ROTHAMSTED RESEARCH

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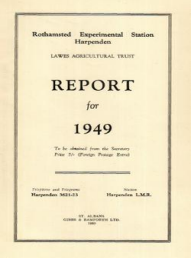

The Relation Between Soil Cultivation and Crop Yields

E. W. Russell

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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

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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 design-

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ed 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 :—

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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 and after singling
	before Singling	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 throughout 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

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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

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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.

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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

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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.

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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.

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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

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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

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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

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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

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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.

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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.

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