Better Crops
WITH PLANT FOOD

October, 1958 10 Cents

FERTILIZATION MADE THE DIFFERENCE

" . . . *In the Years to Come*"

Concerning future timber needs of our nation, U. S. Forest Service experts have said: "In thinking about growth and cut, the most important consideration should be whether there is enough of the right kind of timber to meet our current needs and, at the same time, provide the timber capital we will need *in the years to come.*"

When the American Potash Institute sent one of its staff members, Dr. E. T. York, to Europe and Scandinavia to survey the forest nutrition problems of nations that have pioneered in forest management, it had one thing in mind: To determine what role forest fertilization might play in helping America meet its growing demand for wood supplies in the years to come.

The institute's concern is based on reasonable deductions made by Forest Service experts. Assuming industrial wood maintains its present relative place in the economy, forest experts predict the total demand for wood in 1975 may be 40 per cent greater than it is today—and *twice as great* in 2000 as it is today.

Prompt and very substantial expansion and intensification of forestry in the U. S. is necessary if timber shortages are to be avoided by 2000, they say. This acceleration in forestry will have to come soon, and very largely within the next two decades—or it will be too late to meet the demands of 2000.

With such demands facing forestry, there is no danger of timber becoming a surplus crop. The problem, perhaps, is to make sure it doesn't become an inadequate crop.

In view of this, it is not unreasonable to believe that more emphasis will be put on forest fertilization in the future. We might suggest *in the near future*, because of the nature and growth of trees which require time and long-range management to produce adequate crops.

sm-editor

ON THE COVER . . .

. . . when red pine received potash on a New York plantation, its annual height-growth *doubled.*

The tree on left is from an *unfertilized* plot. The tree on right is from a *potash-treated* plot. Both trees were the same height seven years before this picture was taken.

Work by New York College of Forestry turned up areas where 200 pounds of KCl per acre increased annual height-growth of red pine *from 46 to 104%* over unfertilized plots.

Even 50 pounds of muriate per acre showed good responses. And potash was still stimulating growth 6 years after initial application.

Interest in forest fertilization is growing—and for good reason. One-quarter of all forest land is in poorly-stocked condition. Over one-third of all commercial forest land is in medium or poor productivity. Forestry experts predict we will need twice today's production in 40 years.

Americans use 5,129 articles made from wood, and the list is growing. Farmers are beginning to look on their forests as a crop, not a "mine" to be mined and left bare as the miners move on.

Such forest crop growers may soon use fertilizer as another silvicultural tool to speed up growth, increase crop yield, improve its quality, and reduce their risks.

For these reasons, the Potash Institute devotes this issue of *Better Crops* to Forest Fertilization—a new era, a new tool, an open field—interpreted by well-known authorities in forestry research and management.

Better Crops WITH PLANT FOOD

The Whole Truth—Not Selected Truth

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IS IN THE GROWTH

Better Crops with PLANT FOOD

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We enter a new era of . . .

FEEDING FOREST CROPS

Jeff McDermid

(ELWOOD R. MCINTYRE)

That new world forestry service bulletin (issued in 1957) from the State University College of Forestry at Syracuse jolted me wide awake and gave me a needful brain bath. It has about 300 pages of bibliography with abstracts on forest fertilization.

In delayed reaction, I said to myself: *"Fertilizing forests?* How far behind am I in the conservation parade—and the wood production parade? But wait a bit, confound it! I'm just where I was back there when they began to fertilize *hay meadows and pastures.* It seemed a freak idea, but we soon found out that forage fertilization was really a *boon*—not a bust. Maybe we've reached that same spot with forests—*trees and grass being our two best bets in land conservation."*

Compiled by Donald P. White, assistant professor of silviculture, and Albert L. Leaf, research assistant, the booklet has a short introduction by Svend O. Heiberg, also of Syracuse. White and Heiberg have also contributed an abstract on correcting potassium deficiency of reforested pine and spruce in northern New York. Major work on the abstracts was supplied by Dr. Antonin Nemec of Prague, top contributor in this field. Great assistance also came from Dr. Tamm of Sweden, Dr. Leyton of Oxford, and Dr. Van Goor of Holland. Cover color plates show magnesium and potash deficiency in white pine and spruce.

Anyhow, the circulation of this valuable booklet sends us scurrying to review a whole litter of questions raised when proposals to extend research in forest tree feeding confront us.

Suppose our farm cereals grew on trees. Suppose these grain trees took several seasons to mature a harvest. At what price per bushel would it pay us to fertilize these towering crops? The grower of quick growing cash crops and the patient forest and wood lot managers here come into strong contrast. To fertilize our farm wood lots and forest plantations economically poses a research riddle that must be studied and eventually solved. Forest crops are vital to our welfare. They're not only cashable five, ten, or forty years ahead—but in every passing hour of the present soil and water conserving era which we claim to uphold and perpetuate.

Studying the proper treatment of the nation's 1,185 different kinds of forest trees in relation to all sites and soils and water supplies available is a task hardly begun. And fertilization in this respect has more than mineral fertilizer as its weapon against erosion, fire damage, degraded forests, and devastated forest floor cover.

We break in here to offer a quote from Prof. Heiberg, page 9 of the new bulletin: "Many forest areas have been mistreated. Fires have burned much of the available organic matter, erosion has washed all or a part of the topsoil away, and most of the old agricultural areas open to forestry have been depleted of nutrients prior to being abandoned. It is in such areas that forest fertilization experiments have yielded the most impressive results. It is on this kind of land that forest fertilization will find most practical application."

You'll also find on scanning the new bulletin that fertility tests are more common in the forest tree nurseries and on young forests than on middle-aged and very old stands. Authorities have observed that the seeds of trees and the growing tips are rich in phosphorus. Calcium is involved in cell wall building. Potassium is abundant in the growing parts of trees and is said to have something to do with the translocation of sugars. *And without potassium in proper quantity, the tree cells do not divide for steady growth.*

Main object of the Syracuse bulletin is to report experiments in forest stands, then fertilizers for nursery management, followed with discussions included on shade trees, greenhouse and pot culture. Scientific periodicals from which most of the 690 separate abstracts were taken numbered 236, with 58 of them published in the United States.

This notable contribution comes at a strategic time. On October 27, the commemorative postage stamp for *forest conservation* was released at Tucson, Arizona, date of Theodore Roosevelt's birth. Who knows—perhaps the biggest key to future building of our wild woods resources will lie in *the further study of forest nutrition?* ◄◄◄

Sacks were designed for potatoes, not for tomatoes.

"How come you beautiful redheads marry men who are feeble, bald, nervous and weak?"

"We don't. They get that way."

A Texan had a small farm with just a few sheep. One day his wife while dyeing some bedspreads blue had a little lamb fall into the bucket of dye. A passing motorist saw the lamb with the blue fleece and bought it for $50. So the Texan figured he had a good thing going and colored more lambs which brought big profits.

"Pretty soon," he recalled, "I was coloring them pink, blue, yellow, green, lavender and you know—now I'm the biggest lamb dyer in Texas."

Quoted here, exactly as it appeared in a San Luis Valley, California, newspaper, is a little item that got us to thinking: "Always cut roses with a sharp knife or sharp garden scissors to avoid injuring the bust."

Such advice requires some thought —whether we understand it or not.

A low neckline is about the only thing a man will approve of and look down on at the same time.

All it takes to make a successful farmer is faith, hope and parity.

The little country girl said she preferred to go out with the city fellows because the farm hands were too rough.

The county agricultural agent picked up the phone when it rang with a cheery "Hello."

A woman's voice answered: "Say, I have a flock of chickens, and I want to know if I put a rooster in with my hens how long will it be before I can expect fertile eggs."

"Just a minute," said the courteous farm advisor, as he picked up the pamphlet which might have the information.

"Thank you," replied the lady as she hung up.

He: I only go out with girls who wear glasses.

She: Why?

He: I breathe on them, and they can't see what I'm doing.

He: Shall we sit in the parlor?

She: No, I'm tired. Let's play tennis.

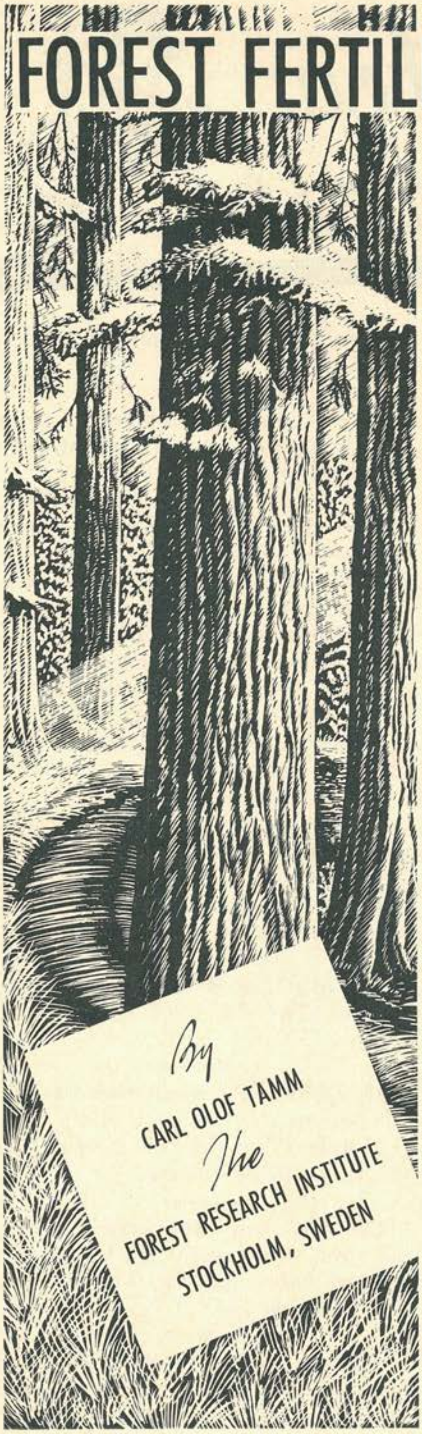
Daughter: "I'll never marry a man who snores."

Mother: "Yes, but be careful how you find out."—*Philnews.*

Ole, the yard man, sez: "Ay vonder yust how menny fig leaves Eve tried on before she sez, 'Vel Ay spose Ay'l take this von'."

When a woman meets a man who looks her straight in the eye—she'd better do something about her figure.

FOREST FERTILIZATION IN EUROPE



• *WHERE fertilizer is already an important forest treatment . . . and forest fertilization concerns mainly evergreen stands or mixed-woods.*

Experiments on fertilizing forest soils have been conducted for more than 50 years in some European countries—particularly in Germany and Belgium. The nutrition of forest tree seedlings has been studied in nurseries since the beginning of this century (Möller 1904). Yet, interest in forest nutrition is even older. This branch of research started with the classical paper of Ebermayer (1876): "Die gesamte Lehre der Waldstreu" (A complete treatise on forest litter).

Removal of forest litter for use in stables was a common practice in Germany and other Central European countries in the 1870's. Soon foresters began to note a difference in productive capacity between sites which had escaped litter removal and those regularly deprived of their litter and parts of the humus layer. Ebermayer could show that most of the annual nutrient uptake of a forest stand—for some nutrients about nine-tenths—is used to form leaves or needles and branches, while only a minor portion is immobilized in the stem.

... ITS RESEARCH AND PRACTICES

• *WHERE most hardwoods need lime and nutrients on poor sites . . . and future nutrition will concentrate on* nitrogen, phosphorus, potassium, *and* calcium.

Of course, "harvest" in the forest, removal of logs, implies a certain loss of nutrients from the site. But the loss is much less than that experienced in agriculture, because ordinary crops are much richer in nutrients than wood.

On the other hand, litter removal is bound to deplete soil nutrient reserves sooner or later, unless replenished by outside supply or by intense weathering. Although we now possess more accurate data, Ebermayer's investigations on the nutrient turnover of forest stands still constitute fundamental information on forest nutritional ecology. *The difference between forestry and agriculture as related to nutrient cycle deserves the same attention today as in Ebermayer's days.*

Much of the early work on plant nutrition, in forestry as well as in agriculture, started from the assumption that correct fertilization would replace quantitatively the amounts removed with the plants.

Ebermayer and his contemporaries found that lime was the main constituent in wood ashes. Frequently about half of the ashes of both stems and other organs could be accounted for as CaO. Soon, they also found, soil from better sites generally contained more calcium than soil from poor sites. The same was found true with tree leaves and needles from different sites. This explains why liming has played such a dominating role in the forest nutrition of Germany.

The relatively low price of lime and the experiences with conifers on former hardwood forest land are additional circumstances contributing to this fact. A serious soil exhaustion was reported and ascribed to the detri-

Dr. Carl Olof Tamm, graduate of the Universities of Stockholm and Lund, is a member of Sweden's Forest Research Institute staff. Recognized as one of Europe's top authorities on forest nutrition, he has studied the problem throughout the major forest areas of western Europe and Scandinavia.

mental effect of the acid conifer litter. The opinion is still widespread among German foresters that this development must be counteracted by liming. Although investigations by pedologists have given some support to this idea, they have found the relationships are far more complicated than first assumed.

Germany

Results of early German experiments with forest fertilization and liming were summarized by Wiedemann (1932) in an important paper, containing descriptions of 139 series of experiments. About half the experiments on Norway spruce and one-fourth those on Scots pine showed *a clearly positive effect of fertilizer treatment*.

Wiedemann concluded that on dry sandy soils in eastern Germany, where many of the pine experiments were located, artificial fertilizers would give slight effects only. After adding slash or straw, which improved the water conditions, results were better. When the supply of water was adequate, both pine and spruce reacted well to the introduction of plants with symbiotic nitrogen fixing bacteria (mostly lupines, herbs of the pea family, used for natural fertilization).

However, liming and fertilizer supply was often a prerequisite for the growth of lupines (see also Wittich 1954). A strong and long-lasting effect was observed in a pine plantation after heavy application of basaltic rock dust (Albert 1936).

For Norway spruce and Douglas fir plantations, Wiedemann recommended in the first place the use of lupines in combination with fertilizers and lime since the success of fertilization alone was considered uncertain. For pine, he emphasized the advantages of working the soil and, where possible, improvement of the water conditions existing in dry soils. Wiedemann also recommended the use of lime in spruce stands with a heavy mor layer as an "insurance" against soil deterioration, pointing out several cases where fertilization should be tried on a large scale.

A summary of reports published more recently has been made by Hausser (1953). A number of successful applications of lime, basic slag, and other fertilizers especially in spruce stands were reported between 1932 and 1953. Yet, Hausser points out that in *all Germany there are hardly more than three series of experiments where the growth of a stand has been followed over several decades after fertilization (Owingen,—effect of basic slag; Kotsemke,—effect of basaltic rock; and Neuenheerse,—effects of lime).*

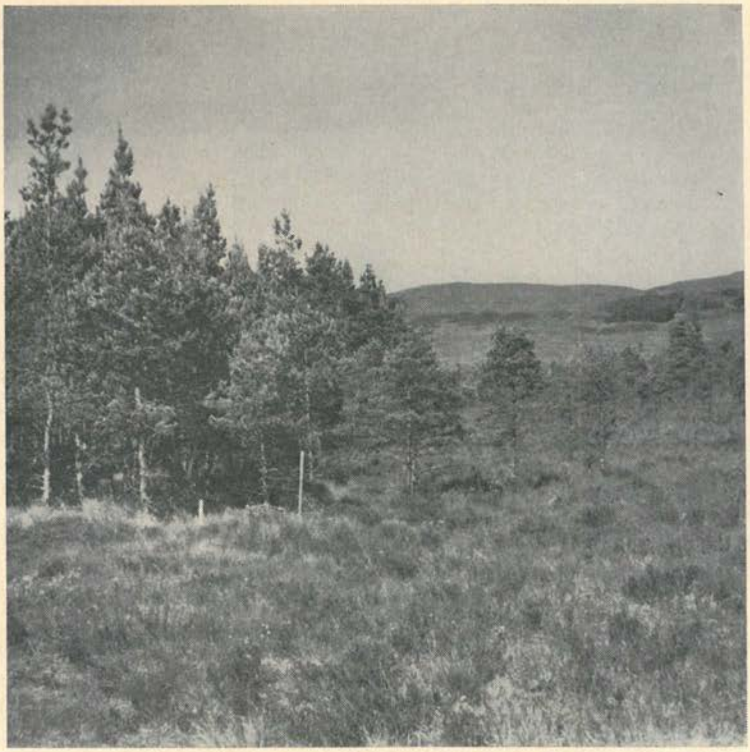
Stressing the urgent need for more systematic experiments, Hausser refers to an official plan for forest fertilization experiments, agreed on by the German forest research institutes (Anonymous 1955).

Simultaneously with silvicultural measurements on fertilized plots, detailed pedological studies have been carried out, particularly by Wittich in Hann.-Münden and his school. The joint work of foresters and scientists has largely explained what happens after different improvement treatments.

Liming benefits the activity of earthworms and soil bacteria, which prefer a higher pH than that usually occurring in mor formed beneath conifers.

Ammonia, if available in the soil or supplied by fertilizers or root bacteria, forms a relatively stable dark humus rich in nitrogen. This improves the physical properties of the soil and also constitutes a steady but restrained supply of nitrogen.

Where there is a shortness of nitrogen (a high carbon/nitrogen ratio), liming may even enhance the nitro-



Here are Scots pine planted about 1928 in Scotland. The trees on left were planted with basic slag in the plant holes. The trees on the right were planted at the same time, but *without phosphate*. Note sharp contrast in size. (Photo by Tamm)

gen deficiency. Accelerating the humus decomposition by supplying lime may also be a disadvantage in soils with low humus content.

Pedological investigations have stimulated new field experiments with a fertilizer never before used in forestry —gaseous ammonia (Mayer-Krapoll 1956, Laatsch 1957). The ammonia should simultaneously *increase pH, stimulate soil fauna and bacteria activity, improve humus quality,* and *supply nitrogen to the stand.* Applying it, however, is technically difficult except in old stands on stone-free soils. Calcium cyanamide is also tried as a substitute for ammonia.

Simultaneously with more scientific investigations, practical experimentation has continued in different parts of Germany. Among the best known experiments are those by Lidl in south Bavaria (see Wittich 1952). Lidl has succeeded in transforming heavy mor layers in spruce forests to mull by heavy applications of lime combined with perennial lupines and (unintentionally) earthworms. Natural regeneration as well as introduction of more exacting species is possible after suitable methods of cutting, and Lidl claims to have increased yield in the stands by liming. Similar results have been reported by Trümper in Meschede (Central Germany).

Scientifically more advanced experiments have been conducted by Hassenkamp in Syke (northwest Ger-

PEATLAND WITH AND WITHOUT

Figure 1—Here, in the foreground, is peatland drained in 1910, still without trees. In the background is a plot fertilized with 12.5 metric tons of wood ashes per acre in 1926, now with a good self-sown birch stand. *(N. Hällmyren, Västerbotten, Sweden)*

many). He has also changed mor humus to mull by fertilizer treatments, most effectively by two years agricultural use before planting of clear-fellings. Lime was added after cutting, and the farm crops received normal amounts of artificial fertilizers. Due to the special economic conditions in Germany during the thirties and forties, this system was profitable. Lime was also used in stands to change humus form and to improve growth and natural regeneration (the latter particularly in beech stands). (It now appears that some of the most rapidly growing pine stands in Hassenkamp's experiments are severely attacked by root-rot, *Fomes annosus*. The causal relationships are not yet known, but it is a common experience in Scandinavia and elsewhere that the risk of Fomes attacks is highest on *old agricultural land*.

Although the treatments certainly increased growth, Hassenkamp has recently abandoned liming and soil working in conjunction with pine and spruce regeneration. Deciduous species, however, cannot be established on acid-poor soil without such measures. Hassenkamp has also laid out experiments with basic slag and other fertilizers in order to transform the mor layer without liming.

Lime and fertilizers are now used on a large scale in German forestry, even if many do recommend "natural silviculture" such as soil improvement by admixture of certain tree species and by avoiding clear-fellings and even-aged stands. But these people begin to realize the desired species *often cannot grow without liming and other treatments*.

On the other hand, they believe some of the most ardent liming advocates are ahead of science when they try to change the balance of nature.

It is clear that intensive forestry, like that in Germany, requires detailed soil mapping for deciding the right treatment for every soil. The technique for soil description is highly developed in Germany, and soil samples are taken for chemical testing in conjunction with the mapping. Yet, the interpretation of the analytical data meets with some difficulties as soon as

BOOSTING SLOW GROWING SPRUCE

Figure 2—Here are old slow-growing spruces, an increment in a basal area, resuming growth after fertilization with ammonium nitrate. *(Kulbäcksliden, Västerbotten, Sweden. Romell's data, from Anonymous)*

more detailed information is required (Laatsch 1957).

Lime and fertilizers are often spread by means of blower equipment at a fixed price per hectare. The method gives an even distribution but requires a relatively dense tractor road system.

Belgium

Already in the beginning of this century, extensive experiments with additions of phosphates, lime and potassium were laid out in Belgium forest plantations on former heathland. Results have been reported occasionally, most recently by Galoux (1954).

The greatest improvements were obtained with basic slag and, in some cases, lime, while the effect of potassium (applied as kainite) was less pronounced. The growth increase persisted over the whole observation period (up to 50 years) and corresponded roughly to two years' current growth on the pine plots and three to fours years' growth on spruce.

A slight decrease in response between the last revisions seems natural considering the small size of the plots, which does not exclude the possibility of root penetration into adjacent plots. Unfortunately, it is difficult to discuss causal relationships on the basis of these data, since some of the fertilizer treatments were combined with soil working and because of the lack of plots fertilized with nitrogen.

Forest nutrition research in other countries, particularly Britain, seems to have been stimulated by early Belgian experiments more than Belgain forestry itself. Excepting poplar management, which is combined with fertilization in most European countries, very little fertilizer usage in practical forestry has been reported from Belgiun.

The Netherlands

Much forest fertilization work in the Netherlands has been concerned with reclaiming heathlands, where basic slag and lime often proved useful.

Recently, nutrition research has undergone fast development, with fertilizer applications now considered a part of the regular silvicultural treatments on certain sites. Ranges of acidity and nutrient content of the soil have been recommended for different tree species. (Anonymous, 1957).

On sites where nutrition or pH is unsuitable for the species considered preferable from other viewpoints (e.g., moisture conditions), the deficiency can be corrected. In many Dutch soils, phosphorus content is very low, *and potassium deficiency occurs on light sandy soils (van Goor 1956 a and b)*. The striking effect of phosphate applications on some sites is probably one reason why forest fertilization has become readily accepted in the Netherlands.

From an economic viewpoint, it is much more difficult to justify fertilizer additions in countries where nitrogen is the major element limiting forest growth. Their intensive use of *all* agricultural land also makes it easy for the Dutchmen *to understand the need for nutrient supply in the forests.*

Czechoslovakia

Forest nutrition research in Czechoslovakia is very much linked with the name of Dr. A. Nemec. He has devoted a long life to such problems. Most of his papers are published in Czech, as well as several in German. Most of the reports are abstracted in English by White & Leaf (1957).

Though contributions to this field have been numerous in many countries, Nemec's work on *forest nursery fertilization* is the most comprehensive one.

Nemec has also been interested in growth disturbances on forest soils, where he tried various measures in order to improve the sites—for example, lupines with fertilizers and basic rock dust. Nemec has reported very good results with rock dust, recommending an application of two or three kgs per planting hole on mineralogically poor soils which is considerably less than that used in the early German experiment at Kotsemke.

Basic rock dust is certainly a very good mineral fertilizer for forest trees, exerting its action during a long period of the trees' life. Only disadvantage is the cost of distribution.

Other Continental Nations

From Switzerland, France and most other continental countries, relatively few reports on forest nutrition research have been published (e.g., Burger 1952, Duchaufour 1957). References to Russian work on forest nutrient turn-over are given by Ehwald (1957).

Britain

In Britain, a casual experiment with application of basic slag at tree planting was made in 1907 (see Leyton 1958). However, a clear positive response to basic slag treatment (on drained poor peat in northwest Scotland) was not obtained until 1925 (see Zehetmayr 1953).

Applying about 2 ounces of basic slag or ground rock phosphate per planting hole soon became standard practice in peatland plantations for all tree species and also in heathland afforestations for some species—for example, Sikta spruce.

Subsequent development of some peatland plantations that had received phosphate at the establishment seems to indicate *a lack of potassium (experiments are now being carried out with supply of K, Mg, and N).*

In the beginning, there were small or no positive effects of plant nutrients other than P on both swamps and heathland. Later on, many spruce plantations on heathland entered a stagnation period since nitrogen is the major limiting nutrient (Leyton 1953).

For Sitka spruce, repeated additions of ammonium sulphate or nitrochalk seem to break the check. But the short effect of these fertilizers makes the cost prohibitive. For this reason, current silvicultural practice tries to eliminate the strongest competitor for nitrogen (heather) by shading rather than a direct supply of nitrogen to the young spruce. The shading can be achieved by interplanting rows of Japanese larch, a fast-growing species demanding small amounts of soil nitrogen.

Nevertheless, a cheap gradual nitrogenous fertilizer is desired by British as well as Scandinavian and German foresters.

With the exception of phosphate application at planting and, of course, nursery practice, fertilizers are not used in practical forestry in Britain. However, nutrition research is carried on at an accelerated rate (Leyton 1958).

Scandinavia

As in Britain, forest nutrition research in Scandinavia has followed domestic lines. Two different avenues of research may be recognized, *one for peatlands* and *one for mineral soils.*

Large areas of swampland in Sweden, Norway, and Finland have challenged foresters. They soon found that large swamp areas could be changed into productive forest land by draining only. But some swamps with deep peat remained barren, or almost so, no matter how well drained.

The difference in response was caused by the low mineral nutrient content of the peat. This was shown by the results of some simple experiments in northern Sweden, laid out in 1918 and 1926 by W. Ålund, who applied wood ashes in considerable amounts on two experimental plots on a well-drained swamp with barren deep peat. A beautiful birch stand soon developed naturally within the plots, whereas the swamp surrounding the plots is still unproductive (Figure 1 and Malmström 1935).

The early experiments have been followed by many others in Sweden, Norway, and Finland. Wood ashes, as well as commercial fertilizers, have been used. While there are peatlands where the vegetation suffers from a deficiency in one particular nutrient, *as P or K,* the best results are usually obtained *by compound fertilizers (for example, basic slag + potassium salts).*

Where the peat contains sufficient nitrogen (approximately above 1.5 per cent D.W.), a strong and gradual effect is usually obtained by applying a compound mineral fertilizer. In Norway, application of NPK fertilizer has transformed low-nitrogen peat into productive forest land. However, the cost will be relatively high since the treatment has to be repeated.

On nitrogen-rich peat, as in the Ålund plots, the effect of wood ashes applied at a rate of 3000 lbs per acre lasted for about 25 years without visible decrease. The same effect could probably have been obtained by a lighter application of commercial fertilizers, *since wood ashes contain P and K in relatively low proportions* (cf Malmström 1949, and Tamm 1956 b).

Large-scale experiments are now being conducted in Sweden and Norway to determine suitable dosages for different fertilizers on various types of swampland. Although effective drainage is considered a prerequisite for good fertilization response, there are many swamps, no doubt, where the future yield will justify *both draining and fertilizer costs.* Large areas of mineralogically poor peatland have already been drained.

In Scandinavia, forest nutrition research in mineral soils has been dominated by the names of Müller, Hesselman, and Romell. Working with problems of soil and humus, they stressed the importance of nitrogen nutrition for the forests. Their field experiments also showed clear effects of nitrogen addition. The early experiments of Müller and his collaborators on heathland in Denmark have recently been succeeded by extensive experimentation in young plantations on various Danish soils. The first report is already published (Möller & al. 1957).

The effect of ammonium nitrate in old spruce forests in northern Sweden was exceptionally strong in the experiments of Hesselman and Romell Figure 2). Many experiments have been laid out in Sweden during the last few years, both in old conifer stands and in young plantations. So far, earlier results have been confirmed since the only visible effect has been obtained by nitrogen addition. Quantitative data on the yield will be available in the next few years (see also Tamm 1956 a).

Although previous liming experiments in Sweden have not given any clear positive responses limed plots are also included in some of the series. Some effect of liming has been reported from a Finnish experiment (Viro 1950).

With the exception of young plantations, where certain fertilizer usage seems probable in the future, several problems must be solved before forest fertilization of mineral soils can become common practice in Scandinavia.

The most serious disadvantage is the short durability of improvement combined with the relatively high price of nitrogen fertilizers. Many of the North Scandinavian sites where the nitrogen deficiency is most obvious have only thin humus layers, so little can be expected from treatments with gaseous ammonia or cyanamide to improve humus quality. But repeated distribution of moderate amounts of nitrogenous fertilizers by airplanes will possibly prove practical in the future.

General Comments

Use of commercial fertilizers is already an important part of the silvicultural treatments in many European countries. It is generally agreed that most hardwoods need a supply of lime and nutrients on poor sites. But on these sites, foresters usually prefer conifers. Although poplars may return fertilizer costs even on relatively good sites, the question of forest fertilization concerns mainly pure conifer stands or mixed-woods.

The element most often limiting forest growth is nitrogen. But under favorable climatic conditions it has proved possible to improve the nitrogen nutrition of mineralogically poor soils not only directly but also—and sometimes more efficiently—by indirect measures, including *additions of lime and mineral nutrients.*

In dry or cold areas, prospects for soil improvement are less favorable, unless some mineral nutrient is limiting the forest growth, as is often the case in peatland.

In various European countries, there are cases of trace element deficiency reported, from both forests and nurseries. However, these deficiences—and also magnesium and sulphur deficiencies—appear to be of local importance only.

Forest nutrition research in Europe will be concentrated in the future on the four elements, *nitrogen, phosphorus, potassium,* and *calcium.*

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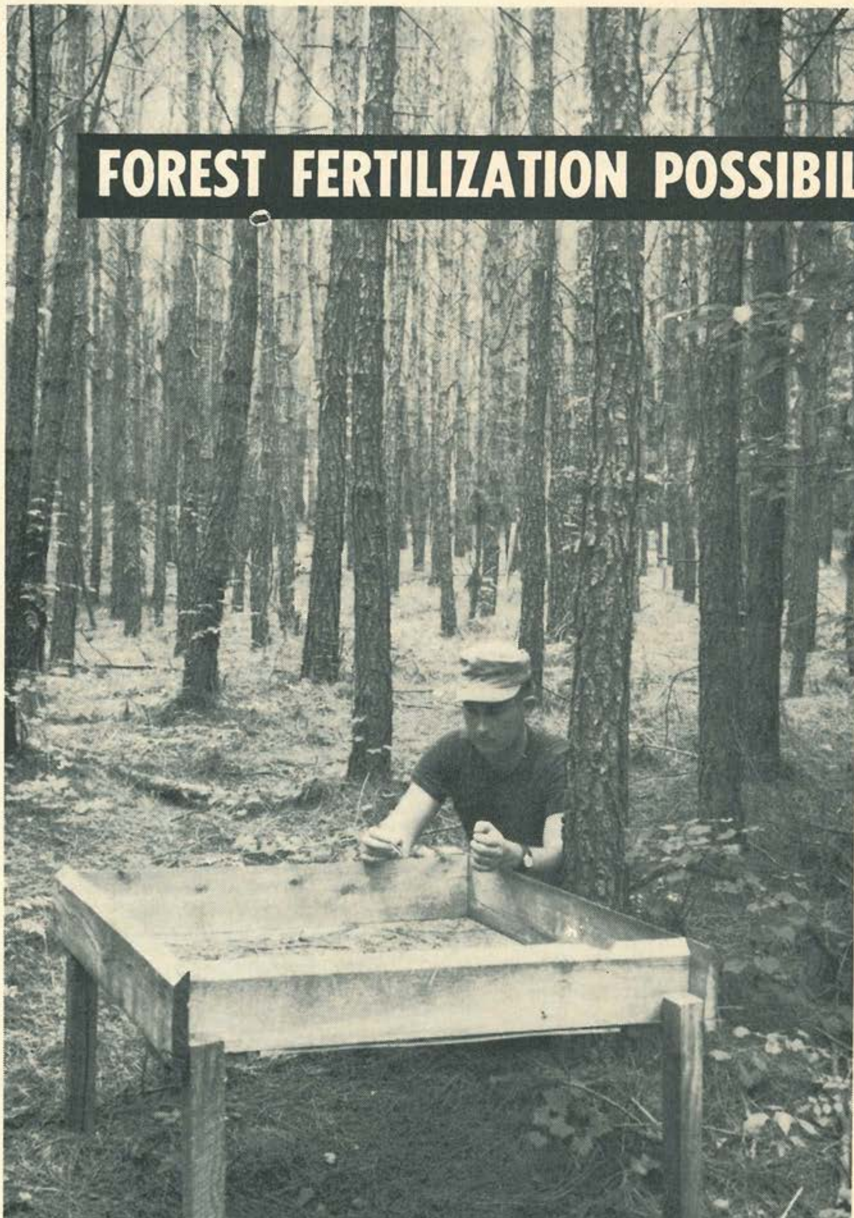
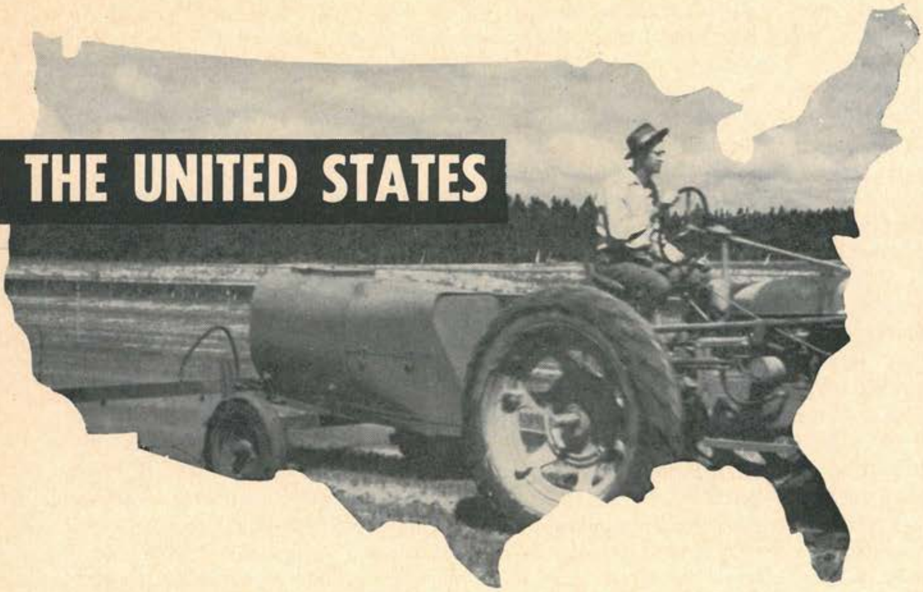
FOREST FERTILIZATION POSSIBILITIES



Here is one of the fertilized loblolly pine plots on the Hill Demonstration Forest in Durham County, N. C. Now 17 years old, this plantation was 9 years old when the first of 3 annual fertilizer applications was made. The litter trap, shown in the foreground, is one of many used to assess possible treatment effects on litter production. This is an N. C. State College School of Forestry photo.

IN THE UNITED STATES



■ *WHERE fertilizers might be used to boost plantings for erosion control . . . and to grow commercial timber crops on "beat up" lands close enough to mills and plants to cut wood transportation costs.*

■ *WHERE fertilization may pay in getting seedlings off to a vigorous start on large but low-fertility sites . . . and fertilizing established stands may be economically sound when research answers certain questions now before us.*

■ *WHERE fertilizer usage is well established in forest nurseries and has shown definite stimulation on seed production . . . but where much research must still be done to formulate efficient prescriptions and to produce consistently high quality, husky, drought-hardy planting stock.*

■ *WHERE fertilizers seem promising in production of Christmas trees and stimulation of gum flow in naval stores operations.*

By T. E. Maki
School of Forestry
North Carolina State College

Modern forestry, *or tree farming*, is rapidly moving toward the goal of using every acre of commercial forest land in the most efficient way—land that is accessible, available, and suitable for growing commercial crops of wood.

There is no clever short cut to this goal. Efficient tree growing requires many silvicultural and related practices, such as:

(1) Effective forest protection from fire, insects, and disease.

(2) Site preparation, land rehabilitation, and drainage.

(3) Seeding, planting, and weeding.

(4) Thinning, pruning, and prescribed burning.

(5) Selection and breeding to develop trees of more uniform wood qualities, better form, more rapid

growth rate, higher fecundity, greater drought hardiness, and other desirable characteristics.

And to this list we should add fertilization, which is simply one aspect of managing soils, for efficient forest production, like production of agricultural crops, results from management applied not only to the growing plants but to the soil itself.

Although foresters still select tree species, types, and practices mainly to fit the soils, future forest management may increasingly alter practices and modify sites to obtain fuller production of the most desirable species.

In this intensified program, fertilization, including liming, may likely play an important role.

Fertilization offers no magic cure-all or panacea, despite glowing results we may occasionally see reported in Sunday supplements or elsewhere. Rather, fertilization should be regarded as simply another tool available to the forest manager where and when circumstances justify its use.

Let us examine, then, under what circumstances fertilizer usage is now being made and what the possibilities for its use are in the future. In several rather distinct phases of forest production, *fertilizer usage has proved, or should prove advantageous.*

Forest Nurseries

First, of course, are forest nurseries. Some might question whether forest nurseries should be considered in a discussion of forest fertilization, but actually the only excuse for such nurseries is to produce seedlings for restocking forest land.

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As yet, a relatively small acreage of annual forest renewal in the United States is accomplished by planting, but for such acreage it is not too far-fetched to regard forest fertilization as beginning in the nursery bed.

Performance of seedlings when outplanted depends to a large extent on the kind, amount, combination, timing, and balance of fertilizer applications, and the watering program under which the seedlings are grown to plantable size.

Nursery soil management practices often influence seedling quality so much that growth rates after outplanting may differ over 100 percent, with the capacity to endure drought and adverse site conditions differing even more frequently.

Fertilizer usage is already an accepted practice in nurseries, though frequently too meager to offset the annual nutrient drain from the soil.

Maintaining satisfactory fertility levels in nursery soils usually requires higher fertilizer rates than those used on farm crops, such as cotton and corn. The dry weight of an annual crop of southern pine seedlings, for example, may well exceed 8 or even 10 tons per acre. And practically the entire crop is removed, leaving negligible crop residues in the soil.

Seedling crops of this magnitude remove up to 250 lbs. of elemental nitrogen from the soil, plus about 150 lbs. of K_2O and possibly a similar quantity of P_2O_5 per acre.

In 1957, there were over 190 forest nurseries in the United States, and 69 of these were within the 15-state Southern Forest Region.[1] These southern nurseries produced over 800 million seedlings last year, and future production undoubtedly will exceed a billion and a half seedlings annually.

Such production (even in the South, where most species attain plantable size in one growing season) requires only about 2,000 acres of nursery bed space each year. But

Here is a scrub oak ridge in the Sandhills State Forest near Patrick, S. C., as it appeared one growing season after site preparation and after a crop of watermelons had been harvested. At one time these ridges supported pure stands of longleaf pines. But through destructive cutting and wild fires, the pines failed to restock the land, permitting scrub oaks and brush to take over. Through drastic site preparation, this land is now being converted to pine that may reap benefits from both the cultivation and fertilization applied to the interim crop of watermelons.

total cultivated nursery area may be double or triple this acreage, depending on the rotation system used between seedling and soiling crops.

In any event, total acreage in forest nurseries of the South, or even the entire nation, is not large. And fertilizer application presents no special problems.

Numerous problems, however, must be solved on *basic seedling nutrition,* especially in relation to effects of nursery soil management practices on drought hardiness and other residual effects that may show up after outplanting.

Seed Orchards

As artificial reforestation rapidly expands, the shortage of seed, especially from desirable phenotypes, will undoubtedly spur efforts toward adequate seed orchards and also (as a stop-gap measure) suitable seed-production areas.

These orchards and areas will require fertilizer application rates commensurate with those used in fruit orchards, but the backlog of horticultural experience may not prove too helpful, especially on production of coniferous tree seed.

Many aspects of seed orchard development need to be intensively studied before any generalized prescriptions for efficient fertilizer use can be formulated.

We cannot readily estimate for the whole country the actual acreage eventually to be encompassed by seed orchards. Even for the pineries of the South, no accurate estimate is available, but a calibrated guess would suggest *at least 3,000 acres and perhaps as many as 6,000 acres would be involved in seed orchards when the*

FIGHT WEEDS

This slash pine planting in the Sandhill region of North Carolina shows the weed and grass-free environment that comes from deep furrowing before planting. These seedlings are in the middle of the second growing season after planting.

program is well established.

In addition, in the interim there would be a considerable, but indeterminable, acreage in seed-producing areas which are simply natural stands that have been rogued and thinned to provide enough room for development of well-spaced, choice seed trees.

Special Products

Christmas trees. The Christmas tree business in this country has grown into a multi-million dollar industry producing over 40 million trees, of which about 9 to 10 million are imported from Canada.

In recent years, interest in developing plantations for the specific purpose of supplying this market has grown on the assumption that *fertilized, evenly-spaced, sprayed, plantation-grown trees will develop into more uniform, symmetrical, and more readily saleable products.*

If present interest continues to mount, perhaps at least half of the Christmas trees marketed annually will be plantation-grown products.

Fertilizing Christmas tree plantations looks attractive on the basis of exploratory studies. On many species suitable for Yule trees, an investment in a pound or two of fertilizer may mean *one or two feet of added height in a period of 5 to 8 years, and a more healthy appearance to boot.*

Gum Naval Stores. Although the future of gum naval stores may not look too bright at the moment, improvements in mechanization and development of high-yielding strains of "turpentine pines" may cause this industry to continue to be an important

AND GRASS

This is a plot on the same plantation shown on the opposite page—an adjacent plot where the rows received a dose of NPK fertilizer before the second growing season began. Vigorous crabgrass and weeds around each seedling marks the area over which the fertilizer was broadcast. Though not readily visible, the seedlings are vigorous enough here to survive the weed and grass competition.

element in the forestry picture.

We already know that *fertilizing will stimulate gum production.* So it seems reasonable to predict that with high yielding strains, *fertilization to stimulate gum yields* will become standard practice.

Site Preparation

Substantial areas of land are now being subjected to scarification or other site preparation measures prior to planting or to expected natural seeding.

Such site preparation is frequently intensive enough to make the land suitable for growing farm crops.

In the Sandhill region of the Carolinas, for example, forest land subjected to thorough site preparation has been leased for a year to watermelon growers. Renting the land for this purpose has helped defray land preparation costs, while interim cultivation has left the soil in excellent shape for later pine planting.

Interim use of the land for farm crops obviously involves fertilizing which may leave residual effects. Such residual effects, particularly from the less mobile salts like superphosphate, may subsequently benefit the planted trees.

It may also prove practical and profitable on such well prepared land to *fertilize and cultivate the tree crop for one or more years after planting,* giving the seedlings a vigorous start in an essentially weed-free habitat.

Plantation Establishment

Fertilizing may eventually find wider use in plantation establishment, but many of the trials so far have not

Here is a gall spot—or "scald"—planted to loblolly pine and still suffering from active erosion. Although initial survival and growth have been acceptable, we are not sure these pines will ever reach marketable size. A much better program here would have included deep subsoiling, with fertilizer and organic matter (such as sawdust) put into the subsoil slits, followed by planting, with possible mulching as an added insurance. Such management costs more at first, of course, but in this case would have stabilized the soil surface quickly and enhanced the chance for a marketable crop of pine in 15 to 20 years.

been too encouraging.

Direct application at time of planting or soon thereafter sometimes threatens salt injury, especially to coniferous species. There is also the ever-present danger of stimulating weed and grass growth so excessively that the slower growing tree seedlings will suffer.

For a few aggressive hardwood species, direct fertilizer application is practical at planting time, and at least one species, *namely black locust, will respond rather phenomenally to fertilizer application.*

With either softwood or hardwood species, fertilizing at planting time, or within a few years after, seems advantageous when native fertility is not sufficiently high to stimulate vigorous early growth. Such practice, of course, depends on weed and grass growth being kept in check.

We cannot readily estimate the magnitude of such a program, but we believe in the South this type of fertilizing could make a worthwhile contribution to plantation performance on as much as *twenty per cent of the annually planted acreage.*

Land Rehabilitation

As land-use patterns continuously shift, a fairly important amount of impoverished farm land goes back to forest use almost every year. Parts of such reverted land are frequently so poor they won't produce a marketable crop of pine in the first rotation *unless drastic steps are taken to ameliorate the soil.*

Foresters have attempted to plant such lands in the bullish faith that trees, regardless of land quality, are capable of growing to economic maturity without benefit of fertilizers, mulches, subsoiling, or other ameliorating measures. *Stubborn faith of this sort has frequently been rewarded by ultimate failure.*

Frequently the cause of failure may not be wholly or even significantly due to low fertility. Quite often it may stem mainly from poor physical condition, shallow depth, or other similar factors. Problem areas of this type may total *one and a half million acres in the South alone.*

Where the soil is not too shallow, renovation of such land through a combination of physical treatment and fertilization *seems entirely practical and justified.* This is especially true where the tract is close enough to the mill or plant to mean a smaller outlay for transportation of wood, once the land becomes restored to productive forest growth.

Established Stands

In most of the situations outlined

above, fertilizer usage seems justifiable enough, at least on the basis of present studies.

The biggest question regarding fertilizer usage in forestry is in the area of stimulating *volume growth and improving wood quality of established stands beyond the seedling and small sapling size, possibly already of marketable size.*

Even here no question can be raised in situations where *known deficiencies* exist and are of such nature that relatively small amounts of one or two elements added at the right time spell the difference between success and failure. Good examples are (1) the extremely successful correction of zinc and phosphate deficiencies in pine plantations in Australia, (2) the successful response of heath and peat plantations to phosphatic fertilizers in Great Britain, (3) the response of pine and spruce plantations in New York to potassium, and (4) the response of some northeastern pines to magnesium.

But what about those situations where no drastic deficiencies are evident?

What about the hope that a moderate dosage of fertilizer might trigger a significant increase in growth rate or prolong the period of high value increment in timber stands?

What about improving the quality of wood properties through fertilization?

What about growing some desirable species on soils previously too infertile to produce acceptable growth—through fertilization?

Unfortunately, only meager evidence indicates these objectives can be economically achieved today, although *some optimistic reports are beginning to appear in some parts of the world, including our own country.*

In our studies of loblolly pine plantation fertilization on the Hill Demonstration Forest in Durham County, N. C., we have found *measurable responses* to nitrogen applied at rates

Here are the remnants of a loblolly pine stand planted on an eroded "scald" of an abandoned field 20 years ago. This plantation grew well for about 5 or 6 years, then gradually began to deteriorate and die out. The trees have failed to reach pulpwood size and are still deteriorating, as shown by the dead branches and the thin short crowns. Both the poor physical condition and *low fertility of the soil* have contributed to the failure of this plantation.

of 80 and 160 lb. of N per acre, alone and *in combination with P and K*, in each of 3 consecutive years.

Undertaken in 1950, this study is now in its eighth year. It is probably the oldest study on loblolly pine fertilization and was made possible through grants from the Nitrogen Division of the Allied Chemical and Dye Corporation.

Four different plantations were used in the study. These were 6, 9, 12, and 16 years old when the first application of fertilizer was made.

We have meaningful volume growth figures only for the oldest plantation, and these figures indicate that the best treated plots have *40 per cent more wood on them than was found on the control plots.*

Since this increase in volume was achieved only with the 160 lb. application of nitrogen, it does not yet appear to be sufficient to offset the cost of treatment, *unless there has also been a significant improvement in the quality of wood.*

For the time being, this one study has demonstrated several interesting biological responses, *but it has not yet shown sufficient promise in terms of volume and value differentials to warrant being considered as a "break through" of the economic barrier to fertilizing established stands of loblolly pine timber.*

Summary

In this article, we have attempted to point out the present use and future possibilities for forest fertilization in the United States. The picture seems to shape up like this:

1. Fertilizer usage is well established in forest nurseries, but much needs still to be learned about basic seedling nutrition and soil management to enable production of consistently high quality, husky, drought-hardy planting stock.

2. Fertilizers are being used to help develop seed orchards and seed producing areas on the basis of sketchy preliminary information that *nevertheless shows quite definitely the stimulating effects of fertilizers on seed production.* Much basic and applied research is needed, however, before efficient prescriptions can be formulated.

3. Fertilizers seem promising in such special areas as *Christmas tree production* and stimulating of *gum flow in naval stores operations, particularly where* high-yielding strains have been developed.

4. Fertilizers should be used in many situations where erosion control and soil stabilization plantings are attempted. In some instances, it may be possible to raise site quality enough to grow commercial crops of timber on "beat-up" lands, particularly near mills and plants where subsequent savings in wood transportation costs may permit a relatively substantial investment in site improvement.

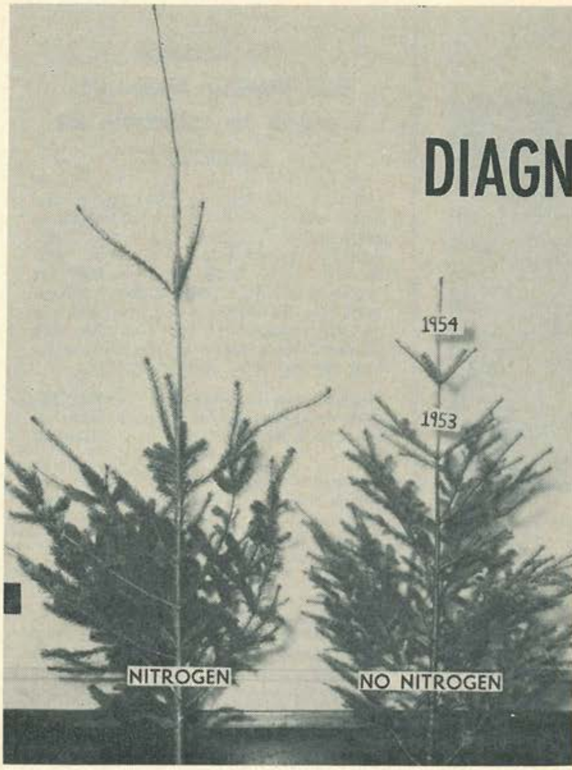
5. On a considerable acreage of plantings—particularly in the South where rainfall is usually ample and growing seasons are long—it may *prove profitable to use fertilizers at planting time or soon thereafter to get seedlings off to a vigorous start on the less fertile sites.* Also, fertilizing established stands may prove economically practical in the future when enough research information has been accumulated to answer some of the questions that now confront us. ◄◄◄

[1] Including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

For further information on the *Forest Fertilization Bulletin, a bibliography, with abstracts, on the use of fertilizers and soil amendments in forestry* —write for Technical Bulletin 81, State University College of Forestry, Syracuse University, Syracuse 10, New York

Here are spruce transplants on completely ploughed ground. No manure. Plants are in almost complete check. After another few years, they were practically all dead. Compare with good growth in parallel picture where transplants received 1 oz of slag to get them started. (G. D. Holmes photo, Forestry Commission, Forest Research Station, Farnham Surrey)

Here are spruce transplants on completely plouged ground. They received 1 oz. of basic slag per plant. Compare with poor growth of plants in parallel picture. It should be noted that the good effect of slag lasted only 3 to 4 years after which the plants went into check. (G. D. Holmes photo, Forestry Commission, Forest Research Station, Farnham, Surrey)



Here is the effect of added nitrogen to height growth and foliage of field grown Douglas fir.

THROUGH SOIL TESTS

DIAGNOSING NUTRIENT

Soil testing as a diagnostic tool is valuable, although data collection is time consuming and difficult.

Many problems must be overcome in sampling soils and anaylzing forest needs before soil tests can be used as readily as they are now used in agriculture.

Soil testing can be made into a more useful tool by standardizing procedures and relating results to nutrient absorption and use in the tree.

The general objective of modern forestry is *maximum production of quality wood from a given acre.*

Trees are being advertised as a crop and foresters are seeking the best way to grow this crop. The aim is to understand nature well enough to *accelerate production* rather than merely harvest what happens to be on the land. This management goal has caused foresters to look at their basic resource—the soil—in order to answer some of their problems.

However, the answers are not always readily available at this time. This is partly explained by the fact that in the exploitation stage of for-

Dr. S. P. Gessel, associate professor of forest soils at University of Washington, is past chairman of the Forest Soils Division of Soil Science Society of America. He has trained in both forestry (B.S., Utah State) and soil science (Ph.D., California), conducted extensive research, and published many related papers.

By

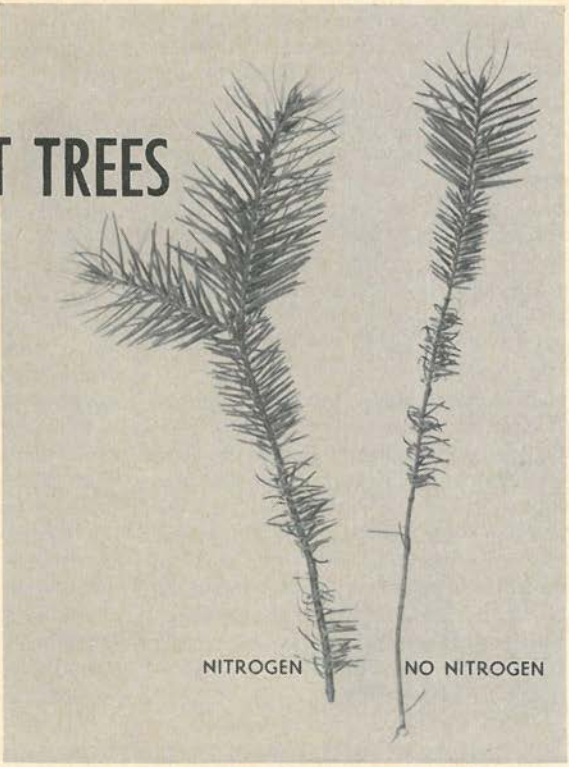
S. P. Gessel

and

R. B. Walker

THROUGH LEAF TESTS

NEEDS OF FOREST TREES



Here is the effect of added nitrogen on the foliage of field grown Douglas fir.

Foliage testing is an effective way to diagnose nutrient needs of forest trees, because samples can be taken in most forest areas and subjected to standard testing procedures.

With adequate background facts, nutrient needs for maximum growth can be interpreted.

The practicing forester can usually relate foliage composition to foliage color, crown density, and general health-appearance of the trees—making the findings more useful.

estry, basic physiological and soils problems have been neglected.

Foresters have usually been interested in practical answers to everyday problems, so that improvement of soil conditions and the understanding of processes of plant growth have seemed to be outside the realm of practicality.

In addition, forest trees have usually been assumed to have mysterious powers that enable them to grow vigorously on the most infertile soils, requiring only water to accomplish this growth. In most older literature, trees have been described as a soil conserving crop and nutrient needs considered unimportant.

College of Forestry

and

Botany Department

University of Washington

Dr. Richard B. Walker, associate professor of botany at the University of Washington, has conducted nutrition reseach on coniferous species of the Pacific Northwest. Among the courses he teaches is one taken by all forestry majors. He earned his B.S. from Illinois, his Ph.D. from California.

With land management becoming intensified, foresters and forest research workers are beginning to look more critically at forest production in relation to the forest environment. Forest site-forest soil studies have been and are being made in many areas. Such studies have caused foresters to look at forest growing conditions closely. Many obvious general relationships *between soil properties observed in the field and forest tree growth* have been put into practical use through such studies.

However, many forest production ratings, based on physical soil properties, have considerable prediction error on some soils. In fact, some soils may appear to be well suited for trees but produce very poorly. Soil-site studies have also highlighted the fact that not all growth problems can be explained on the basis of soil physical properties. Many workers throughout the world have begun to consider the nutrient needs of forest trees.

For example:

(1) Solution and pot cultures using forest trees have demonstrated elemental needs for various species and approximate levels in some species.

(2) Field fertilizer trials and related soil studies[1] *have demonstrated marked growth responses to various fertilizer elements on certain forest soils in many areas of the world.*

(3) A recent summary by Rennie[2] *has also shown that nutrient uptake by a managed stand is considerable and that a forest crop can produce an appreciable drain on the soil.*

Obviously, then, the modern forester needs to consider the mineral elements essential for tree growth and how his forest soil can or cannot supply these elements. To do this, he must have some means to diagnose the nutritional need of his trees.

Forest research workers have been attacking this problem for some years and there have been many examples of corrective actions, as other articles

Western red cedar foliage grown in *low nitrogen nutrient* solution.

Western red cedar foliage grown in a *Boron-lacking nutrient* solution.

in this journal indicate. But most of these actions resulted from trial and error procedures. The main purpose of this article is to deal with *systematic methods for recognizing or predicting nutrient needs of forest trees,* thus minimizing the dependence on trial and error.

Diagnostic Procedure

Fortunately, the forester has a considable *background of information to* serve as a basis for diagnosing needs of forest trees.

Agriculturists have worked on nutrition problems for many years and have evolved two basic approaches—(a) *soil testing* and (b) *foliar analysis.*

Problems of application to field diagnosis have not been completely solved in either approach and certainly not all results are transferable to forestry, but the principles have been worked out. Let us examine how these approaches can be applied to forest problems.

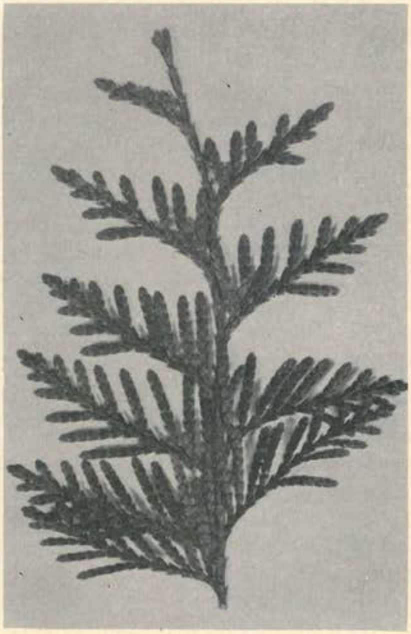
Soil Testing

It is quite conceivable that a balance sheet of soil chemical composition should be useful to predict needs of plants growing on a particular soil. This approach has been explored by many workers and used with considerable success in certain areas of agriculture when related to yield data and fertilizer response.

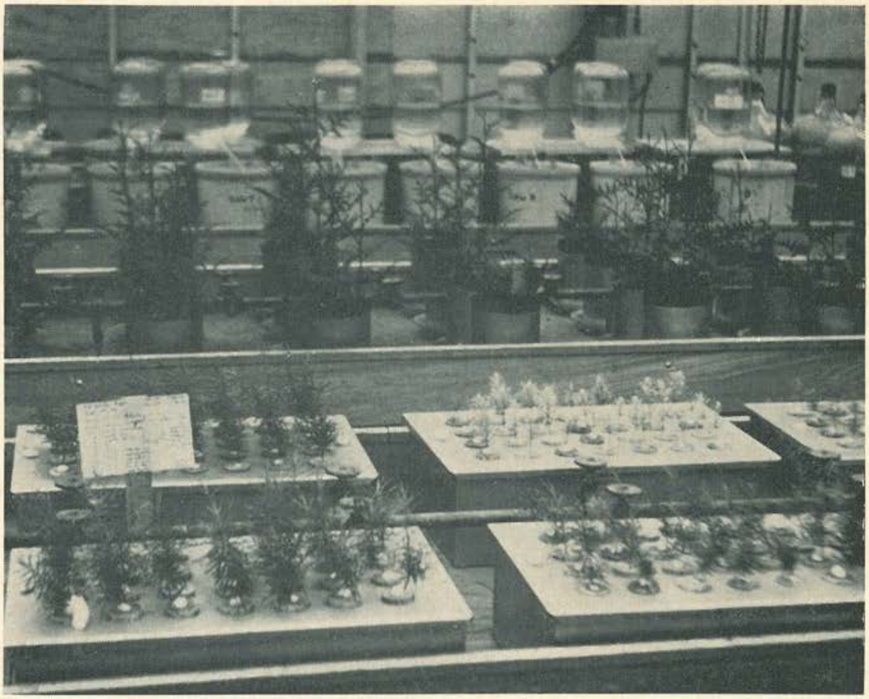
However, this approach also has many difficulties, and we are not in a position to correctly diagnose forest nutrient needs on the basis of a simple soil test. In fact, foresters have often been misled by soil testing results into thinking nutrient levels should be adequate to support forest trees.

In the first place, this type of diagnosis requires a rather complete understanding of how forest trees absorb and utilize elements and what the basic nutrient requirements of each species are. Although we may know the quantity of elements in a forest soil, we are not able to relate this to

Western red cedar foliage grown in a *low magnesium nutrient* solution.



Western red cedar foliage grown in a *complete nutrient* solution.



Greenhouse setup for nutrient requirement studies of forest trees.

needs of the tree except in a very few cases.

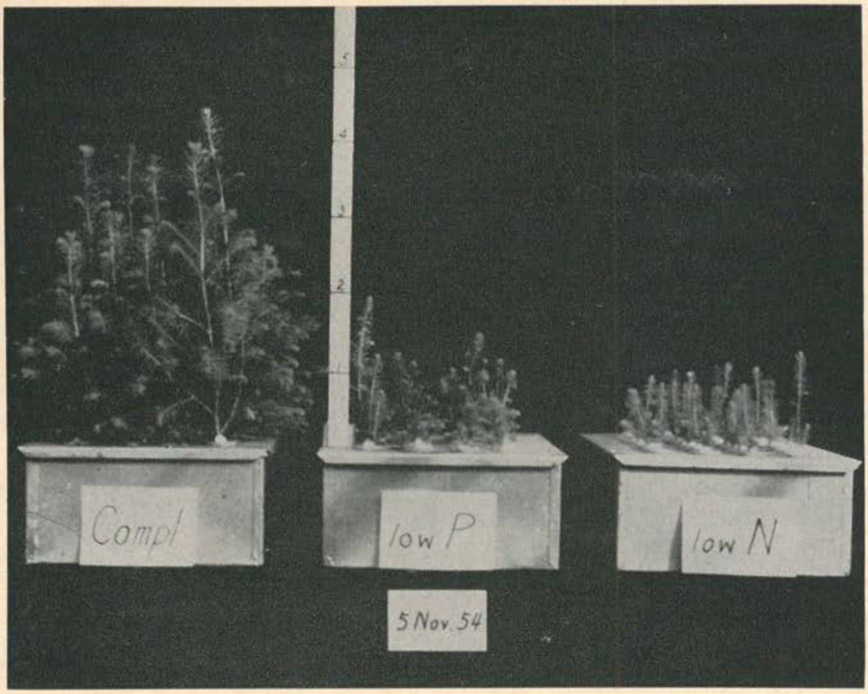
A partial substitute would be fertilizer response of each species on soils of known analysis. Adequate (detailed) information of this nature is not available at the present time. However, some of the presently successful employment of fertilizers to forest areas originated with known fertilizer responses on tested soils.

The soil test approach is further complicated because basic studies have not progressed to the point that we know *what portion of the soil to sample to reflect the needs of the tree*. For example, most research workers in forest soils would not want to predict which soil layer must be sampled for this purpose, or what the total depth to forest areas of soil sample should be.

We do have fairly definite evidence that the elemental composition of one particular soil layer does not tell the complete story. The sum of all elements within the profile is a much more useful value and probably more adequately reflects the ability of a tree to secure nutrients from a soil.

The forest soils worker must also deal with a very perplexing problem of sampling to represent a given area. Forest soils are frequently quite variable, even within the same defined soil unit. This is especially true if the area has had logging disturbance. This variation, coupled with the time and expense required to properly test a soil, imposes a sampling limitation that is difficult to overcome.

Another extremely difficult problem is what type and method of testing to use on the soil samples. A large number of availability tests for various elements have been worked out and used successfully for agricultural plants. But we have reason to believe these do not apply in the same manner to forest crops.



Sitka spruce grown in different nutrient solutions.

Each tree species would probably require a different standard availability test. These tests also have greatest value when related to a program of field fertilization and response. Some work of this nature is now being carried out in forestry, but many years of data must accumulate before availability tests will be very useful for diagnosis.

Mycorrhizal relations of forest trees probably affect these availability concepts very markedly. We know this is the case with phosphorus and probably with many other elements. For example, *much of the phosphorus available to a Douglas fir tree is not available to lettuce plants*. Therefore, the whole *concept of availability of elements in soils* has to be modified, or at least substantiated for forest trees before soil results from these tests can be applied to diagnosis.

The alternative is to use some type of a total element analysis, assuming that trees are able to extract more of certain elements than cultivated plants. In some cases, notably with phosphorus in Australia,[3] this has been done successfully. The same investigator is attempting to work out similar procedures for phosphorus in forest soils in British Columbia.

This does not mean that soil testing is not a valuable aid in diagnosing nutrient needs of trees. It is—and will become more valuable as correlation work on soil testing and forest growth proceeds.

We have notable examples of success. At the University of Washington we feel we can predict nitrogen needs of Douglas fir on the basis of total soil nitrogen. All results indicate that if nitrogen content of the soils is less than 0.10 or 0.12 per cent, Douglas fir will suffer a nitrogen deficiency. This does not rule out the possibility of nitrogen deficiency in

(Continued on page 34)

Ground limestone is blown into a growing stand of trees—a European practice.

Part of the
no fertilizer.
The trees on
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"IT IS WRONG TO SAY FOREST FERTILIZING IS UNN

Due to compact forests that must serve over 70 million people in an area smaller than Texas, Germany has traditionally pioneered in good forest management. And one of its best known authorities in this field is Dr. W. Wittich of the Soil Science Institute in Hann Munden, Germany. *Better Crops* wrote Dr. Wittich for his comments on forest fertilization in Germany. And we were honored to receive the facts presented here.

Dr. Wittich contends, "It is entirely wrong to say that forest fertilizing is unnecessary, believing that the soil profile—even when the ground rocks are poor—will be adequately enriched in plant nutrients by the activity of the roots and the falling leaves and so forth."

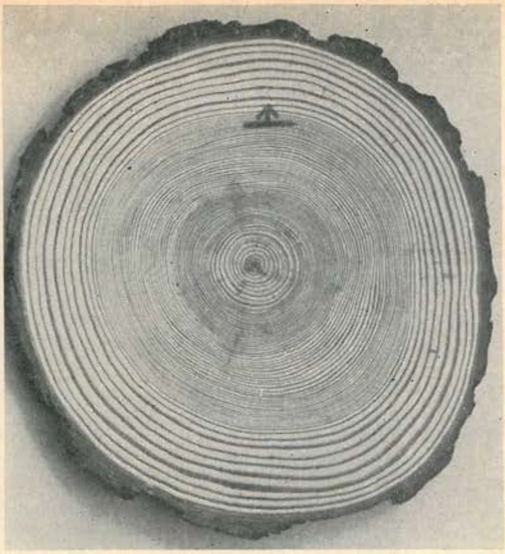
In modern German forestry, he reports, fertilization has become a rather common means of developing better soil conditions. Liming is already used on a large scale to increase biological activity in bad humus types. And he says it is preferable to lime growing stands, because the trees will use the mobilized plant nutrients.

Uncertain results of many old fertility trials are easily explained by (or due to) deficient plans and poor experimental techniques, he says.

"To get results of fertilization," Dr. Wittich concludes, "we need more knowledge about soil fertility at different places—that is, how much above or below optimal conditions are different nutrients. As yet, we are not able to make *entirely reliable* diagnoses—but we know some limiting values. And when results from new trials come in, we will get much better possibilities of fertilizing in a proper way."

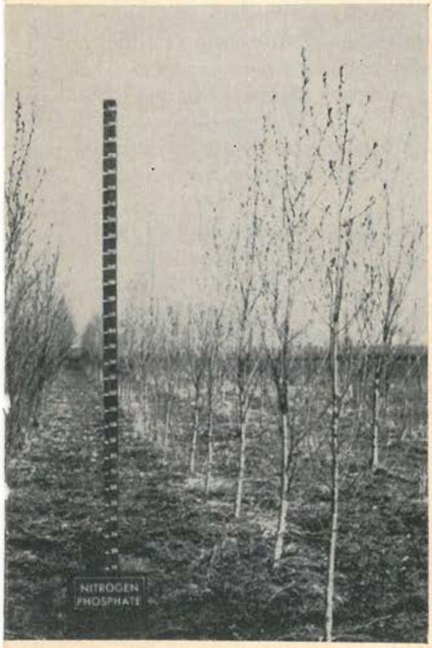
This experimer
of *balanced* fertiliz
When muriate of p

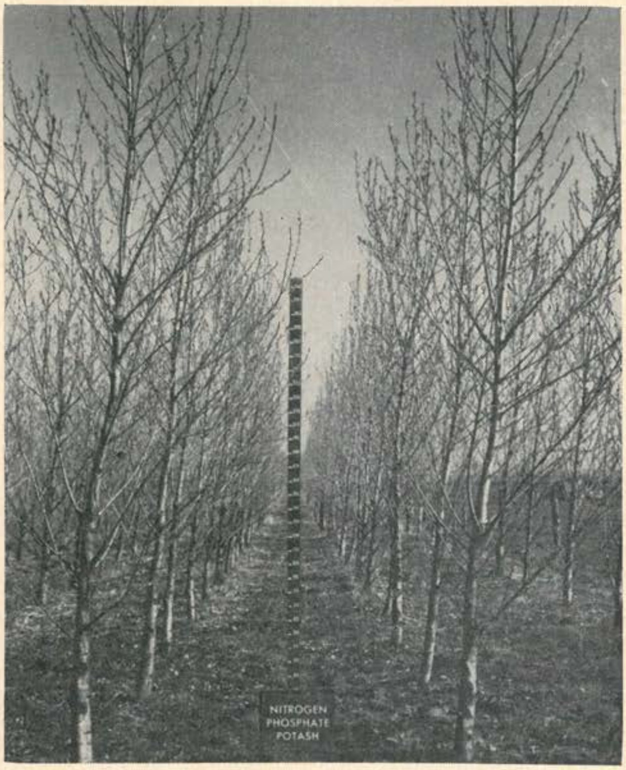
forest in this scene received fertilizer and part The wood in the center received *no* fertilizer. each side of the center were fertilized with *200 potash salt* per acre at planting. Note the sharp growth and height.



Here is a section of pine from a stand where mosses, etc., were removed for litter. When *perennial lupines* (providing natural fertilization) were introduced to the stand 4 years ago, the pine's growth increased rapidly, shown by the rings.

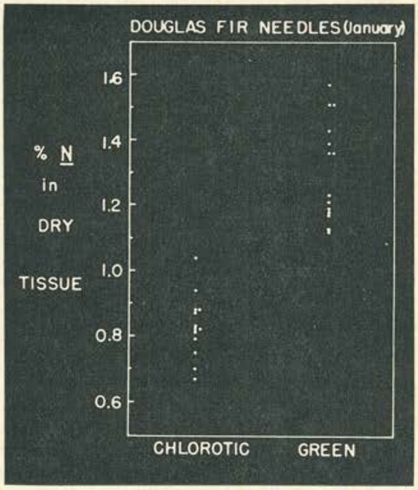
IECESSARY"





it—laid out in 1953 at the State School and Experiment Institute at Weihenstephan in Franzheim—shows the effect zation on growth of poplar trees. With only nitrogen and phosphate (left), growth was limited in this instance. otash was added (right), growth picked up. The contrast speaks for itself.

Continued from page 31—



Nitrogen content of chlorotic and green naturally grown Douglas fir.

trees on soils of higher nitrogen values, *if the biological decomposition cycle is slow and nitrogen accumulates in raw humus.*

In summary, soil testing as a diagnostic tool does have definite value even in the sketchy stage of our knowledge. However, collecting data on the soil is time consuming and difficult. Many problems have to be overcome in soil sampling and the interpretation of analytical results in terms of forest needs before soil tests can be used as readily in forestry as they are now used in agriculture.

We must continue to secure data on forest soil composition, but use results with caution at the present time.

Foliar Analysis

An obvious alternative approach to diagnosing elemental needs of forest trees is foliage analysis, which is simply collection and analysis of tree foliage.

As in the case of soil testing, foresters can draw on a broad background of experience developed in agriculture,[4] as well as some useful work along these lines using forest tree species.[5] But we should point out that *most of the forest tree work has been in plantations and not in natural stands.*

Foliar analysis has a number of obvious advantages, if we assume that elemental composition of given tissues reflects the ability of a soil to supply the needs of trees and also the ability of the tree to extract nutrients from the soil. Such results are even more valuable if there is a quantitative relationship between *composition* and *growth rate.*

Foliage material is relatively easy to collect and testing is more straight forward and more subject to direct interpretations than in the case of soils.

Foliage analysis can also be directly related to visual symptoms involving color and morphological development, and the results combined into a simplified table for direct field diagnosis. Some data on this kind will be presented later covering certain tree species.

In greenhouse cultures, for example, we know that visual symptoms of chlorosis, the content of nitrogen in foliage, and rate of growth are closely related. Growth rate is markedly reduced by a critically low level of this nitrogen and rises with increasing concentration in the foliage, but at a diminishing rate. At high levels of nitrogen, no further increase in growth rate is noted, and depression may even be evident.

Data from larger trees sampled in conjunction with field fertilizer treatments indicates the same trends. Douglas fir growing in western Washington under natural conditions may have a foliage nitrogen content of 0.8 per cent. When 100 pounds of nitrogen per acre are added, this will rise to 1.5 to 2.0 per cent. In this case, nutrient concentration in the foliage provides a quantitive estimate of nutrient availability and growth, as well.

But foliar analysis is not free from problems. In practice, foliage sampling and foliage analysis procedures must be carefully standardized. The *age of the tree* (and needle in the

TABLE 1. DEFICIENCY (AND OPTIMUM) LEVELS OF NUTRIENT CONCENTRATION FOR TREE SPECIES.

Species	Age (Years)	Deficiency level per cent	Optimum level per cent	Authority
Pinus sylvestris	1		N 3.0	Gast (1937)
Pinus sylvestris	1	Mg 0.078–.095		Nemec (1942)
Pinus sylvestris	Adult	N 1.2 –1.3 : P .08		Tamm (1954)
Pinus strobus	1	N .70–1.33 : P .10–.28	N 3.26 : P .67	Mitchell (1939)
Pinus strobus	1	K < .82–1.02 : Ca .23–.24	K 1.72 : Ca .33	Mitchell (1939)
Pinus strobus	≲25	K < .34		Heiberg and White (1951)
Pinus resinosa	≲25	K .34		Heiberg and White (1951)
Pinus resinosa	≲25	Mg .08– .12		Stone (1953)
Picea abies	Adult	N .8 –1.0 : P .06		Tamm (1954)
Picea abies	≲25	K .13– .21		Heiberg and White (1951)
Picea glauca	≲25	K .13– .21		Heiberg and White (1951)
Quercus borealis	47–59	N < 1.87	N 2.46–2.47	Mitchell and Chandler (1939)
Q. alba; Q. montana	47–59	N < 2.22	N 2.72–2.80	Mitchell and Chandler (1939)
Populus tremuloides	35–45	N < 2.00	N 2.64–2.77	Mitchell and Chandler (1939)
Acer rubrum	47–59	N < 1.70	N 2.55–2.68	Mitchell and Chandler (1939)
Hicoria glabra	40–59	N < 1.75	N 2.37–2.42	Mitchell and Chandler (1939)
Acer saccharum	40–59	N < 1.75	N 2.77–2.85	Mitchell and Chandler (1939)
Fagus grandifolia	45	N < 1.95	N 2.77–2.85	Mitchell and Chandler (1939)
Nyssa sylvatica	47–59	N < 1.83	N 2.75–2.85	Mitchell and Chandler (1939)
Fraxinus americana	40–59	N < 2.01	N 2.80–2.86	Mitchell and Chandler (1939)
Liriodendrum tulipifera	57–59	N < 2.15	N 2.97–3.02	Mitchell and Chandler (1939)
Tilia americana	40–59	N < 2.32	N 3.12–3.15	Mitchell and Chandler (1939)
Betula spp.	Adult	N 1.8 –2–1 : P .08–.10		Tamm (1954)
Pseudotsuga menziesii	Adult	N 1.2	N 2 – 2.5	Gessel and Walker (1955)

case of conifers), *season of sampling*, and *position in the crown* are all variables that must be controlled to insure adequate and reliable comparisons.

Leyton [2] as well as White,[6] have recently considered problems of forest foliage sampling in some detail. Their results indicate that in trees other than seedlings sampling should be standardized by removing the needles *from the top two or three whorls of the tree*. Current growth sampled in the fall of the year gives the best results. The foliage should be oven dried at 70° – 80°C as soon as possible after sampling, then ground and stored free from contaminants. In the case of conifers, needle tissue should be separated from twig tissue and only the needles used.

Testing procedures on tissue are standard enough that they will not be considered in this review.

Sampling from the top portion of the crown of large trees presents a problem. If trees are being cut for intensive mensuration studies, then the sample is easily taken. Another

TABLE 2. YIELDS AND MINERAL COMPOSITION OF WESTERN RED CEDAR PLANTS GROWN IN TANK CULTURES.[6]

Treatment	Yield per tank (dry g.) Shoot	Root	Total	Mineral composition of dry foliage (m.e. per 100 g.) Ca	Mg	K	Na	SO_4	N (per cent)	PO_4 (per cent)	Fe (ppm)	B (ppm)
Complete	71.5	19.0	90.5	52.0	19.2	46.3	....	20.7	2.64	1.23	325	90
–B	62.7	17.1	79.8	47.2	20.6	44.5	....	....	2.65	1.27	...	12
–Fe	51.8	15.8	67.6	47.2	19.7	58.6	....	....	2.73	1.31	304	..
Low N	11.8	10.8	22.6	72.0	25.3	61.2	....	....	1.54	0.81	...	..
Low P	30.3	13.7	44.0	51.5	16.9	43.5	....	....	2.67	0.36	...	..
Low K	43.2	11.6	54.8	62.0	27.4	9.1	0.37	....	3.07	1.37	...	..
Low Ca	38.5	12.5	51.0	9.5	37.8	59.1	0.44	....	3.18	1.44	...	..
Low Mg	62.9	17.1	80.0	52.5	13.2	48.6	....	....	2.68	1.32	...	..
Low S	49.6	16.5	66.1	48.8	17.8	44.8	....	11.1	2.76	1.22	...	..

[6]Walker, R. B., Gessel, S. P. and Haddock, P. G. Greenhouse studies in mineral requirements of Conifers Western red cedar. Forest Science 1. 1955. P. 51–60.

method is to shoot branches out of the top of the tree—or climb the tree and sample appropriate branches.

We should reiterate that *variations in sampling procedure can completely invalidate results of foliage testing.* For a given tree, samples from the top, middle, and lower sections of the crown give quite different results, depending on the element.

Combining several ages of needles and comparing with current needles would also destroy the significance. Therefore, a study of mineral requirements of trees based on variable sampling procedure is not reliable.

Another matter of considerable concern in sampling is whether one tree should provide the base or whether a composite sample is best to represent a particular site. A valid measure of a variation in leaf composition of trees grown under identical conditions is not now available. *It is probable that adjacent forest trees may not have the same fertility environment, and composition is likely to vary.*

Probably most foresters have had the experience of looking at adjacent trees and observing great differences in color and form. How much of this can be ascribed to local soil differences and how much to other factors is not known. But until we have better information on this subject, it would be *unwise to base an area diagnosis on the basis of one tree, even if this was selected to represent the average.*

Also, different portions of a plant may have better diagnostic value than leaf tissue. For example, leaf petioles have been successfully used in diagnosing the nitrogen and phosphorus requirements of sugar beet. Perhaps *cones, seeds, petioles,* or some other tree organ would be better material to analyze than *leaves* or *needles* in some instances.

Useful results might possibly be obtained by testing a rather widely distributed understory plant. Composition of such a plant might be used to reflect soil fertility and to predict nutrient composition of the forest trees.

Certainly many plants are now used to indicate forest growing conditions in a general way. Elemental analysis of these plants may be even more useful than direct testing of tissue from forest trees. This type of work has definite possibilities but needs to be explored further before its practical value is known.

Table 2 gives data originally tabulated by Leyton,[5] and supplemented

TABLE 3. MINERAL DEFICIENCY SYMPTOMS OF WESTERN RED CEDAR AS OBSERVED IN SOLUTION, SAND, AND SOIL CULTURES.

Element	Deficiency level[1]	Deficiency Symptoms
Nitrogen	1.5%	Foliage very yellowish; stems reddish in young seedlings; dying of older foliage conspicuous, but little shattering noted; roots abnormally long in solution cultures; foliage sparse.
Phosphorus	0.4% (PO_4)	Stems and older foliage reddish or purplish during the first year, turning to a reddish brown and becoming necrotic in older seedlings; oldest foliage dies but does not shatter. Youngest foliage retains good green color.
Potassium	10–20 m.e.	Stems limber, causing a drooping appearance in the foliage; foliage sparse, apparently because fourth order branches do not elongate; foliage at the tips of the branches remaining a good green in color, but older foliage necrotic or dying, with many of the lower leaves and branches dead and brown.
Calcium	5–10 m.e.	Browning and dying at the tips of the leader and branch shoots; good green color maintained in lower foliage; in solution cultures browning and dying of roots obvious.
Magnesium	5–15 m.e.	Plants made good growth in height, and the youngest foliage remained green, but the older branchlets turned yellow or white then became brown and showed a marked tendency to shatter. This resulted in plants with a tuft of green at the top, but with bare branches below. Other deficiencies do not seem to produce the white or yellow stage in necrosis which is characteristic of magnesium.
Sulfur	5–10 m.e.	Foliage becomes yellowish, this being more apparent in the younger portions. In iron deficiency the older foliage remains a good green color, whereas in sulfur deficiency the older foliage is paler than normal, although not so yellowish as the younger portions of the plant. In dealing with both sulfur and iron deficiencies it must be remembered that all young growth tends to be yellowish for a time, especially during the seasons in which weather conditions are favorable for rapid growth.
Boron	15 ppm	Elongation in growing regions much restricted, so that the needles are closely bunched, approaching the "rosette" in angiosperms; stems weak, so that upper parts of plant lop over; older foliage near normal; younger foliage becoming "bronzed" in advanced stages; roots short, with the branches somewhat bulbous on the ends.
Iron	——	Youngest foliage quite yellow; older foliage green. This difference was more striking as the plants became older.

[1] These studies were not sufficiently detailed to establish critically the required levels of the various nutrients. The quantities given (in % or m.e. per 100 dry g.) were the levels found in deficient foliage.

Reference same as #6.

by the authors, on *the deficiency and optimum levels or nutrients in different tree species.* If an element is present in foliage at deficiency level or below, the plant would be expected to show growth response to any additional supply of the element in question.

Tables such as this *for all species at different ages* would be valuable and necessary aids for diagnosing needs based on foliage analysis.

An optimum level in the foliage would generally indicate the tree is not in need of supplements. But both deficient and optimum level values can be complicated by *luxury consumption* and by a *dilution effect*.

In other words, a tree may be taking up more of a particular element than it needs, meaning the stated optimum level is too high. Or the concentration of one element may be unduly reduced by rapid growth or abnormally high uptake of another element. Both of these possibilities must be considered when foliage analysis is being used to diagnose nutrient needs.

Foresters may also have special diagnostic needs or special problems, such as the production of maximum seed crops.

In the Douglas fir area, for instance, there is considerable interest in boosting seed production through nutrient supplements. Initial work in this field has produced very promising results. It seems likely that composition of foliage or other parts of the tree may need to be at different levels for adequate seed production than for growth alone.

The authors have often seen seed crops cause a severe nitrogen drain on Douglas fir foliage, resulting in a very chlorotic color of the tree and a low nitrogen content for a portion of the year. This condition is accentuated on nitrogen deficient sites. Certainly adequate diagnostic procedures must consider all forest production purposes.

From results of a number of greenhouse experiments, as well as field observation and foliage analysis, Tables 2 and 3 have been prepared for Western red cedar, giving yields and foliage composition, deficiency levels for each element, and character and color of the foliage.

An information table for each tree species, supplemented with good color photographs, would be very good guides for diagnosis. These tables were made from *observations on greenhouse-grown trees*, but the same symptoms have been observed *in field grown trees*, particularly for nitrogen. In this case, nitrogen application will correct the symptoms and the foliage resumes a normal color and appearance.

Summary

In summary, we feel that foliage analysis, *when all details are carefully standardized*, does offer definite advantages in diagnosing nutrient needs of forest trees.

Samples can be readily taken in most forest areas and subjected to standard testing procedures. With a sufficient background of information, the results can be interpreted in terms of nutrient needs for maximum growth.

The practicing forester can usually relate *foliage composition* to *foliage color*, *crown density*, and *general health and appearance of the trees* and thus make the informaton more useful.

Soil testing can also be made into a more useful tool through standardization of procedures and relating results to nutrient absorption and use in the tree.

[1] Forest Fertilization. A bibliography, with abstracts, on the use of fertilizers and soil amendments in forestry. World Forestry Series Bulletin #2, 1956. State University of New York, College of Forestry, Syracuse.

[2] Rennie, P. J. The uptake of nutrients by mature forest growth. Plant & Soil 7-49-95. 1955.

[3] Stoate, T. N. Nutrition of the pine. Bulletin Forestry Timber. Bureau Aust. No. 301. 1951.

[4] Goodall, D. W. and F. C. Gregory. Chemical Composition of Plants as an index of their nutritional status. Imp. Bms. Hart. Plant. Corps. Tech. Comm. No. 17. 1947.

[5] Leyton, L. 1958. The Mineral Requirements of Forest Plants. Handb. Pflanzenphysiologie Vol. IV In Press: 1026-1039.

[6] White, D. P. Variations in the nitrogen, phosphorus, and potassium contents of pine needles with season crown position and sample treatment. Proc. Soil Sci. Soc. Amer. 18. 326-330. 1954.

Cauliflower: left, boron treated; right, brown curd with boron deficiency

Alfalfa yellows and rosetting due to boron deficiency

EXAMPLES OF BORON DEFICIENT CROPS

Apples with external cork cracks, necrotic areas and dwarfed

Tobacco with die-back of terminal bud rolling of upper leaves

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POTASH MADE THE DIFFERENCE. This picture was taken 14 growing seasons after the red pine on the right received 200 pounds potash per acre, while the pine on the left went unfertilized. The white bands show height at time of treatment.

IN U. S. AND CANADA

FOREST RESEARCH STUDIES PLANT FOOD USAGE

By

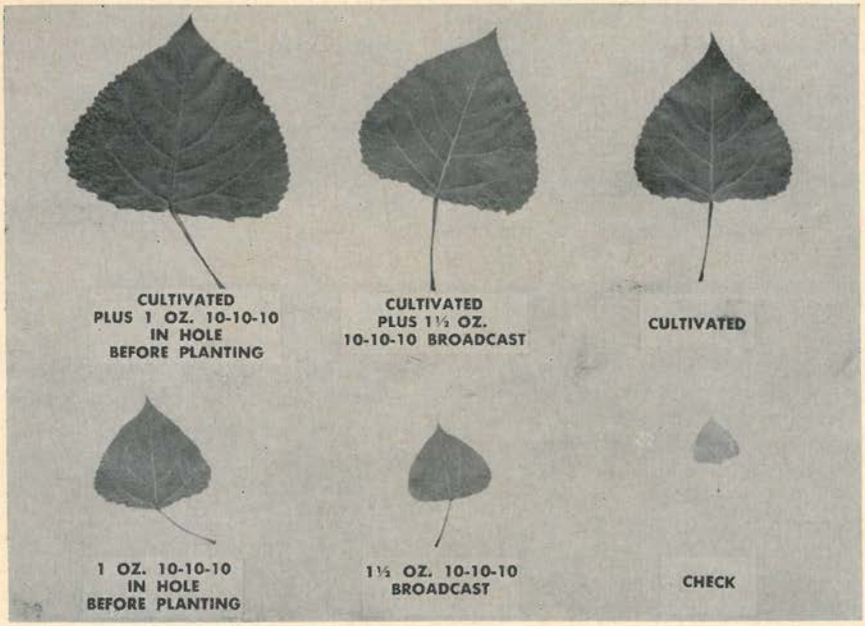
Donald P. White
Michigan State University

Development of forest management practices and techniques has followed a rapidly changing pattern in the past half-century.

Until about 1930, forestry was largely concerned with fire protection and methods of cutting timber. Following extensive reforestation efforts of the depression years, foresters recognized many problems in selecting site and species, and establishing plantations were related to *no understanding of forest-soil relationships in the nursery and in the field.*

Nursery Soil Management Gets Initial Attention

Though a few fertilizer field trials were reported during the early 20th Century, many experiments were negative and went unreported. The real effort in the beginning was on nursery soil fertility management. The Wisconsin workers, led by S. A. Wilde, started a research program on all phases of nursery soil management that has resulted in a scientific basis for growing the large number of tree seedlings required annually in the ever increasing reforestation program.



Here are some interesting effects cultivation and fertilization had on the relative leaf size of hybrid poplar (Raverdeau). Hardwoods have always been the forester's riddle. They are generally more demanding in soil requirements than conifers (evergreens) and will respond more vigorously to plant food usage. Successful growth has frequently required the use of supplemental fertilization.

Pioneering work in the soil fertility phase of the reforestation program was also made by H. A. Lunt of the Connecticut Agricultural Experiment Station and P. C. Wakeley of the U. S. Forest Service.

More recently, research on suitable nursery soil fertility programs, particularly on stock quality, have been conducted at Oregon State College, the University of Georgia, and Mississippi State University.

Most progressive tree nursery managers now realize what a drain tree crops make on nursery soil fertility. Using balanced fertilizers based on soil and plant tests and in connection with cover crops and other soil management techniques is now standard practice.

Plantation Fertilization Offers Hope on Many Depleted Areas

Many early attempts to stimulate forest growth with fertilizers were made on slow growing stands established on depleted, abandoned fields —particularly in New England, the Lake States, and the South.

Frequently these early attempts failed to achieve any tangible results. In some cases, lack of conclusive results was due to *poor choice of fertilizer materials, inadequate rates of application, absence of adequate experimental controls,* and *failure to provide for long term records.*

Contrasted with the many negative results was the singular success achieved on stagnating pine and spruce plantations *by potash and potash-containing materials* on the course sandy outwash soils in the Upper Hudson Valley of New York. These experiments, started over 25 years ago by S. O. Heiberg and continuing to the present, have been widely reported and visited by many foresters from all over the world.

One outstanding characteristic of the response to potash on these sites, impoverished by a century of agriculture, is the *rapid increase in height growth following 200 pounds of potash fertilizer per acre (Figure 1).* This stimulation lasted for many years after the single application (Figure 2).

Recently, LaFond of Laval University and others have recognized and reported *potash deficiency in spruce and pine plantations throughout extensive areas of eastern Canada.*

In the South, where the rapid growth of native species offers the most favorable economic conditions for a profitable forestry enterprise, fertilizer usage presents an appealing opportunity.

Fertilizer experiments in southern pines were slow getting started, especially against the widespread regional opinion that southern pines needed only sand, water, and air.

Recently, numerous reports of southern pines responding to both nitrogen and phosphorus have appeared. Today this area which had lagged behind in forest fertility research is now a beehive of activity sponsored by both public and private organizations. The scope of this enterprise is discussed in a companion article.

In the Pacific Northwest, the major soil fertility problems in plantations—predominantly of Douglas fir—seem to be associated with the soil depleting effects of heavy burning which usually followed the clearcutting of the original forest.

This problem has been investigated by Gessel at the University of Washington and others in Oregon and British Columbia. Substantial response to nitrogen fertilization has been demonstrated, especially on growth and seed production, and the economic possibilities are being explored.

What About Hardwood Plantations

Hardwood plantations have always been the forester's riddle. To be sure, we have only scratched the surface in hardwood plantation management. But several aspects seem apparent.

Hardwoods are generally more demanding in soil requirements than conifers (evergreen), and they will respond more vigorously to soil amendments. Such valuable and rapidly growing species as tulip poplar, ash and hybrid poplar respond dramatically to higher levels of soil fertility—especially to supplemental nitrogen.

Hardwoods have also been used extensively to stabilize coal mining spoil banks and to control erosion in the Central States. Successful growth has frequently required the use of supplemental fertilization.

Dr. Donald P. White, associate professor of forestry at Michigan State University, is well known for his work on tree nutrition and forest fertilization research in Wisconsin, New York, and Michigan. He earned his B. S. from New York State College of Forestry, his M.S. and Ph.D. from Wisconsin.

S. O. Heiberg, widely known authority on forest fertilization, points to the stimulation that 200 pounds potash per acre had on the *height growth* of red pine. Heiberg is professor of silviculture at the State University College of Forestry at Syracuse University.

Fertilization at Time of Planting Can Be Beneficial

It used to be an old German custom to grow seedlings for adverse sites by subjecting them to a similar harsh nursery environment. This "hardening" process has now been rejected along with "Lysenko genetics," and the most vigorous seedlings are selected for difficult sites.

But the amount of nutrients that can be assimilated by a tree seedling in the nursery is limited, and *even the most vigorous plant may soon suffer from lack of nutrients under certain field soil conditions.*

Pine fertilization at the time of planting was tried in Wisconsin several decades ago without any conclusive results. The practice is generally considered to be without merit.

But, hardwood seedlings such as tulip, ash, maple, locust, and poplar will *usually benefit from an ounce or two of complete fertilizer placed in the planting hole well below the roots.*

Several years ago the author noted *a favorable response from a ring application of 4 ounces of muriate of potash around red pine at the time of planting on potash deficient soils.*

Spruce plantations are notoriously slow starters, often seeming literally to "sit still" for three to four years after planting. This "planting shock" has been attributed to the inability of spruce to compete adequately with the sod, weeds, or brush on most planting sites. Some of this difficulty is overcome by furrowing, as practiced in the Lake States.

Experiments by the author in New York and Michigan indicate this "planting shock" of spruce may be corrected by applying a 2-ounce ring of a complete fertilizer at planting time. When the sod is heavy or furrows are not used, the effect may be lost or even detrimental through excessive stimulation of competing grasses. Placing the fertilizer in the hole before planting was harmful in Michigan trials.

Fertilization of Mature or Second Growth Forest Not Usually Recommended

The natural forest soil is an excellent reservoir of moisture and nutrients. Under relatively crude forest management or even exploitation without burning, the forest soil retains its inherent structure and nutrient capacity. Applications of soil amendments under natural forest conditions found in North American forests are not likely to improve substantially the site for tree growth.

A noteworthy exception is the natural second-growth stands of Douglas-fir on shallow residual soils or coarse glacial outwash in the Pacific Northwest. Many of these areas have a history of repeated burning after logging. Gessel at the University of Washington and Stoate in British Columbia have obtained important growth response to nitrogen fertilization on these sites.

Long term drain of field cropping, loss of soil by erosion, and destruction of humus by fire sets the stage for nutrient deficiencies when trees again occupy the site.

Admittedly, *the maximum growth potential of natural forest soils under optimum levels of fertility by natural or artificial means has never been adequately tested. Frankly, we don't know what these optimum levels are.*

Christmas Tree Plantations May Be Improved By Fertilizer

Prospect of large cash returns has attracted many farmers and absentee owners into the Christmas tree business. Under proper management, this crop is one of the most attractive investments that can be made of idle and low value land.

But all is not a bed of roses. Ask the growers who have watched plantations turn yellow before harvest or waited impatiently for the spruce to make some showing above the weeds.

In the northern states, many growers are seriously concerned about the fall yellowing of Scotch pine. Soil or foliar applications of fertilizer offers little promise for this genetic characteristic.

Christmas tree plantations of spruce on *potash deficient sandy soils have been significantly improved in quality by 300 lbs. per acre of muriate of potash.* Similarly off-color spruce or low-fertility sites have responded favorably to about one-half pound of *high analysis complete fertilizer applied in a ring around each tree in the spring.*

Foliar sprays of urea and fall fertilizing to improve the color quality of Christmas trees are now being tested in Michigan.

Fertilization for Gum, Seed, and Sap Production

A number of accessory forest crops are influenced in yield and quality by the tree's physiology. Experiments in Florida are now studying the effect of fertilization on gum yield in slash pine for naval stores.

A number of reports from Florida, North Carolina, Georgia, and Louisiana indicate seed production in pine and oak can be increased by fertilization.

Reports from California say soil treatment increased sugar pine seed production. This practice, which has important implications to management of seed orchards, has attracted widespread interest. Over a dozen agencies, including many forest industries, now sponsor research plots to measure the effect of fertilization on seed production.

Recent Michigan trials showed increased maple sap yields after nitrogen and phosphorus fertilizers had been applied broadcast.

Application Techniques Need Further Study

For research plots, *hand broadcast methods using a calibrated container are usually satisfactory*. Most experiments have been established in this way.

The problem of distributing fertilizers on large or inaccessible tracts has been studied in New York, New Jersery, and Washington by modifying *aerial techniques* used in other branches of agriculture. In the New York trials, *200 pounds potash per acre were distributed satisfactorily by airplane at an estimated cost of $8 per acre*.

In the Wisconsin trials, *pneumatic blowers* were able to treat an area 50 to 100 feet wide, using pelleted material. In these experiments, access lanes had to be cut for machinery to pass. Recent plantations are being laid out with access lanes for thinning and spraying, making the use of distribution machinery more feasible in the future.

Nutrient foliage sprays have not been fully tested, except for special crops such as horticultural fruits. Suitable distributors on tree planting machinery will be inevitable if the advisability of this treatment is demonstrated by future research.

Tree Nutrition Research—the Key to Fertilizer Needs

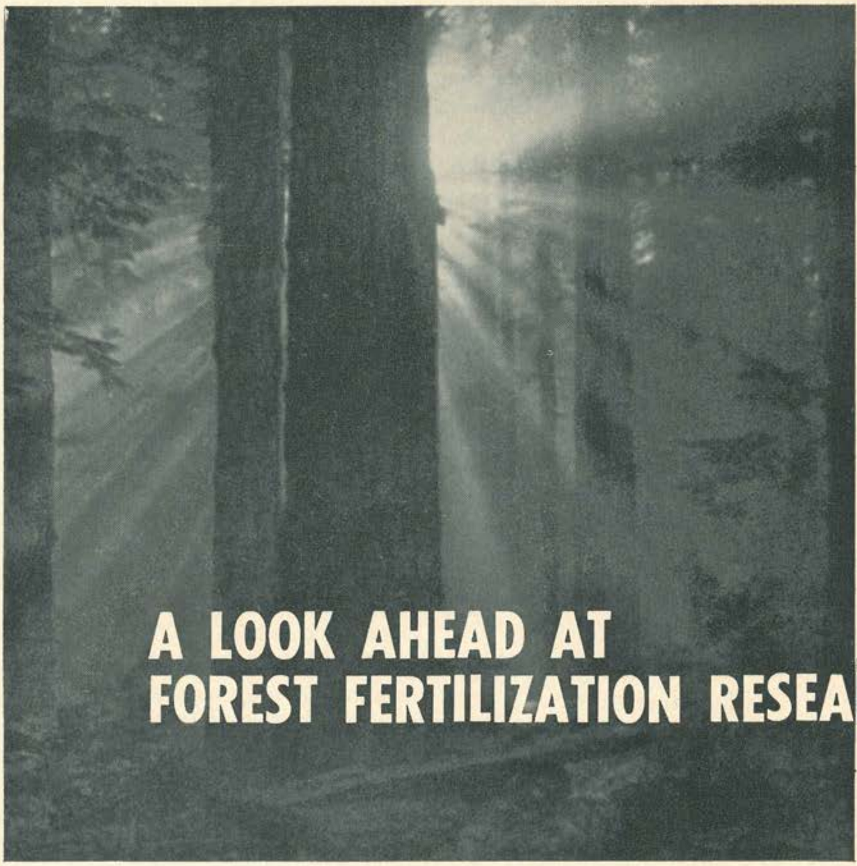
A sound basis for forest fertilization rests on fundamental studies in tree nutrition.

Some 20 years ago, Mitchell and coworkers on the Black Rock Forest in New York conducted a number of basic studies on the mineral nutrition of trees. These investigations still serve as a guide.

Unfortunately, private and public support for this type of research has been woefully lacking. Only recently has renewed interest in the practical applications of physiological research opened the purse strings for more activity in this area.

Currently many organizations—including the U. S. Forest Service, North Carolina State College, Michigan State University, Ohio Agricultural Experiment Station, University of Washington, the Canadian Federal Forestry Branch, and others—are pursuing basic tree nutrition studies. Much of this fundamental activity, it's important to note, is supported in part *by forest and chemical industries*.

Forest fertilization research in North America has demonstrated the possibility of growth improvement under a variety of situations. But practical application is still fairly limited. Much work remains to be done, especially in *basic physiology* and *economic analysis*. ◄◄◄



A LOOK AHEAD AT FOREST FERTILIZATION RESEARCH

A look ahead at forest fertilization research! The most remarkable thing about this topic is that it should be discussed seriously in this country. Even a decade ago the suggestion of forest fertilization in many quarters would have aroused a stock answer, "Forests ordinarily don't need fertilizer, and even if they do, we can't afford it."

Neither timber land values nor available information contradicted this generality—*then*. And, indeed, we are still not certain how widely such attitude can be disputed.

What, then, has happened to change this view, to make the present discussion possible? Primarily, *repeated demonstrations of substantial responses to fertilization by forest and other wildland vegetation*. Per-

By Earl L. Stone . . . . Cornell University

. . . *a New Silvicultural Tool*

haps the first major American example was the increased growth of native hardwood species following nitrogen fertilization—results obtained by H. L. Mitchell and R. F. Chandler in New York.

Later came a spurt of reports: potassium and magnesium with pine and spruce in New York, nitrogen with Douglas fir in Washington, nitrogen and phosphorus with southern pines, and again with brush species of California watersheds. These and other examples in this country and abroad made one point clear—*forest species in their normal habitat on occasion do need fertilizer for satisfactory growth, whether or not it can be afforded.*

These findings might have remained outside the forest manager's concern were it not for the *increasing*

. . . Who says, "Forest fertilization is perhaps most properly seen as a relatively new and untried silvicultural tool."

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Just a decade ago, even the mention of forest fertilization caused many people to say, "They don't generally need it, and we can't afford it."

value of timber and forest land. Also influencing the attitudes of both investigators and land managers has been the *pervasive example of increasing agricultural production from a shrinking area.* So the topics of soil fertility, tree nutrition, and forest fertilization have become at least reasonably respectable considerations, although their economic importance may seem limited or obscure. We need no great vision to see that earlier concepts of forest ecology and productivity limitations must now take account of the new findings.

Being at this point, where to? What do we need to know about forest nutrition and fertilization? And how should we go about getting the information?

In this writer's view, the needs for information cluster about three general subjects: *(1) The capabilities, or properties, of trees and other economic forest plants; (2) the capabilities of forest land sites; (3) the future development of forest land management.*

What, then, has changed the view toward forest fertilization—largely *repeated* demonstrations of substantial responses to fertilization by forest and other wildland vegetation.

Broadly speaking, "capabilities" of our numerous economic species includes their entire physiology and ecology. More narrowly it ("capabilities") is the behavior of whole plants in relation to nutrition—such as the effects of nutrient supply on development or the response of the plant to changes in nutrient status.

These effects may be measured in terms of *growth rate* or *wood quality*. But again, *seed production, seedling survival, competitive ability in mixed populations,* or *density of vegetative growth* can be the feature of greatest interest. Some of these effects are best measured on small plants under controlled conditions. Others involve large trees in their normal environment for relatively long time spans.

This aspect of nutrition is so large and self evident that it may obscure the second subject, *site capabilities.* For both ecologists and land managers, however, nutrient relationships are important somewhat in proportion to the area and kind of vegetation affected. The ecologist and land manager are not concerned merely with nutritional relationships but also with demonstrated effects on the vegetation of some appreciable land area. Only by appraising such areas can they know the actual extent and importance of relationships discovered at selected localities or through controlled studies.

For example, magnesium deficiency produces conspicuous, almost gaudy symptoms on planted pines in New York. Such symptoms are quite distressing to Christmas tree growers concerned with foliage color, while severe deficiency can markedly reduce growth. Finding the cause and remedy disposed of a malady that had previously puzzled foresters and pathologists. But the economic importance of this finding is slight, for the area severely affected is small, and even there intensity of deficiency varies.

In decided contrast are the results from Mitchell's and Chandler's survey of nitrogen deficiency. Foliar tests from some seventy localities, together with similar results by others, indicate that inadequate nitrogen *limits growth in many northeastern hardwood forests.* Adequacy of nitrogen supply varies according to species, but also with kind of soil and with past fire and cultivation. Not enough is known to estimate the true extent of the problem, but it is evidently large. Among the soil properties or "capabilities" that must be appraised for an understanding of this problem are *rate of nitrogen supply, changes (natural or man-induced) in this rate with time,* and *limitations of moisture or other nutrients which may control response to nitrogen.*

Progress in forest nutrition—progress in site characterization — progress in forest fertilization—all this progress can come *only through studying forests.* We shall do more rather than less of this in the future.

How will these subjects—*site and species capabilities*—be investigated in the future? I suspect our basic procedures will remain much the same as now, though the actual techniques of soil and plant testing, forest measuring, and experimental design will continue to change and provide new opportunities.

First among the basic procedures, however, should be one of the oldest methods of progress: *selective borrowing from the neighboring tribes.*

In this instance, the neighbors are investigators in *agronomy, horticulture, soil science,* and *plant nutrition.* As a group, they have had long-standing advantages of numbers, equipment, and experience.

Forest investigators have, indeed, borrowed their analytical methods freely—though not always selectively—from these neighbors. But full use of this vast information has been limited—perhaps by unawareness, perhaps by a belief in the essential "differentness" of forest plants and growth processes. In fact, however, nutritional requirements of horticultural plants already studied—from camellias and blueberries to alfalfa and apple trees—certainly embrace those of many forest trees. Orchard crops, large, deep-rooted, long-lived perennials have obvious parallels with forest plantations as do the experimental designs used to investigate them.

Soil treatments that allow prodigious crops of Coastal Bermuda grass or vigorous tung trees on infertile sands also suggest ways to greater yields of pine on similar soils. So few are the investigators of forest nutrition and so numerous the combinations of species and soils to be dealt with, that any reasonable progress *requires use of knowledge already at hand.*

"Borrowing," then, will hasten progress over well mapped ground and limit exploration of alleys known to be blind. The modest resources of forest nutrition research can be turned to producing information not otherwise available, as well as to unknown species and soils.

The horticultural sciences have grown through *a wide spread in research methods and objectives*—ranging from wheat seedlings in nutrient cultures to the wheat yields of long-term fertility and rotation experiments. In forestry, this spread extends over a greater range of plant development, environments, and measures of response. Controlled studies in laboratory and greenhouse are essential for advances in *tree* nutrition and knowledge of simple soil properties. But progress in *forest* nutrition, as well as in site characterization, or forest fertilization, *can come only through studying forests.* We shall do more rather than less of this in the future.

There are so few forest nutrition investigators and so many species and soils to be dealt with that they should use many facts already at hand to make any reasonable progress — that is, borrow from agronomy, horticulture, soil science, plant nutrition, fields that have had the advantage of numbers, equipment, and experience.

Forest nutrition investigations involve one or more of three procedures: *(1) Recognition and characterization of fertility status, (2) modification of fertility status,* and *(3) study of the forest as a nutrient system.*

Characterizing Fertility Status

Methods of characterizing fertility status of plants and land areas are still evolving. Visual deficiency symptoms do call attention to infertility and may be invaluable evidences during the early stages of investigation. *But growth and function are usually impaired well before symptoms appear.* So recognition by visual symptoms alone greatly underestimates *the extent of deficiency.* This is illustrated in our results with red pine. Marked deficiency symptoms occurred only when the foliage content of potassium was 0.33% or below, yet site index increased steadily over a range of foliar concentrations, from .25 to about .45%. Appearance of well marked foliar symptoms represented a reduction in volume growth to 65% or less of pine on adjacent soils *better supplied with potassium.* Hence, we need better graduated scales of deficiency.

Foliar or tissue testing is a more widely useful means of characterizing nutrient status. For the major elements in the range of greatest interest, relationships between supply, tissue content, and growth are sometimes remarkably straightforward. This method may be even more reliable in forests than with many crop plants, due to the conservative influence of permanent root systems and large tissue masses. Correlation of tissue tests with growth rate, fertilizer response, or other behavior provides yardsticks for estimating the expected behavior of species. A further use of foliar or tissue testing is in surveys (as Mitchell's and Chandler's mentioned above) to appraise site capabilities and nutrient status.

Nevertheless, the method is no panacea. Its limitations and complexities are well known. Establishing correlations is time-consuming, the sampling season often brief, and sources of extraneous variation sometimes large.

In contrast to tissue testing, use of soil testing in forest nutrition studies has scarcely been investigated. To be sure, explorers passing through the territory have taken pot shots with conventional equipment, and a few, both well and poorly armed, have made special safaris. Varied accounts of success have been reported, but without notable agreement on either prospects or suitable gear.

In fact, "soil testing" in this connection is *an entire process rather than a simple method of chemical analysis.* It also entails selection and sampling within the soil mass, extraction methods chosen with some purpose, and inferences about the meaning of the results. "Borrowing" must extend to mastering the whole process rather than easy or fashionable methods of testing. When this is done, many useful relationships will appear, though their value may be greater than their elegance.

An urgent task for the future is to establish fertilizer trials that are large enough and sufficiently designed for making precise estimates of long-term effects—because many technical and economic questions can be answered *only* through such trials and results.

For example, an overlooked role of soil testing is simply *to set limits about the ranges of probable deficiency and response*. These at once concentrate attention on a few variables of greatest interest. Thus, in our studies, red pine on sandy soils was free of potassium deficiency wherever the exchangeable content of the surface exceeded .050 m.e./100 gms. This simple test stratifies plantations or planting sites into two classes, *non-deficient and possibly-deficient in potassium.* The non-deficient are sufficiently characterized. The possibly-deficient can be examined by additional means.

Soil nutrient supplies, as well as conditions governing root development and nutrient uptake, are frequently tied to soil classification units. To the extent this is so, soil mapping units become better guides to site capabilities.

Where this is not the case, as with nitrogen availability in the disturbed soils of northeastern U. S., correlations between growth rate and soil mapping units may be weaker. Conversely, a disparity between the growth potential suggested by physical attributes—such as depth, aeration, and moisture supply—and actual growth should direct attention to soil fertility.

Modification of Fertility Status

The second procedure mentioned above—*modification of fertility status*—includes straightforward tests of fertilizer response. Elements, rates, and timing of application will be tested, perhaps in combination with silvicultural treatments. But since plot dimensions must be scaled to the root spread and stand variability at the end of long-term trials, experimental designs in forests are likely to be simple. This places great importance on preliminary investigation to single out variables and treatments of greatest interest. At present, few trials have adequate plot size and experimental design for precise estimates of long-term effects. Establishing such trials is clearly an urgent task for the future, for many technical and economic questions can be answered only through their results.

The effects of a single fertilizer application may persist for several years—at least 7 to 10 in *various potassium and nitrogen studies in New York.* This persistence presumably is due to storage in soil and tissue, recycling of nutrients, and minor crop removal. Such long-term modification of the chemical environment means *fertilizer trials can contribute much more than yield data.* Such trials can be as well viewed as experimental ecology, and changes in vegetation or plant development studied in this way.

Forest fertilization is now suggested as a technique for increasing production per acre through greater yields, more effective management, or lower risks—aims identical with those of other silvicultural treatments.

The New York treatments mentioned above, for example, had unanticipated effects on wildlife feeding and on seed production. Testing of soil and tissue from these plots can be calibrated directly against plant response. (Such responses, indeed, are the ultimate tests of causal relationships, as distinct from mere associations, inferred from statistical correlations between tree behavior and nutrient supply.) In turn, soil and plant tests from treated plots will help explain the results obtained and generalize their application.

Fertilizer application is only one means of modifying fertility status. An alternative, wherever nitrogen appears limiting, is to introduce or increase nitrogen-fixing plants—*herbs, shrubs,* and *trees.* Black locust, the only leguminous tree of consequence in many regions, has repeatedly increased the growth rate of nitrogen-demanding species associated with it. The recent unequivocal demonstration of fixation by such non-legumes as *Alnus, Myrica,* and *Ceanothus* will doubtlessly renew interest in their influence.

A good possibility for providing sustained nitrogen supply for young stands during their period of greatest uptake would be to mix them with nitrogen-fixing associates. Nitrogen has been the cardinal topic in past studies of forest nutrition, and its importance is unlikely to diminish in the future. We must still echo Ebermayer's words of 1890, *"The nitrogen nutrition of forest tree species is not yet completely solved."*

Liming, though popular in some European forests, has produced little results in the very few American trials known to the writer. Cost consideration also discourages views of practical applications. At very least, however, liming affords a useful experimental approach *wherever soil reaction or base status are considered critical.*

Finally, we cannot ignore the possible effects of cutting, thinning, and other management practices on fertility status. Though too complex for more than mention here, accelerated decomposition, "green manuring" effects of slash and severed root systems, fire, and changes in plant species suggest some of the possible influences. The complexity of such treatments makes evaluation difficult. But here as with other indirect influences, tissue testing *to determine nutrient availability,* and fertilization trials, *to duplicate assumed changes,* are tools for distinguishing nutritional effects amid other environmental changes.

Tissue tests and fertilization trials are good tools for distinguishing nutritional effects amid various environmental changes—tissue testing, to determine nutrient availability; fertilization trials, to duplicate assumed changes.

Forest As A Nutrient System

Persistence of fertilizer response, annual recycling, and periodic release of nutrients stored in the biomass and soil organic matter all point to the third procedure —*study of the forest as a nutrient cycle or system.*

The textbook model of a cycle is simple and schematic but knowledge of its real details and quantities is largely lacking. Yet, such knowledge is basic—whether to understand the place of nutrients in the ecological system, or to account for the prolonged action of added fertilizers.

This writer's forward vision does not extend to the third subject mentioned in the beginning—*development of forest land management.* So the following is merely reflective.

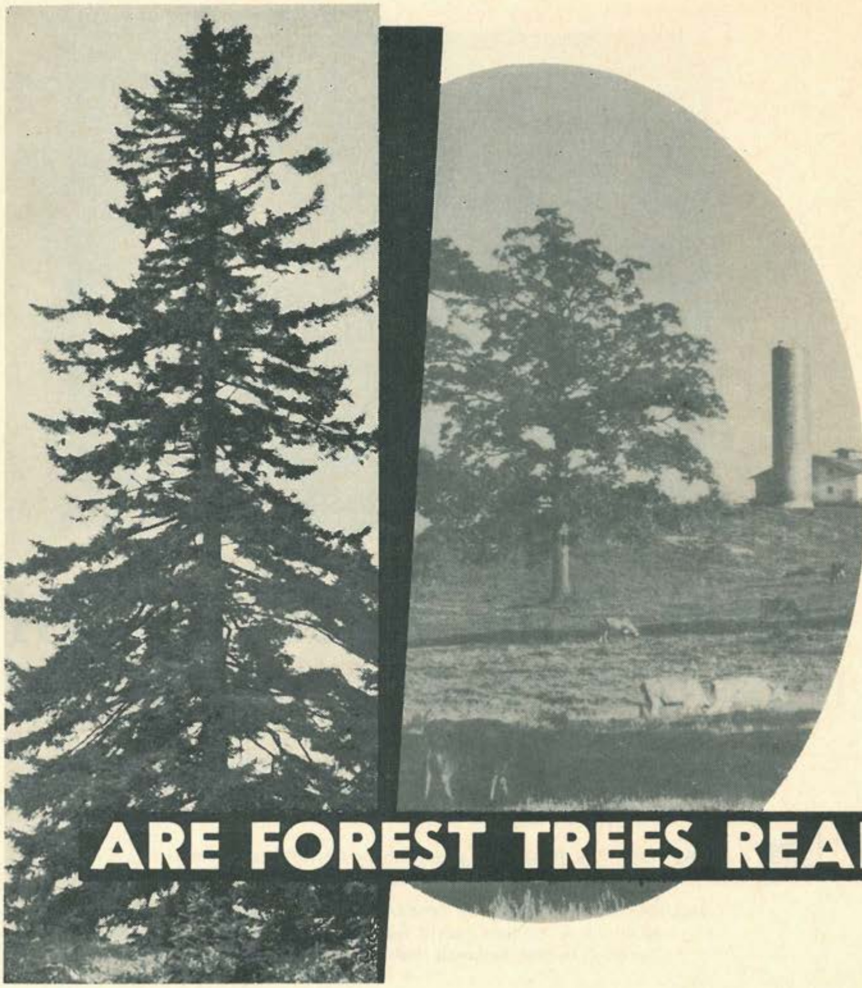
Industrial forest management in the United States has been developing rapidly. Its methods obviously cannot utilize the heavy per-acre investments of man hours (both labor and technical) that have created European forests. On the other hand, industry has been willing to invest capital, as shown by the purchase prices of southern timber lands and outlays for converting brushland to young forests. There are many competing needs for these capital investments—further land acquisition, road systems and other physical facilities, planting, and improvement of growing stock—all directed toward long-term productivity of the entire holding.

Similar considerations apply to many wildlands in public ownership, except capital availability is less and non-timber values often paramount. Little need be said here about the remaining non-industrial lands and for much the same reasons.

Forest nutrition studies are part of the scientific foundations for forestry and forest ecology, and scarcely need further economic justification. But forest fertilization is now suggested as a technique for increasing production per acre through greater yields, more effective management, or lower risks. These aims are identical with those of other silvicultural treatments, and *forest fertilization is perhaps most properly seen as a relatively new and untried silvicultural tool.* Its usefulness and place are only now being investigated. If its promise is fulfilled, the economic considerations affecting its use should be similar to those governing other silvicultural applications.

The developing forest management is not likely to have a separate science or economics of fertilizer use. Rather, there will be economic and technical justification for major silvicultural objectives (or their counterparts on non-timber lands)—objectives such as *regeneration, adequate stocking, increase of preferred species, higher yields or quality, and others specific for the area.* The use of fertilizers or application of nutritional knowledge will be determined by their contribution to the fulfillment of these objectives. We may plan our research accordingly. ◄◄◄

Looking up from a main road, we see Japanese larch that *received no fertilizer* and *received slag*. Growth on left was controlled, received *no* plant food. Growth on right was slagged or fertilized. Note growth difference. Achnashellach, Experiment 9, p. 28. March, 1943.



ARE FOREST TREES REALLY

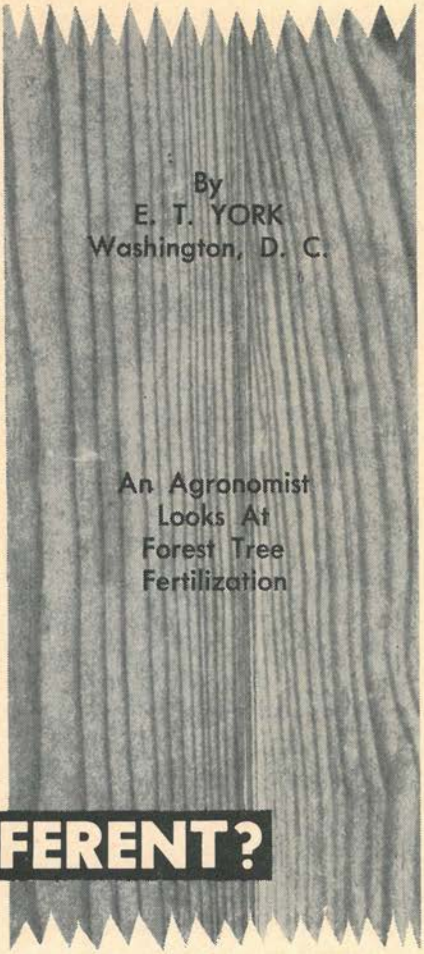
During the past 100 years, use of chemical fertilizers has become such an accepted practice in agriculture that some 20 million tons of plant food (N, P_2O_5, and K_2O) are used annually throughout the world—with usage increasing steadily each year.

This plant food is greatly influencing agricultural productivity. In fact, approximately ¼ of total crop production in the United States is estimated to be due to *fertilizer use alone*.

With fertilizers playing such an important role in agriculture, it is not surprising that more attention is being directed to their possible use in forestry. Indeed, one outside the forestry profession might wonder why this interest has developed so slowly.

The little attention given to forest nutrition problems in the past has tended to suggest that forest species may be unique when compared to field and horticultural crops. While there are certain differences between these two great groups of plants, there are unquestionably *many similarities*.

A previous author has emphasized the desirability of the forestry profession "borrowing from the neighboring tribes"—from the horticulturists,



DIFFERENT?

An Agronomist Looks At Forest Tree Fertilization

By
E. T. YORK
Washington, D. C.

agronomists, and soil scientists—facts on crop and soil management that might be applied to the study of nutritional problems in forestry. Examining some of the information developed by these "neighboring tribes" over the past several decades should help answer the question, "Are forest trees *really* different?" This borrowing of information and experience should also materially hasten development of more specific information on the possible role of fertilizers in forest management.

Nutrient Requirements of Plants

Nothing suggests that forest species are any different from other plants as far as their basic nutritional requirements are concerned. In agriculture, it is recognized that one or more of the so-called essential nutrients may be deficient in *most* soils for optimum plant growth. The same is likely true in forestry. The problem, of course, is one of determining what elements, if any, are deficient in a given soil for a given crop or species of plants.

Other authors have emphasized the place of soil and foliar analyses in determining nutrient needs of forest plants. While soil analysis can serve a useful purpose in forestry, its application will undoubtedly be more limited than in agriculture due to difficulties in sampling and correlation. On the other hand, foliar analysis techniques are particularly well suited for diagnosing nutrient needs of forest trees—just as in the case of perennial horticultural crops. However, to be used effectively, carefully standardized sampling techniques must be developed and analytical results thoroughly correlated with field response.

Nitrogen, Phosphorus, and Potassium

The three so-called "major" nutrients—nitrogen, phosphorus, and potassium—are of primary concern in fertilizing agricultural crops and will undoubtedly be the elements *most likely* to be deficient in forest soils.

Virgin soils are generally low in available phosphorus. Consequently, when new land is brought into agricultural production, phosphorus is usually needed. Research has shown that phosphorus is especially important for young plants.

Such experiences in agriculture suggest that particular attention should be given to the phosphorus nutrition of forest trees. Adequate phosphorus should be very useful in stimulating the growth of seedlings in helping them overcome competition from weeds.

The need for phosphorus has already been demonstrated in large areas of heathland under afforestation in Britain and the Netherlands, as well as in other areas of Australia and elsewhere.

Most agricultural soils are also low in available nitrogen. While the level of organic matter in many of these soils may be relatively high, the rate at which nitrogen becomes available is usually too slow to meet plant needs.

A similar situation undoubtedly exists in many forest soils. In fact, many reports in the literature indicate sizable responses to nitrogen with different forest species under widely different soil conditions. Indeed, one might expect a more extensive need for nitrogen than for any other nutrient.

Experiences in agriculture suggest that, initially, potassium would not be found limiting the growth of forest trees so much as nitrogen and phosphorus. In the early days of crop production in this country, yield levels were quite low and many crops could obtain most of their potash requirements from the soil. But, as better varieties were developed and management practices improved, yields were increased so much that the soil supply of available potash became inadequate. Consequently, it became necessary to apply higher and higher amounts of potash to meet plant needs. *It seems reasonable to expect a similar situation in forestry.*

There are, of course, exceptions to these general observations. Sizable areas of red pine growing on glacial outwash sands in New York have been found to be acutely deficient in potassium, without showing any response to nitrogen or phosphorus. Large areas of potassium-deficient spruce have also been observed on peat soils in Sweden—in an area where both phosphorus and nitrogen appeared adequate.

Secondary and Trace Elements

Many forest soils are quite acid and low in exchangeable bases—suggesting the possibility that calcium and/or magnesium might be deficient. Magnesium deficiencies have already been observed with various forest species in the United States, Britain, Denmark, and elsewhere.

Lime, as a source of calcium and magnesium, may serve other useful purposes in forestry, just as in agriculture. Its favorable effect in stimulating the activity of soil micro-organisms—both for fixing nitrogen and breaking down organic matter—has been emphasized in Germany where large amounts of lime are already used in forestry.

Sulfur needs of most agricultural plants have been supplied more or less incidentally by using sulfur-bearing phosphorus and nitrogen compounds. There is growing evidence of sulfur deficiencies, however, when these compounds are omitted from fertilizers. The possibility of sulfur deficiencies in forest species should not be overlooked — particularly in areas where the amount added to the soil in precipitation is low.

The remainder of the essential elements—manganese, iron, boron, zinc, copper, molybdenum, and chlorine—are needed in relatively small quantities and are usually adequately supplied by soils. But there are many instances where these elements are deficient among agricultural crops. *Such deficiencies may be expected in forestry as well.* In fact, zinc deficiency in pine has already been reported in Australia, copper in England, boron in Yugoslavia, etc.

Experiences in both agriculture and forestry suggest that none of these essential elements should be taken for granted. Any one of them *could be* a major limiting factor.

Deficiency Symptoms

In the past, foliar symptoms have

been widely used to characterize nutrient deficiencies in agricultural crops. Although knowledge of these symptoms may help characterize problem areas, their use as an absolute diagnostic tool is limited. Plants may suffer from nutrient deficiencies long before hunger signs become visible. Consequently absence of symptoms is no assurance nutrient levels are adequate.

Factors Limiting Response to Fertilizers

Maximum response of agricultural crops to fertilizers is often limited by other factors—both *genetic* and *environmental*. This is merely an expression of Justus von Liebig's "Law of the Minimum" which says *plant growth is limited by that growth factor in shortest supply.*

Agronomic and horticultural research is full of studies where various other factors have limited the response of crops to fertilizers. This has often led to erroneous conclusions regarding nutrient requirements and emphasizes the need for extreme care in planning, executing, and interpreting fertilizer experiments.

Multiple Nutrient Deficiencies

Erroneous conclusions have often resulted from single-factor fertilizer experiments *where multiple deficiencies exist.* Obviously, little benefit may be derived from applying nitrogen alone—even if deficient—if phosphorus *also* is limiting growth.

There are also many examples in agriculture where a single element may limit crop production initially, but when this deficiency is corrected, *other nutrients become deficient.* Leyton reported such a situation in England where pines or spruce became acutely deficient in nitrogen, *after large initial responses to phosphorus. Potassium deficiencies have* likewise developed on spruce in Holland two to three years *after fertilizing with phosphorus.*

During the past two years, Dr. E. T. York of the American Potash Institute has studied forest nutrition problems throughout Western Europe, Scandinavia, and the United States. Former Professor and Head of the Agronomy Department at N. C. State College, he received B.S. and M.S. degrees from Alabama Polytechnic Institute and the Ph.D. from Cornell.

These experiences in both agriculture and forestry emphasize the need for a continuing appraisal of nutrient requirements as conditions change—particularly as yield levels are increased.

Fertilizer Application

The effectiveness of fertilizers may depend greatly on how they are applied. Problems of fertilizer placement are undoubtedly more complex with forest species than with most agricultural crops. Yet, many of the principles involved are the same. Fertilizers should be placed to afford:

(1) Maximum utilization by the plant—making the applied nutrients easily accessible to the roots with minimum losses from leaching and fixation.

(2) Minimum burning or other injurious effects.

(3) Minimum stimulation of weeds or other competitive plants.

Proper fertilizer placement is particularly important with young plants having limited root systems and where competition is a major problem. Experiences in agriculture can help develop satisfactory fertilizer placement techniques for new plantings or for young trees.

Aerial topdressing offers the most logical means of applying fertilizers to older stands of trees. Already, 40 per cent of all fertilizer used in agriculture in New Zealand is applied by airplanes—at a cost of some $12 per ton of material applied. Many farmers in that country are finding this method cheaper than more conventional forms of application, especially where low rates are used.

Satisfactory results have already been obtained from limited aerial application of fertilizers to forests in this country.

Genetic Limitations

A principal factor causing increased fertilizer use with agricultural crops has been the development of higher yielding varieties. The inherent yielding ability of many older crop varieties was so low that they could not utilize higher levels of plant food to any advantage.

This was well illustrated by the development of hybrid corn. At low fertility levels, many of the old, open-pollinated corn varieties yielded equally as well as the improved hybrids. But with high fertility levels, the hybrids proved markedly superior. Thus, the superiority was due, in large measure, to their ability *to utilize higher levels of plant food.*

Much of our woodlands today are populated with trees having essentially the same germ plasm as those growing when Columbus first arrived in this country. Obviously, many present forest species, through centuries of natural selection have become reasonably well adapted to their environment—an environment that is often quite infertile. It should not be surprising if *this* genetic material fails to show a marked response to fertilization! Imagine how futile it would be to apply present-day fertilizer rates to the same Indian corn that was being grown here when Columbus landed!

In recent years, much interest has been generated in the genetic improvement of forest species. Experiences with agricultural crops suggest excellent opportunities exist for increasing the productivity of forest lands by using higher soil fertility levels with improved germ plasm.

A single plant nutrient in short supply could seriously limit growth and frustrate the expression of any superior germ plasm that might be developed. This would strongly suggest the desirability of evaluating new breeding material at higher fertility levels.

There are already many indications that site class of forest lands might be improved by fertilization. This could extend the growth range of desirable species, permitting them to grow on land previously considered unsuitable. Many examples of similar situations exist among agricultural crops.

Nutrient Losses and Removal by Crops

The opinion that fertilizer needs of forest trees might be different from needs of agricultural crops is usually based on two reasons:

(1) The fact that trees have deeper, more extensive root systems which enable the plants to exploit a greater volume of soil. This is true. But this more extensive root system must sustain a much *larger plant above ground,* as well. Furthermore, most of the high nutrient-bearing organic matter is found near the soil surface, which means the tree gains little advantage from its deeper roots as far as exploiting the nutrients in the organic fraction of soils more thoroughly.

(2) The fact that forest tree crops are so infrequently harvested, compared to agricultural crops—resulting in less removal of nutrients from the soil. Nutrient removal by harvested crops, is of course, a very important factor in agriculture.

With trees, a certain amount of absorbed nutrients are immobilized in the wood, while other fractions are found in the leaves. When these leaves are shed, the more soluble nutrients may be leached from the soil or re-absorbed by the plant. The less soluble forms—those immobilized in organic compounds—may eventually be released to follow the same path as those that were more soluble initially.

There is only fragmentary evidence of the amount of nutrients removed from the soil by trees. Rennie of England has estimated that over a 100-year period almost as much calcium would be absorbed and removed from the site by a stand of hardwoods as by a standard rotation of agricultural crops. Rennie estimates trees would remove considerably less phosphorus and potassium.

Other work in Europe and the United States in recent years has shown the effects of a single application of nitrogen may not be evident after one to two years—indicating the nitrogen is immobilized in the plant tissues. This suggests that where nitrogen is deficient, *fairly frequent applications might be needed.*

The limited removal of plant products or residues indicate that *far less of certain nutrients should be needed in forestry than under comparable conditions with agricultural crops.* However, leaching losses and immobilization of nutrients in plant tissues constitute a *steady "drain" on the amount of nutrients available for recycling through the plant to sustain new growth.*

Economics of Fertilizer Response

Work in Europe, the United States, and elsewhere has emphasized one basic point—that with forest trees we are dealing with plants that are similar in many respects to agricultural crops. These trees require the *same nutrient elements* as other plants and they tend to exhibit the same type of nutrient deficiency symptoms.

Where the soil is deficient in nutrients, there is no question about trees responding in growth to fertilizer applications.

We might add that it should not be too surprising that nutrient deficiencies are encountered in forest soils since trees are usually found on the less fertile soils while the more productive ones are used for agriculture.

The big question is the economics of this fertilizer response. The previous articles of this issue have indicated numerous specialized situations where, even now, fertilizers are needed and can undoubtedly be used profitably. But our research is so limited that we cannot yet predict with assurance the magnitude of response that may be expected under *most* conditions, or *whether this response will be economic.*

Consequently, as a member of a "neighboring tribe" our only suggestion is that our "brother tribe" keep an open mind on the subject until it is thoroughly explored.

It is not difficult to recall that only 20 to 30 years ago agronomists generally considered it uneconomical to fertilize *forage crops.* Today, our experiment stations recommend *higher levels of fertilizers for forage crops than for many of the high-valued row crops.*

Agriculture is full of examples where changing conditions have resulted in marked changes in fertilization practices.

Are forests trees *really* different?

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SPECIAL ISSUE INTO HANDBOOK

This special issue of *Better Crops* will be put into handbook form. For extra copies, write: Forest Fertilization Booklet, Dept. B. C., American Potash Institute, 1102 16th Street, N. W., Washington, D. C.

NEWS AND VIEWS

FOREST

European foresters have long advocated using lupine, Scotch broom, and other legumes for improving the fertility of unproductive forest soils. So in 1945, experiments with a variety of legume crops were initiated in Wisconsin. After three years testing, red clover appeared to be the most suitable green manure crop, from the economic standpoint. It was used at all trials. Fertility of the soils proposed for reforestation was first augmented by limestone. In the majority of cases, *the treatment included an equivalent of 2 tons of lime and 400 pounds per acre of 0-9-27 fertilizer.* When surveyed in 1954, the established red pine plantations revealed that green manuring failed to fulfill expectations. It seems the green manure provided ideal ground for white grubs that helped decrease survival rate of growth on fertilized areas. But spectacular results achieved in 1955 in controlling white grubs with one per cent emulsion of aldrin *may make fertilized legumes an important method of forestry improvement.*

(Agricultural Chemicals, June, 1958)

Tree fertilization brings different responses. Studies made in California timberland indicate that Redwood, Ponderosa Pine, and Douglas Fir trees respond differently to the fertility level of the soil and to the application of fertilizers. When N, K, and P were applied equivalent to 300 lbs. per acre of each element, Douglas Fir in sandy loam and in a greenhouse showed good response. Redwood seedlings under the same conditions also showed good response in the California tests.

(Croplife 5(30):17, July 28, 1958)

Last year, an experiment in fertilizing slash pine near Lake City, Florida, caused a 36.6% growth increase and a 23% increase in gum yield, according to *Agricultural Chemicals*. In a 4-year test by the Southeastern Forest Experiment Station, 500 pounds of nitrogen fertilizer per acre were applied annually. The study, however, did not test the economic feasibility of fertilizing trees.

(Agricultural Chemicals, June, 1958)

Donald White, well known forest nutrition scientist at Michigan State and a contributing author to this issue, has estimated that *an expenditure of $9-$13 an acre for forest fertilization can reduce culling costs up to $30 an acre.* Spurring growth of desirable trees often results in rapid closing of the canopy, and unwanted vegetation is shaded out.

(Cyanagrams, Fall 1957)

-GRAMS ON FOREST NUTRITION

A new technique of fertilizing pulpwood forests with standard agricultural equipment has been developed by Rayonier, the chemical cellulose producer, on its tree farm in Florida. The firm used a standard farm tractor, pulling a spreader borrowed from a local farmer who used it for pasture fertilization. The company's experimental area was divided into 84 plots—with 18 different treatments given to 72 plots and 12 used as control plots. Fertilizers applied at varying rates and in several combinatons were *urea, ammonium nitrate, ammonium nitrate-limestone, triple superphosphate,* and *muriate of potash.* Detailed comparisons between trees in the control plots and the fertilized plots will be made in about 5 years and at intervals thereafter. Comparisons between size and general health of the fertilized trees will be made now and later. The purpose is to improve tree growth and obtain better wood fiber for quality pulp. The project was supervised by Dr. T. E. Maki, professor of forest management at N. C. State and contributing author to this issue. It is believed to be the nation's first large-scale forest fertilization program for comparing responses to several plant food carriers and application rates.

(From News Release of Rayonier, Inc., Sept 15, 1957, 52 Vanderbilt Ave., New York 17)

At Canada's Laval University, Andre Lafond is experimenting with a miniature forest. Under lab conditions he simulates years of growth in a few months by applying hydroponic techniques—that is, growing plants with their roots immersed in an aqueous solution containing the essential mineral nutrient salts, instead of in soil. Already, his results show that seedling loss can be reduced from 70% to 1% and that planting costs can be cut as much as $10 an acre *by planting "prepared" seedlings in fertilized soil.*

(Cyanagrams, Fall 1957)

Two methods of applying fertilizer were tested in experiments in Spain, using a complete NPK fertilizer on one-year-old plantations of 3 different clones of poplars. The two methods were (1) to scatter the fertilizer on the surface, in a radius of 50 cm. from each tree, (2) to put it in holes at a depth of 20 to 30 cm. and 40 cm. from the tree. There seemed to be no great difference between the two methods. *But the fertilizer treatment produced striking increases in diameter and height growth over trees not receiving the fertilizer.*

(Agricultural Chemicals, June, 1958)

In a fertilizer trial with poplars, preliminary results on heavy calcareous clay soils of pH 8 indicated that application of 2 kg per tree of complete fertilizer (5-12-24) greatly increased growth and checked the cryptogamic disease caused by Dothichiza populnea. 10:10:20 or 8:16:16 fertilizer should be applied.

(Potasse 31, 199-202, 1957 Abs. Soils and Ferts. 21(3):1256. June 1958)

In a study of the nutrition and growth of nodule-bearing trees, some experiments were made on the water culture of black wattle (*Acacia mollissima*) and alder (*Alnus sieboliana*) in different nutrient conditions. In K-free inoculated cultures nodulation was poor and seedling vigour decreased; deficiency symptoms occurred in black wattle, but not in alder.

(Bull. Govt. For. Exp. Sta. Tokyo 99, 1-24, 1957, Abs. Soils & Ferts. 20(5):1931, Oct. 1957)

University of Wisconsin forest soils scientists find that grazing sets up a continuing cycle of soil depletion, and that soil in grazed woodlots becomes more and more lacking in plant nutrients each year. Decaying leaves are the chief source of plant food elements to renew those taken out of the soil by plant growth. Chemical analyses showed that soil in grazed woodlots contained an average of 10% less, N, Ca, and K than soil in ungrazed woodlots.

(Wis. Agr. Exp. Sta. Ann. Rpt. Part II, Bul. 527, p. 85, July 1957)

White birch appears to assert an appreciable influence in increasing exchangeable K in the surface of K-deficient sandy soils. As a result, young white pines grow well under birch crowns, while those in adjacent openings show symptoms of K deficiency. Foliar and soil analyses are presented.

(Jour. Forest. 53(6):451-452. 1955. Abs. Biol. Abs. 30(D-9):27030. Sept. 1956)

University of Wisconsin wildlife researchers fertilized some oaks in sandy soil of the arboretum with varying amounts of KCl, NH_4NO_3, and mixed fertilizer—rates varying from 2 to 10 lb. per tree. When acorn yields of fertilized and unfertilized trees were compared, no yield increases were found due to the fertilizers. The fertilization question needed investigation because acorns contain a high percentage of K. This need for K might limit acorn production.

(Wis. Agr. Exp. Sta. Ann. Rpt. Part II, Bul. 527, p. 91, July 1957)

In studies on mineral nutrition and mycorrhizal association of bur oak, general chlorosis of the leaves of seedling whorls was the principal symptom of induced N deficiency in sand cultures. P deficiency was manifest in deepened green color adjacent to large veins & reduced leaf size, while in K deficiency the general intervenal chlorosis was followed by small intervenal necrotic spots more abundant near leaf margins.

(Llyodia (Cincinnati) 18(3):101–108, 1955, Abs. Biol. Abs. 30(D-9):27232, Sept. 1956)

The use of aircraft is the most practical way of applying fertilizer to vast, inaccessible forest areas. A single plane can apply fertilizer to commercial stands at a rate of 400 pounds per acre with 40-foot swaths. Rutgers University has demonstrated growth increases of from 40 to 65% on red pine after aerial application of 12-12-12 at 400 pounds per acre.

(Potash News Letter for Northeast, November 1956 and Cyanagrams, Fall 1957)

One hundred acres of pine and spruce plantations on coarse, sandy, outwash soils of the Adirondacks province of New York were fertilized in the early summer of 1954 with granular muriate of potash fertilizer. The material was applied by aircraft at a rate of 200 pounds per acre. A test of the soil and foliar potassium before and after treatment showed *significant uptake and a satisfactory distribution of the material.* Improved growth of trees following treatment was indicated by *better color and increased needle length after a single growing season.*

(Agricultural Chemicals, June, 1958)

Weyerhaeuser Timber's research foresters, near Yacolt, Washington, report they have increased seed cone production of Douglas fir sixfold *by applying plant nutrients.* Such results could boost productivity of the Pacific Northwest's forest land by as much as 10%. With present methods, tree farmers in that area expect to get enough seed to reforest harvested lands only three years out of every ten.

(Cyanagrams, Fall 1957)

Poplar trees in Canada have been substantially boosted in growth by fertilization. Applying 310-480 pounds of 10-10-10 fertilizer, the Harrington Forest Farm of the Canadian International Paper Company in Quebec reported a "very significant increased growth of poplar." Directed by Paul L. Aird, the project showed that *method of placement* is very important. *Fertilizer applied deep gave much better results than fertilizer applied broadcast on the surface.* Also, response to fertilizer applied on tilled plots was greater than plant food applied to non-tilled plots. This suggests that *without tillage there was competition for nutrients.*

(Agricultural Chemicals, June, 1958)

Analytical techniques for the determination of the influence of soil on the growth of red pine & white spruce plantations are reported. The ecological homogeneity of the plantation or portion thereof is checked by a transected survey of tree heights and diameters and soil analysis. The estimate of the rate of growth is made on the basis of stem analysis of the average sample tree. The field and labor investigation of the soil properties is supplemented by foliar analysis and in the case of hydromorphic soils, by the determination of properties of ground water. The importance of an accurate estimate of the density of nursery stands is stressed. The applicability of suggested methods is illustrated by concrete examples. Table 1 includes K data on the relation between soil properties and growth of red pine. The results of foliar analysis thus far secured are not sufficient to establish a definite relationship to soil fertility status.

(Soil Sci. Soc. Am. Proc. 20:110-112. Ref. Jan. 1956)

Poplar has a very rapidly developing root system and will respond to fertilizers especially during the first 4 years of growth. The planting holes should be treated with 8-10 kg manure, 240 g superphosphate, 60 g $(NH_4)_2SO_4$ and 60 g K_2SO_4. At the restart of vegetative growth, 600 kg per ha superphosphate, 150 kg $(NH_4)_2SO_4$ and 150 kg K_2SO_4 should be applied in bands or in increasing distances from the tree.

(Ital. Agric. 94, 571-578, 1957, Abs. Soils & Ferts. 20(5):1928, Oct. 1957)

FIRST SOUTHEAST CONFERENCE

The Southeast's first conference on Mineral Nutrition of Forest Trees will be conducted at Duke University in Durham, N. C., December 4 and 5.

The conference is expected to attract 150 delegates from over the eastern part of the United States—Federal, state, industrial, and university research personnel interested in the mineral nutrition of trees.

The purpose is "to review the status of knowledge and opportunities for basic and applied research in the field of mineral nutrition of trees," according to Dr. Charles W. Ralston, program committee chairman and a member of the Duke School of Forestry faculty.

The conference is being sponsored by Duke University, N. C. State College, The American Forestry Association, and the American Potash Institute.

Speakers from Duke, N. C. State, U. S. Forest Service, Rutgers, Cornell, Beltsville, TVA, LSU, and the American Potash Institute will discuss important topics related to mineral nutrition of trees. They include:

Dr. Harry A. Fowells, staff specialist of U. S. Forest Service, Washington, D. C., speaking on Determination of Macro-element Requirements; Dr. Robert L. Barnes, research forester, U. S. Forest Service, Duke University, on Study of Mineral Requirements of Excised Tree Roots; Dr. Norman F. Childers, chairman of Horticulture at Rutgers University, on Visual Symptoms of Nutrient Deficiencies of Trees; Dr. Damon Boynton, professor of pomology, Cornell University, on Leaf Sampling and Analysis; Dr. John C. Cain, professor of pomology, N. Y. State Agricultural Experiment Station, discussing Observations on Antagonistic Effects in Leaf Analysis.

Dr. Paul J. Kramer, professor of botany, Duke University, on Physiological Aspects of Research on Inorganic Nutrition of Forest Species; Dr. Edward Hacskaylo, physiologist at USDA Beltsville Agricultural Research Service, Maryland, on the Role of Mycorrhizae in the Mineral Nutrition of Trees; M. X. Schumacher, professor of forestry, Duke University, on Statistical and Mensurational Aspects of Field Experiments in Tree Nutrition; Dr. George Standford, chief, Soils and Fertilizer Branch, Division of Agricultural Relations, TVA, Wilson Dam, Alabama, on Nutrient Source Materials for Tree Nutrition Studies.

Dr. Walter E. Ballinger, assistant professor of Horticulture, N. C. State College, discussing Horticultural Viewpoints on Field Experiments in Tree Nutrition; Dr. E. T. York, Jr., eastern manager, American Potash Institute, Agronomic Viewpoints on Field Experiments in Tree Nutrition; Dr. Warren T. Doolittle, Division of Forest Management Research of the U. S. Forest Service on Tree Nutrition Research Status Report—Federal and State Programs; Martin B. Applequist, assistant professor of forestry, Louisiana State University, Tree Nutrition Research Status Report—Colleges and Universities.

Serving with Dr. Ralston on the program committee are Dr. T. Ewald Maki, N. C. State College School of Forestry, Dr. Fowells, and Dr. Kramer.

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