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Statistical Methods and Results

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- XXVII. E. M. CROWTHER (with D. N. McARTHUR). "*Report on Scottish Field Experiments in 1935.*" Appendix II, Fourteenth Interim Report of Permanent Committee on Basic Slag, Ministry of Agriculture, 1936.

A series of seven 48-plot field experiments was carried out to compare single and double dressings of four kinds of basic slag and also of ground limestone. The relative effects of high- and low-soluble slags followed their citric acid solubilities, but of two new medium-soluble slags one was better and the other worse than would be judged from their citric acid solubilities. Second year residual effects on oats were very small and were shown only by the two more soluble slags which had given the best immediate results.

STATISTICAL METHODS AND RESULTS

(Department of Statistics)

(a) DESIGN OF EXPERIMENTS

- XXVIII. F. YATES "*Incomplete Randomized Blocks.*" *Annals of Eugenics* 1936, Vol. VII, pp. 121-140.

The paper describes a general method of arranging replicated experiments in randomized blocks when the number of treatments to be compared is greater than the number of experimental units in a block. This new type of arrangement, for which the name of symmetrical incomplete randomized blocks is proposed, is such that every two treatments occur together in a block the same number of times. This restriction enables estimates of the treatment effects and of the experimental error to be obtained expeditiously by the ordinary procedure of the analysis of variance. Estimates of block differences can also be obtained if required. The special case in which the blocks are formed of pairs of experimental units is capable of specially simple treatment. The method of symmetrical incomplete randomized blocks is likely to be of most use in cases in which the experimental material naturally divides itself into groups, such as litters of experimental animals, containing numbers less than the number of treatments that it is desired to test, especially if the differences between these natural groups are of interest.

The necessary formulae are presented and their application illustrated by numerical examples, one based on the numbers of local lesions produced by a virus on half leaves of susceptible plants, the other on the scores of rats in a discrimination test. The minimum number of replications required for different numbers of treatments and block sizes is discussed, and actual arrangements are given for the cases likely to be of general utility. A short discussion of the relative efficiency of an arrangement of this type and an arrangement in ordinary randomized blocks is also included.

- XXIX. M. M. BARNARD. "*An Enumeration of the Confounded Arrangements in the $2 \times 2 \times 2$ Factorial Designs.*" Supplement to the Journal of the Royal Statistical Society, 1936, Vol. III, pp. 195-202.

The structure of the 2^n factorial system is described, and the various possible types of confounding are enumerated for designs involving up to six factors.

- XXX. F. YATES. "*A Further Note on the Arrangement of Variety Trials: Quasi-Latin Squares.*" *Annals of Eugenics*, 1937, Vol. VII, pp. 319-331.

The principles of quasi-factorial design are extended so as to enable varietal trials involving a number of varieties which is a perfect square (not 6^2 or some other numbers, however) to be arranged in the field so that differences between rows and between columns are eliminated from the varietal comparisons. It is proposed to call this type of arrangement an arrangement in quasi-Latin squares, from the analogy with ordinary Latin square design.

As a numerical example a quasi-Latin square design for twenty-five varieties is superimposed on the uniformity trial on oranges which was used in a previous paper to illustrate quasi-factorial designs in randomized blocks. A gain in efficiency over an arrangement in ordinary randomized blocks of 91 per cent. resulted, the corresponding gain in a quasi-factorial design in randomized blocks (two groupings) being 41 per cent.

Various other possible applications of the quasi-Latin square principle are briefly discussed.

- XXXI. F. YATES. "*The Design and Analysis of Factorial Experiments*." Imperial Bureau of Soil Science. Technical Communication No. 35, 1937. Price. 5s.

This Communication has been written to satisfy the growing need of experimenters in agricultural and other fields for a comprehensive survey of the principal types of factorial design, and the appropriate statistical analyses. It can be regarded as a logical continuation of Technical Communication No. 10* of this series, and as a useful supplement to Prof. R. A. Fisher's recent book "*The Design of Experiments*."

Factorial designs with factors at two levels only are first discussed, since these are capable of specially simple treatment, and enable the structure of confounded arrangements to be more easily understood than do designs containing factors at three or more levels. There follows an account of designs with factors at three levels, with factors both at two and three levels, and with factors at two, four and eight levels. Finally various special types of design, such as designs with split-plots and their derivatives, and designs for variety trials involving a large number of varieties, are described. Attention has throughout been paid to providing numerical illustrations of all new statistical processes.

The following designs and processes are described for the first time in this communication :

- (1) The adaptation of confounding to Latin-square designs, so as to enable, for instance, a 2^5 experiment to be arranged in the form of an 8×8 Latin square.
- (2) Latin-square designs with whole rows, or rows and columns, subjected to auxiliary treatments, e.g., sown with different varieties, or cultivated differently.
- (3) Designs containing five and six factors at two levels only.
- (4) Designs involving some factors at two and some at three levels, in particular $3 \times 2 \times 2$, $3 \times 2 \times 2 \times 2$, $3 \times 3 \times 2$ and $3 \times 3 \times 3 \times 2$ designs in blocks of 6 plots.
- (5) $3 \times 3 \times 3 \times 3$ design in blocks of 9 plots, this being an extension of the popular $3 \times 3 \times 3$ design.
- (6) New methods of analysing experiments with factors at two levels only, and the $3 \times 3 \times 3$ design.
- (7) *The Graeco-Latin square*, which is similar to the old "semi-Latin square" design, but overcomes the statistical defects inherent in this design in its original form. Graeco- and hyper-Graeco-Latin squares provide useful designs for varietal trials involving 10-20 varieties. Thus 7 replications of 14 varieties can be arranged in a 7×14 rectangle of plots, and 7 replications of 21 varieties in a 7×21 rectangle.

- XXXII. W. G. COCHRAN. "*A Catalogue of Uniformity Trial Data*." Supplement to the Journal of the Royal Statistical Society, 1937, Vol. IV.

Uniformity trial data have many uses in the study of field experimental technique. Among the important questions on which they throw light are the optimum size and shape of plot, the advisability of discarding edge rows, the gain in efficiency due to confounding, the relative accuracy of any newly proposed type of design, the bias in systematic arrangements and the applicability of the *t*- and *z*-tests to the results of actual field experiments.

This catalogue is an attempt to make accessible to students the yields of trials which have been carried out and to rescue from oblivion trials which have never been published. The information given about each trial is the crop, the size and shape of the smallest unit harvested, the number of plots and the source whence the individual yields may be obtained. Where the yields have not been published, the author has been invited to file a copy at Rothamsted ; some 25 trials have come to light in this way, and it is hoped that future authors will be encouraged to send us a copy of their yields.

*R. A. Fisher and J. Wishart. The arrangement of field experiments and the statistical reduction of the results.

(b) ANALYSIS OF DATA

- XXXIII. W. G. COCHRAN. "*The χ^2 Distribution for the Binomial and Poisson Series, with Small Expectations.*" *Annals of Eugenics*, 1936, Vol. VII, pp. 207-217.

Some examples are given of the agreement between the exact and the tabular χ^2 distribution in samples from the binomial and Poisson series with small expectations. The ordinary χ^2 distribution tends slightly to underestimate the probability of discrepancies in the region used in tests of significances, but appears to give a satisfactorily close agreement except in very extreme cases (e.g. with expectations less than unity). Correction for continuity does not improve the agreement.

A method is given for obtaining for any population approximations to any given order for the mean and variance of χ^2 in samples in which the mean of the sample is fixed, and from this the exact normal approximation to the χ^2 distribution for the binomial series is obtained. Except for the Poisson series, this is not the same as the normal approximation to the ordinary χ^2 distribution.

A brief discussion is given of the general problem of testing discrepancies between observation and hypothesis, in which it has been suggested that the likelihood, as defined by Fisher, is more appropriate than χ^2 as a test criterion.

- XXXIV. W. G. COCHRAN. "*The Efficiencies of the Binomial Series Tests of Significance of a Mean and a Correlation Coefficient.*" *Journal of the Royal Statistical Society*, 1937, Vol. C, pp. 69-73.

In a preliminary survey of a set of data, a rapid test of significance of the mean of a set of differences is sometimes useful. With a symmetrical distribution of errors, such a test may be obtained by ignoring the sizes of the differences and counting the number of positive differences. A similar test of the correlation coefficient may be made by counting the number of pairs of deviations from the respective means of like sign.

A table is given of the 5 per cent. significance points. With a normal distribution of errors, the efficiencies of the method from the point of view of the estimation of the mean or the correlation coefficient are calculated, and in particular the efficiencies of the tests of significance are shown to be $2/\pi$ or 64 per cent. for the mean and $4/\pi^2$ or 41 per cent. for the correlation coefficient.

- XXXV. W. G. COCHRAN. "*Problems Arising in the Analysis of a Series of Similar Experiments.*" Supplement to the *Journal of the Royal Statistical Society*, 1937, Vol. IV, pp. 102-118.

The importance of repeating the same field trial at a number of centres or for a number of years is now realised in most comprehensive schemes of agricultural research. The statistical analysis of the results of such experiments has, however, received little attention.

The analysis of variance, used with discretion, provides a convenient preliminary analysis of the data when the individual experiments may be regarded as having equal accuracy; but this is rarely the case. As a preliminary to a more detailed examination of such questions as the correlation of the treatment responses with weather, soil type or mean yield, the experimenter wants to know whether the responses have varied from centre to centre. A test of significance for this question is given which takes into account the variation in the precision of the different experiments.

The estimation of the mean response is important when the response has not varied from centre to centre. A comparison is made of the efficiency of four types of mean. The weighted mean, weighing inversely as the estimated variance, is recommended if at least 15 degrees of freedom are available in the estimates of the weights. With fewer degrees of freedom, the extra precision given by the maximum likelihood solution is worth the additional labour it involves. With very few degrees of freedom to estimate the weights, the method of weighing inversely as the estimated variance, but with an arbitrarily chosen upper limit to the weights, is useful. The tests of significance of these means are discussed.

When the responses vary from centre to centre, the unweighted mean is generally to be recommended. The test of significance of the mean in this case is discussed, though it is important mainly where the causes of variation in response cannot be controlled or predicted.

(c) SAMPLING

- XXXVI. F. YATES. "*The Place of Quantitative Measurements on Plant Growth in Agricultural Meteorology and Crop Forecasting.*" Conference of Empire Meteorologists, 1935, Memorandum No. 36.

An account is given of the reasons that have led to the introduction of the "Precision Records" on Wheat in the Crop-Weather Scheme of the Ministry of Agriculture and Fisheries. The purpose of these measurements, and the directions in which they are likely to be useful, are briefly described, and a plea is entered for their extension to other crops. A complementary scheme, recently introduced, of sampling commercial fields in order to test the feasibility of providing objective estimates of wheat yields throughout the country, is also described.

- XXXVII. F. YATES. "*Applications of the Sampling Technique to Crop Estimation and Forecasting.*" Manchester Statistical Society. Collected Papers. Session 1936-7.

This address (read before the Manchester Statistical Society) gives an account of the methods that are likely to be of use in the estimation and forecasting of agricultural crops, and describes the results already obtained with wheat. The general principles underlying a sound sampling technique are also discussed and illustrated by actual examples of defective sampling.

THE SOIL

(Departments of Chemistry and Physics)

(a) CULTIVATION AND DRAINAGE

- XXXVIII. B. A. KEEN. "*The Scientific Basis of the Art of Cultivation.*" Programme and Papers of the Second Conference on Mechanized Farming. Oxford, 1937, pp. 27-35.

The capillary-tube theory of water movement in soil, which has long been used to explain the control of soil moisture by cultivation operations, is shown to be erroneous. The pore-space of the soil must be regarded as a series of cells communicating with one another through relatively narrow necks. The boundaries of these cells and necks are formed by the soil aggregates or crumbs, which can be likened to small sponges. The crumbs imbibe water from the rain that percolates down the pore-space, and water is held at the points of contact of the crumbs and also partially fills the pore-spaces. Any surplus drains away and eventually reaches a water-table. When drying conditions occur at the surface, evaporation proceeds by the progressive downward drying of the top layers of crumbs rather than by the upward movement of water from below to the surface. In other words, most soils are naturally "self-mulching." Similarly, when root hairs absorb water, inward movement to the region of absorption will be very slow and over very limited distances. The water held by the soil is to be regarded as relatively static; modern theory shows, in fact, that it resists movement.

The effects on soil water content and movement attributed to operations such as harrowing and rolling are therefore much less than the old capillary theory asserted. The main function of cultivation is not to exercise a delicate and precise control of soil moisture, but to remove the competition of weeds, to obtain a seed-bed of suitable consistency, and to prevent crusts or "caps" forming on certain classes of soil.

- XXXIX. B. A. KEEN and G. H. CASHEN. "*Some Aspects of Cultivation and Other Power Operations on the Farm.*" Journal and Transactions of the Society of Engineers (Inc.), 1936, Vol. XXVII, pp. 114-135.

(This paper was awarded the Bessemer Premium of the Society of Engineers)

Two contrasting aspects of farming are discussed in this paper; (a) the value of soil cultivation, and (b) the comparison of electricity and oil fuel as sources of power for farm machinery.

Numerous cultivation trials made by the Soil Physics Department have led to the unexpected conclusion that cultivation has much less effect on the yields of produce than is generally supposed. These conclusions, however, are in harmony with the laboratory studies of soil water movement made in the Department which show that little or no control of soil moisture is effected by cultivation operations.