The Role of FOREST SITE in FERTILIZER Response

by Raymond E. Leonard
Albert L. Leaf
John V. Berglund

U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-243
1972

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
WARREN T. DOOLITTLE, DIRECTOR

The Authors

RAYMOND E. LEONARD was trained in forestry at Paul Smith's College. He received a B.S. degree from the University of Vermont, an MMM at the University of Helsinki, an M.S. at Yale University and a Ph.D. from Syracuse University. After 3 years of work in forest administration with the Vermont Forest Service, he joined the Northeastern Forest Experiment Station in 1957. He is now a research forester with the Experiment Station's forest amenities project in Pennington, N. J.

ALBERT L. LEAF received his B.S.F. and M.F. degrees in forest management and forest soils from the University of Washington, and his Ph.D. in soil science from the University of Wisconsin. In 1957 he joined the faculty of the State University of New York College of Forestry at Syracuse, where he is now professor of forest soil science and chairman of the Forest Resources Council of the School of Environmental and Resources Management.

JOHN V. BERGLUND, associate professor of Silviculture at the State University of New York College of Forestry at Syracuse, received his B.S. (1962) and M.S. (1964) degrees in forestry from the Pennsylvania State University, and his Ph.D. degree from the College of Forestry at Syracuse. He has been with the College of Forestry since 1964, teaching and conducting research in the general area of silvics-silviculture.

MANUSCRIPT SUBMITTED FOR PUBLICATION 23 NOVEMBER 1971.

FOREST FERTILIZATION is one of many cultural practices available for intensive forest-resource management. It is a potentially useful practice for improving quantity or quality of goods or services, whether the management objectives involve timber, fiber, wildlife, recreation, or water. As with other cultural practices, it should be used if it helps to meet management objectives in an efficient manner. Also, as with other practices, it involves a commitment of investment on the site; it may result in an array of side effects in the ecosystem; and it must fit logically into long-range management plans.

There are two general philosophies about the role of forest fertilization in forest-resource management. One advocates the relative widespread use of a so-called general "complete" fertilizer formulation, based on the premise that one or more parts of the formulation may be beneficial for meeting the predetermined objectives, and that the remainder will be incorporated into the ecosystem and dissipated with time. This philosophy involves no lengthy and costly diagnosis of the forest site. And it allows the most widespread and — in terms of cost per unit area — the least expensive means of application: aerial broadcast. With this philosophy, consideration of forest site condition is minimal.

We reject this philosophy as irresponsible. We believe that it is not in the best interests of mankind because it results in the inefficient use of resources and may have deleterious effects on the quality of the environment.

The second philosophy advocates use of specific fertilizer formulations that alleviate site-organism limitations and meet managerial objectives. This more responsible philosophy implies a greater expenditure of time and funds to obtain the necessary information upon which to base decisions about all aspects of an efficient fertilization program. With this philosophy, the management objectives and site conditions become the driving forces in the decision-making processes. The proper diagnosis of possible fertilizer needs may be the most time-consuming and expensive portion of such a program. This may be appropriate, because proper diagnosis is the key to success of a fertilization program in meeting management objectives. This philosophy is compatible with today's concerns for environmental quality.

FOREST SITE -- ORGANISM RELATIONS

Site, as considered historically, is synonymous with the term "environment". It is defined as the sum total of all factors and substances affecting the growth, structure, and reproduction of an organism. This includes both the physical and biotic aspects of the environment.

A particular site may be considered as an energy system. Energy assumes several forms, including chemical, radiant, and thermal; and conversion from one form to another is possible — for example, radiant energy to chemical energy, or chemical energy to thermal energy. As stated in the Law of Conservation of Energy, energy cannot be created or destroyed; it can only be redistributed or changed in form. Thus, in a given geographic area, natural production of the biota, whether macro- or micro-plants or animals, will be limited ultimately by the energy level available in that area.

Traditionally, cultural treatments to forested areas — such as thinnings, weedings, or animal-population control — are manipulative mechanisms designed to redistribute the available energy to favor certain desired portions of the biotic community. However, cultural treatments such as fertilization are designed to change or add to the level of energy in a given area.

The utilization of the energy level on a site depends upon the total complex of organism and community characteristics and influences. In considering the impact of the physical environment on organisms, one must consider the roles of the physical environmental factors according to the concepts of limiting factors, compensating factors, and the holocenotic environment, along with the implied temporal and spatial significance embodied in these concepts. The concept of the holocenotic environment, in particular, recognizes that interactions take place among the environmental factors and between these factors and the organisms in the environment. Therefore, each factor must be considered in relation to all other factors and the tolerance limits of the organisms.

Site-organism relationships include interactions at the organismic and community levels. The adaptability of an organism to a site depends upon its requirements, tolerances, and efficiency. *Requirement* refers to the quantities or intensities of the energy and physical environment factors, including nutrient-element levels, required to sustain life in the organism at some near-optimum level. *Tolerance* refers to the resistance of the organism to excess or deficiency of one or more of these environmental factors. *Efficiency* refers to the capacity of the organism to utilize these resources of the site.

The composition of a forest community depends not only upon the site-organism interactions, but also upon the ability of organisms to compete effectively for the necessary energy. Competition within the community occurs as intraspecific competition and as interspecific competition. Competition in all plant communities occurs both above ground and below ground, and the importance of each type depends on the stage of community development — for example, tree seedling-herbaceous growth competition, interspecific tree competition, etc.

FOREST SITE ASSESSMENT

The objective of cultural treatments, whether they be energy-manipulative or energy-additive, is to change the character of the site to meet certain objectives. Determination of whether or not these objectives have been or can be met efficiently depends on quantitative assessment of the site and site-organism relations, both before and after treatment.

Thus the quantitative assessment of forest site is an essential initial phase of a successful and responsible forest-fertilization program to determine: (1) the nature and degree of the site limitations, and (2) what must be done to meet stated objectives. Similar quantitative assessment is also essential after treatment for evaluating the degree of success attained.

For a successful fertilization program, therefore, it is essential for managers to understand the site conditions sufficiently so they can ascertain: (1) whether nutrient-element limitations are controlling the quantity or quality of goods or services, and not some other environmental factors, physical or biotic in nature; (2) what the specific nutrient-element limitations are; and (3) what are the appropriate or efficient levels of the nutrient elements to add to correct the limitation.

Fertilizing a site triggers a host of complex and dynamic events, the results of which eventually affect the objectives sought if the treatment is to be considered a success. However, this measure of success may not occur until a few years after treatment, depending upon the nutrient elements involved and the site-organism relations. An appreciation of these events and an understanding of the processes involved are essential inputs into management decision-making. This knowledge can be gained only by using stringent quantitative assessment techniques designed to monitor the total environment and site-organism relationships.

Forest fertilization may be used for a great variety of reasons, and the measure of response depends on the treatment objectives — timber production, seed production, vegetative erosion control, vegetation health and vigor, browse production, etc. Each objective requires its own evaluation for possible fertilizer needs and measures of response. Though many examples could be described, it will suffice to say that, where control of abiotic diseases is the objective, measures of increased wood production may not be appropriate. Or, where establishment of vegetation to control trail, road, and riparian erosion hazards is the objective, measures of water quality and quantity may be very appropriate.

Regardless of the measures of response and the objectives that are sought, the adequacy of sampling, the accuracy and precision of the analyses, and the interpretation of results pose numerous problems. Questions about what, how, and when to sample, the types of analyses employed, the actual expressions of results, the interpretation of results, and the extrapolation of interpretations need careful consideration. Recognition of spatial and temporal variations in relation to site-organism conditions as well as type of treatment is essential.

INCREASED WOOD PRODUCTION

Site Assessment

If we restrict ourselves to only one of many possible objectives for a forest-fertilization program — say increased wood production — we have a sufficiently difficult task to consider. Fertilizer additives have a marked effect on the entire ecosystem, and in time they will cause in the system various changes besides the response that is sought. The magnitude of these changes depends on the site conditions, organism characteristics, and other cultural practices performed in conjunction with the fertilization program.

Researchers have for too long selected the least productive sites for making fertilizer trials. Trials on such sites are extremely valuable when accompanied with detailed monitoring of the environment and organisms, because they contribute to the body of knowledge in physiological ecology. But forest managers would not concentrate their fertilization program efforts on such sites. For an economic gain, fertilization programs that increase product quantity or quality from "good" to "very good" on a relative scale are far better than those that result in an increase from "very poor" to "intermediate".

Therefore the expression of treatment responses in relative terms alone is of limited value. If we say that 100- to 200-percent responses in increment can be obtained with a particular fertilizer additive on a particular site, this is of limited practical significance without specific reference to absolute increment data. The old adage, "100-percent increase of near-nothing is still near nothing", applies in this case.

The future of forest-fertilization programs to obtain increased wood production depends upon evaluation in terms of absolute responses in merchantable products. We must learn to evaluate forest-fertilization programs to determine the feasibility of converting relatively good sites to still better sites, of increasing marketable yield, of improving marketable product quality, of shortening rotations, or of meeting whatever the management objectives may be.

This places additional burdens on researchers because it requires more sophisticated site-evaluation techniques and experimental designs to quantify a statistically significant, modest relative response as may be expected of good sites to make them still better, than those required to demonstrate a large relative response as may be the case on very poor sites to make them intermediate in productivity. Yet this so-called "modest response", if real (*vs.* an artifact of the design and procedures employed), may provide the margin that would make the fertilization program important to management.

These burdens on researchers also include consideration of several other factors, including measurement techniques and diagnostic criteria. Responses should be measured in actual units upon which the decision-making processes hinge — volume, dry-weight, etc. — rather than diameter at 1.5 m, height or height increments. Many of the currently used indirect measures are not reliable or sensitive enough to be used to precisely measure increased marketable yield. Careful judgment must be made on the intensity of response measurements and the practical or economic feasibility of such measurements. This latter point implies consideration not only of the type of instrumentation used, but also of the frequency of measurements and the time-from-treatment effects.

The state of the art today does not permit the determination of specific nutrient-element needs based on current site-evaluation techniques. Current site-classification schemes have developed at two intensity levels. The first of these, in vogue in the past two decades in the United States, is the *extensive* scheme that utilizes primarily the readily measurable edaphic and physiographic variables, with emphasis on soil moisture availability as the determinant of site quality. Few of these studies include soil fertility considerations. This type of scheme has concentrated on indirect measures — soil texture, structure, depth, color, etc. — of the prime properties of site that are of major importance to organism needs, rather than on the energy relations and the moisture, aeration, and nutrient element availabilities. And some indirect measures of site conditions are often not included in the extensive classification that do have importance in the nutrient-element status; for example, degree of erosion or magnitude of previous land use or abuse.

The other intensity level is represented by the very detailed *intensive* studies of the growth requirements of a particular community on a particular site. This involves considerable monitoring of the organisms and environmental variables. Neither scheme, extensive or intensive, has direct applicability to the evaluation of large areas for fertilization; the first is too general and the latter is to restrictive. The role of classification of sites for operational forest-fertilization programs should lie within these extremes; it should be intensive enough to provide adequate information for fertilizer prescriptions and extensive enough to make this information applicable to large areas.

Appropriate diagnostic techniques must be developed to fulfill these site-classification criteria. For many years it has been advocated that the only positive test for determining nutrient-element needs is to establish fertilizer trials of appropriate design to evaluate the need for various nutrient elements, singly and in combination. However, such trials have limitations due to the length of time required to obtain results, the sophistication of response measurements, the determination of duration of response, and the dependency upon year-to-year variation in the physical environmental conditions; for example, precipitation amounts and distribution patterns.

Various diagnostic techniques such as greenhouse cultures, vegetation visual symptoms, and soil and plant tissue analyses are being used with varying degrees of success, depending on their intended use. However, all these techniques have interpretive limitations in determining the need for fertilization and the responses to it.

Effects of Treatments

As previously stated, addition of fertilizer to a site results in a host of complex and dynamic changes, some sought in the managerial objectives and some possibly detrimental to those objectives. This type of treatment can affect the composition of both the macro- and micro-biota of a forest community by altering competitive-efficiency relationships within the community and by changing vegetation succession trends.

In such cases the benefits of increased wood production of the desired tree species may be offset in part by the possible stimulation of competitive organisms, which require additional cultural inputs to counteract this undesirable side effect of the fertilization treatment. Such complementary treatments as brush control, disking the sod, thinning, and chemical treatment of understory vegetation also have an influence on the objectives sought; and the magnitude of their influence depends on the total environmental conditions of the area. Forest-fertilization programs must be considered as integral parts of the long-range management considerations for the area in question.

Our experiences at the Charles Lathrop Pack Forest Environmental Laboratory in New York State have indicated that the environment within a forest stand is influenced by the structure, age, species composition, and density of the stand. A more rapidly growing stand will be made up of larger trees with greater crown masses and greater root distribution throughout the soil than a slower growing stand of comparable age, species composition, and stocking. The dry-weight or biomass differences in these two stands affect the amount and distribution of precipitation reaching the ground, the wind activity, and the solar-radiation distribution as well as the patterns of temperature and humidity variation. An appreciation of these relationships helps us to understand the energy budget of the forest as it relates to the effects of cultural treatments within forest stands.

If rapidly growing and slowly growing stands receive similar energy inputs of solar radiation at the crown surfaces, they have different energy-distribution patterns within. The more rapidly growing stand would be composed of taller trees with greater crown masses, having greater surface area per unit area of land. As a result, this rapidly growing stand would intercept more precipitation; thus less would reach the understory and forest floor. Even with the greater production of biomass, this rapidly growing stand may not have a greater forest floor dry weight because of a richer soil fauna and a higher rate of organic-matter decomposition than the slowly growing stand. The net precipitation reaching the mineral soil rooting zone, therefore, may in fact remain less in the rapidly growing stand.

Turbulent air flow within the crowns of the rapidly growing stand, because of the greater crown mass and foliage weight, would be less than in the slowly growing stand.

The rapidly growing stand, which would have foliage with darker, healthier green color, would absorb more of the incoming solar radiation; and the proportion of incoming solar radiation that reaches the forest floor would be less than in the slowly growing stand.

Because of the larger crown mass, the rapidly growing stand would have lower maximum and higher minimum air temperatures within and below the crown. On clear summer days the slowly growing stand would warm more rapidly in early morning. By early afternoon, however, temperatures within the crowns would be similar for the two stands. In late afternoon, the sparse canopy of the slowly growing stand would cool more rapidly; and in the evening this stand would be cooler.

Below the canopy, higher air temperatures would prevail in the slowly growing stand until about noon. In afternoon the temperature below the canopy would start dropping so that by evening these temperatures would be about the same in both stands. The sparse crown in the slowly growing stand would allow continued cooling at a faster rate than in the rapidly growing stand, so that at midnight the slowly growing stand would be cooler.

In the morning, soil temperatures on clear summer days would be similar in the two stands. However, increased solar radiation reaching the forest floor will raise the near-surface soil temperature of the slowly growing stand above that in the rapidly growing stand for the remainder of the day. A similar pattern, with increasing lag time with soil depth, would persist in the A and B soil horizons. From evening until next morning there will be differential cooling in the soils of the two stands until similar near-surface soil temperatures are again reached in the two stands, in accordance with the ambient temperature.

Related to the differences in wind and temperature, the humidity in the lower crown and stem space of the rapidly growing stand would be higher. Therefore evaporation from the forest floor would be less in this stand, whereas transpiration would be greater because of tree crown and root characteristics of this more rapidly growing stand. The combination of these two water losses may result in similar moisture levels in the soils of the two stands.

The marked amplitude of the climatic variables in the slowly growing stand affects this stand's ability to utilize the energy inputs as efficiently as in the rapidly growing stand. In a sense, with wood production as the objective, energy in the slowly growing stand is wasted by being expended for non-productive purposes.

Without treatment in stands like the slowly growing stand, the inefficient system persists, and "the poor-get-poorer and the rich-get-richer". If the site conditions of the poor stand are assessed correctly by appropriate diagnostic techniques as nutrient-element limiting for near-optimum growth, proper fertilization with the suboptimal nutrient will serve as a catalyst to alter the inefficient system. Such a treatment for the slowly growing stand may trigger a conversion to that approaching the more efficient energy utilization of the rapidly growing stand.

When appropriately used on nutrient-element suboptimal sites, fertilization markedly influences the energy balance of forest stands, further demonstrating the interaction among environmental components.

RECOMMENDATIONS

A major task in developing a successful forest-fertilization program is the proper assessment of the site conditions and organism relations so that efficient site-dependent fertilizer prescriptions may be developed for the most effective and least wasteful use of fertilizer additives.

This would result in applications of the right fertilizers in the right forms at the right time at the right rate to meet the objectives sought without endangering the quality of the environment. This implies fertilizer prescriptions that would depend upon the physical environment conditions, competitive plant and animal life, and stage of development of the vegetation to be treated. Such prescriptions must also be an integral part of the long-range intensive management program for an area so that the prescription may be modified to be compatible with manipulative cultural treatments.

Site conditions determine (1) the native nutrient-element resource; (2) the complex and dynamic processes that regulate the availability of these elements in this resource — chemical and biological reactions; and (3) nutrient-element cycling. It is essential that researchers perfect the diagnostic techniques necessary to properly assess the nutrient-element resource and the processes of availability within it and effectively meet management's objectives.

Detailed information is also essential about the specific requirements and tolerances of organisms to serve as a basis for proper site assessment and fertilizer prescriptions. Of primary concern is the mobility of the native nutrient elements and those from the fertilizer additions within the soil volume in relation to the patterns of rhizospheric absorbing surfaces and nutrient uptake. Such information, together with the quantification of related site conditions, would help in management's decision-making processes.

More work is needed in greenhouse culture and soil and tissue analyses, not only to develop so-called critical nutrient-element levels of species, but also to develop the range of near-optimal levels of nutrient elements and nutrient-element interactions with total environment conditions — energy status and levels of available moisture and aeration. Such fundamental information is necessary as inputs into management decision-making processes to determine the practicality of forest fertilization that may increase the quantity or quality of goods and services.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1972-707-934/383