable N-fixing trees provide several additional opportunities. Continuous cropping with red alder is one example. In this paper, however, we will discuss alternate cropping or crop rotation which involves one rotation of a N-fixing species followed by one or more rotations of non-N-fixing species.

Nature provides numerous examples of changing or rotating species; examples include revegetation after fire, volcanic eruptions, mud slides, or retreat of glaciers. Many of the Douglas-fir stands cut in the early part of this century regenerated naturally to red alder. Some of those alder stands have been removed by harvest or other conversion techniques, and sites were planted with Douglas-fir. Preliminary assessments of the biological and economic aspects of alternate cropping of Douglas-fir and red alder have been published (Atkinson et al. 1979, Miller and Murray 1979). The general conclusions are that alternate cropping is not as profitable as fertilizer application at the present time; also, increased value of alder stumpage or cost of N fertilizer could substantially enhance relative profitability of alternate cropping.

Potential benefits from crop rotation in forestry are illustrated in a report on growth of eastern hardwoods planted on a site previously supporting black locust (Carmean et al. 1976). Yellow-poplar, sweetgum, and black walnut made far superior growth when planted after locust than when planted on sites which had supported native hardwoods, pine species, or herbaceous oldfield vegetation. Improved hardwood growth after locust was attributed primarily to improved nutrition, as evidenced by increased foliar N. Significant accretion of soil N is known to occur beneath black locust stands (Ike and Stone 1958).

Specific advantages of alternate cropping are (1) environmental conditions will favor maximum growth and fixation by the N-fixing plant while it is on the site, and (2) compatibility of growth patterns of two species is not a concern. This system may have special merit where soil-borne root disease (e.g., *Phellinus weirii*) is a problem because susceptible host plants will be absent from the site for an extended period. The system may also be needed to rehabilitate sites which have been drastically altered by man (e.g., strip-mined areas). Disadvantages may include having a less valuable crop as sole occupant of the site for long periods. Also, conversion from one species to

another may be difficult if one species sprouts or seeds prolifically and continues to compete with the subsequent crop.

CONCLUSIONS AND RECOMMENDATIONS

Nitrogen-fixing plants could replace or supplement synthetic N fertilizers in some managed forests. The two techniques differ in the way they add N to the forest's N system. Nitrogen-fixing plants are more likely to provide auxiliary benefits to forest productivity. Moreover, the two techniques offer an attractive trade-off between energy-intsnsive and labor-intensive systems.

Some things must be done, however, before the potential of N-fixing systems can be realized in the Douglas-fir region:

1. Pilot-scale trials with red alder—used in both mixed overstory and crop rotation systems—are needed.

2. Other N-fixing species also need to be evaluated, especially for use in understory mixtures and on sites where red alder does not grow well. For example, Miller and Zalunardo (1979) compared the growth performance of eight legumes on forest sites in southwest Oregon. *Ceanothus*, Sitka alder, and some of the clovers deserve attention.

3. A systematic program of research and development which involves cooperation between researchers and managers is needed to get to the application stage in an efficient manner.

Although we cannot at present recommend N-fixing plants over N fertilizers for wide-scale operations, changes in any of several factors could greatly affect such recommendations. Economic and sociopolitical factors, such as timber and energy supplies and costs as well as national strategies regarding timber and energy, can have major impacts on the relative profitability of N-fixing systems. Restrictions on herbicide use will also have an important influence. Such factors are constantly changing as is our understanding of biological factors. Thus, profitability could be increased because added or increased benefits are recognized or because risks are reduced with increased knowledge.

Past efforts in forest nutrition in the Douglas-fir region have been concentrated primarily on developing technology for using synthetic N fertilizers. Although some refinements in that technology are still needed, application of chemical fertilizer is currently a cost-effective option for many forest owners in this region.

We believe it is time to develop systems for using N-fixing plants. In the future, we may be forced to use these natural systems because cost and availability of synthetic N fertilizers may render its application either not viable or unprofitable. Or—and we hope this will be the case—we will want to use N-fixing plants because they offer a better option than chemical fertilizers in some forest situations. In any event, additional research and development is necessary before N-fixing systems can provide practical options for intensive forest management.

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