Report for 1927-28

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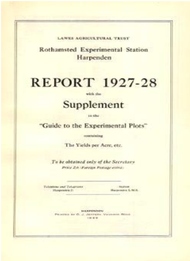
LAWES AGRICULTURAL TRUST

Rothamsted Experimental Station
Harpenden

REPORT 1927-28

Supplement

"Guide to the Experimental Plots"

The Yields per Acre, etc.

Crop Experiments

Rothamsted Research

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as to be of maximum service to those who are seeking to help the farmer.

Two important conferences were called at Rothamsted in the winter 1928-29 to discuss the agricultural situation. From these it was quite clear that the old four-course rotation is no longer a suitable basis for arable husbandry. Roots are too expensive and uncertain. Wheat-growing in general does not pay. This is not peculiar to England : one of the remarkable agricultural changes of the twentieth century is the shifting of wheat cultivation from the wetter to the drier regions of the world. It is taking place in Australia and Canada just as much as here : regions of 30-inch annual rainfall which produced wheat in the nineteenth century do so no longer : wheat has gone into regions of 24 inches or less. Here in England wheat is similarly being restricted more and more to the dry Eastern counties, where it will doubtless continue.

But it also appears that grass farming pure and simple, however well done, is no complete remedy. For the grass farmers must buy store animals in spring, and sell animals in summer and autumn : where too much land is in grass, prices of spring stores are forced too high and of autumn animals too low.

The new agriculture that is emerging out of the present series of changes includes the following features :—

(1) a closer connection between arable and grass land than formerly, especially an improvement in the grass and the lengthening of the grazing season; longer leys in arable regions and use of prolific fodder crops such as lucerne; the fattening of young animals on grass, as far as is practicable, instead of keeping them to be fattened during the following winter;

(2) the growth of cheap winter food for animals to ensure cheap production of milk in winter and to avoid the necessity for the present forced sales of unfinished animals in autumn;

(3) the substitution of crops of value, such as potatoes, sugar beet, Brussels sprouts, cabbages, etc., for the present root crops; extension of fruit growing and market gardening;

(4) improvements in the methods of fallowing;

(5) the use of poultry, pigs, etc., to complete the conversion of home-grown produce into more valuable products such as fresh meat and eggs, thus avoiding the necessity for forced sales of grain.

All these problems are being studied on the Rothamsted and Woburn farms, and the information yielded by the experiments is applied to them as rapidly as is possible.

CROP EXPERIMENTS.

Replacement of the Old Root Break.

Potatoes. If potatoes are to be grown at all they must be grown well, and in particular must be adequately fertilised.

Since 1921, an experiment has been made each year to discover the effects of sulphate of ammonia and sulphate of potash on potatoes : the results show that the two fertilisers are closely linked, and neither gives its best effect without the other. The results were, in tons per acre :—

		1927				1928		
Sulphate of Ammonia.		0	2 cwt. per acre.	4		0	1½ cwt. per acre.	3
Sulphate of Potash Cwt. per acre.	0	6.54	7.06	7.16	0	6.60	8.75	8.26
	2	6.56	7.74	7.85	1	7.67	9.03	11.05
	4	6.90	7.70	7.45	2	7.06	8.79	10.63

With sufficient potash and phosphate the increases given by 1 cwt. sulphate of ammonia per acre have been, at Rothamsted :—

Year.	Date of Planting.	Date of Lifting.	Yield without Sulphate of Ammonia Tons per acre.	Increase in cwt. for 1 cwt. Sulphate of Ammonia.
1925	April 25 ...	October 6 ...	7.25	24
1926	April 24 ...	October 21 ...	7.8	26
1927	May 23 ...	October 6 ...	6.5	10
1928	April 17 ...	October 19 ...	7.6	20

Excepting only in 1927, when the potatoes were set very late, the increases are round about the usual 20 cwt. per acre.

At Woburn, the increments have been more varied :—

Year.	Date of Planting.	Date of Lifting.	Yield without Sulphate of Ammonia Tons per acre.	Increase in cwt. for 1 cwt. Sulphate of Ammonia.
1926	May 10 ...	Oct. 11-12 ...	6.5	9
1927	June 25 ...	Oct. 27-28 ...	6.5	9
1928	May 5-9 ...	Oct. 24-26 ...	11.9	30

With sufficient sulphate of ammonia the increases given by 1cwt. sulphate of potash are much more variable: they have been, at Rothamsted :—

Year.	Date of planting.	Yield without Potash. Tons per acre.		Increase for 1cwt. Sulphate of Potash. Cwt.		Increase for 1 cwt. Muriate of Potash. Cwt.		Hours of Sunshine, July, Aug., Sept.
		No dung.	Dung.	No dung.	Dung.	No dung.	Dung.	
1922	April 22-24 ...	2.48	9.21	58	20	67	18	379
1923	May 4-5 ...	9.73	11.70	25	10	30	23	668
1924	May 6-10 ...	6.20	9.18	10	No increase	9	6	523
1925	April 29–May 4	5.03	—	40-46	*	48	—	441
1926	April 23 ...	—	9.45	*	20-23	—	22	479
1927	May 23 ...	—	6.92	*	Depression	—	1½	420
1928	April 17-20 ...	—	7.69	*	—	—	28(1)	681

(1) Mean of muriate and 30 per cent. potash manure salts.
* No experiment made.

The effectiveness of the potassic fertiliser is lessened by late planting : indeed, for potatoes, as for sugar beet, we know of no profitable scheme of manuring a late planted crop.

Potassic fertilisers are clearly much more dependent on the season than nitrogenous fertilisers : the explanation is that they increase the efficiency of the leaf, an action which is advantageous

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in sunless seasons; also they increase the vigour of the plant, thus helping it in seasons of spring drought or other difficulties.

Sulphate of potash in our experiments usually excels the other potassic fertilisers for yield, though not by much, muriate running it very close and the 30 per cent. potash salt is not far behind. The average yields, in tons per acre, of the last six years for the dressing of 2 cwt. sulphate of potash[1] per acre and equivalent amounts of the other salts, have been :—

	No Potash.	Sulphate of Potash.	Muriate of Potash.	Potash Manure Salts 30%.
1922	F.Y.M. 8.03	9.55	9.21	—
	no F.Y.M. 2.48	8.30	8.32	—
1923	F.Y.M. 11.70	12.47	13.03	12.07
	no F.Y.M. 9.73	12.23	12.00	11.43
1924	F.Y.M. 9.18	8.82	8.70	9.22
	no F.Y.M. 6.20	7.27	7.15	7.77
1925	no F.Y.M. 5.03	9.68	9.42	9.36
1926	F.Y.M. 9.45	11.36	11.52	10.97
1927	F.Y.M. 6.92	7.38	7.16	6.86
		7.35	7.04	6.46 double dressing

F.Y.M. = Farmyard Manure.

The figures from 1925 onwards, when the new methods were introduced, have more value than those for the earlier years.

Superphosphate was included in the tests in 1928. The results show an average gain of 5 cwt. potatoes per cwt. of 36 per cent. superphosphate at Rothamsted, and the following at other centres, adequate supplies of sulphates of ammonia and of potash being given :—

Wisbech	... ...	3 cwt. potatoes.
Stowbridge	... ...	19 cwt. ,,
Woburn	... ...	8 cwt. ,,
Rothamsted	... ...	5 cwt. ,,
Aberystwyth	... ...	Nil

Average : 7 cwt. potatoes per cwt. superphosphate.

At three of the five centres increases in yield continued (though not at this rate) up to 8 cwt. superphosphate, at one (Aberystwyth) there was no clear increase, and at one (in Lincolnshire) there was apparently a decrease : this is being more fully examined this year. The yields are given on pp. 143, 156, 170-4.[2]

The effect of the superphosphate is dependent on the presence of sufficient nitrogen and potash as shown in the following yields at Rothamsted in tons per acre :—

Varying nitrogen, adequate potash 1928.

	Sulphate of Ammonia. 0 cwt.	1½ cwt.	3 cwt.
With super	7.67	9.03	11.05
No super	7.62	9.15	9.76
Gain due to super	Nil	Nil	1.29

[1] Rather less on the farmyard manure plots of 1922, 3 and 4.
[2] Full Report.

Varying potash, adequate nitrogen 1928.

	Sulphate of Potash. 0 cwt.	1 cwt.	2 cwt.
With super	8.26	11.05	10.63
No super	8.00	9.76	9.74
Gain due to super (3-cwt. per acre)	0.26	1.29	0.89

It has now become possible to arrange for a satisfactory investigation into the influence of manuring on the quality and keeping value of potatoes. Dr. Lampitt, Head of Messrs. J. Lyons' laboratories, is conducting cooking tests (boiling and frying) of all our samples fresh from the field and after storage, and with his help we hope also to obtain the percentages of dry matter, starch, nitrogen and other constituents likely to influence quality.

Sugar Beet. The Beet Sugar Factories—Anglo-Dutch Group —generously made grants in 1927, 1928 and 1929, enabling us to carry out extensive fertiliser trials at Rothamsted and Woburn, and to repeat typical experiments elsewhere. These trials, being in much more detail than was previously possible, have brought out a number of important points, but they have also shown that we do not yet properly understand the manuring of sugar beet and, therefore, are not obtaining as large yields as we ought. The Continental recommendations which most farmers follow are not altogether suitable to English conditions.

In 1927, sowing was unavoidably delayed at Rothamsted and the purpose of the experiment was to discover whether in these conditions, which are always liable to arise in a heavy soil, any fertiliser scheme could make up for lost time. Unfortunately, none of the forms or combinations of nitrogen, potash, phosphate proved successful, and we do not yet know how to get over the difficulties of late sowing.

The other experiments of 1927 and those of 1928 were to discover the effects of the various fertilisers on the crop, both on roots and leaves, the latter being important as stock food.

The leaves behave normally towards fertilisers. Nitrogenous fertilisers deepen their colour and increase their size : an additional hundredweight of nitrate of soda gave about one ton of additional leaf per acre.

The roots, however, are much less affected than the leaves and are not nearly so responsive as mangolds. One ton of mangold leaf will commonly give about 4 to 6 tons of root, but one ton of sugar beet leaf may give only one ton of root and sometimes much less. Sulphate of ammonia applied with the seed had but little effect : muriate of ammonia was rather better, but nitrate of soda was best of all. None of the nitrogenous fertilisers, however, did much to increase the yield, while they all lowered the sugar content and the weight of root formed per 100 parts of leaf. Phosphate had but little effect either on yield or sugar content. Potassic fertilisers also had only little action, but, of these, potash manure salts was somewhat better than the muriate.

The results suggest that sodium, perhaps magnesium and chlorine, play some part in the nutrition of the sugar beet, and that the plant cannot make full growth unless they are supplied.

Rothamsted, 1928.

	Nitrogenous Top Dressing. Nitrochalk.		Potassic Fertilisers.		Phosphatic Fertilisers.	
	2 cwt.	4 cwt.	Muriate of Potash.	Potash Manure Salts.	None.	Super-Phosphate.
Roots, tons per acre	9.25	9.19	9.08	9.23	9.06	9.25
Tops, tons per acre	11.59	12.39	11.26	11.60	11.32	11.54
Sugar, per cent. in root	17.63	17.27	17.61	17.61	17.60	17.63

Woburn, 1928.

	Sulphate of Ammonia. No top dressing.	Muriate of Ammonia. No top dressing.	Sulphate of Ammonia and Nitrochalk.	Muriate of Ammonia and Nitrochalk.
Roots, tons per acre ...	13.82	14.42	14.00	15.10
Tops, tons per acre ...	11.47	11.98	12.49	13.59
Sugar, per cent. in root	18.07	18.00	18.22	17.76

The effect of nitrogenous manure in lowering the efficiency of the leaf as a producer of root is shown by the weight of root made by 100 of leaf :—

Top dressing (Nitrochalk) ...	None	Single dose	Double dose
Muriate of potash	89.4	78.6	73.8
Potash manure salts	88.6	80.5	73.0

The results are disappointing and show that we still have much to learn about the manuring of sugar beet, and about the varieties best suited to our conditions. Our present varieties come from the Continent, and in the long continued process of selection the search has been for roots rich in sugar suitable for the factory, but not necessarily for the farmers. As compared with the sugar beet grown sixty years ago at Rothamsted, the 1928 roots are much richer in sugar, but the yield per acre, both of roots and of sugar, has decreased, and the efficiency of the leaves has fallen considerably. The improvement has apparently been mainly a shrinkage in size of the root, thus compacting the sugar into a smaller space :—

Years.	Yield, tons per acre.		One ton of top made roots in tons.	Sugar.	
	Roots.	Tops.		Per cent. in root	Cwt. per acre.
1871-3 ...	18.9	5.1	3.7	11.0	41.6
1928 ...	9.4	12.2	0.8	17.6	33.1

Apparently there is room for considerable improvement, both in varieties and in management of this crop, the restricted response to fertilisers suggesting some kind of congestion in the plant; it is not always obtained : for example, at one of the outside centres (Durham) muriate of potash was distinctly effective, the yields being in tons per acre :—

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No Potash.	Muriate of Potash, cwt. per acre. 1	1½	2
9.75	10.25	10.87	12.32

Each plot also received 1 cwt. sulphate of ammonia and 4 cwt. superphosphate per acre.

Increase per cwt. muriate of potash—20 cwt. sugar beet.

It is somewhat curious that the factory determinations of the percentage of sugar in the roots were consistently lower than ours made on samples taken direct from the field.

Cereals.

Under British conditions the most important fertilisers for cereals are the nitrogen compounds : these act with considerable uniformity, 1 cwt. sulphate of ammonia giving increases that range about 4½ bushels of wheat, 6 bushels of barley and 8 bushels of oats. The figures vary from season to season, but their relationships to the meteorological data are not yet fully known.

Barley. The experiments on barley are made in conjunction with the Institute of Brewing to ascertain the effect of soil, season and manuring on the yield and malting quality of barley. During 1927 and 1928 they have been continued at Rothamsted, Woburn, Wellingore (Lincs.), Chisleborough (S. Somerset), Fitzhead (Vale of Taunton) and Longniddry : they were, however, discontinued at the other centres, sufficient information having already been obtained. The most striking effect again was the increase given by 1 cwt. sulphate of ammonia per acre; this was greatest in years of low yield and least in years of high yield so that the effect of the fertiliser is to even up the results : the yields have been, in bushels per acre :—

	Lowest	Highest	Range of Variation
Without nitrogenous fertiliser	19.9	47.9	28.0
With nitrogenous fertiliser ...	32.5	44.4	11.9

So far as the data go, the increments of yield seem to be affected by :—

(1) sufficient rainfall in spring to allow of tillering proportionate to the nitrogen supply;

(2) sufficient sunshine in July to allow of head formation proportionate to the nitrogen supply.

The values of the increments for the past eight years have been at Rothamsted :—

	1923.	1927.	1924.	1928.	1921.	1925.	1922.	1926.
Increment of yield, bushels ...	12.6	10.4	7.7	7.0	6.8	6.0	5.0	−3.5
Yield without nitrogenous manure, bushels ...	19.9	23.6	22.1	28.6	27.2	25.0	31.0	47.9
Rainfall in inches :								
March ...	2.48	2.38	1.14	2.40	1.07	1.22	2.29	0.22
April	1.48	1.86	3.18	0.91	1.57	1.70	3.52	2.96
May	1.68	1.19	4.63	1.45	1.45	2.48	1.58	1.95
July sunshine hrs.	223.8	130.4	236.6	276.3	240.0	183.6	149.5	151.1

The high increments are associated with years of 3 to 4 inches March and April rain and 200 or more hours of July sunshine, 1927 being the only exception. A higher increment might have been expected in 1924, but the abnormally wet summer and autumn greatly encouraged the growth of weeds and protracted the harvest.

The New Nitrogenous Manures.

Four nitrogenous fertilisers have been compared in detail. The results were, at Rothamsted, for barley :—

	1927.				1928.			
	Grain, bushels per acre.		Straw, cwt. per acre.		Grain, bushels per acre.		Straw, cwt. per acre.	
	Single dose.	Double dose.	Single dose.	Double dose.	Single dose.	Double dose.	Single dose.	Double dose.
Sulphate of ammonia	34.0	37.8	20.4	22.2	35.5	34.6	32.1	34.5
Muriate of ammonia	36.2	47.0	20.0	27.0	34.6	37.5	31.3	36.2
Urea...	32.8	43.8	20.0	24.3	35.0	35.8	31.1	32.8
Cyanamide	36.0	35.8	20.8	20.7	33.4	37.5	28.8	33.8
No nitrogen ...	23.6		15.4		28.6		24.4	

All fertilisers markedly increase the yield, with muriate of ammonia coming out best as usual in 1927, and quite well in 1928. In both years cyanamide has done well : it was applied a few days before sowing. Urea does not come up to muriate of ammonia.

These nitrogenous manures act best when they are applied with the seed—cyanamide should go on even earlier. Used as top dressing, even ammonium nitrate (nitrochalk) is ineffective, and when given late it only raised the percentage of nitrogen in the grain.

Barley sown.	No top dressing.	Nitrochalk applied : May 12.	June 4.	June 19.
Grain, bushels per acre	31.1	30.8	33.0	31.4
Straw, cwt. per acre	30.1	31.9	32.1	29.5
Nitrogen per cent. in grain	2.075	2.118	2.110	2.160

Superphosphate on barley. The Hoosfield barley plots afford the best demonstration in the world of the effects of phosphate, potash and nitrogen starvation on the barley plant. In British practice, phosphate starvation is rare, the barley being grown only one or two years after a root crop which has been manured with a phosphatic fertiliser. The farmer is more interested in the other problem : the effect of doses of phosphate larger than are needed to supply the bare necessities of the plant. This depends very much on the season, but also on the soil. In the outside experiments the glacial drift soils at each of the three Norfolk centres have always responded to superphosphate. On other soils, however, the response varies from season to season : *e.g.*, at Rothamsted, a response was obtained in 1927, but hardly in 1928 :—

Rothamsted.

	Grain, bushels per acre. 1927.	1928.	Straw, cwt. per acre. 1927.	1928.
Superphosphate	35.0	33.6	20.7	30.3
No superphosphate	31.4	32.8	18.9	29.4
Effect of superphosphate	+3.6	+0.8	+1.8	+0.9

The figures for the straw vary in the same direction. No connection between the meteorological data and the response to phosphate has yet been traced.

Potassic fertilisers on barley. The effect of potassic fertiliser, like that of phosphate, is much less marked than that of nitrogenous fertiliser. Few soils, except perhaps the thin chalks and light sands, show signs of potash starvation, and it is not clear that excess of potash over and above a margin of safety is advantageous: indeed, in some seasons, especially the good ones, sulphate of potash appears to be harmful. During its 77 successive years under barley, Hoosfield has passed through three stages: the first, when sulphate of potash not infrequently reduced the yield; the second, when it had no effect; and the third, when it increased the yield, potash starvation having set in at the end of about 32 years. The yields of grain have been, in bushels per acre :—

	Plot.	Early years. 1st 8 yrs. 1852-59.	1863.	1864.	1865.	1866.	Mean of 40 years. 1852-91.	Mean of 8 years. 1908-15.	Mean of 12 years 1916-27.
Complete artificials	4A	45.4	55.4	55.4	46.5	47.0	43.5	40.4	32.0
No potash	2A	44.9	61.6	58.5	48.4	50.5	42.75	28.5	26.5
Difference[1]		+0.5	—6.2	—3.1	—1.9	—2.5	+0.75	+11.8	+5.5

(1) Sulphates of soda and of magnesia are also omitted as well as sulphate of potash, but other plots show that their effects are relatively small.

Sulphate of potash caused a marked depression in yield of malting barley at Rothamsted in 1924 and at certain of the outside centres in other years: this is not common, but it appears to be a true result. The present data suggest that :—

(1) in years of high spring rainfall and good ripening weather, *i.e.*, years favourable to the formation of well-matured grain of low nitrogen content, sulphate of potash may decrease the yield of barley;

(2) in years unfavourable to ripening, sulphate of potash has less depressing effect and may even raise the yield of barley.

These variations are of the same kind as for wheat and potatoes, on both of which sulphate of potash acts beneficially in unfavourable seasons, and has less effect in good seasons, the badness of the season being in each instance measured by the yield of crop receiving no potash.

Actual depression of crop, however, seems to be confined to barley, and apparently to sulphate of potash, for it has been observed with muriate of potash only in 1924; whether the chlorine ion is beneficial and the sulphate ion harmful, is not known.

Effect of Fertilisers on Composition and Quality of the Grain.

The percentage of nitrogen in the grain of barley depends on the amount of nitrogen the plant has taken from the soil and on the amount of carbohydrate it has synthesised during its growth. A high nitrogen uptake makes possible considerable growth and sufficient carbohydrate formation to over-balance the nitrogen: the grain then has a low nitrogen content. It depends on the favourableness of the conditions whether this possibility eventuates. Late sowing, or a check in growth due to drought, or a late supply of nitrogen to the plant, may so cut down the available time that the plant cannot make the necessary carbohydrate: the nitrogen content of the grain then becomes high. On the other hand, high rainfall in the weeks after sowing, by reducing the nitrate in the soil, but otherwise favouring growth, lowers the nitrogen content of the grain, as shown by the following data, obtained at Woburn :—

Nitrogen per cent.	2.01	1.95	1.71	1.57	1.23
Year	1925	1922	1923	1926	1924
Barley sown ...	March 31	April 19	April 10	March 4	March 11
Rainfall in inches after sowing.					
March ...	—	—	—	0.09	0.35
April ...	1.59	1.93	1.34	2.59	2.97
May 1st-15th inclusive	1.18	0.35	0.79	1.43	1.35

In sufficiently favourable conditions, sulphate of ammonia may still further increase the carbohydrate production and thus further reduce the proportion of nitrogen in the grain; in less favourable seasons, however, insufficient carbohydrate is produced and the nitrogen content of the grain may be raised. As the nitrogen content is already low in favourable and high in unfavourable seasons, it follows that sulphate of ammonia tends to lower the nitrogen content of the grain in years when it is low and to raise it in years when it is high. Larger quantities (2 cwt. per acre) tend to raise it in any case. The Rothamsted results have been :—

Percentage of Nitrogen in Grain.

	1925.	1926.	1927.	1928.	
No Nitrogen...	1.597	1.599	1.452	1.915	
				Single.	Double dressing.
Sulphate of Ammonia ...	1.585	1.711	1.442	2.029	2.220
Muriate of Ammonia ...	1.552	1.684	1.438	1.985	2.112

As in previous years muriate of ammonia gave grain of lower nitrogen content than sulphate of ammonia. Potassic fertilisers counteract to some extent the tendency for sulphate of ammonia to raise the percentage of nitrogen; at Woburn, in 1928, the percentages of nitrogen in the grain were :—

Effect of Sulphate of Ammonia. Superphosphate and Sulphate of Potash.		Effect of Sulphate of Potash. Superphosphate and Sulphate of Ammonia.		Sulphate of Ammonia and Sulphate of Potash. No Superphosphate.
+Sulphate of Ammonia.	No Sulphate of Ammonia.	+Sulphate of Potash.	No Sulphate of Potash.	
1.372	1.310	1.372	1.398	1.346

The nitrogen content of the barley, more than any other single factor, determines its malting value. It is closely connected with the amount of " extract " and with the diastatic power of the malt, the extract varying inversely and the diastatic power directly with the nitrogen : it has also more subtle effects.

The investigations by Mr. Bishop on the nitrogen compounds of the barley grain have reached an interesting stage. The proportions of hordein, glutelin, and salt-soluble compounds are all connected with the percentage of nitrogen in the grain : for different samples of the same variety (Plumage-Archer) the glutelin increases proportionately to the nitrogen, the hordein increases more rapidly, and the salt-soluble compounds less rapidly than the nitrogen. The relationships are the same, whether the variation results from changes in soil, season or manuring; it appears, therefore, that the ratio glutelin/nitrogen may be a varietal constant of considerable interest to the breeder of barley for quality, and this is being determined for some of the new barleys grown by the National Institute of Agricultural Botany : the barleys are also being malted by the experts of the Institute of Brewing.

The large number of analyses of British-grown barleys made in recent years at Rothamsted has shown that the grinding barleys are richer in protein than is usually supposed. The figure quoted in the standard British tables is 8.6 per cent. of protein, corresponding to 1.38 per cent. of nitrogen; our results show that the figures have been, for barleys which buyers would not take for malting :—

	Valuation 45/- and less	Valuation below 40/-
1922	1.72	1.76
1923	1.73	1.95
1925	1.86	2.16
1926	1.58	1.65
Mean	1.72	1.88
Protein on conventional basis ...	10.8%	11.8 %

The results show that less protein concentrates, such as decorticated cotton seed cake or meal, or decorticated ground nut cake, than is usually recommended, need be mixed with barley meal for feeding to farm animals.

Winter-Sown Oats and Wheat.

The experiments have given further information as to the effect of time of application of the sulphate of ammonia, and we are now able to sketch out the following as the probable facts. In its relation to nitrogen supply, the life of a cereal plant has two well-marked periods: the first, in which roots and tillers are formed but no heads; the second, in which heads develop on the tillers, but no more new tillers are formed. For autumn-sown cereals, the first stage is so long drawn out that it can be sub-divided into a first period, starting at the time of germination and continuing all through the winter, when root formation is the chief process, and a second period when tillering proceeds actively; at Rothamsted, this is mainly in the spring, about March, or early April. Roots, tillers and heads are all increased by nitrogen supply. The heads, however, are increased in number only, and not in size or number of grains: there is even a small tendency for the number of fertile grains to decrease.

Applied during the time of tillering (which at Rothamsted is about the month of March) the nitrogenous fertiliser increases the number of tillers.

Applied after tillering has ceased, it can still increase the amount of grain, and also the amount of straw, though not as much as if it had gone on early enough to increase the tillers also. The earlier application has therefore at first sight the advantage. It suffers, however, in that some of the nitrogen may be washed out by rain, leaving insufficient for the crop unless an excess has been added. In practice, the ordinary dressing of 1 cwt. sulphate of ammonia per acre is best applied late, as it gives more grain and but little less straw than if applied early, while the larger dressing of 2 cwt. sulphate of ammonia is best applied early, as it then gives considerably more straw and somewhat more grain than if applied late. The averages of all results for the four years 1925-28 have been :—

Increases over No Nitrogen.

	Grain.				Straw.			
	Single.		Double.		Single.		Double.	
	Early	Late	Early	Late	Early	Late	Early	Late
Sulphate of Ammonia.								
Oats (2 years)	5.8	8.1	9.4	10.8	7.1	6.6	14.0	8.7
Wheat (3 years)... ...	1.9	4.3	5.3	2.8	3.8	4.6	7.5	4 3
Mean of all Tests with Sulphate of Ammonia and Muriate of Ammonia ...	3.5	6.0	6.7	5.1	5.1	4.8	10.8	4.6

Muriate of ammonia gives substantially the same results as sulphate of ammonia. The details are as follows :—

	No Nitrogen	Grain, Bushels per Acre.							
		Sulphate of Ammonia.				Muriate of Ammonia.			
		Single dose.		Double dose.		Single dose.		Double dose.	
		Early.	Late.	Early.	Late.	Early.	Late.	Early.	Late.
Oats, 1925	49.6	59.4	64.2	66.4	69.3	61.6	—	62.3	—
Oats, 1926	75.4	77.2	77.0	77.4	77.3	78.8	82.4	77.6	78.4
Wheat, 1926	27.0	24.5	32.8	30.8	32.1	35.4	34.4	37.0	29.5
Wheat, 1927	44.2	49.5	44.0	51.0	49.9	44.0	49.3	50.1	48.9
Wheat, 1928	43.3	44.4	50.6	—	—	48.5	48.1	—	—

	No Nitrogen	Straw, Cwt. per Acre.							
		Sulphate of Ammonia.				Muriate of Ammonia.			
		Single dose.		Double dose.		Single dose.		Double dose.	
		Early.	Late.	Early.	Late.	Early.	Late.	Early.	Late.
Oats, 1925	23.5	31.8	30.8	36.7	34.6	31.8	—	37.4	—
Oats, 1926	44.1	50.0	50.0	58.9	50.3	52.6	48.6	58.2	47.2
Wheat, 1926	41.3	43.7	44.9	46.2	46.7	46.4	44.8	50.3	43.1
Wheat, 1927	45.8	51.4	48.6	55.8	48.9	48.4	50.0	55.3	49.1
Wheat, 1928	29.2	32.5	36.7	—	—	33.3	33.7	—	—

Cereal mixtures for green feed, hay or silage, and therefore grown for leaf rather than grain, should receive their nitrogenous dressing during tillering time.

Nitrogen in wheat grain. An experiment was made in 1928 in conjunction with the Research Association of British Flour Millers to ascertain how far the nitrogen content of wheat can be altered by variations in time of application of nitrogenous fertiliser. No significant effect was produced by manuring, although there were differences between the varieties: Yeoman II and Square Head's Master both contained more nitrogen in the grain than Swedish Iron or Million III. The percentage of nitrogen in the dry grain was :—

Different Varieties.		*Different Times of Applying Nitrogenous Fertiliser.*	
Yeoman II	1.700	No nitrogenous fertiliser	1.646
Square Head's Master	1.698	Early top dressing ...	1.642
Million III	1.565	Late top dressing ...	1.639
Swedish Iron	1.539	Early and late top dressings	1.657

Grassland.

Grass presents special problems because it is not a single crop but a mixture, the members of which are competing with one another. Further, the value of grass is not sufficiently expressed by its weight: it depends not only on the kind of plant but on the way the plant grows, whether leafy or stemmy. Two qualities are important to the farmer: palatability and feeding value. Palatability is tested in the Woburn experiments in Broadmead, where grass is treated with lime, basic slag, superphosphate, potassium salts on separate unfenced plots, all of which are then grazed by animals free to wander where they will. They congregate on the most palatable herbage and leave the rest: they choose always the plots treated with lime and phosphate. Feeding value is tested at Rothamsted; the plots are fenced in and the animals are given no option as to where they shall go: they are weighed each fortnight. The results again show the value of phosphate, especially the basic slag of high solubility: within certain limits they show that a 2 per cent. solution of citric acid is a useful agent for estimating agricultural value, though others are being tested with promising results. The experiments have emphasised the importance of skilful and close grazing in the management of grassland; this is even more important than manuring and, indeed, some of the records show that a properly manured pasture badly grazed may be worse than one left unmanured.

Grazing experiments are, however, the most unsatisfactory of all field trials; they are crude and liable to gross errors. They answer well enough to show strikingly obvious differences, such as those obtained at Cockle Park; and, with proper precautions to ensure success, they can make effective demonstrations, but they give little or no information beyond what a competent grazier could deduce on mere inspection of the herbage. The variations in the individual animals, the marked difference in results according as one more or one less is put on a particular plot, and the impossibility of allowing for their maintenance requirements, complicate a problem already rendered difficult by the variations in the land itself. We are endeavouring, during the present season. to improve the method so as to make it yield more useful results. We are also testing the mowing method used successfully in certain investigations.

The results have given some interesting measurements to show what grassland can do in various parts of the country. The live weight increases in pounds per acre of the sheep grazed on the unmanured plots have been :—

	Leicestershire. Thrussington.	Somersetshire. Fiddington.	Hertfordshire. Rothamsted.
1921–4	—	—	115
1925...	133.8	242	81*
1926...	217.0	187	204
1927...	274.6	297	—
1928...	203.8	428	91*
Average	207.3	313	

* Part of Season only.

The live weight increases on the slag plots at Rothamsted when that on the unmanured is put at 100 are :—

Per cent. soluble in Citric Acid.	81	77	71		28	Gafsa.
Average—						
1921-4	98	112	141	128	100	99
1925	95	127	90	168	59	123
1926	112	110	104	104	104	95
1928	94	112	109	109	115	125
Mean	99	114	124	128	95	105

The first dressing was given in 1921, and the plots were redressed in 1925.

Much clearer results are obtained in the manuring of hay land. Experiments on this subject were begun in 1856 on grass which even then was very old, and they have been continued ever since, the land being hayed every year, two crops being taken without grazing. The results are given on pp. 126-7[1]; they show the importance of potassic and phosphatic fertilisers for ensuring quality, and of nitrogenous fertilisers for giving bulk and early growth.

The effect of slag depends on its solubility: slags of 60 per cent. or more solubility in the 2 per cent. citric acid solution are

[1] Full Report.

https://doi.org/10.23637/ERADOC-1-85

more effective than those of 40 per cent. or less. The results were :—

	Yield, cwt. per acre : No manure. Old meadow. Enmore, Somerset.	Yield, cwt. per acre : No manure. New ley. Brooke, Norfolk.	Improvement given by slag. Yield when unmanured=100. Enmore, Somerset. Solubility. 37%	Enmore, Somerset. Solubility. 87%	Brooke, Norfolk. Solubility. 37%	Brooke, Norfolk. Solubility. 87%
1926 ...	27.4	45.7	109	112	100	116
1927 ...	26.1	18.8	115	123	133	169
1928 ...	9.4	14.9	119	125	128	171

The rapid fall in yield of hay from the new ley is characteristic of the Eastern counties, and illustrates one of the difficulties of grassland farming there.

The experiments show that the old citric solubility test is of considerable practical utility in discriminating between the various slags now offered to the farmer, and they show the wisdom of insisting on a high solubility in general. Low soluble slags may serve a useful purpose in special conditions, but they should be bought only when the farmer has good reason to know that they will act well.

FALLOW.

One of the most striking of recent changes in agriculture has been the increase in land under bare fallow. This represents a loss of crop in the current year, but a gain, and sometimes a marked gain, in the next, so that it is not necessarily as wasteful as it appears. The fallowing of part of Broadbalk has given us opportunities of observing some of the results : on part of it that has had a two years' fallow, the yields have been :—

	Plot.	1928. Grain. Bushels per acre.	1928. Straw. Cwt. per acre.	Average 77 years, 1852-1928. Grain. Bushels per acre.	Average 77 years, 1852-1928. Straw. Cwt. per acre.
No manure since 1839	3	27.9	27.8	11.8	9.9
Complete artificials	13	55.2	32.0	29.2	30.8
No potash	11	56.9	31.4	21.4	21.8
No potash or phosphate	10	47.0	25.8	18.8	18.1
No nitrogen ...	5	35.2	34.8	13.6	10.6
Farmyard manure ...	2B	48.4	61.4	33.2	34.5

The result is a remarkable increase in the yield of grain and in the proportion of grain to straw. Never in the 86 years of successive wheat growing has Broadbalk grown a crop so thick set with grain, and we are unable at present to explain it. The season was very favourable, but probably not more so than some of the great wheat seasons of the past, 1854, 1857, 1863, 1894, yet in none of these was so much grain produced. Much of the effect is probably attributable to the fallow, but whether the action is the suppression of weeds, the decomposition of vegetable and other matter, or some physical change in the soil, we cannot decide. Something more seems to be involved than an increase in plant nutrients, for no fertiliser scheme we have yet tested produces this great increase in the proportion of grain. The ordinary fertilisers increase both grain and straw : the fallowing somehow caused the plant to produce grain and not straw. The investigation is being continued.

LUCERNE.

The value of lucerne as fodder is well recognised, but only a comparatively small area has hitherto been grown, and this is mainly restricted to the south-eastern part of England: elsewhere it often fails to survive. Investigations made by Mr. Thornton during the past five years have revealed both the cause and the remedy. Like other leguminous plants, lucerne is dependent on the bacteria living in the nodules of its roots, and as these are not normally carried in the seed they must enter the plant from the soil: if they do not occur there, the plant fails to grow well. The experiments show that the organisms are absent from many of the soils of the north and west of England, but they occur in the home counties and East Anglia, where lucerne has been grown for many years: they occur also, though probably in smaller numbers, in the flat region stretching away from the home counties to Cheshire—the region known to geographers as the Midland Gate. Mr. Thornton has developed a method of adding the necessary organisms by a process of inoculation which is both successful and inexpensive, increasing the yield of crops by 20 per cent. or more in districts where the appropriate bacteria are absent from the soil, and usually increasing the nitrogen content and therefore the feeding value. Inoculated lucerne seems to have as good a chance of survival in the north and west as in its old home in the south-east and East Anglia. Inoculation is particularly advantageous where lucerne is sown with a cover crop.

Inoculation, however, is not the only thing necessary to ensure success. Lucerne is very liable to weed infestation, in spring with the usual annuals, in autumn with special weeds like groundsel and chickweed. Trials showed no advantage, however, in delaying the sowing for the sake of extra cleaning: spring sowing in a cover crop has given the best results in our trials as widely separated as Somerset, Monmouth, Montgomery, Cumberland and Rothamsted.

Soil acidity is a potent cause of failure of lucerne, being harmful both to the plant and the organism. Acid soils must be limed before inoculation. Alway has obtained evidence that in Minnesota a second crop of lucerne sown immediately after the ploughing in of a first crop that has partially failed has a greater chance of success. No evidence for this was found at Rothamsted, nor of any acid resistant strain of organism that could be used on acid soils. Up to the present liming remains the only way of making an acid soil fit for lucerne.

Mr. Thornton, assisted by Mr. P. H. H. Gray and by generous grants from the Research Fund of the Royal Agricultural Society of England, has developed methods for preparing cultures of the bacteria on a large scale for distribution to farmers; he has also worked out a simple and effective way of putting the cultures on to the seed. The bacteria travel safely and are still vigorous at the end of their journey: indeed a package of them is being sent round the world to see if they will tolerate the 12 weeks of travel thereby involved. The cultures can be kept on the farm for at least two months before they need be used.

Although no advertising has been attempted the demand

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for cultures has increased rapidly. In 1927, 900 were sold, sufficient to inoculate 6,300 lb. of seed. In 1928, the cultures were further improved so that each one would inoculate twice as much seed: 1,750 were sold, representing 24,500 lb. of seed or nearly 1,000 acres of lucerne. The business of selling cultures, however, is not suited to the Rothamsted organisation; it is, therefore, being handed over to a trustworthy and efficient firm who are undertaking to keep close touch with the Rothamsted workers and embody in the process such improvements as from time to time may be effected.

THE ACCURACY OF THE FIELD EXPERIMENTS.

A new method of field experiments was introduced here in 1925 and has been used exclusively in all the new field experiments both at Rothamsted and at Woburn. Its purpose is to get over the difficulty of soil variation, and to measure the probability that the result is due to the treatment and not to soil differences or mistakes by workers. Dr. R. A. Fisher and the staff of the Statistical Department have worked out suitable arrangements of plots, the most convenient in practice being a grouping into blocks each of which contains one each of the proposed treatments, or into a latin square, each row and each column of which contains one, but no more, of each treatment. From the figures for yield, a standard error is worked out which shows the degree of trustworthiness of the result. A difference in yield equal to the standard error of this difference can be obtained about once in three trials even when the experimenter is convinced that he has given exactly the same manuring and cultivation to each of the plots, but a difference twice this size would be obtained by chance only once in 22 times: it is therefore much more likely to be true. The chances against the difference in yield being due to causes other than the difference in treatment are:—

For difference	equal to its	Standard error	...	...	3 to 1
,,	,,	double	,,	...	22 to 1
,,	,,	three times	,,	...	370 to 1
,,	,,	four times	,,	...	15,780 to 1

For most agricultural purposes a chance of about 30 to 1 is good enough. The "standard errors" given in the following tables are those for the yield values, and they have to be multiplied by 1·414 (*i.e.*, $\surd 2$) in order to give the standard error of the difference between treated and untreated plots—the figure one usually wants. To attain a probability of 30 to 1, a difference must be roughly three times the standard error given in the tables. [1]

The method necessitates a large number of plots: during the year 1928 there were at Rothamsted and Woburn:—

Cereals	... ...	240
Potatoes	... ...	250
Sugar Beet	... ...	222

Remarkable accuracy can, however, be obtained: in 1927, the potato experiment of eighty-one plots testing different quantities of nitrogen and different quantities and kinds of potassic fertiliser had a standard error of only 1.14 per cent. The values for all the experiments so far done are given in Table 1.

[1] Full Report.

Table I.

Standard errors per plot, and of average results in the REPLICATED EXPERIMENTS, 1925-28, ROTHAMSTED and WOBURN.

Year and Page in Report.	Crop and Field.	Nature of Experiment, Fertilisers tested.	Area.	Number of Plots.		Standard error per plot, %	Standard error of means, %
1925, p. 138	Potatoes, West Barnfield ...	Potassic	1/50	16		4.9	2.4
1925, p. 139	Potatoes, West Barnfield ...	Potassic and S./A., varying quantities ...	1/50	48		8.6	4.3
1925, p. 144	Mangolds, West Barnfield ...	S./Amm. basal and Top Dressed	1/20	18	roots	14.8	10.5
					tops	10.8	7.7
1925, p. 145	Oats, Long Hoos	S. & M./Amm., Early and Late	1/40	24	grain	8.9	4.5
		Single and Double			straw	4.8	2.4
1925, p. 154	Wheat, Sawyer's Field ...	Uniformity Trial	1/10	47	grain	4.2	4.2
					straw	3.9	3.9
1926, p. 138	Potatoes, Stackyard	Potassic	1/50	16		3.8	1.9
1926, p. 140	Potatoes, Stackyard	Potassic and S./Amm., varying quantities ...	1/50	64		11.0	5.5
1926, p. 155[1]	Potatoes, Woburn	Nitrogenous, varying quantities	1/50	25		6.1	2.7
1926, p. 141	Sugar Beet, Woburn... ...	Potassic	1/60	25	roots	4.3	1.9
					tops	8.5	3.8
1926, p. 142	Sugar Beet, Rothamsted ...	Nitrate of Soda Top Dressing	1/145	16	roots	3.5	1.7
					tops	4.1	2.1
1926, p. 143	Sugar Beet, Woburn... ...	Nitrate of Soda Top Dressing	1/60	25	roots	14.5	6.5
					tops	15.0	6.7
1926, p. 146	Oats, Long Hoos	S. & M./Amm., Early and Late	1/40	96	grain	7.9	1.4, 2.0
		Single and Double			straw	12.5	2.2, 3.1
1926, p. 147	Wheat, Gt. Harpenden ...	S. & M./Amm., Early and Late	1/40	48	grain	14.0	3.5, 5.0
		Single and Double			straw	10.4	2.6, 3.7
1926, p. 149	Malting Barley, New Zealand	S. & M./Amm. Sulphate & Muriate of Potash	1/25	32	grain	9.0	4.5
					straw	5.0	2.5
1926, p. 150	Oats, Long Hoos	S. & M./Amm., Urea	1/40	12	grain	6.4	3.7
					straw	4.4	2.6
1926, p. 153	Swedes, Sawyer's Field ...	Cultivation	1/4	9	roots	6.5	3.8
					number	10.8	6.2
1926, p. 155	Swedes, Sawyer's Field ...	Uniformity Trial	1/10	47	roots	6.7	6.7
					tops	16.4	16.4
					number	7.7	7.7
1927, p. 135	Wheat, Great Knott... ...	S. & M./Amm., Early and Late	1/40	48	grain	11.6	2.9, 4.1
		Single and Double			straw	8.6	2.1, 3.0
1927, p. 131	Barley, Gt. Harpenden ...	Nitrogenous, varying quantities	1/40	48	grain	10.3	2.1, 5.2
		Superphosphate...			straw	10.7	2.2, 5.4
1927, p. 140	Potatoes, Long Hoos ...	Potassic and S./Amm., varying quantities ...	1/40	81		6.1	1.2, 1.4, 2.0
1927, p. 157	Potatoes, Woburn	Nitrogenous	1/40	36		7.4	3.7
1927, p. 156	Potatoes, Woburn	Superphosphate...	1/40	16		5.2	2.6
1927, p. 150	Swedes, Long Hoos	Phosphatic and Nitrogenous	1/25	25	roots	3.2	1.4
					tops	5.2	2.3

[1] 1927–28 Report.

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REPLICATED EXPERIMENTS, 1925-28—*contd.*

Year and Page in Report.	Crop and Field.	Nature of Experiment, Fertilisers tested.	Area.	Number of Plots.		Standard error per Plot, per cent.	Standard error of means, per cent.
1927, p. 144	Sugar Beet, Long Hoos	S./Amm. & Cyan., with Top Dressing	1/40	72	roots	10.2	1.5, 4.1
					tops	10.9	1.5, 4.4
1927, p. 160	Sugar Beet, Woburn...	Nitrogenous, varying quantities	1/40	54	roots	13.7	5.6
					tops	17.2	7.0
1927, p. 153	Oats, Sawyer's Field...	Uniformity Trial	1/10	47	grain	10.6	10.6
					straw	7.7	7.7
1927, p. 151	Barley, Sawyer's Field	Cultivation, Simar, etc.	11/40	9	grain	8.5	4.9
					straw	4.1	2.4
1928, p. 136	Wheat, Pastures	S. & M./Amm., Early and Late	1/40	96	grain	12.5	2.9
		Single and Double		(72 used)	straw	15.6	3.7
1928, p. 133	Barley, Long Hoos	Nitrogenous, varying quantities	1/40	96	grain	10.1	3.6
		Superphosphate...			straw	8.9	3.1
1928, p. 142	Potatoes, Gt. Harpenden	Potassic and Nitrogenous	1/90	162		9.4	1.3, 3.8
		Superphosphate...		(54 used)			
1928, p. 158	Potatoes, Woburn	Nitrogenous	1/40	72		7.1	2.5
1928, p. 156	Potatoes, Woburn	Superphosphate...	1/40	16		4.0	2.0
1928, p. 154	Malting Barley, Woburn	Nitrogenous and Potassic	1/40	32	grain	22.5	11.3
		Superphosphate...			straw	19.4	9.7
1928, p. 147	Sugar Beet, Gt. Harpenden...	Potassic, Superphosphate	3/200	144	roots	9.6	1.1, 1.4
		Top Dressing of Nitrochalk			tops	10.0	1.1, 1.4
1928, p. 162	Sugar Beet, Woburn...	Nitrogenous, Top Dressing of Nitrochalk	1/40	78	roots	9.3	2.2
					tops	15.1	3.6
1928, p. 139	Barley, Long Hoos	Nitrogenous Top Dressing	1/40	16	grain	7.7	3.8
					straw	7.2	3.6
1928, p. 152	Swedes, Gt. Harpenden	Cultivation, Ridged and Simar	1/20	16	roots	4.8	2.4
					tops	12.1	6.0

Average Standard Errors of Single Plot for Different Crops obtained from above table.

No. of Experiments on which Average is based.	Crop.		Average Standard Error of Single Plot. per cent.
11	Potatoes		6.69
7	Sugar Beet	roots	9.30
		tops	11.54
5	Swedes or Mangolds	roots	7.20
		tops	11.06
4	Wheat	grain	10.58
		straw	9.62
5	Barley	grain	9.12*
		straw	7.18*
4	Oats	grain	8.45
		straw	7.35

* But if Woburn, 1928, be included, these become 11.35 and 9.22 respectively; see page 154 of Report.

The standard error per plot is, for a number of the experiments, about 5 per cent. of the average yield; for others, including those on mangolds and sugar beet, about 10-15 per cent., the larger errors being at Woburn. One of the many advantages of the method is to show up the faulty experiments and so indicate the need for improvement. Thus the increased error in the wheat and potato experiments at Rothamsted in 1928 as compared with 1927, was traced to certain special circumstances which were fully investigated and will be sedulously avoided in future. The increased error for the Woburn barley in 1928 has not yet been explained.

The large number of plots treated alike in any one experiment enables the average yield for this treatment to be determined much more accurately than could be done with only one plot. Consequently, the " Standard error of the mean," the figure which is quoted in the summaries of results of experiments (pp. 131-175[1]) and which varies inversely with the square root of the number of plot yields averaged, is much lower than the standard error of a single plot, as is seen by comparing the two adjoining columns of the Table. It is, for many of the experiments, only 1½ to 3 per cent., while for most it is less than 5 per cent.

Efforts are now being made to improve the accuracy still further by eliminating the waste occurring at harvest and during cartage and storing : a method has been worked out in the Plant Physiological and Statistical Departments which has the further advantage of reducing the labour of harvesting; it consists in taking, just before harvest, a large number of samples from measured lengths of the rows, chosen at random, weighing them, and, for cereals, threshing in a miniature machine. The rest of the crop is then left to be harvested in the usual way, but no measurements need now be taken : the whole labour of separate harvesting, separate stacking, and separate threshing, with all the losses involved, is eliminated. A comparison of the new with the old method was made last year and will be carried out on a much larger scale this year : at present, the method seems distinctly promising in providing more accurate figures, better samples for analysis, and speedier results than could be obtained before.

The great advantage of knowing the standard error is that the figures for yield can be safely used for a wide range of purposes.

At present, they are being correlated with the meteorological data, the methods of collection of which have been constantly improved. This enquiry has been extended beyond the scope of our own station. Dr. Fisher has developed appropriate statistical methods for working up the masses of meteorological and crop data that have already accumulated in this country, aided by Dr. Wishart, who has supplied tables for testing the significance of results reached by means of these methods, while Mr. J. O. Irwin, working under the Ministry of Agriculture Crop Recording Scheme, is studying the problems connected with the technique of observation.

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[1] Full Report.

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PLANT GROWTH AND QUANTITY OF FERTILISERS.

Of the many attempts to find the relationship between the amount of plant growth and the quantity of fertiliser applied, the most widely discussed is the attractive one of E. A. Mitscherlich, which, however, is open to some criticism. Professor Balmukand, working in Dr. Fisher's laboratory, has shown that the results may be expressed in terms of two constants, one representing the importance of the nutrient to the crop, while the other represents the amount of nutrient the crop can extract from the unmanured soil. The first of these constants is presumably a crop and even a varietal factor, and the second is a soil factor: the constants promise to afford a means of estimating both, and so of expressing numerically both the crop need and the amount of available plant food in the soil.

DETAILED LABORATORY AND POT CULTURE INVESTIGATIONS ON FERTILISERS.

The laboratory work is carried out in the Chemical Department by Mr. R. G. Warren and Dr. H. L. Richardson, under Dr. E. M. Crowther, and the pot culture work by Dr. W. E. Brenchley and Miss K. Warington.

Cyanamide. No experiments had been made at Rothamsted with this substance since 1920 and, as the method of manufacture has considerably altered, an extended series of investigations was begun in 1927 and is being continued. The modern material is practically free from the dicyanodiamide which used to cause much trouble, and it is also easier to handle than the old samples: it still needs, however, to be applied a few days before sowing. In our experiments, it has been as effective as sulphate of ammonia on barley at Rothamsted, but less on potatoes at Woburn and sugar beet at Colchester. The increments in crops for 1 and 2 doses of cyanamide and of sulphate of ammonia have been :—

	No Nitrogen.	One dose.			Two doses.			Cyanamide value when Sulphate of ammonia = 100	Urea value when Sulphate of ammonia = 100
	bushels	Sulphate of ammonia	Cyanamide	Urea	Sulphate of ammonia	Cyanamide	Urea		
Rothamsted.									
Barley, bushels.									
1927	23.6	10.4	12.4	9.2	14.2	12.3	20.2		
1928	28.6	7.0	4.8	6.4	6.0	8.9	7.2		
Additional bushels per lb. nitrogen.									
1927	—	0.45	0.54	0.40	0.31	0.27	0.44	106	110
1928	—	0.31	0.21	0.28	0.13	0.19	0.16	94	100
Woburn.									
Potatoes	tons.	cwt.	cwt.		cwt.	cwt.			
1926	6.50	17.6	15.2	—	27.2	25.0	—		
1927	6.53	12.8	7.2	11.0	−2.0	4.0	8.0		
1928	11.9	44.4	16.6	—	—	—	—		
Additional cwts. per lb. nitrogen.									
1926	—	0.76	0.66	—	0.59	0.54	—	89	—
1927	—	0.37	0.21	0.32	−0.03	0.06	0.12	79[1]	129
1928	—	1.29	0.48	—	—	—	—	37	—
Colchester.									
Sugar beet.	tons.				tons.	tons.			
1928	6.09	—	—	—	1.32	0.70	—		
Additional cwts. per lb. nitrogen ...	—	—	—	—	0.44	0.23	—	52	—

[1] Single dressing.

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The comparison is made on the basis of the increments and not of the yield figures: it therefore carries all the errors of the experiments and acquires validity only as data accumulate. The very low value at Woburn in 1928 is probably fictitious and arises from the circumstances that the increment for sulphate of ammonia was abnormally high, being indeed the highest we have ever obtained.

Much work has been done in the Chemical Department by Dr. E. M. Crowther and Dr. H. L. Richardson on the decomposition of cyanamide in soil. The first reaction giving urea is brought about by some chemical change not understood: the urea then changes rapidly to ammonia and this, through the action of micro-organisms, is oxidised to nitrate.

While the general course of the decomposition is probably the same in all soils, the rate at which it proceeds varies in different soils. The most striking result is the delay in the formation of nitrate even after all the cyanamide has decomposed: the ammonia remains unnitrified for some long time. In spite of this, however, plants make good growth, suggesting that they are using the ammonia.

Ammonium Chloride.—The experiments described in the preceding pages and the earlier reports, show that ammonium chloride is, in general, superior to ammonium sulphate in equivalent amounts for cereals and, so far as the experiments have gone, for sugar beet but not for potatoes. Further information is being accumulated.

Urea. This substance compares very favourably with sulphate of ammonia in equivalent quantities; it has the advantage of high concentration, containing 46 per cent. of nitrogen against only 20.6 in sulphate of ammonia. Further, it has less tendency to make soil acid.

Basic Slag. Mr. R. G. Warren has shown that a solution of sodium chloride affords a better means of assessing the agricultural value of basic slag than the official 2 per cent. citric acid. Basic slag increased the amount of manganese in the barley grown in pot experiments: if it did the same for oats it might be expected to cure the "grey fleck" disease, which is attributed to deficiency of manganese. The manganese in the slag, however, did not appear to increase the yield of barley.

Superphosphate. In spite of much experimental work by the staff of the Chemical Department, no indication can be found that superphosphate ever makes a soil acid. Farmers in the west country and in the north maintain that it increases the liability to finger and toe in swedes: on this we have hitherto been unable to make experiments.

Dr. Brenchley has shown (in confirmation of Gericke's earlier work) that barley utilises phosphate for increased growth only in its early stages of growth, although absorption of phosphate continues almost throughout the whole life of the plant. Early sown barley can utilise phosphate for at least 12 weeks (varying with different varieties) while later sown barley cannot, its period of utilisation being shorter. Further, the period during which phosphate can be withheld without injury is longer for early sown than for late sown barley. These advantages in favour of early sowing have not previously been recognised.

Sodium Silicate. Sodium silicate has long been shown to benefit the barley crop at Rothamsted : evidence is now obtained that this is due to an action in the soil enabling the plant to take up more phosphate, rather than an action in the plant enabling it to use phosphate better, as was previously supposed.

Elements needed only in small amounts. The necessity of boron and of manganese in small amounts has already been demonstrated in earlier reports. Recently, R. V. Allison, in Florida, obtained striking crop increases by the use of copper sulphate on certain Florida " muck " soils, which apparently resemble some of our fen and peat soils. Dr. Brenchley has made trials on a number of crops on these soils, but found no response to copper sulphate : there seems, therefore, no likelihood of it proving useful here.

SOIL CULTIVATION.

The experiments on soil cultivation follow three general lines. Measurements are taken in the field of the draught or drawbar pull of the implement and of the effect it has had on the soil. Laboratory experiments are made to study the physical properties of the soil, including stickiness, tilth, its relations to water, air and temperature, and so to explain the field observations. Finally, field experiments are made to test other and simpler methods of achieving the same results as present-day cultivation methods.

Earlier work had shown that heavy dressings of chalk, such as were formerly given in Hertfordshire, markedly reduced the drawbar pull necessary to get a plough through the soil. The smaller dressings now customary have been tried during the past three years : five tons per acre of finely divided chalk and 30 cwt. per acre burnt lime ; but at Rothamsted neither caused any appreciable reduction in drawbar pull, though another property was affected, as shown later.

Among the attempts to simplify cultivation, the rotary cultivator is one of the more promising : it achieves in one operation what the usual implements do in two or three, and thus offers the possibility of reduction in cost. It proved better in 1926 than either the ordinary ridge or flat cultivation for swedes during the first part of their growth, but not afterwards ; the rotary cultivated plots then "capped " or hardened considerably ; ordinary cultivation methods were used for the succeeding barley in 1927, but the effect of the 1926 rotary cultivation was still visible and was entirely beneficial—a residual effect that was not expected and cannot yet be explained. The values for yields were :—

Barley, 1927.	Former rotary-Cultivation.	Horse Cultivated.	Horse Ploughed.	General Mean.	Standard Error.
Grain.					
Per cent. ...	117.0	91.0	92.0	100.0	4.89
Bushels ...	27.8	21.6	21.9	23.8	1.16
Straw.					
Per cent. ...	111.1	95.3	93.6	100.0	2.35
Bushels ...	21.7	18.6	18.3	19.5	0.46

In 1928, swedes were again grown, but on different land: this time, however, rotary cultivation caused no "capping" and no difference in growth, as compared with ordinary cultivation. This variation of result with season was expected, and is being studied: the bad effect in the summer and autumn of 1926 is not easily understood. The rotary cultivator produced in each year as nearly as can be measured the same degree of disintegration of the soil as ordinary cultivation, except when the soil was in an unkind or difficult condition for cultivation: in this case rotary cultivation was less effective than the ridging plough. The experiments further showed the value of the ridging plough in breaking up an unkindly soil.

The purposes of cultivation are threefold: (1) the formation of tilth, (2) the conservation of moisture, (3) the suppression of weeds. It is not agreed how closely (2) and (3) are linked, but it is certain that weed suppression is an important function, and this has been studied by Dr. Brenchley and Miss Warington on the permanent plots of both Woburn and Rothamsted. One of the chief factors is the time the weed seeds can live in the ground. Cultivation encourages the germination of Black bent (*Alopecurus agrestis*). Poppy (chiefly *Papaver rhoeas*), however, survives much longer in the soil: its seeds are still germinating in a sample of Broadbalk soil taken in 1925 and continuously cultivated ever since in a glasshouse, where contamination is reduced to a minimum. The seedlings are removed as they appear, so that no fresh seeds reach the soil, yet already the number of plants appearing has been at the rate of 33 millions per acre on the plot receiving no nitrogen and up to 205 millions per acre on one of the completely manured plots.

The principles of cultivation: the meaning of tilth.

A great deal about cultivation must remain obscure until we know what it does to the soil and how it does it. The science of cultivation is only in its infancy, and is far behind the science of manuring; advice can be given only empirically and tentatively. The subject is, however, steadily being developed by Dr. Keen and his staff, Dr. Schofield, Mr. Scott-Blair and Mr. Cashen. The mechanical principles involve the movements of layers of soil against and over each other and against the metal surface of the implement. Special methods have been designed for working these out: measurements are made of the Static Rigidity, *i.e.*, the energy required to cause a soil paste just to flow; and of the viscosity (more strictly pseudo-viscosity) of the paste once it has begun to flow. The measurements of static rigidity are closely related to the observed Draw Bar Pull, but represent only one group of the factors involved, *e.g.*, a dressing of one ton per acre of slaked lime reduces the static rigidity, but not the dynamometer values.

"Single value" soil constants. The only method at present available for the physical specification of a soil is mechanical analysis, but this is tedious, and the results have only a qualitative value. Attempts have been made from time to time to develop other simple measurements of some single property (or group of properties) easily expressed by a figure, and thus serving as "single-value" soil constants. The subject has now been

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re-opened at Rothamsted. The " sticky point " (*i.e.*, the moisture content at which a plastic mass of soil and water is just about to become sticky) is promising. It is closely correlated with the loss on ignition which may be taken as an approximate measure of the amount of the organic and the inorganic colloids: it is not, however, correlated with the percentage of clay. The amount of moisture in air dry soil is correlated with the percentage of clay, but not with the loss on ignition, *i.e.*, not with the total colloids: this moisture is therefore presumably held in the minute interstices between the small particles. On the other hand, the clay and the sticky point, and the ignition loss and the air dry moisture content, are significantly correlated. These results indicate two ways in which the water is held in the soil. The organic and the inorganic colloids control the sticky point, while the minute interstices between the small particles control the air dry moisture content. Confirmation has been obtained by repeating the measurements after treating the soil with hydrogen peroxide to remove the non-structural organic matter. The two values are therefore of help as a means of soil specification, and an extended co-operative comparison of them for many different soil types has been agreed to by the International Society of Soil Science. This work will be controlled from Rothamsted.

THE CONSTITUENTS OF THE SOIL.

The Organic Matter.

For some years past the chemical changes occurring during the decomposition of plant residues in the soil, and especially those concerned in the formation of humus, have been studied by Mr. H. J. Page and his staff, G. V. Jacks, C. E. Marshall, C. W. B. Arnold and others.

Lignin is the main, though not the only source of humus, but the plant residues apparently humify as a whole.

Humus is very complex in composition, and its effects in the soil are not yet fully known. There is an important difference between the humus of the soil and that of leaf mould and peat: while all three kinds of humus yield up ferric iron after hydrolysis with acid in boiling solution, soil humus gives ferrous iron also.

Now iron may play an important part in the oxidation processes in the soil: for example, the artificial production of humic acid from lignin by atmospheric oxidation in strongly alkaline solution takes place only in the presence of organically combined iron.

The clay and the reaction of the soil.

The reaction of the soil is closely associated with the amount of the bases, particularly calcium, that can be replaced by other bases when the soil is mixed with a salt solution. Much work is being done on the amounts of these replaceable bases in the Woburn soils.

The exchangeable calcium is greatly reduced by sulphate of ammonia, and slightly increased by nitrate of soda, superphosphate and farmyard manure. The exchangeable potassium is very low: it is hardly affected by nitrate of soda or sulphate of ammonia in spite of the fact that this reduces the calcium, but it is much increased by farmyard manure. A method is badly needed for estimating the extent to which the soil is saturated with bases, or, alternatively, the extent to which the bases have been replaced by acid hydrogen: attempts are being made to solve this problem by mixing the soil with excess of calcium carbonate and extracting with sodium chloride.

The most widely used and most convenient way of measuring the reaction of the soil is the quinhydrone electrometric method. Miss Heintze and Dr. Crowther used it for a series of Gold Coast soils and obtained clear and definite results at least one-third of which subsequently proved to be quite erroneous.

The trouble was traced to the manganese dioxide present in certain soils in a form which reacts with the quinhydrone producing a base and a corresponding reduction in acidity. Similar errors have been found in English soils and methods of detecting and avoiding them are being worked out.

SOIL MICROBIOLOGY.

The investigations in soil microbiology fall into two main divisions: (1) the study of the micro-organisms living in the soil, their kinds, numbers, mode of life, their various activities and their relation to one another.

(2) A detailed study of soil micro-organisms directly affecting plants: the nodule organisms of the leguminosæ, organisms parasitic on plants and producing diseases.

The chief groups of soil micro-organisms are: bacteria, fungi, including actinomycetes, algæ, protozoa and nematodes: all are studied at Rothamsted except the nematodes, which are left to the Institute of Helminthology, St. Albans, though it is hoped to effect some co-operation with this body as the work is now beginning to suffer through so artificial a restriction.

All the organisms, except some of the protozoa, feed on the organic matter in the soil, some of them also ferment part of it: in either case, they decompose it, producing humus, nitrates, phosphates and compounds of calcium, potassium and other elements of great importance in soil fertility. Soil micro-organisms are, to a large extent, the producers of soil fertility, though they also reduce it by assimilating to themselves nitrates and phosphates that would otherwise serve for plants. It is this close connection with soil fertility that justifies the extended study made of them at Rothamsted.

Broadly speaking, fungi predominate in acid soils and bacteria in neutral soils, and of the substances they decompose fungi assimilate more, build up more protoplasm and retain more nitrogen than do bacteria: they are less economical as plant food producers because bacteria convert more of the organic matter into carbon dioxide, water and ammonia. For this reason less of the nitrogen can be nitrified in an acid than in a neutral soil.

There is considerable difficulty about estimating the numbers of fungi and studying their activity: Dr. Brierley has shown how to obtain comparable data under strictly controlled conditions, but the results have no absolute value and the higher figures are not intrinsically more probable than the lower ones. More can be done with the bacteria. Their numbers can now be estimated by Messrs. Thornton and Gray's direct method much more rapidly and completely than before: when the counts were first made at Rothamsted by the old plating method, a usual estimate (known, however, to be very incomplete) was 10-30 millions per gram, and the experiment took ten days to complete: now the estimate (which, however, includes dead organisms) is 1,000-5,000 million per gram, and the experiment takes only two hours. The numbers are related to those of the protozoa; they are high when the protozoan numbers are low, and low when the protozoan numbers are high: this is because the protozoa feed on the bacteria. The "nutritive values" of the various bacteria differ; for one of the most "nutritious" an increase of 3,400 amœbæ (*Hartmanella hyalina*) per gram involved the disappearance of 1,444,000 bacteria, *i.e.*, something over 400 bacteria were consumed to produce one amœba. The effect of the protozoa on the decomposition of plant residues by bacteria and fungi is being studied: it apparently differs according as the action is a fermentation or a consumption for food.

One of the most far-reaching factors in the situation is that micro-organisms need adequate supplies of nitrogen and of phosphate and can decompose carbohydrate only in proportion to the amounts of these substances present. This is the fundamental principle underlying the making of farmyard manure. Straw is put under the animals as litter and, being mingled with their excretions, is decomposed by micro-organisms to form the familiar black, sticky substance known as humus. In doing so, however, the organisms assimilate some of the ammonia of the excretions, converting it into their body tissue, in which form it is insoluble and some of it is not easily nitrifiable. Thus the nitrogen in farmyard manure is of three kinds: the original complex nitrogen compounds of the straw and solid excreta; simple and easily nitrifiable compounds (urea and ammonia) of the liquid excreta; and complex nitrogen compounds of the bodies of the micro-organisms derived from these simple compounds. Not all of this nitrogen is readily nitrified; Dr. Jensen, in the Bacteriological Department, shows that only the excess of nitrogen over a certain amount is quickly nitrifiable, the proportion of non-nitrifiable and therefore less useful nitrogen depending on the amount of carbon present and also on the reaction of the soil. In a neutral or alkaline soil, for every 20-25 parts of carbon, one part of nitrogen nitrifies only slowly; for an acid soil the figures are one part nitrogen for every 13-18 parts of carbon. This accords with the observation that farmyard manure is much more effective in a neutral than in an acid soil, and it explains why farmyard manure and other plant residues containing less than about 1.5 per cent. nitrogen in the dry matter supply very little nitrate and are therefore of little help in soil fertility, thus emphasising the very serious nature of the losses when the soluble nitrogen compounds in farmyard manure are leached out by rain.

Artificial farmyard manure. This fuller knowledge of the mechanism of the decomposition of cellulosic materials is not only useful in the management of farmyard manure: it forms the basis of a method of producing an artificial farmyard manure, closely resembling the ordinary material. Straw need not be