ROTHAMSTED RESEARCH

XIII. The Technique of Field Experiments

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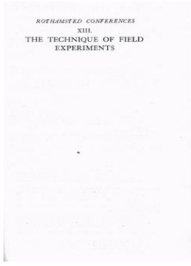
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Principles of Plot Experimentation in Relation to the Statistical Interpretation of the Results

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PRINCIPLES OF PLOT EXPERIMENTATION IN RELATION TO THE STATISTICAL INTERPRETATION OF THE RESULTS

By R. A. FISHER

The greatest source of error in field experimentation is that due to the heterogeneity of the soil. This fact is the conclusion universally to be drawn from uniformity trials, and may be illustrated by the contours of fertility found in a trial carried out by Mercer and Hall at Rothamsted in 1910, in which an acre of wheat, chosen for its apparent uniformity, as is the land allotted to experiments, was treated uniformly and harvested in 500 small plots. The yield, even after smoothing out the variation ascribable to extremely local fluctuations, varied from about 27 bushels per acre in the areas of low fertility to about 37 in the areas of high fertility, a range of about 30 per cent. of the mean yield.

We may utilise the experience, not only of uniformity trials, but of experiments in which replication is employed, to show that the yields of plots of about $^1/_{40}$ acre frequently vary among themselves owing to soil heterogeneity with a standard deviation higher than 10 per cent. of the mean yield. With ordinary care all working errors may be kept down to a much lower figure. It is therefore important to see that the time and labour at our disposal is not wasted in attaining over-meticulous precision in factors which in fact contribute little to the field errors, but that they should be employed where the advantage to be gained is greatest in overcoming the errors due to soil heterogeneity.

In addition to its quantitative importance the uniformity trials have sufficed to establish quite generally (i) that the soil fertility cannot be regarded as distributed at random, but to some extent systematically, so that neighbouring plots are on the average more alike than those further apart, and, on the other hand, (ii) that the distribution is seldom or never so systematic that it could be satisfactorily represented by a simple mathematical formula, as a simple fertility gradient can be represented by a function linear in the co-ordinates.

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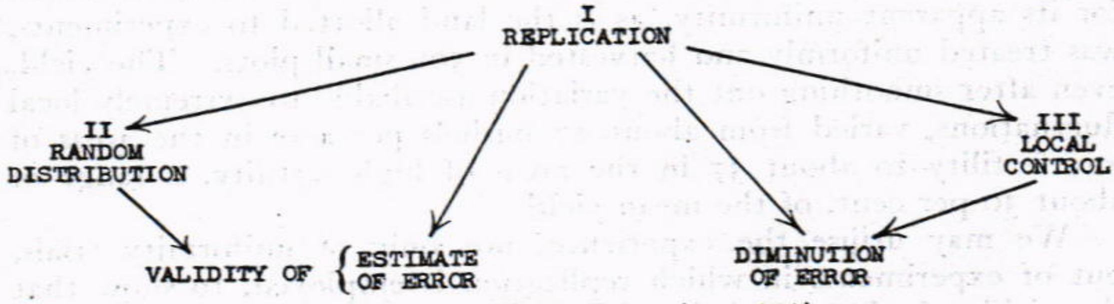
The difficulty arising from soil heterogeneity may be overcome in theory by *replication*; we are therefore concerned with the objects which replication is designed to fulfil and with the conditions on which these objects are best achieved. There are two objects, shown in the diagram, which replication is always required to fulfil, namely to diminish the experimental error, and to provide an estimate of the magnitude of those errors.

With respect to the diminution of error by improved replication it should be noted that the precision can in this way be increased indefinitely. It has indeed been argued that since increased replication requires that an experiment must occupy a larger area of land, the soil heterogeneity will thereby be increased, and that in consequence a point will be reached beyond which further replication will give no further increase in accuracy. This seeming difficulty cannot, however, be effective if the different treatments to be compared are always compared locally within relatively small pieces of land, for then only the natural irregularities within such



Principles of Field Experimentation.

small pieces can affect our results. The easiest demonstration of this principle of *Local Control* is to divide the land into a number of blocks, each containing as many plots as there are treatments, of which one is assigned to each treatment. However many blocks may be used in such an experiment the error of our comparisons will be due wholly to soil heterogeneity within blocks, and this element of the heterogeneity has no tendency to increase as the number of blocks is made greater. The increased heterogeneity of the whole area is in fact wholly accounted for by the increasing disparity in yield between different blocks. This element of the soil heterogeneity is, however, entirely eliminated from our comparisons by the arrangement of our experiment. That this fact was not at once realised is due to the use of erroneous methods of estimating the error, which failed to eliminate in the arithmetical procedure elements of variation which had in fact been eliminated from the real errors by the arrangement in the field. This illustrates a point which is of special importance to the question of the estimation of error, namely that it is necessary that our methods of arrangement in the field must be brought rigorously into harmony with the methods of computation to be employed. For given methods of arrangement it is possible that there shall be at most one correct method of computation, and this one we must be able to recognise and to use. For many methods of arrangement, however, no method of estimating the error, which is strictly valid, can possibly exist.

It is thus seen that the second object of replication, the diminution of error, may, if a sufficient number of plots can be used, be carried to any required degree of precision, at least if the primary principle of replication is supplemented by the principle of Local Control. With respect to the first object of replication—to provide an estimate of error—we must now note that, if we are to obtain a strictly valid estimate of error, then it is necessary, in order to satisfy the mathematical conditions on which the use of such an estimate is based, that, apart from such restrictions as are introduced in the complete elimination of certain components of the soil heterogeneity, the different treatments or varieties to be tested shall be arranged at random on the land available. One may say that the heterogeneity of the experimental land is in this way divided into two parts, one of which is totally eliminated from the experiment by the field arrangement, and subsequently in the arithmetical procedure, while the other part is scrupulously randomised in the field arrangement, in order that that portion of it which will be available for the estimation of error shall be truly representative of that portion which necessarily will appear as real errors in our results. The methods by which these principles of experimentation have been worked out in detail are very various, and several examples of these will be given by later speakers.

METHODS OF FIELD EXPERIMENTATION AND THE STATISTICAL ANALYSIS OF THE RESULTS

By JOHN WISHART

The two simplest methods of layout which fulfil the conditions of supplying a valid estimate of error and eliminating a large portion of the soil heterogeneity are (1) the method of Randomised Blocks, and (2) the method of the Latin Square. In what follows these