ROTHAMSTED RESEARCH

# Report for 1927-28

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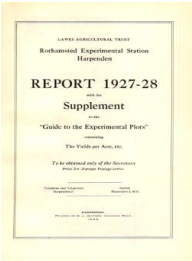


## The Accuracy of the Field Experiments

### Rothamsted Research

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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.*, $\sqrt{2}$) 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.

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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.

## 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.