ROTHAMSTED RESEARCH

Rothamsted Report for 1938

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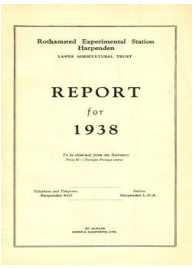

Statistical Methods and Results

Rothamsted Research

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responded only on the artificial soil. The fact that rye-grass grew well on a soil on which turnips had failed completely from phosphate shortage in the field in the previous season suggests that some of the poor residual effects observed in field experiments are due to the ability of other crops to utilise soil phosphates which are not available to swedes. In the pot experiments in the soil but not in the sand the turnips gave better results when the slags were concentrated in a narrow band than when they were distributed more diffusely.

In conjunction with the Forestry Commission two experiments were laid down on young trees in Scotland to test three rates of application of three slags and mineral phosphate.

XI. E. M. CROWTHER and R. G. WARREN. "*Report on Pot Culture, Laboratory Work and Other Investigations*, 1937." Appendix I to the Sixteenth Interim Report of the Permanent Committee on Basic Slag, Ministry of Agriculture, 1939, pp. 4-9.

The pot experiments of the previous year were continued with clover, perennial rye-grass and timothy. In the sand cultures, from which about half of the citric soluble phosphoric acid of the slags had been removed in the previous year's crops, the clover failed and the two grasses did not grow well. In the soil all three crops grew well but the responses to basic slag residues were so small that it was not possible to differentiate between slags or between the responsiveness of the different crops.

Laboratory extractions under controlled pH values brought out the unexpected result that the relative solubilities of two medium soluble slags were different in citric acid and in other acids at the same pH value.

XII. E. M. CROWTHER (with D. N. MCARTHER). "*Report on Field Experiments in* 1936." Appendix II to Fifteenth Interim Report of the Permanent Committee on Basic Slag, Ministry of Agriculture, 1937, pp. 12-22.

Four field experiments were conducted on swedes to compare two rates of application of three less soluble types of slag with four rates of application of a high-soluble slag. The yields from the less soluble slags were generally similar to those from high soluble slag supplying equal amounts of citric-soluble phosphoric acid. The phosphoric acid contents of the dry swedes were increased considerably by the higher rates of application of the more soluble slags and this allowed comparisons of the slags to be made over a much wider range than was possible from the yields alone.

XIII. E. M. CROWTHER (with D. N. MCARTHER). "*Report on Field Experiments in* 1937." Appendix II to the Sixteenth Interim Report of the Permanent Committee on Basic Slag, Ministry of Agriculture, 1939, pp. 10-22.

Five experiments similar to those of 1936 again gave very steep response curves to basic slag, one-eighth of the customary dressing of high-soluble slag doubling the yield of swedes. Such results emphasise the importance of working well below the upper limit of yield in comparing the availabilities of different slags. The results were generally related to the amounts of citric soluble phosphoric acid supplied, except that those from the more soluble of the two medium-soluble slags were definitely better than would have been expected on this basis. This failure of the citric acid method was far more striking than in any of the three preceding years.

STATISTICAL METHODS AND RESULTS

(Department of Statistics ; and Field Experiments Section)

(*a*) THEORETICAL

XIV. F. YATES. "*An Apparent Inconsistency Arising from Tests of Significance Based on Fiducial Distributions of Unknown Parameters.*" Proceedings of the Cambridge Philosophical Society, 1939, Vol. XXXV, Part IV.

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The problem of testing whether the means of two samples are significantly different, when there is no reason to suppose that the variances of the observations on which the means are based are equal, presents certain features which do not arise in other tests of significance.

Behrens and Fisher have proposed an exact test based on the fiducial distribution of the ratio of the variances of the two sets of observations, which at first sight appears to give rise to certain inconsistencies. The cause of these apparent anomalies is explained and it is shown that the criticisms based on them are invalid, being due to (*a*) neglect of the relevant information provided by the estimated values of the variances, and (*b*) an insufficient appreciation of the fiducial basis of all tests of significance (including the ordinary t-test) on small samples.

The problem of testing the weighted mean of the means of two sets of observations concerning whose relative accuracy no prior knowledge is available is shown to be similar to that of testing the difference of the means of two samples.

xv. F. YATES. "*Tests of Significance of the Differences between Regression Coefficients Derived from Two Sets of Correlated Variates.*" Proceedings of the Royal Society of Edinburgh, 1939, Vol. LIX, pp. 184-194.

Tests of significance of the differences of regression coefficients derived from two sets of correlated dependent and independent variates are described. The necessary computations are reduced to a systematic and easily calculable form, and are illustrated by a numerical example.

xvi. F. YATES. "*Orthogonal Functions and Tests of Significance in the Analysis of Variance.*" Supplement to the Journal of the Royal Statistical Society, 1938, Vol. V, pp. 177-180.

In many types of statistical analysis based on the method of least squares, it is necessary to test the significance of one group of effects while admitting the possible existence of other groups of effects.

In the present paper explicit proof is given of the procedure adopted for such tests of significance. The general properties of orthogonal functions are also described.

xvii. F. YATES. "*The Adjustment of the Weights of Compound Index Numbers Based on Inaccurate Data.*" Journal of the Royal Statistical Society, 1939, Vol. CII, pp. 285-288.

The problem of choosing the weights of the components of compound index numbers based on inaccurate data is discussed. It is shown that a process analogous to that adopted for the formation of a discriminant function will give the set of index numbers agreeing most closely with the entities they are intended to represent.

xviii. W. G. COCHRAN. "*The Omission or Addition of an Independent Variate in Multiple Linear Regression.*" Supplement to the Journal of the Royal Statistical Society, 1938, Vol. V, pp. 171-176.

If tests of significance of the regression coefficients are required in a multiple regression, the normal equations are usually best solved by finding first the components c_{pq} of the inverse matrix. When it is desired to omit or to add one or more independent variates after the original regression equations have been solved, the new c's and regression coefficients may easily be calculated from the original c's and regression co-efficients. A numerical example of the addition of an independent variate is given to illustrate the computations.

xix. W. G. COCHRAN. "*An Extension of Gold's Method of Examining the Apparent Persistence of One Type of Weather.*" Quarterly Journal of the Royal Meteorological Society, 1938, Vol. LXIV, pp. 631-634.

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If a meteorological event is classified into two types only, for instance wet or dry months, a tendency towards persistence of the same type of weather may be tested by examining the distribution of lengths of runs of the same type. Gold's formula for the expected number of runs of length r from m events is extended to the case in which the probabilities of the two events are unequal. A simple test of significance of persistence is found by classifying the data in a 2×2 contingency table, according to the results at the current and previous trials.

(*b*) Design and Analysis of Experiments

xx. F. Yates. "*The Recovery of Inter-block Information in Variety Trials Arranged in Three Dimensional Lattices.*" Annals of Eugenics, 1939, Vol. IX, pp. 136-156.

The quasi-factorial and incomplete block designs, as originally put forward, although in general considerably more efficient than designs involving the use of controls, had the defect of being *less* efficient than ordinary randomized blocks if the reduction in variability resulting from the use of the smaller blocks was in fact small. This was a consequence of the fact that certain of the varietal (or treatment) comparisons were confounded with block differences, and the information contained in the inter-block comparisons was wholly discarded.

In the present paper an account is given of the method of estimating the relative accuracy of these comparisons, and of recovering the information contained in them. Only the case of the three dimensional lattice is discussed here. It is proposed to deal with the other types of design in subsequent papers.

The procedure consists of so arranging the analysis of variance that an estimate of the inter-block variance is provided, freed from varietal effects, and then calculating adjustments to the varietal means such that the inter and intra-block comparisons are correctly weighted according to their relative accuracy.

The computations are fully illustrated by a numerical example. It is shown that the amount of computation required for the full analysis is scarcely greater than that required for the complete elimination of block effects, which was the method of analysis originally proposed.

With this modification the efficiency of these designs is shown to be always greater than that of ordinary randomized blocks, except for the limiting case when there is no reduction of variance due to the use of the smaller blocks: in this case a small amount of information is lost due to inaccuracies of weighting, but in general this loss is quite trivial.

It is also pointed out that it is quite legitimate to analyse the results of a quasi-factorial experiment as if it were an experiment arranged in ordinary randomized blocks. This is a valuable property of the designs, since it enables subsidiary measurements which are unlikely to be much affected by block differences, or for which high accuracy is not required, to be abstracted with a minimum of computation.

xxi. F. Yates. "*The Comparative Advantages of Systematic and Randomized Arrangements in the Design of Agricultural and Biological Experiments.*" Biometrika, 1939, Vol. XXX, pp. 440-469.

The recent claims advanced in favour of systematic arrangements by Gosset ("Student") and others are examined. The conclusion is reached that in cases where Latin square designs can be used, and in many cases where randomized blocks have to be employed, the gain in accuracy with systematic arrangements is not likely to be sufficiently great to outweigh the disadvantages to which systematic designs are subject. In particular the available evidence, though not conclusive, indicates that the half-drill strip arrangement, which Gosset particularly favoured, is likely to be somewhat less accurate than suitable random arrangements occupying the same plots. On the other hand, systematic arrangements may in certain cases give decidedly greater accuracy than randomized blocks, but it appears that in such cases the use of the modern devices of confounding, quasi-factorial designs, or split plot Latin squares, which are much more satisfactory statistically, are likely to give a similar gain in accuracy.

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As an example the uniformity trial chosen by Barbacki and Fisher to demonstrate the defects of the half-drill strip arrangement is re-examined. It is shown that Gosset's criticisms of Barbacki and Fisher's work, though at first sight convincing, are not as conclusive as he supposed, and that in fact this particular trial provides a striking example of just those defects which have always been attributed to the half-drill strip method by its critics.

XXII. F. YATES and R. W. HALE. "*The Analysis of Latin Squares when Two or more Rows, Columns, or Treatments are Missing.*" Supplement to the Journal of the Royal Statistical Society, 1939, Vol. VI, pp. 67-79.

Methods of analysing a Latin square with two or more missing treatments, rows or columns are described, and illustrated by an example.

Attention is drawn to a special type of incomplete square, introduced by Youden, which is capable of simple analysis. Youden squares provide valid experimental arrangements, which are likely to be of value in biological experiments and occasionally in variety trials.

The evaluation of the reciprocal matrix when redundant constants or regression coefficients are introduced into least square solutions is also discussed.

XXIII. W. G. COCHRAN. "*Long-term Agricultural Experiments.*" Supplement to the Journal of the Royal Statistical Society, 1939, Vol. VI, Part II.

The various types of long-term experiment are described. The design of experiments on a single crop or on a fixed rotation of crops with fixed treatments is discussed and the statistical analyses are illustrated by numerical examples. Where treatments are applied at fixed intervals only, the residual as well as the direct effects can be assessed. The possibility of obtaining greatly increased accuracy on the residual effects by ensuring that the periods of the crops and treatment cycles are different is pointed out. The method of separating the direct and residual effects when the treatments rotate from plot to plot in successive years is examined and illustrated by a numerical example. The design of long-term experiments on the effects of different crop sequences and the advisability of including indicator crops are discussed. In conclusion, some practical considerations of importance are mentioned.

(*c*) ANALYSIS OF DATA

XXIV. F. YATES and D. J. WATSON. "*Factors Influencing the Percentage of Nitrogen in the Barley Grain of Hoosfield.*" Journal of Agricultural Science, 1939, Vol. XXIX, pp. 452-458.

The effect of rainfall, sowing date and yield on the percentage of nitrogen in the barley grain of certain representative plots on Hoosfield is studied.

All these factors are shown to have marked effects. The farmyard manure plot differs from the others, both in mean percentage and in the effects of rainfall and yield.

Changes in variety appear to have had little influence, but there is a progressive decrease in the percentage of nitrogen which cannot be accounted for by changes in any of the above factors.

Comparison is made with the results of the similar study on the permanent barley plots at Woburn.

XXV. D. A. BOYD. "*Correlations Between Monthly Rainfall at Eleven Stations in the British Isles.*" Memoirs of the Royal Meteorological Society, 1939, Vol. IV, pp. 143-156.

The paper is based upon rainfall records for the months of January, April, July and October at eleven stations in the British Isles over the period 1870-1929.

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The means, variances and covariances were computed. Percentage standard errors were obtained and mapped, the distribution proving similar in all months.

A correlation coefficient for each pair of stations in each of the chosen months was evaluated, and transformed to z. The value of z was dependent to a considerable extent on the inter-station distance and bearing. The linear regression of z on distance between stations was significant in each month, but the quadratic term was small and non-significant. The remaining two terms of the regression, associated with the bearing between pairs of stations, reached significance on only two occasions out of the possible eight; but, as a whole, they gave a reasonably coherent picture of monthly changes in the inter-station bearing at which correlation reached a maximum.

To account for such changes, and for changes in $\bar{z}$, data given by other workers were examined. The variations appeared to be closely associated with the persistence of a pressure gradient for winds from the south-westerly quadrant.

A large part of the residual variance is shown to be due to a marked regional variation, the association between monthly rainfalls being greatest in the south and least in the north. Maps of the residual z's show that the association within groups of stations on the west coast or on the east coast was greater than that between the west and east coast groups.

XXVI. D. A. BOYD. "*The Estimation of Rothamsted Temperature from the Temperature of Oxford and Greenwich.*" Annals of Eugenics, 1939, Vol. IX, pp. 341-353.

It is proposed shortly to analyse the effect of temperature on the Rothamsted crop-yields. For this purpose the mean temperature Q_0 for each crop year is required, and also quantities $Q_1 \ldots Q_5$ proportional to the regression coefficients of a fifth degree polynomial fitted to the weekly mean temperature of each crop year. Rothamsted's temperature record did not commence until 1878, whereas yields for most of the classical experiments are available from 1852. The possibility of estimating the required values from the longer records of Oxford and Greenwich for the period 1852-3 to 1877-8 has therefore been investigated.

As a first step, the quantities Q were evaluated for a period of years (1878-9 to 1907-8) during which the three stations were concurrent, and the means, variances and covariances of each set of Q's were calculated. Greenwich appears to have had a slightly more extreme climate than Oxford or Rothamsted, but this may have been due in part to the unorthodox exposure of the thermometers there. A significant increase in mean temperature over the period was noted, amounting to about 0.05°F. a year. Changes in the seasonal distribution of temperature were not significant. The variance of Rothamsted temperature was significantly smaller than that of Oxford or Greenwich, both from week to week, and from year to year. This noteworthy difference was doubtless due to the more upland situation of Rothamsted.

The linear regressions of the Q's for Rothamsted on the corresponding values for Oxford and Greenwich were evaluated, taking the two stations individually and simultaneously. Oxford gave a better fit than Greenwich in every case, and the partial regression on the two stations was little better than the regression on Oxford alone. The fit was very good for the regression of Rothamsted on Oxford, the residual variance in no case exceeding 5 per cent.

Very satisfactory estimates of the mean annual temperature and of the regression coefficients up to the 5th degree may therefore be obtained for Rothamsted from the temperature records of Oxford only. At the same time differences of surprising magnitude have been revealed in the variability of weekly and annual temperature at Rothamsted as compared with Oxford and Greenwich.

(*d*) SAMPLING

XXVII. W. G. COCHRAN. "*The Use of the Analysis of Variance in Enumeration by Sampling.*" Journal of the American Statistical Association, 1939, Vol. XXIV, pp. 492-510.

The results of a properly planned sampling investigation, in addition to providing an estimate of the accuracy of the method, often give estimates of

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the accuracy of various alternative methods of sampling which might have been used. These estimates are helpful in increasing the efficiency of sampling in future studies on similar material. The use of the analysis of variance of the sampling results for this purpose is discussed and illustrated by a numerical example. The case in which an appreciable fraction, say, more than 10 per cent., of the total population is sampled is discussed briefly. The estimate of the relative accuracy of two methods of sampling is shown to be in most cases a simple function of the variance ratio, so that its sampling limits are easily obtainable. Some advice is given on the problem of analysing the results of large samples without excessive labour.

XXVIII. W. G. COCHRAN. "*The Information Supplied by the Sampling Results.*" (Appendix to a paper by W. R. S. Ladell). Annals of Applied Biology, 1938, Vol. XXV, pp. 383-389.

In any field experiment which involves sampling of a laborious nature, it is important to know as soon as possible what degree of accuracy in the treatment mean values will be reached with a given amount of work, how much work must be done to reach a given standard of accuracy and how best to distribute one's resources between the amount of sampling and the amount of replication.

The first sampling, whether it contains experimental treatments or is uniformly treated, can supply information on all these points if properly carried out. Ladell's first wireworm sampling is taken as a simple numerical example of the way in which these questions can be answered with the help of an analysis of variance.

The sampling and experimental errors of Ladell's experiments are discussed. The sampling error accounts for a large proportion of the experimental error in most cases, as it is always advisable where the labour involved in sampling is high.

Ladell's sampling errors agree well with those obtained under widely different conditions by Jones, and both may be recommended to other workers as an indication of the amount of variability to be expected in field sampling for wireworms.

XXIX. W. G. COCHRAN. "*Expected Errors in Diluting Bacterial Suspensions.*" (Appendix to a paper by H. L. A. Tarr). Annals of Applied Biology, 1938, Vol. XXV, pp. 633-643.

A knowledge of the amount of variation introduced by the process of dilution in the number of spores or vegetative cells in a solution is often of interest to bacteriological workers. The variations introduced by diluting consist of two parts (1) a sampling error, which with careful work will tend to follow a Poisson series distribution (2) the error involved in extracting rather more or less than the volume of liquid stated on the pipette. By making reasonable assumptions about the second source of error, standard errors and 5 per cent. limits of variation can be assigned to the number of spores or vegetative cells in the volume which is being used for experimental purposes. A table of these errors and limits is given, covering the range from 10^6 to 10 spores per unit volume. Examples of its use are worked out.

THE SOIL

(Departments of Chemistry and Physics)

XXX. G. NAGELSCHMIDT. "*On the Atomic Arrangement and Variability of the Montmorillonite Group.*" Mineralogical Magazine, 1938, Vol. XXV, pp. 140-155.

A classification of clay minerals is based on their lattice structures and the quality of their X-ray powder diagrams. The montmorillonite group, with a three layer lattice and poor powder diagrams, is shown to have three end-members, which in the completely dehydrated state and free from isomorphous replacements are montmorillonite $Al_2Si_4O_{11}$, nontronite $Fe_2Si_4O_{11}$ and magnesium beidellite $Mg_2Si_4O_{11}$. Calculations of the isomorphous replacements for six of these materials showed that the excess cations balanced the negative charges resulting from the replacements. Further it was shown that for three of these materials all the excess cations were exchangeable, though there were discrepancies with magnesium beidellite.

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