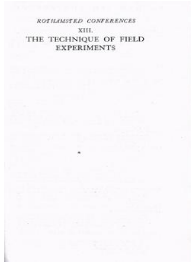
XIII. The Technique of Field Experiments


ROTHAMSTED CONFERENCES
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Full Table of Content

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METHODS OF ESTIMATION OF CROP GROWTH AND YIELD

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Field experiments are usually laid down as yield trials, in which often the only recorded results are the final weights of produce obtained from the differently treated plots. Such results are of course of great value in determining agricultural practice, but their scientific value is much increased if it is possible to interpret the differential effects of treatment in terms of physiology. The analysis of yield in terms of physiological processes in the plant presents many difficulties, because of the large number and the complexity of the variable factors inside the plant and in the soil and climate which are involved.

Some information can be obtained by careful visual observation of the crop throughout the growing period. In this way differences in the amount of growth, for example, or the incidence of disease may be detected, but it is always difficult to make numerical estimates of such observed differences, and any estimates made are apt to be unreliable, depending as they do on the experience and preconceptions of the observer. It is obvious that if an attempt at an analysis of yield is to be made, direct measurements throughout the growth of the crop are essential. To begin with, we may examine the simpler aspects of growth, such as growth in height, growth of leaf area or tillering. This is a comparatively simple matter, but the problem becomes much more difficult if we attempt to push the analysis a stage further, by investigating the fundamental processes in the plant of which growth is the expression. At the present time there is a scarcity of methods of measurement of these physiological processes, which are at the same time reasonably accurate and sufficiently simple and quick to be employed in field work, and which do not involve destruction or damage to part of the crop.

Whatever aspects of the growth of a crop in a field-experiment we may wish to study a further problem presents itself. Because of the very large number of plants on an experimental plot, it is only possible to make measurements on a small fraction of the whole, and a sample must be selected from the plot for this purpose. Since there is usually a high variability between the plants, the validity of conclusions derived from measurements made on a sample, depend on whether the sample is really representative of the plot from which

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it is taken or not. A reliable sampling method is therefore essential for field study of growth and physiology.

Recently at Rothamsted a new technique of sampling has been evolved by Mr. Clapham,[1] in which use is made of the statistical method of the Analysis of Variance. This sampling technique was first used for making growth measurements, but it has been shown that it could be adapted for estimating the yield of a plot with sufficient accuracy. Its use for this purpose has been most fully worked out for cereal crops, but it also has been applied, perhaps less successfully, to root crops. It will be simplest to discuss first the principles involved in the technique as applied to the estimation of yield of cereals.

A good sampling method must satisfy two requirements. First, the sample must be sufficiently large and so distributed in the plot as to be representative of the whole plot. Secondly, and more important, the sampling must be carried out in such a way as to make a statistically valid estimate of the error introduced in taking the sample possible. Unless such an estimate of error can be made the validity of the conclusions drawn from the observations on the sample remains in doubt, and also it is not possible to investigate the causes of the sampling error, and then by suitably rearranging the method of sampling to reduce the sampling error. A statistically valid estimate or error can be made only if the sample from a plot consists of a number of parts, or sampling units, which are distributed at random in the plot, that is to say, if the sampling units are a random selection from a large population of such units. Older methods of sampling, as for example, those used by Engledow,[2] and by American workers [3, 4] have involved a systematic distribution of the parts of the sample over the plot, and though a systematic arrangement reduces the labour involved in sampling, it is open to the objection that no valid estimate of error can be obtained.

Clapham took as his sampling-unit a metre-length of drill row. From a plot of about $^1/_{10}$th of an acre he cut thirty such metre-lengths, which were distributed at random. The yield of each of these metre-lengths was determined separately. The sums of squares of the deviations of the yields of each metre-length from the mean yield per metre-length, divided by the number of degrees of freedom, which is one less than the number of metre-lengths, and by the number of metre-lengths, gives the variance due to sampling, and the square root of this variance is the sampling error per plot. The sampling error worked out at about 6 per cent., and indicated that for an equal number of sampling units taken from a plot of $^1/_{40}$ acre, the usual size of the experimental plots at Rothamsted, the sampling error would be not more than 5 per cent. The standard error of plots of this size due to causes other than sampling is usually from 8 to 10 per cent., and the superposition of a further error of 5 per cent. would increase this only to from 9 to 11 per cent., so that the increased inaccuracy due to sampling was satisfactorily small. The yield of the whole plot was calculated from the mean yield of a metre-length, by multiplying it by the total length of drill row, which is easily calculated from the area of the plot and the distance between drill-rows.

Several refinements have been made in this original simple technique. The sample can be made more representative of the whole plot, by dividing the plot into a number of parts from each of which the same number of randomly distributed sampling units is taken. The procedure has the additional merit that the total variation between metre-lengths can be analysed into a portion representing differences between the mean yields of the parts of the plot and a portion representing differences between metre-lengths within the same part. The former portion of the variation may fairly be eliminated as due to differences in mean fertility between the parts of the plot, and consequently the sampling error calculated from the remaining variance is reduced.

The metre-length proved in some conditions to be too coarse a unit. This was shown by dividing the metre-lengths into halves, and harvesting each half separately. When this was done it was sometimes found that there was a significant correlation between the yields of the two halves of metre-lengths. That is to say, successive half-metres of drill-row were more alike than randomly distributed half-metres, and a given number of randomly placed metre-lengths was a less representative sample of the plot than twice the number of randomly placed half-metres. Doubling the number of randomly placed sampling units would of course increase the labour of sampling. A better solution of the difficulty was found by using a dissected metre-length of drill row. Various methods of dissection have been used. In one arrangement the metre was divided into quarters each of which was separated from its neighbour by half a metre of unsampled corn. In another the metre was divided into halves, which were taken from adjacent drill rows. With either of these arrangements the correlation between separate parts of the metre disappeared. A half-metre length of drill row is then a satisfactory unit for sampling a cereal crop, and it may be profitable in some cases to use a quarter-metre. Smaller units than this would be impracticable, as Professor Engledow [2] has pointed out, owing to the increased importance of end errors. American workers have used the rod-row (5½ yards) and the square yard as units, but these are much too large.

The general principles involved in Clapham's sampling technique may therefore be stated thus :—

The *sample* on which an estimate of yield of the plot is based consists of the aggregate of a number of *sampling units*, which are distributed at random over the plot. The *sampling unit* itself may be divided into a number of *units*, which are arranged systematically within the sampling unit. The particular systematic arrangement adopted is determined by two considerations. A good arrangement tends to make the sampling-units themselves representative of the plot, and therefore like one another, thereby reducing the sampling error. Also the arrangement must be such as to reduce as far as possible the labour of sampling.

The estimate of sampling error is derived from the variation between sampling units, and in order that an estimate of error may be made, at least two sampling units must be taken per plot. The size of the sampling error is influenced by the number and distribution of units within the sampling unit.

The accuracy of the estimate of sampling error depends on the number of degrees of freedom on which it is based, that is to say on the number of sampling units. For assessing the yield of a single plot it is therefore necessary to take a fairly large number of sampling units, depending on the size and uniformity of the plot, but probably not less than ten would need to be taken. When, however, a large number of plots, such as form a modern replicated experiment, is being sampled, each plot can be made to contribute to the estimate of sampling error, if it can be assumed that the variation from sample to sample is of the same order on different plots. There is considerable evidence to justify this for plots which are manured at ordinary agricultural rates, but it would not be true for a very wide range of manuring such as is often given in pot experiments. If the assumption can be made, the number of sampling units per plot may be cut down, often to as low as two per plot. There is then one degree of freedom per plot for estimation of sampling error, and if there are n plots, the sampling error for the plots taken together is based on n degrees of freedom. Since n would not usually be less than 16, and often considerably more, a sufficiently accurate estimate of error is obtained.

If the number of sampling units per plot is reduced in this way, it is necessary to increase the number of units in the sampling unit, to sample the plot effectively. For example, in a 4×4 Latin square experiment on barley, four sampling units were cut from each plot of $^1/_{40}$ acre, each consisting of ten half-metre lengths of drill arranged according to a simple systematic scheme. A considerable saving of labour is obtained by using a small number of large sampling units, since the number of random placings is reduced, and the number of threshings and weighings is also decreased. It is not necessary to determine the yield of each unit of the sampling unit separately, unless it is desired to test whether the systematic arrangement of units within the sampling unit is a satisfactory one.

The size of sample to be taken from a plot depends on the crop and on the accuracy required. It can only be determined by direct experiment. For cereals it has been found in a considerable number of trials that a sample of 20 to 30 metre-lengths per plot of about $^1/_{40}$ acre is sufficiently large, and gives a sampling error of between 5 and 6 per cent., which causes an increase of between 1 and 2 per cent. in the experimental error per plot, by which treatments are compared.

The technique has been applied to the estimation of yield of a potato crop.[5] A single plant was taken as the unit. Two sampling units were taken from each plot, each consisting of every twentieth plant in the rows of the plot, starting at a plant selected at random from amongst the first twenty plants. Thus each sampling unit was distributed over the whole plot and in itself representative of the whole plot. This is a good example of the way in which the advantages of a systematic arrangement in the saving of labour can be combined with the element of randomness which is necessary for a valid estimation of error.

The real test of the efficiency of a sampling method is made by comparing the yields estimated by sampling with the yields obtained by harvesting and weighing the whole produce of the plots. This has been done in a number of experiments,[6] and it was found that little information was lost by sampling, and the results obtained by the two methods were substantially the same.

We may turn to the use of the sampling technique for making observations and measurements during the growth of a crop. The procedure of selecting a sample for this purpose is precisely similar to that used in sampling for yield. But since counting and making measurements on the plants in a sampling unit takes very much longer than merely cutting out the unit and tying it up, as is done in sampling for yield, it is usually necessary to reduce the size of the sample considerably. Alternatively in a large replicated experiment, labour may be cut down by sampling from only a selected few of the replicates. This leads usually to an increased and less accurately determined standard error for treatment comparisons, since the number of degrees of freedom on which it is based is reduced. It is probably preferable therefore in most cases to reduce the number of sampling units taken from each plot rather than to reduce the number of plots sampled.

Reducing the size of the sample, of course, leads to an increased sampling error, and a loss of accuracy. But since the sampling error can always be calculated, and the significance of the results obtained from the samples determined, there is no danger of drawing unwarranted conclusions. In some recent counts of plant number and tiller number on the plots of a wheat experiment, where the crop was not abnormally uniform, 3 metre-lengths of drill row were counted in each plot of $^1/_{50}$ acre. The sampling error per plot was just under 12 per cent., but highly significant differences were found for the differently treated plots. There were 48 plots in the experiment, so that in all 144 metre-lengths were sampled, from an area of about one acre. Although this is small compared with the size of sample taken for estimation of yield, it represents a larger sample than has often been used in studies of crop development. Engledow,[2] for example, in his "Census of an acre of corn," took 100 foot-lengths of drill from an area of one acre, and concluded that this was a sufficiently representative sample.

The procedure of sampling in the field is very simple. A list of random placings for the sampling units is prepared beforehand. Usually each placing is fixed by two numbers, the first being the number of rows along one side of the plot, and the second the number of paces into the plot. After the numbers have been selected they are arranged in such an order that in observing successive sampling units the observer moves steadily over the plot, from one side to the other, and the amount of trampling is thus reduced. The sampling unit is measured out by means of a rod, in the case of a cereal crop, which is placed along the drill-row. If the sampling unit is a small one, a dissected metre-length, for example, it can be fixed by one placing of the measuring rod, but if a more complex sampling unit is used, a number of placings are necessary, following a systematic distribution from the randomly determined starting point. In sampling for yield, each sampling unit is cut out by means of large scissors or shears, and tied up and labelled with the number of the plot. The ears are protected by enclosing them in a paper-bag, which is perforated with holes, which are small enough to prevent the grains passing through them, in order that the ears may be adequately ventilated and the growth of moulds prevented. When all the sampling units have been taken from a plot, they are tied up together and brought back to the laboratory, where they are stored until it is convenient to weigh and thresh them.

The advantages which the sampling method gives may be summarised as follows :—

Many of the errors which are involved in large scale harvesting of cereals are avoided by sampling, as for example, losses of grain in the stook and in the stack. Inaccuracies due to weighing of weeds as straw are eliminated. Edge-rows can be discarded without the necessity of cutting them out. The bulked produce of the independently located sampling units form an excellent sample for chemical analysis. Smaller plots can be dealt with by the sampling method than by ordinary farm methods, and this is of great importance, since for a given experimental area, greater replication can be obtained by reducing the size of plot, and the accuracy of the experiment so increased. Where large scale machinery suitable for dealing with small experimental plots is not available, the sampling method may be used, and the problem of harvesting complex field experiments at farms some distance from the organising centre can be solved. Finally, since sampling in some form is necessary for the study of crop growth and development, a statistically sound method of sampling is indispensable.

REFERENCES

[1] Clapham, A. R., *J. Agric. Sci.* **19,** 1929.
[2] Engledow, F. L., *J. Agric. Sci.*, **16,** 1926.
[3] Arny, A. C., and Garber, R. J., *J. Amer. Soc. Agron.*, **11,** 1919.
[4] Arny, A. C., and Steinmetz, F. H., *J. Amer. Soc. Agron.*, **11,** 1919.
[5] Wishart, J., and Clapham, A. R., *J. Agric. Sci.*, **19,** 1929.
[6] Clapham, A. R., *J. Agric. Sci.*, **21,** 1931.

THE IMPORTANCE OF FIELD EXPERIMENTS

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During the last few years the number of artificial fertilisers placed on the market has considerably increased. In particular Imperial Chemical Industries has placed before the farmer a number of concentrated fertilisers such as have not previously been available in this country.

It is of the greatest importance to the fertiliser industry that it should know as accurately as possible the value of its products.

Numerous institutions and agricultural stations in this country are engaged in establishing the general value of fertilisers. There are some, however, who do not care to include the new concentrated fertilisers in their programme of work because they were made by one commercial firm.