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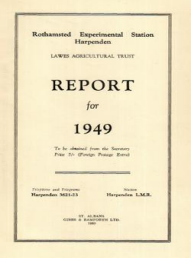

Nutritional Problems in Forest Nurseries

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REVIEW OF WORK ON NUTRITIONAL PROBLEMS IN FOREST NURSERIES

E. M. CROWTHER

Forest nurseries and forests offer excellent facilities for investigating soil fertility and crop nutrition problems. The levels of fertility in many nurseries and most forests are far below those common in farms, gardens and orchards. Nursery management is exhausting as the same crops, mainly conifers, are grown repeatedly, and both tops and roots are removed. Until recently little was added to the land beyond occasional dressings of leaf mould, farmyard manure or a variety of composts. Sometimes mustard or other green crops, receiving lime and ammonium sulphate, were dug in. Conifer seedlings grew very poorly in many of the older " established " nurseries, but there had been some spectacular successes with heavy dressings of carefully prepared composts in nurseries on heathlands or forest clearings. These results have been ascribed to an improvement in the mycorrhizal associations of the tree seedlings, and it has often been suggested that the effects of composts in relation to mycorrhiza might have important bearing on the nutrition of other kinds of crop and, thus, on general questions of soil fertility.

Opportunity to study these questions arose towards the end of 1944 when the Forestry Research Advisory Committee set up a Sub-Committee on Nutritional Problems in Forest Nurseries, under the Chairmanship of Professor F. T. Brooks, F.R.S.

Each year since then many experiments have been carried out in several nurseries and forests, mainly on Sitka spruce and Scots pine, in a most intimate collaboration between the Research Division of the Forestry Commission and several members of the Rothamsted Chemistry Department. When the broad lines of the programme have been approved by the Sub-Committee, Miss Benzian and Miss Roscoe are responsible for drawing up the detailed working plans, applying the treatments in all nurseries and forests in South and East England and in all forests in Wales, supervising the general conduct of the experiments and analysing the data. Mr. Warren, with Mr. Udall for part of the period, supervises the chemical analysis of soils, manures and crops and the preparation of special composts and manures. Mrs. Cooke undertakes pot experiments at Rothamsted. The Commission staff prepare the sites and do all cultural operations and assessments ; they also apply the experimental treatments in North England and in the seedbed experiments in West England and Wales.

For experiments continued only for a few seasons it has been found convenient to work with plots of one square yard. In this way it has been possible within a small area to test many factors in experiments of modern design. Sitka spruce, a particularly sensitive species, has been used throughout ; from 1945 to 1948 the plots in many nurseries were split to test Scots pine as well ; a few experiments have included many other species. The statements in this summary of results from nursery experiments are limited to mean heights of Sitka spruce. Seedbed experiments are assessed by height because this provides the only measurement which can be taken

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conveniently on large numbers of plants which are to be tested subsequently in " extension experiments " in transplant lines and forests. The critical test of seedbed treatments lies in the subsequent establishment and growth of the plants. Many samples are also taken from seedbed plots for other measurements, such as diameter, dry weight, chemical analysis and root examination to see how far these provide better criteria than height for assessing the effects of treatments and for forecasting subsequent performance. In this summary the word " seedlings " refers to plants at the end of the first season (1 + 0) and " transplants " to plants after one season in seedbeds and one in transplant lines (1 + 1). In forestry practice Sitka spruce is generally planted out as 2 + 1, 1+2 , or 2 + 2 but a few successful trials with 1 + 0 seedlings had been made. The target put before the Sub-Committee was to find means of producing 1 + 1 transplants fit for planting and of avoiding such progressive deterioration of nurseries as had been so often experienced in the past. As the work proceeded increasing attention was given to planting one-year seedlings directly into the forests and to manuring them.

Composts

Dr. M. C. Rayner had suggested that composts acted through their effects on mycorrhizal and other fungi in the soil rather than by supplying nutrients directly to the seedlings. Thus, with Professor W. Neilson Jones (" Problems in Pine Nutrition," 1944, p.99), she had written " increase in the supply of available nutrients plays a relatively insignificant role in the maintenance of healthy and vigorous growth that follows addition of composts to the soil." Chemists were not unnaturally sceptical of this interpretation of the effects of materials rich in some of the major plant nutrients when used on soils singularly deficient in them. Dr. Rayner had supported her conclusion by the results of a critical pot culture experiment in which " soluble salts of nitrogen, potash and phosphoric acid corresponding to those in the composts evoked surprisingly little response in pine seedlings." (ibid, p.97). The evidence was, however, greatly weakened by the assumption that the amounts of available plant nutrients in composts could be estimated by growing oats in mixtures of compost and sand and interpreting their responses to additional fertilizers as in the Mitscherlich method for estimating fertilizer requirements of soils. There are good grounds for supposing that the composts would supply to the pine much more nitrogen, phosphorus and potassium than were provided in the small amounts of soluble salts assumed to correspond with the available nutrients in the composts.

In preliminary experiments in 1945 and 1946 at four nurseries several kinds of compost and farmyard manure were tested in factorial conbinations with fertilizers. At Sugar Hill Nursery, Wareham, Dorset, seedlings grown with fertilizers supplying nitrogen, phosphorus and potassium were much more vigorous than those receiving composts alone. The effects of contrasted kinds of compost were well related to their chemical compositions. Thus, hop waste compost was relatively rich in nitrogen and phosphorus but deficient in potassium, and seedlings receiving hop waste compost therefore responded particularly well to additional potassium as sulphate or chloride. Bracken compost was relatively deficient in phosphate but

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well supplied with potassium. From 1947 onwards many special batches of experimental composts have been prepared and tested. A compost from bracken (preferably cut in early summer) and fresh hop waste has tentatively been adopted as the standard because it supplies moderate amounts of the three major plant nutrients, is easily prepared and has satisfactory physical properties. A good deal of attention has been given to preparing suitable composts from straw and to devising new kinds of compost intended primarily to protect added phosphates from too rapid inactivation by the soil.

In some nurseries the responses to compost or fertilizers were much smaller than at Wareham, especially where the soils were only moderately acid. At the responsive centres there were no consistent differences between the results from composts and those from fertilizers. In several experiments the plants with inorganic fertilizers were taller than those with composts, but in some other experiments, especially in dry seasons, the plants with compost were the taller. The combination of compost and fertilizers commonly gave larger plants than either kind of manure alone. It is to be expected that composts will improve the physical properties of the soil and liberate available nutrients more steadily and for longer periods than inorganic fertilizers. The use of fertilizers in forest nurseries is such a recent development that both in experiments and in practical trials there is a risk that unsuitable forms or amounts may sometimes be applied at inappropriate times. But difficulties also arise with composts and other bulky manures. The raw materials are often of indefinite and highly variable composition and the resulting composts may be deficient in essential plant nutrients. Sometimes they introduce weed seeds and excessive quantities of lime. They may also leave the seedbeds too open in dry seasons, as happened at several centres in 1949 when the compost plots carried fewer plants than the fertilizer plots. Raw bulky organic manures, *e.g.* fresh hop waste, dried bracken and chaffed straw have reduced plant numbers in most seasons.

Although the best results are to be expected from a judicious combination of organic manures and fertilizers, suitable raw materials are too scarce and the costs of transport and handling too high for manuring in forest nurseries to be limited to the use of composts. In forest nurseries, as in farms and gardens, the value of bulky organic manures and fertilizers should be assessed by direct experiment and interpreted mainly in terms of their effects on the chemical and physical properties on the soil and the nutrition of plant, until any clear evidence can be found to establish specific microbiological effects of benefit to the plants. So far, in experiments limited to tests over five years, no such evidence has been obtained from the subsequent behaviour of plants in transplant lines or forest plantings or from root examinations for mycorrhizal equipment made by Dr. Rayner and Dr. Levisohn. Many additional experiments are in progress to provide further evidence on these questions.

Fertilizers

When the present series of experiments was commenced it was believed that soluble fertilizers were dangerous when applied directly to seedbeds, transplants or newly planted trees. In many experiments excellent results have been obtained with ordinary agricul-

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tural fertilizers, though the proper timing of nitrogen applications still presents difficult problems, especially in dry years and on weedy sites. Superphosphate has often proved markedly better than Bessemer basic slag, one of the few fertilizers previously tried in forest nurseries and forests. Very good results have also been obtained from a slowly acting nitrogen fertilizer, a plastic waste derived from formalized casein. In a large number of trials there have only been two instances of damage from fertilizer, both in 1948 on a very acid soil (pH around 4·0) at Wareham, Dorset. When superphosphate was used with late supplies of available nitrogen, either from organic forms in the seedbed or from late top-dressings of soluble salts, seedlings developed yellow needles. Transplants were scorched by top-dressings of ammonium sulphate but not by " Nitrochalk " or urea. There was no such damage at Wareham on lightly limed land in 1949 or at other nurseries in 1948 or 1949.

There was no evidence that seedlings provided with abundant supplies of nitrogen in the seedbed suffered in any way in transplant lines or in forest plantings. Indeed they often grew better than those with less nitrogen. During the droughts of 1947 and 1949 big seedlings were grown with inorganic nitrogen on watered plots. Transplants in 1948 brought out the interesting contrast that the extra height produced by additional nitrogen in the 1947 seedlings was maintained in the 1948 transplants but that due to watering was not.

In many experiments differences produced by seedbed treatments evened out when the weather was favourable for growth in the transplant year or after a couple of years in the forest. In some seasons of poor growth seedbed differences have been maintained or even increased, especially when the subsequent manuring was incomplete. It must be remembered that even moderate increases in mean height are often associated with large increases in the number of seedlings fit to transplant.

During the moist season of 1946 doubts were expressed whether the particularly large seedlings grown with fertilizers at Wareham would withstand the rigours of transplanting in distant nurseries. Batches of a thousand plants were distributed to several widely separated nurseries where they grew very well during the drought of 1947, beating the local stock.

Soil Reaction in Forest Nurseries

Many of the older nurseries of the Forestry Commission were established on agricultural land and in most of them Sitka spruce and other conifers now grow very poorly. The Research Nursery at Kennington, Oxford, is typical, though here the problem is not complicated by excessive weed growth as at several other nurseries especially during the war. Most of the older parts of the nursery has soil around the neutral point. Preliminary experiments in boxes at Rothamsted in 1945 showed that acidifying this soil greatly improved the growth of Sitka spruce. In several nurseries moderate improvements have since been effected by acidifying the soils with such materials as sulphuric acid, aluminium sulphate, sulphur and ammonium sulphate, but the general level of growth has not been raised to that obtained with suitable manuring on very acid soils. Residues from the acidifying agents often had harmful effects,

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especially when dry summers followed. Experiments are in progress to test the effect of a year's fallow after acidifying the soils.

The possibility that poor growth at high pH values depends on some minor element deficiency has been repeatedly tested both by direct applications of salts to the plants or the soils and by growing agricultural and horticultural crops known to be particularly sensitive. No positive evidence of such a deficiency has been found, apart from repeated failures of yellow lupins, presumably from iron-deficiency, in one nursery on an isolated patch of highly calcareous soil on which conifers also failed. It is still quite uncertain whether the major defect in neutral soils is nutritional or microbiological.

The correlation between poor performance of conifer seedlings and high pH value of the soil was good enough to justify steps to prevent further liming of " established " nurseries or the unintentional introduction of basic material in seed covers, basic slag, composts and sewage sludge. The Forestry Commission has also decided to concentrate the bulk of its production of conifer seedlings in new nurseries on very acid heathland or forest clearings.

To provide information on the optimal pH range for tree seedlings and rotation crops, plots were established in 1947 at two nurseries with the widest range of pH values that could be obtained by steeply graded dressings of aluminium sulphate or calcium carbonate. In the first season many species of conifers grew poorly at high pH values and most of them grew well at pH values so low that possible rotation crops failed. As these plots settle down they may provide useful chemical and biological material for further investigations on the ways in which soil reaction affects tree seedlings.

If, as appears likely, conifer nurseries should be kept very acid to favour the seedlings and to restrict weeds, it will be difficult to devise suitable rotations with leys or green manure crops intended to maintain soil organic matter. A number of observation plots have been laid down on crops with low lime requirements, *e.g.* lupins, birdsfoot trefoil and various grasses. Rotation experiments have been started using, where necessary, the minimum amounts of limestone believed to be necessary to allow some choice of resting crops. Early results suggest that great caution must be exercised in applying agricultural cropping systems to forest nurseries. Sitka spruce in 1949 after white clover in 1948 was much inferior to that after a previous crop of Sitka spruce or a bare fallow. Some evidence has been obtained of a residual benefit from a grass ley.

Steam and formalin

Each year since 1945 Mr. J. A. B. Macdonald, Sylviculturist (North) of the Forestry Commission has obtained notable improvements in Sitka spruce seedlings on slightly acid or neutral soils by " partial sterilization " with steam or formalin, and similar results have been obtained in many experiments by the Rothamsted staff since 1946. Then in 1948 formalin (1 lb. commercial solution and 9 lb. water per square yard) applied a few weeks before sowing improved mean heights in 24 out of 26 experiments in nine nurseries. Steam and formalin given in the winter of 1947-48 improved growth in successive Sitka spruce crops in both 1948 and 1949. The benefits were sharply localized, the edges of treated plots and bands standing out clearly in continuously sown beds. Whatever the mechanism of

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"partial sterilization" it is not easily annulled by reinfection from nearby untreated soil.

A special set of experiments was started in 1949 in an old nursery on neutral soil over Lower Greensand near Ampthill, Bedfordshire to allow microbiologists and chemists at Rothamsted and mycologists at Cambridge to make detailed studies of the changes occurring in treated soils. In one of these experiments the mean heights of Sitka spruce were increased from 1·1 inches on untreated soil to 2·1 inches with formalin and 2·5 inches with steam. Most of the plants on the treated plots but very few of those on the untreated plots were fit to transplant or to plant directly in forests. Steam and formalin also check weeds, especially in the critical early stages of growth. Although this would be of great practical value in large-scale applications, it complicates the interpretation of experimental results and serves to illustrate the way in which effects of "partial sterilization" depend on the balance and interactions between different kinds of organisms.

Hitherto, most investigations on such drastic soil treatments as steam and formalin have had to be restricted to greenhouse crops unsuited for adequately replicated factorial experiments. The possibility of applying modern laboratory methods to large numbers of small plots of a sensitive crop opens up many promising lines of investigation. When more is known about the mechanism of the effects it may become possible to devise cheaper methods fit for more extensive use in forest nurseries and, perhaps, in market gardens.

Forest experiments

In each season since 1947 batches of seedlings and transplants have been planted in three or four forests to test their performance. So far only the assessments for the 1947 plantings on acid heaths or moorlands have been fully analyzed. Establishment was good for both seedlings and transplants. On the average of all experiments plants raised with fertilizers were slightly taller than those raised with compost. A tentative general conclusion is that seedlings large enough for transplanting in the nursery may safely be planted in the forest, whatever their manurial treatments have been on the nurseries. If this finding is confirmed in further experiments and large-scale trials, it will point the way to great economies in nursery work.

The Forestry Commission rarely uses fertilizers in the forest, except on peaty soils in the West of Scotland, when newly planted trees may receive basic slag. In the present work striking results have been obtained in manurial experiments with seedlings and transplants on poor acid soils. Thus, on a Calluna site at Broxa in the North Yorkshire Moors there were very big responses to each of the elements nitrogen, phosphorus and potassium. On a grassy site on Dartmoor there were good responses to nitrogen and smaller ones to phosphorus and potassium. Some typical results from assessments late in 1949 on Sitka spruce transplants planted early in 1947 were:

	Broxa, Yorkshire		Dartmoor, Devon	
	Height inches	Diameter mm.	Height inches	Diameter mm.
Unmanured ..	14·6	10·3	26·4	13·4
NPK fertilizers ..	29·4	17·7	34·9	17·3

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In several experiments manured seedlings (1 + 0) grew more vigorously than unmanured transplants (1 + 1), which after two seasons were already showing all the symptoms of " going into check." It is not yet known whether manuring will enable the young trees to withstand competition with aggressive Calluna, or whether on grassy sites the weeds may respond more rapidly than the young trees. Promising results have been obtained from slowly acting forms of nitrogen fertilizers. Soluble compound fertilizers have been used successfully by applying them on two sides of the tree, either in patches on the surface or in notches as granules or as compressed one-ounce pellets. Much more work will be needed to find fertilizers and methods of application likely to have sufficiently prolonged effects.

Pot Culture Experiments

A considerable amount of time has been devoted to developing a suitable pot culture technique for testing soils from many nurseries under comparable conditions and for examining more materials and combinations of treatments than can be tried in the nurseries. After a number of failures, suspected to have been partly due to " damping-off," success was attained in 1949 in experiments on the effects of steam, formalin and acid on soils from three nurseries in which conifers grow poorly. Additional tests were made on mixtures of treated and untreated soils to study re-infection. Acid, steam and formalin all reduced " damping-off " and improved growth. Early in the season the formalin treatments were outstanding but later the heights evened up considerably. The rough parallelism between control of " damping-off " and general early vigour of growth suggests that one important factor in " partial sterilization " may be the control of parasitic fungi.

Tops, Roots and Mycorrhiza

From the experimental plots it appears that in any one season and nursery the top-root ratio and the general form of the roots vary fairly regularly with the size of the plant. There are, however, large differences in root form between contrasted nurseries, some giving abundant fine fibrous roots and others pronounced tap roots or very large wiry laterals. It is not yet known which kind of plant is the best for various types of forest site. Until much more detailed work has been done on roots, it may suffice to judge the vigour of plants by the size of the tops or the thickness of the stem.

Good top growth and good root growth are not necessarily antagonistic. Although additional nitrogen may increase tops relative to roots, the larger reserves in plants with more meristems may help establishment and early growth after transplanting or planting-out in the forest. Acute nitrogen starvation is likely to set in only too rapidly in most forests, and it seems reasonable therefore to give the young plant the best possible start against its grim environment. The old view that plants intended for poor sites must be tough and wiry may be a relic from the times when nutritional conditions in nurseries were so poor or unbalanced that three or four years were required to allow the plant to pick up sufficient nutrients to withstand transfer to still poorer soils. The chemical view outlined above is not inconsistent with the theory that good mycorrhizal associations should be established as soon as

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possible in the life of the tree. Whatever benefit the tree may ultimately derive from the fungus, the fungus must draw most of its carbohydrate from the plant. Even where additional nitrogen delays the plant's production of surplus carbohydrate for roots and fungus, this may be more than compensated for by the larger total amounts of surplus carbohydrate supplied later from the larger plants. The significance of mycorrhiza in young conifers is not sufficiently well understood for these matters to be settled deductively. The appeal must be to the actual behaviour in the forest of seedlings and transplants raised in adequate experiments.

The effects of compost in improving the growth of conifer seedlings in heathland soils were ascribed by the late Dr. Rayner to a stimulus from materials produced within the soil by mycorrhizal and other fungi. This hypothesis has the disadvantage that it can be developed only by difficult anatomical observations made by a few specialists working on quite small numbers of specimen plants. An alternative hypothesis, in much closer accord with the results of our experiments, is that the major plant nutrients in composts act directly on tree seedlings, and, through their better nutrition, encourage mycorrhizal associations in the roots. This interpretation has the advantage of simplicity and allows problems of soil fertility and nutrition in forest nurseries to be attacked by methods which have proved their value in agriculture and horticulture.

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