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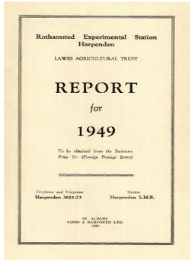
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REVIEW OF WORK ON NUTRITIONAL PROBLEMS IN FOREST NURSERIES

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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 agricultural 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 "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

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 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.

THE RELATION BETWEEN SOIL CULTIVATION AND CROP YIELDS

By E. W. Russell

Introduction

The Physics Department has been concerned with the effects of soil cultivation on crop yield ever since 1926. The results of the first eleven years' work were summarized in the Annual Report for 1936, and this report will carry the summary up to 1949. The work initially fell into two distinct sections : the effect of hoeing root crops on their yield, and the effect of different ways of preparing a seed bed on crop yield. Since 1936 two further sections of work have been added : the effect of earthing-up potatoes, and the effect of deep and very deep tillage on crop yields.

Summary

The great difference between this report and the one written in 1936 is that whereas in the former report practically no experimental cultivation treatment gave any appreciable increase of crop yield, some of those done subsequently have given consistent and occasionally quite large increases of yield. The reason for this difference reflects our greater knowledge on what cultivation treatments can and cannot do.

The original object of these cultivation experiments was to check the validity of some of the reasons commonly given by the farmer and farm adviser for carrying out certain cultivation operations, and the conclusion drawn from these experiments up to 1936 was that many of these reasons were in fact invalid. All subsequent work has reinforced the correctness of that conclusion.

The basis of much of the subsequent work has been to assess, independently of tradition but in the light of current scientific knowledge, the reasons why certain cultivations may be necessary, and to test the importance of these possible reasons in practice. By working this way round, it has been possible to pick out certain requirements that must always be met.

The first conclusion, which every experiment capable of showing has clearly shown, is that seedling weeds can have a very serious effect on the early development of the crop, and once the crop has suffered a check due to such a cause, it will usually never fully recover from it. One of the fundamental criteria that should be used in judging the necessity or value of a cultivation operation is, therefore, its effect on the weeds in the soil.

The second conclusion, entirely in agreement with that reached in the 1936 Report, is that the exact state of tilth of a seedbed is, comparatively speaking, of minor importance compared with some other factors. One of these other factors is the weediness of the seedbed, and another is its moisture content, but no further analysis of the factors has been made.

The third conclusion is that the principal effect of a moderate increase in the depth of ploughing is that it helps to control weeds in the seedbed but, in general, it has not affected the yields. But, if the depth of ploughing is doubled, from 6–7 inches to 12–14 inches, appreciable increases in yield of potatoes and sugar beet have been

obtained without the subsoil clay which has been brought up having any appreciable residual effect on the subsequent spring corn crop. The experiment has not yet been running long enough for any conclusions to be drawn on the effect of deep ploughing on the yield of winter wheat, as the results have been erratic.

This conclusion has not been fully substantiated in experiments made elsewhere in Great Britain, since one of the general conclusions of this series of experiments is that potato yields are very rarely affected by deep ploughing, although the yield of beet often is.

A fourth conclusion is that the best way of applying potash or phosphate to sugar beet is to broadcast them on the land before ploughing, and this is true whether the land is to be ploughed 6–7 inches or 12–14 inches deep. Again, this conclusion does not appear to be valid generally, but the conditions required for its validity have not yet been fully recognized.

(a) *The Effect of Hoeing Potatoes, Sugar Beet and Lettuce*

The experiments up to 1936 had been made to test if hoeing a soil, that is creating a loose dust mulch on the surface of a soil, reduced the loss of water by evaporation from the soil surface, so allowing more water to be available to the crop. Hence these hoeings were done in midsummer, between mid-June to mid-August, at which time one might expect the crop to benefit most from extra water, and the crops used were sugar beet and kale (1). These experiments showed that the crop yields were in fact either unaffected or were slightly reduced by additional hoeings during this period.

Potatoes. These results with sugar beet and kale were rather unexpected, so the experiments were extended to the potato crop, and were carried out from 1937 to 1939 by Dr. H. C. Pereira, under the guidance of Dr. B. A. Keen, the Head of the Physics Department at that time, on a light soil derived from the Bagshot Sands at Ottershaw Park, Surrey. The results of these experiments were published in 1941 (2).

Pereira's experiments fell into two parts. He examined both the effect of hoeing a bare soil, kept free from weeds, on its moisture content, and also the effect of hoeing between the rows of potatoes on their yield. In the first group of experiments he showed that the moisture content in the top 18–24 inches of soil, kept bare by using an arsenical weed-killer, was unaffected by hoeing the soil surface in each of the three years. Hence the loose soil mulch produced by hoeing could not increase the amount of water in the soil available to the plant.

In the second, and main group of experiments, the effect of frequency and depth of the hoeings and intertillage between the rows of potatoes was investigated. In 1937 some plots were not hoed at all, some were hoed twice and earthed up, some four times and earthed up, but the plots that were not hoed at all were kept free from weeds by hand weeding. The results of this experiment were that the plots hoed four times and then earthed up and the plots kept free from weeds by hand weeding and not earthed up gave almost identical yields of potatoes, namely 12·4 and 12·3 tons per acre, whilst those only cultivated twice before earthing up gave 10·4 tons per acre. These plots however were definitely weedier than those of the other two series. In 1938 and 1939 the experiments were designed to extend these results. In each year plots kept free from weeds, either by hand weeding or using hoes or sweeps set to work no deeper than ½ inch, gave the same yields as plots receiving a number of hoeings, provided these hoeings kept the land free from weeds, and it did not much matter whether the hoes were set to work to a depth of 6 in., 3 in., or ½ in. But if any treatment was used that allowed even quite small weeds to develop in the crop the yield was invariably reduced. Thus the plots which were allowed to become a little weedy in 1938 had their yield reduced from 8·7 to 6·8 tons per acre, and in 1939 from 11·2 to 9·7 tons per acre.

Table 1 summarises the yields of potatoes under the various treatments, and gives in addition the per cent. ware in the crop, and it shows quite clearly that the sole benefit of hoeing to the potato crop was through its control of weeds.

Table 1. *The Effect of Weeds and Hoeings on the Yield and Per cent. Ware of Potatoes : Ottershaw Park.*

	Total Yield of Tubers in tons per acre				per cent. Ware			
	Clean Weeded			Weedy	Clean Weeded			Weedy
	not hoed	few hoeings	frequent hoeings		not hoed	few hoeings	frequent hoeings	
1937	12·3	—	12·4	10·4	91·8	—	89·8	88·1
1938	8·6	8·8	8·8	6·8	91·5	92·1	92·5	84·9
1939	11·8	11·0	10·7	9·7	90·6	90·5	90·7	89·7
Mean	10·9		10·6	9·0	91·3		91·0	87·6

Hence the conclusion drawn from these experiments, which were brought to a close by the outbreak of war, was that hoeing or cultivating the potato crop on the light soil at Ottershaw Park was only beneficial if weeds were killed : mere cultivations for the purpose of loosening the soil did not increase the yield in any of the experiments. Pereira also obtained some evidence to show that the cause of the harmful effect of the weeds was that they reduced the amount of water available to the crop. He further summarised the results of several hundred similar experiments that have been made with other crops all over the world (3), and showed that the general conclusion to be drawn from them was that the value of hoeing lay in its ability to kill weeds and not to make a surface mulch.

Two experiments were made at Rothamsted in 1942 and 1943 bearing on these results of Pereira's. These experiments contained the comparison of cultivating between the rows of potatoes two times and five times before earthing up, as well as comparisons of different fertiliser treatments. The results of these experiments are given in Table 2 :—

Table 2. *The Effect of Additional Inter-row Cultivations on the Yield of Potatoes*

Total produce in tons per acre : Rothamsted

	Two cultivations between rows	Five cultivations between rows	Reduction due to additional cultivations
1942	15·66	14·90	0·76
1943	8·38	8·14	0·24

In both years the additional cultivations, in so far as they had any effect, were slightly harmful.

Sugar Beet. These results of Pereira's received confirmation in a sugar beet experiment carried out at Woburn in 1939. This experiment was designed primarily for another purpose, but it contained a comparison between plots that were intensely hoed and those that received less hoeing. The intensively hoed plots gave a yield of 1·6 tons per acre of beet above the less intensively, and there was reason to suppose that this was largely due to an additional hoeing given shortly before singling. Another experiment with sugar beet at Woburn in 1940 again contained a comparison between two intensities of hoeings, and again the more intensively hoed plots outyielded the less intensively by 2·3 tons per acre when no nitrogen fertilizer was given the beet, but depressed the yield a little when 4 cwts. per acre of sulphate of ammonia were given, as is shown in Table 3 :—

Table 3 *The Effect of Nitrogen Manuring and Intensive Hoeing on the Yield of Beet at Woburn in* 1940

	Clean Beet in tons per acre		
	No Nitrogen fertilizer	4 cwts. per acre sulphate of Ammonia	Response to N.
Intensive Hoeing	18·8	14·7	4·1
Normal Hoeing	19·5	12·4	7·1
Benefit of Intensive	–0·7	2·3	

Once again there was evidence that the benefit of the intensive hoeing was due primarily to an additional hoeing given shortly after singling. Neither in 1939 nor in 1940 were the weeds obviously serious when this additional hoeing was given, and in 1940, but not in 1939, additional nitrogen fertilizer neutralised the harmful effect of the weeds.

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In 1941 onwards, experiments were designed expressly for the purpose of checking points raised by these and by Pereira's results. In the first place it was necessary to prove that the sugar beet at Woburn was responding to the removal of the weeds and not to the mulch produced by the hoeing, and in the second to extend the work to other crops. The first point was established by comparing the effect of hoeing with hand weeding, and this comparison was made with sugar beet in 1941 and 1943. The results of these two experiments are given in Table 4 :—

TABLE 4 *Effect of Weeding by Hoeing or Hand Pulling on the Yield of Sugar Beet*

Yield of Clean Beet in tons per acre : Woburn

1941 *Experiment*

Sulphate of Ammonia Given	Period of Weedings: before Singling	Period of Weedings: after Singling	Before and after singling
None	9·7	8·4	10·7
Benefit due to hoeing compared with hand weeding	0·8	1·5	1·0
4 cwt. per acre	13·9	14·0	13·5
Benefit due to hoeing compared with hand weeding	0·4	–0·3	–0·3

1943 *Experiment*

Sulphate of Ammonia given	Weeding Programme: Minimum	Intensive weeding till 3 weeks after singling	Intensive weeding through-out season
None	6·3	8·7	9·6
2 cwt. per acre	8·9	12·2	11·8
4 cwt. per acre	12·9	13·4	14·0
Benefit due to hoeing compared with hand weeding	–0·7	0·1	–0·5

In both experiments, the yield of beet was not much affected by weeds if 4 cwts. per acre of sulphate of ammonia were used, but whilst this result was entirely accurate for 1941, it is possible that the beet received some set-back from the weeds in 1943. In 1943 there was no benefit in hoeing compared with hand weeding, whilst in 1941 the hoed plots receiving no nitrogen yielded 1·1 tons per acre more than the hand weeded. It is probable that this benefit of hoeing is largely due to the better control of the small weed and twitch that it gave compared with the hand weeding.

The conclusion reached from these experiments is, therefore, that the yield of beet can be very appreciably reduced by quite small weeds up till 2–3 weeks after singling, that hoeing is an efficient means of killing these weeds, and that at Woburn the weeds reduce the yield of beet largely through the reduction in the amount of available nitrogen in the soil that they bring about.

Lettuce. Similar experiments to the sugar beet ones were made with lettuce at Woburn in the three years 1942–44. Lettuce was chosen as several market gardeners who were consulted considered that it was one of the vegetable crops most likely to benefit from the loosening of the soil surface brought about by hoeing. In the first two years, the experiment contained a comparison of frequent weeding with less frequent, weeding by hand with hoeing, and high and low level of fertilizers. In 1944 the experiment was modified a little in that the comparison was between clean weeding throughout the growing season and clean weeding while the crop was young.

The relevant results of these experiments are given in Table 5 :—

TABLE 5 *Effect of Weeding and Hoeing on the Growth of Lettuce : Woburn*

	Mean Yield	Increase due to frequent weeding	Increase due to hoeing compared with hand pulling
	Yields of Lettuce harvested in tons per acre		
1942	7·3	1·7	–0·7
1943	11·3	2·0	0·9
1944	11·8	4·9	0·9
	Numbers of Lettuce harvested in thousands per acre		
1942	26·7	1·9	–0·5
1943	53·1	–1·0	0·7
1944	41·9	11·3	2·1
	Weight per Lettuce in ounces		
1942	9·9	1·6	–0·8
1943	7·6	1·6	0·7
1944	10·1	1·5	0·2

The table shows that frequent, or continued, weeding gave larger lettuces than light or early weeding, though the outer leaves of the clean weeded lettuces were sometimes rather blanched. But it made little difference to the crop if the weeding was done by hand or by hoeing, showing that it is the weed-killing action of the hoe, rather than the loosening of the soil which it causes, that is so important. Further, the harmful effect of the weeds on the lettuce could not be reduced by adding either an inorganic nitrogen fertiliser.

Conclusion. The three sets of experiments, with potatoes, sugar beet and lettuce, all show that weeds can set back crop growth very severely, and that an extra hoeing, by killing quite small weeds, can sometimes give a striking increase in crop. The main effect of the weeds seemed to be that they reduced the water supply to the potatoes and the nitrogen supply to the beet, and in particular for beet at Woburn quite a severe weed infestation sometimes had little effect on the yield if an adequate dressing of nitrogen was given.

In none of the experiments was there clear evidence that hoeing had any benefit apart from its weed-killing action.

(b) *The effect of earthing-up potatoes on their yield*

In the experiments of Dr. Pereira at Ottershaw Park, the potatoes on the unhoed plots were not earthed up, and, as is shown in Table 1, this lack of earthing up has not affected the yield of potatoes in any way. Nor did it affect the percentage of greened tubers appreciably. Hence there appeared to be no justification for earthing up potatoes on this light sandy soil from the point of view of obtaining a higher yield of saleable ware potatoes.

This aspect of Pereira's work received further investigation on the heavier soil at Rothamsted from 1946 to 1948. In 1946 and 1947 the effect of omitting earthing up of potatoes was studied when the inter-row cultivation given to the potatoes was done with tractor hoes set fairly deep and with them set shallow, and at the same time an additional treatment—applying a chaffed straw mulch between the rows of potatoes that received little cultivation and no earthing up—was put in. In 1948 it was intended to compare the effect of frequent with infrequent inter-tillage with and without earthing up, but the potatoes grew so quickly that all the plots received about the same number of inter-row cultivations.

The yield of potatoes, the per cent. ware and the per cent. of greened potatoes in the ware were estimated. In 1946, any potato having a spot of green on was classed as greened, in 1947 two categories of greening were used, that severe enough to prevent the potato being classed as saleable ware and that which was only visible to careful inspection, and in 1948 only one category was used, namely that which would prevent the potato being classed as saleable ware.

These experiments have thus only partially confirmed Pereira's results. In 1947 and 1948 earthing up put up the yield of saleable ware by about 12-16 cwts. per acre, whilst in 1946 it had a much larger effect if shallow intertillage was used but a smaller effect if deep intertillage was used. It is interesting to note that the straw mulch always gave a good yield of potatoes and its yield of saleable ware was about the same as the plots that were not earthed up in 1946, about the same as those earthed up in 1947 and was definitely the highest of all the treatments in 1948.

The results of these experiments are given in Table 6:—

Table 6. Effect of inter-row cultivations and earthing up on the yield of potatoes: Rothamsted

Hoes set	Earthed up		Not earthed up		Not earthed up
	Deep	Shallow	Deep	Shallow	Straw Mulch
	Total Tubers: tons per acre				
1946	12·40	12·96	12·44	11·66	12·68
1947	8·43	8·63	7·86	8·73	8·53
1948	12·74		12·92		14·63
	Ungreened Saleable Ware: tons per acre				
1946(1)	8·06	9·01	7·75	5·65	7·40
1947	7·14	7·68	6·35	7·02	7·25
1948	12·03		11·46		13·51

1 Total ware without any green

Summary: Beneficial effect of earthing up on yield of saleable ware in tons/acre

	Deep intertillage	Shallow intertillage	Mean
1946	0·31	3·36	1·83
1947	0·79	0·66	0·71
1948	0·57		0·57

The effect of the depth of intertillage was small, but there was a tendency for the shallower depth to be preferable if the potatoes were earthed up.

Conclusion. The effect of earthing up on the total yield of potatoes, whether on a sandy or a heavy loam soil has always been small, but it decreases the weight of greened potatoes at Rothamsted. This decrease was about 15 cwts. per acre in two of the years, and considerably more in the third, though a much more severe criterion of greening was used in this year than in the other two.

(c) *The effect of the tilth of the seedbed on crop yield*

A number of the Rothamsted cultivation experiments have given the rather unexpected result that quite large differences in the tilth of the seedbed, although they might visibly affect the early growth of the crop, did not usually affect the yields. No recent experiments have been made specifically on this point, but a mass of relevant information came to hand as a result of the Rothamsted Malting Barley Conferences which used to be held annually up to 1938. For a number of years growers of malting barley used to send in their samples which were then valued by a panel of valuers appointed by the Institute of Brewing. At the same time each grower filled in a questionnaire in which he gave the yield of barley and answered number of questions about the way he had managed the land, and in particular he answered a question about the condition of the seedbed. The springs of 1936 and 1937 were both rather wet and farmers had considerable difficulty in getting suitable seedbeds on the loam and clay soils in these years. These two years thus afford a valuable test of how far the yield and the quality of malting barley is affected by the farmers own estimate of the suitability of the seedbed for this crop.

The results of this examination for the medium textured soils are given in Table 7:—

Table 7 Quality and Yield of Malting Barley as affected by the Condition of the Seedbed

Farmers' samples from medium textured soils

1936

Sowing date	Good Seed-beds			Poor Seed-beds		
	Valuations Sh./Qu.		Yield Bu./acre	Valuations Sh/Qu.		Yield Bu./acre
Before March 18	40/6	(33)	43	40/6	(6)	43
March 18-26	39/6	(32)	39	40/6	(10)	44½
After March 26	39/–	(16)	41	37/–	(16)	43

(The numbers in brackets are the number of fields involved)

1937

Sowing date	Good Seed-beds			Fair Seed-beds			Bad Seed-beds		
	Valuation Sh./Qu.		Yield Bu./acre	Valuation Sh./Qu.		Yield Bu./acre	Valuation Sh./Qu.		Yield Bu./acre
Before April 1	57/6	(7)	34	55/6	(17)	37	57/–	(4)	37
April 1-19	54/6	(10)	33	54/–	(18)	35	55/6	(7)	28
After April 19	51/6	(13)	37	55/–	(5)	30	52/6	(8)	34

(The numbers in brackets are the number of fields involved)

This table shows the surprising result, that taken over the fields available, both the yield and the quality of the malting barley was independent of the suitability of the seedbed for malting barley as judged by the farmer himself. And this point was noticed with surprise by many farmers when they were completing the questionnaire.

(d) *The Rothamsted cultivation experiment: Long Hoos*, 1933-39

The results for the first three years of this experiment were given in the 1936 Report, and the results for the six years the experiment ran have been published (6).

This experiment had two main objects: first to find out if the land benefited by being cultivated to a depth of 7-8 inches instead of 3-4 inches, and second to compare the plough, the tractor cultivator or grubber, and the rotary cultivator as implements for breaking up the old stubble and for loosening the soil preparatory to the preparation of the seedbed. The experiment had three courses—wheat, mangolds, barley—and each crop was taken each year.

In the first place, for the whole of the six years, the yields on the plots ploughed to 3-4 inches every year were almost identical with those ploughed to 7-8 inches, and the few examples when the deeper ploughing appeared to benefit the crop were all on plots that had become rather infested with weed. The average results for the 6 years are given in Table 8:—

Table 8. *The effect of depth of ploughing on crop yields* (1933-39)

	wheat grain cwt./acre	barley grain cwt./acre	mangolds, roots tons/acre
4 in. ploughing	22·8	24·6	23·8
8 in. ploughing	22·7	23·7	24·5
benefit of deep ploughing . .	—0·1	—0·9	0·7
standard error of difference . .	0·4	0·4	0·4

In the second place it was soon found to be impossible to grow mangolds on land that had not been ploughed, because so much weed germinated with the mangolds that the crop was almost smothered. Hence the experiment had to be modified in its third year to allow the whole of the wheat stubble to be shallow ploughed after harvest. Further, neither the cultivator nor rotary cultivator used could go down to the full depth the first time over, so that they had to go over the land twice on the plots receiving deep tillage. This allowed them a better chance to clean the land, and possibly for this reason, deep tillage with these implements almost always gave higher yields and cleaner crops than shallow tillage, as is shown in Table 9:—

Table 9. *Increase in yield due to deeper and double tillage:* 1933-39.

	Wheat grain cwt./acre	Barley grain cwt./acre	Mangold roots tons/acre
Rotary cultivator	1·0	1·7	1·3
Tractor grubber	1·0	0·8	0·8

The general result of the six years' experiments was that land worked with the rotary cultivator or tractor grubber once and shallow always gave lower yields than the ploughed land, whilst land worked deep and twice always gave lower yields if the cultivator was used, and gave lower yields with wheat and mangolds but usually higher yields with barley if the rotary cultivator was used, as is shown in Table 10:—

There is an interesting conclusion to be drawn from the winter wheat results. The very loose deep seedbed prepared in the autumn by running the rotary cultivator over the land twice gives a better crop than the not so loose but more shallow seedbed prepared by running over the land once, as shown in Table 9, and although it

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Table 10. *Reduction of yield due to using a cultivator instead of a plough* 1933-1939

	Wheat grain cwt./acre	Barley grain cwt./acre	Mangold roots tons/acre
Cultivator deep	3·5	1·2	1·9
shallow	4·5	2·0	2·7
Rotary Cultivator			
deep	3·5	—0·4	1·3
shallow	4·5	1·3	2·6

gave a reduction of 3½ cwts. per acre compared with the plots that were ploughed, when averaged over the 6 years of the experiment, yet the reduction only averaged 2 cwts. per acre in the first two years when the land was still fairly clean.

Two conclusions were drawn from this experiment. Firstly the principal benefit of the plough compared with the rotary cultivator or grubber is the cleaner seedbed which it gives. Secondly freedom from weeds when the crop is germinating is more important than the exact state of the seedbed tilth. This last conclusion is entirely in accord with the results of all the other experiments so far discussed. Two other minor conclusions emerge. Barley seems to respond to the finer seedbed prepared by the rotary cultivator, provided there are not too many weeds present, and winter wheat is not unduly affected by being sown in the deep loose seedbed prepared by going over the land twice with a rotary cultivator.

(e) *The Rothamsted deep ploughing experiment: Long Hoos* 1944

This is a six course rotation experiment designed to test the effect of extra deep ploughing, to about 12-14 inches deep, with normal ploughing to a depth of about 6 inches. The rotation used is wheat—potatoes—spring oats—sugar beet—barley—seeds, and half of the plots are deep ploughed for wheat, potatoes and sugar beet. At the same time the response of potatoes and of sugar beet is determined to 20 and to 10 tons per acre respectively of farmyard manure applied just before ploughing, and also to a dressing of phosphate and potash applied either before ploughing or else in the seedbed for sugar beet and in the bouts for potatoes. These dressings have been 0·8 cwts. per acre of P_2O_5 as superphosphate and 1·0 cwts. of K_2O as muriate of potash for the potatoes and 0·6 cwts. per acre of each for the sugar beet. In 1944 only the potatoes and sugar beet courses were taken, in 1945 these and spring oats and barley, and in 1946 all the courses were running, although the wheat crop was on land deep ploughed for the first time that had received no manurial treatments. In the autumn of 1943 a somewhat unsuitable deep plough was used with the consequence that the quality of the work was poor and a depth of 12 inches was not maintained. In the autumn of 1946, owing to very heavy rains, the plots coming into wheat could not be deep ploughed. Otherwise the experiment has run as planned.

The soil on the site is mainly a fairly heavy clay loam, but at one side there is an area of a deep brick earth and elsewhere there are patches where a very tough subsoil clay comes near to the surface, and it has usually taken two deep ploughings to achieve the full 12-14 in. depth on the toughest of these patches.

Potatoes: 6 *years* 1944-49

The yield has been good in four out of the six years, but the yields were low in 1947 and 1949, both years of very dry summers. The yield of ware potatoes, in tons per acre, together with certain treatment responses, for each of the six years is given in Table 11.

Table 11. *Yields and Responses of Potatoes:* 1944-49
Ware in tons per acre

Year	1944	1945	1946	1947	1948	1949	Mean
Yield	10·6	10·3	10·9	5·6	14·7	5·7	9·8
Response to farmyard manure, when ploughing is							
Deep	1·45	3·01	1·91	1·67	4·24	2·00	2·38
Shallow	1·09	3·57	1·01	1·61	5·04	2·72	2·50
Response to deep ploughing when potash is applied in the bouts							
	0·47	1·75	0·78	0·73	2·93	0·88	1·26

Farmyard manure has increased the yield of potatoes in each of the six years, giving an average increase of 2·4 tons per acre of ware, though the annual response has varied from 1 to 5 tons per acre. Table 11 also shows that the increase in yield has been, on the average, the same for the deep as for the shallow ploughed plots, even though much of the dung must have been buried between 6-12 inches deep on the deep ploughed, and all was in the top 6 inches on the shallow ploughed plots.

The effect of deep ploughing on the yield of potatoes has been very dependent on the way the potash in particular, and to a much lesser extent the phosphate, has been applied, as is shown in Table 12:—

Table 12. *Effect of Depth of Ploughing on Yield of Potatoes*
Ware in tons per acre (1944-49)

Depth of ploughing	Potash given			Phosphate given		
	none	ploughed in	in bouts	none	ploughed in	in bouts
12 in.	9·26	10·30	11·55	9·96	9·70	10·77
6 in.	9·28	9·75	10·29	9·26	9·83	10·25
Response to deep ploughing	−0·02	0·55	1·26	0·70	−0·13	0·52

This table brings out clearly the way potatoes have responded to deep ploughing if potash is given in the bouts, and, as shown in Table 11, this result has been found every year, though its effect was small in the first year, 1944, when the full depth of ploughing was not reached. Also the average response of potatoes to potash has been higher on the deep than on the shallow ploughed land. It is possible to analyse these responses in more detail by separating out the yields on the plots receiving farmyard manure from those that do not. This analysis shows that for the 6 years under discussion, the potatoes did not respond to potash where the farmyard manure was given, unless the land was both deep ploughed and the potash was put in the bouts. These plots gave an average yield of 12·57 tons per acre, being one ton per acre larger than the highest yield given in Table 12. In the absence of the farmyard manure, potash increased the yield of potatoes on the deep ploughed plots by 1·9 tons per acre when it was ploughed in and by 2·8 tons per acre when it was put in the bouts, and on the shallow ploughed plots the increases were ·0·7 and 1·8 tons per acre respectively. Deep ploughing, therefore, has not enabled the potatoes to make better use of the farmyard manure, but it has enabled them to make better use of potash. There is no marked effect of phosphates on the response of potatoes to deep ploughing, but there is an indication that deep ploughing is most effective when farmyard manure is given and phosphates are then spread in the bouts. The general conclusion thus seems to be that the more favourable the manurial conditions are for potatoes, the more benefit they are likely to receive from deep ploughing.

Sugar beet: 6 years 1944-49

The yield of beet has varied from 9 to 15 tons of washed beet per acre, averaging 12·85 tons over the 6 years. The average responses over this period are given in Table 13:—

Table 13. *Average Responses of Sugar Beet to Deep Ploughing and Fertiliser Treatments* (1944-49)

	Mean Yield	Response to deep ploughing	farmyard manure	potash	phosphate
beet, tons/acre	12·85	0·75	1·26	0·41	0·19
tops, tons/acre	13·94	0·99	1·40	0·62	0·03
sugar, cwt./acre	43·7	2·8	4·4	1·8	0·8
sugar, per cent.	15·32	0·00	—0·12	0·19	0·03
plant number thousands/acre	23·6	0·4	0·3	0·3	0·1

The six annual values for the yield of total sugar, and for the responses of beet, measured by the amount of sugar produced, to certain of the treatments are given in Table 14:—

Table 14. *Yield and Responses of Sugar Beet in each Year*
Total sugar in cwt. per acre

Year	1944	1945	1946	1947	1948	1949	Mean
Yield	34·1	58·0	50·5	40·7	52·9	26·0	43·7
Response to							
deep ploughing	1·4	3·2	2·5	12·4	—4·5	1·6	2·8
Farmyard manure	2·6	3·4	1·8	9·0	2·6	6·8	4·4
Fertilisers ploughed in							
phosphate	2·9	2·6	2·8	0·3	1·9	—0·8	1·6
potash	5·0	2·0	3·0	3·0	4·6	—0·1	2·9
Fertilisers put in seed-bed							
phosphate	1·1	0·4	2·2	—0·1	—2·6	—1·0	0·0
potash	2·8	1·8	3·6	—0·1	—3·4	—0·2	0·7

The yield of sugar is seen to be very satisfactory in four of the years, but to be rather low in the first year of the experiment and very low in 1949. Deep ploughing increased the yield of beet very considerably in 1947, due probably to a very great germination of seedling weeds along with the beet on the shallow ploughed plots, and it increased it a little in four of the other years, but it depressed the yield in 1947, due to the germination and early growth of the beet being very much poorer that year on the deep ploughed plots. The cause of this poorer germination might have been due to a poorer coarser and lumpier tilth on these plots, but apparently similar tilths in other years have not had this depressing effect.

Farmyard manure has definitely increased the yield of beet in each of the six years, being especially marked in the two dry summers of 1947 and 1949.

The effect of depth of ploughing on the responsiveness of the beet to the farmyard manure, which is applied just before the ploughing is done, depends very much on whether potash or phosphate are or are not given. The average yields and responses, as measured by the total quantity of sugar produced, are given in Table 15:—

Table 15. *Effect of Depth of Ploughing on Responsiveness of Sugar Beet to Farmyard Manure* (1944-49)
Total sugar in cwts. per acre

Depth of ploughing	No Potash given			Potash given		
	with FYM	No FYM	Response to FYM	with FYM	No FYM	Response to FYM
12 in.	48·0	41·1	6·9	45·9	45·5	0·4
6 in.	43·6	38·4	5·2	45·9	41·2	4·7
Response to deep ploughing	4·4	2·7		0·0	4·3	
	No Phosphate given			Phosphate given		
12 in.	46·5	42·7	3·8	47·4	43·8	3·6
6 in.	45·4	38·6	6·8	44·2	41·0	3·2
Response to deep ploughing	1·1	4·1		3·2	2·8	

The only conclusions that are worth the drawing, at this stage of the experiment, are that on the whole the crop usually responds about as well to farmyard manure whether it is ploughed in to 6 or 12 inches, and to deep ploughing whether farmyard manure is given or not. But the Table shows that these conclusions do not apply if potash is also given, for it depresses the yield of beet on the deep ploughed plots in the presence of farmyard manure. These conclusions apply equally whether the fertilisers were ploughed in or put in the seedbed.

Potash and phosphate have also increased the yield of beet, and the response has been very marked in some years. But these responses depend very much on the depth of ploughing, how they were applied, and whether farmyard manure was also given.

In the first place, over the six years, the beet only responded to potash and phosphate on those plots not receiving any farmyard manure, as is shown in Table 16. These fertilisers together were about as effective as farmyard manure, and if the manure is given, no extra benefit was derived from the fertilisers.

Table 16. *Response of sugar beet to farmyard manure and fertilisers*
Total sugar, in cwt. per acre (1944-49)

Fertiliser	None	Potash	Phosphate	Potash and phosphate
No dung ..	39·0	42·4	40·5	44·2
Dung	45·9	46·0	45·8	45·8

In the second place, the beet has given a larger response to potash and phosphate when these fertilisers are broadcast on the land in the autumn before ploughing than worked into the seedbed in the spring. This is shown averaged over the effect of farmyard manure and deep ploughing in Table 14. This result even applies in those plots receiving farmyard manure in which the extra potash or phosphate actually depresses the yield. The depression is greater when the fertiliser is applied to the seedbed than ploughed under. The magnitude of the difference between these two ways of applying the fertilisers also depends on the depth of ploughing, as is shown in Table 17, which gives the mean yields and responses of the beet, measured in terms of the sugar produced, on those plots that do not receive any farmyard manure.

Table 17. *Response of Beet to Potash and Phosphate*
(No farmyard manure given, 1944-49)
Total sugar in cwts. per acre

Depth of ploughing	No potash	Potash: ploughed in	Potash: in seedbed	Response to potash: ploughed in	Response to potash: in seedbed
12 in.	41·1	46·9	44·0	5·8	2·9
6 in.	38·6	41·8	40·6	3·2	2·0
Response to deep ploughing	2·5	5·1	3·4		
Depth of ploughing	**No phosphate**	**Phosphate: ploughed in**	**Phosphate: in seedbed**	**Response to phosphate: ploughed in**	**Response to phosphate: in seedbed**
12 in.	42·7	44·8	42·8	2·1	0·1
6 in.	38·6	41·3	40·7	2·7	2·1
Response to deep ploughing	4·1	3·5	2·1		

* Response to residual effect of ploughing done 3 years previously.

For both potash and phosphate the difference between these two methods of application is larger on the deep ploughed plots than on the shallow, and also the response to deep ploughing is greater when the fertilisers are ploughed in than when put in the seedbed.

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The tentative conclusions to be reached from this experiment are, therefore, that in most years sugar beet yields are increased by deep ploughing, and that it is preferable to plough in the potash and phosphate rather than apply them to the seedbed, no matter whether the land is ploughed to 12 in. or 6 in. deep. Further, the response to deep ploughing is greater if the fertilisers are ploughed in than if they are put in the seedbed. Finally farmyard manure applied before ploughing is equally effective if the land is deep or shallow ploughed.

Wheat

The results for wheat are still a little scrappy. A seeds ley was ploughed deep for the first time in the autumn of 1945, so in 1946 the experiment only concerned the effect of deep ploughing on the wheat yield. The autumn of 1946 was so wet that the experimental deep ploughing could not be given before the wheat, so wheat was grown on land that received the experimental treatments in the autumn and spring of 1943-44, and which had been treated uniformly since. Further, the deep ploughing done in the autumn of 1943 could not be done very well, and the full depth of 12 inches was not reached. In the harvest years of 1948 and 1949 the experiment went according to plan. The yields of wheat are given in Table 18:—

Table 18. *Yield of wheat* 1946-49
(Grain in cwt. per acre)

	1946	1947	1948	1949
Yield	29·0	26·8	40·7	43·8
Response to deep ploughing	2·2	—2·8*	—3·5	1·2
Response to dung	—	1·5	2·2	1·6

* Response to residual effect of ploughing done 3 years previously

Clearly no comments can yet be made on the effect of deep ploughing on the wheat crop. There was, however, no question that in 1948 the wheat was a thinner crop on the deep than on the shallow ploughed plots, and the same result seemed to apply to a few of the deep plots in 1946, though the growth of the wheat on the various plots was very erratic that year.

The response of the wheat to dung is interesting. In 1947 and 1948 this was due to a dressing of 10 tons per acre given three seasons previously to sugar beet (which was followed by barley which was undersown to a one-year ley), whilst in 1949 it was to 20 tons given to potatoes in the autumn of 1943 and 10 tons given to sugar beet in the autumn of 1945. Obviously the residual effect of even 10 tons per acre of farmyard manure is still appreciable in the fourth crop.

Oats, Barley (5 *years* 1945-49) *and Ley* (4 *years* 1946-49)

The spring oats is grown after potatoes and the barley after sugar beet, and the barley is undersown with a mixture of a perennial ryegrass and a late-flowering red clover. None of these crops receives any experimental treatment, but both the oats and barley are given a dressing of sulphate of ammonia in the seedbed, and the barley also receives a dressing of 0·6 cwts. per acre of P_2O_5 as basic slag. The yields and the responses of the crops to the residual effects of the treatments given to the beet and potatoes are given in Table 19:—

Table 19. *Yield and response of oats, barley and ley in cwt. per acre*

	Oats (5 years)		Barley (5 years)		Ley (4 years)
	grain	straw	grain	straw	Hay
Yield	31·3	42·8	34·3	37·2	67·2
Response to the treatment given to the previous root crop					
Deep ploughing ..	—0·2	—0·1	0·7	0·9	0·0
Farmyard manure	1·4	3·8	1·3	3·0	2·5
Phosphate	0·3	—0·6	0·7	0·2	1·0
Potash	0·1	0·2	0·3	1·0	2·4

The yields have been good every year for the barley and the ley, and for 4 years for the oats, but the oat yield was low in 1945.

Deep ploughing has not affected the yield of oats or ley appreciably, but it does appear to have increased the yield of barley a little, and this has been found in every year of the experiment except the first, when the barley was on the land that had not been properly deep ploughed in the autumn of 1943.

The farmyard manure has had a pronounced beneficial residual effect on all three crops, and this has been found in most years for the oats and hay and in all the years for barley. It appeared to depress the yield of oats a little in 1948 and the hay in 1947. It is interesting to note that the barley gives almost the same response to 10 tons of farmyard manure as does the oats to 20 tons.

The response of oats to the residual effect of phosphate and potash is small, but barley grain seems to respond to the phosphate given to the beet and barley straw to the potash. These responses are not large but they have been found consistently each year, and hence are probably real. The response of the ley to the potash given two years previously to the beet is surprisingly large, and for the four years has been 1·5, 1·7, 5·8, 0·6 cwts. per acre respectively. The ley also seems to respond to the phosphate given to the sugar beet, as the responses in the four years have been 1·3, 0·7, 1·0 and 1·1 cwts. per acre. The interesting point of this response is that the barley was given a uniform dressing of 0·6 cwts. per acre of P_2O_5 as basic slag, yet the ley still seems to benefit from the 0·6 cwts. per acre of P_2O_5, given to the sugar beet as superphosphate.

Most of the interactions between the various treatments have been erratic from year to year, but two that have been fairly consistent are relevant to the discussion. The barley straw only responds to potash on those plots that did not receive farmyard manure, in agreement with the sugar beet results, but the ley's response to potash has been about the same on both the dunged and undunged plots.

Summary of the Results of the Deep Ploughing Experiments

The discussion of the results so far has shown that deep ploughing has on the whole given noticeable increases in yield of potatoes and sugar beet without affecting the yield of wheat, barley, spring oats or ley appreciably. This result has an important consequence, for, as already noticed, there are a number of patches on the experimental area where a very tough subsoil clay comes close to the surface. Over these areas the deep ploughed plots have often had a relatively rough and unkind tilth at planting or sowing time, and yet in most years this poor tilth has not affected the yield adversely. Over another part of the area is a much kinder brick earth, which works down more easily to a good tilth, but the young crop on the deep ploughed plots on this area are not usually any more forward than on the areas with the unkind tilth, and there have been occasions when the plant was definitely worse on some of the kinder areas.

Deep ploughing has helped to keep some weeds in control. The most striking example is thistle, which is always much less prevalent on the deep ploughed plots. In 1948 a good deal of poppy was present in many of the spring oats plots but it was less prevalent in the deep than the shallow ploughed areas. In 1947 after a very long winter frost, a great deal of annual weed came up on the shallow ploughed plots drilled to sugar beet or planted to potatoes, and this was much less prevalent on the deep ploughed plots. This was probably the reason why deep ploughing put up the yield of sugar from 34·5 to 46·9 cwts. per acre, or by 12·4 cwts. in that year for this is four times as large as the response in any of the other years.

Finally, this discussion of the results of the deep ploughing experiment may only apply to the particular conditions present in the Rothamsted soil. A large number of simple experiments have been carried out all over the country testing some of these points, and though the results of these experiments have not yet been written up, it is clear that some of the results found at Rothamsted have not been found in most of the other centres.