THE DEVELOPMENT OF FIELD EXPERIMENTS IN AGRICULTURAL RESEARCH PART—III

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INTERACTIONS IN GENERAL

THE behaviour of varieties in different years or on different soils raises the question of how the yield produced is affected by differing climate or soil fertility. For instance, is the yield at any time the sum of two quantities, one depending upon the intrinsic varietal characteristics and the other on the productivity of the land, or the product of these two factors. There are other important factors which in trials of field crops are often working conjointly. Such are variety and manuring, and in manurial trials with a single variety the response to different fertilizers. Fisher and Mackenzie [62] have shown that a summation formula is a poor expression of what actually happens in the interaction of potato varieties with manurial treatment, and that a product formula better fits the data. As calculated in an analysis of variance an "interaction" is a measure of the deviation from the summation formula, and, as in the example quoted above, if such deviations are greater than can be accounted for by random sources of error, they can be made to give information of distinct agricultural value.

One of the most striking studies of interaction is that of Gregory, Crowther and Lambert [63] who studied the interaction between manuring, time of sowing, spacing of the crop and water supply in cotton culture. A summary of significant interactions shows that the wider the spacing the more serious is the decline in yield with late sowing; the later the sowing also, the less effective is increased water supply. The response to nitrogenous manuring was affected by all three other factors, being increased by early sowing, close spacing and more abundant water supply. These workers also showed that interactions were significant even in the higher orders, *i.e.*, when more than two factors were varied simultaneously.

Experiments designed to answer questions of this type are necessarily complex in structure. In order to separate out the relevant effects, every possible combination of factors has to be represented in the plot treatments. In the foregoing example this involved 72 different treatments and these had to be replicated in order to assess significance of interactions. Only in very favourable circumstances can an experiment of this complexity be contemplated, for, especially where land is limited, it would involve very limited replication. This is a distinct disadvantage because limited replication usually means high errors. In point of fact replication is seldom high enough to give decisive high order interactions. Even when attention is concentrated upon first order interactions of two factors, if several are studied, the number of treatments within a block is frequently large. A large block tends to give unsatisfactory control of local soil variability, which again militates against the establishment of low errors. Eden and Fisher [53] give an example of this point with potatoes. In many agricultural experiments high order interactions are of little practical importance and can be neglected. Yates [64] has shown that under these conditions it is not necessary that each block used for the elimination of positional variance should contain every treatment: in his terminology the higher interactions may be "confounded" with block effect. In this way block sizes can be kept to reasonable dimensions with marked advantage to the removal of positional variance and reduction of error. He gives examples and rules for the construction of confounded blocks in a variety of experiments where first order interactions are ascertainable, and higher interactions are consciously made inseparable from block effects.

THE FUTURE OF FIELD EXPERIMENTS

Before attempting to assess the place that field experiments can take in future schemes of agricultural research it will be convenient to sum up briefly the position at the moment, and to review the vantage points that research into the technique of field experimentation have provided.

The first and most important advantage is that by using probability methods, a more uniform criterion of interpretation has been achieved. Although there is no rigid criterion in use by all experimentalists, some preferring to use one level of probability as indicating significance, and others a different one,

since all are based on the same foundation they can be mutually related, and in any case the subjective element in deciding what differences in treatment shall be counted on is altogether eliminated.

Further, the accuracy of comparisons in an experiment has been greatly increased, and provided that adequate statistical treatment is given, the experimentalist is provided with information that can guide him in seeking to reduce still further errors of working. Given a technique such as has been described in the preceding sections, a worker faced with a significant difference of 10 per cent. will neither deny the reality of differences of say 8 per cent., nor will he place misdirected reliance on them. He will rather look to every phase of the experimental operations to see where greater care and accuracy may be achieved. On the other hand, if an experiment justifies taking the significant difference at 5 per cent., and actual differences emerge at the 3 per cent. level, he is justified in deciding that such differences in treatment effect are of negligible agricultural value.

The difficulties of soil heterogeneity have been very largely eliminated in such a way as generally to render unnecessary any recourse to "calculated" or corrected yields. Applying similar considerations to experiments in different places, or in different seasons, standards of consistency are now available which enable the scope of experimental enquiry to be widened and to remove the common reproach that experiments only apply to the peculiar circumstances under which they are carried out. In addition, the interplay of various factors can be accurately judged in a way that was impossible when experiments were restricted to a few unrelated treatments. Moreover in the moderately complicated multiple-factor experiments that are now usual, since each plot has a bearing on each of the questions asked, the experiment gives a maximum of information with a minimum of land utilisation and effort. The author's personal experience has shown that modern experiments, involving randomisation and other intricacies of design, can be successfully carried out employing Indian immigrant labour with a comparatively low standard of intelligence. Provided that the executive officer plans all details carefully before the actual field stage is started, it is his experience that labourers who readily accept a routine can satisfactorily discharge their duties.

Most of the objections to modern experimental technique are based on misconceptions. Salmon [65] criticises recent work in the following terms: "The history of science indicates that the most important discoveries of science have been the result of accurate observations repeated under dissimilar conditions rather than with similar conditions in such a way that probable error may be computed" . . . . . "Few, if any, of the recent contributions of the United States Department of Agriculture are directly traceable to, or depend in any important manner upon replicated plots and interpretations on probable error". Apart from the fact that the phrase "accurate observations" begs the whole question, this writer fails to take account of two things. In the first place, the number of discoveries relating to agricultural effects of great magnitude is steadily decreasing, so that more refined methods must be sought to elucidate the numberless smaller, though not unimportant, effects. Secondly, he takes a very limited view of probable error or statistical computation generally, not realising that, as indicated above, observations repeated under dissimilar conditions need an accuracy of control corresponding with that accorded to nearly similar conditions.

A more fundamental objection is voiced by Vageler [66] in his book on tropical soils. Dealing with the applicability of field experiments to questions of suitable manurial treatment he says:

"Turning now to the question of determining the manurial requirements of soil, we find more and more reason to regard field trials, which were long considered the sole reliable test, as having notable defects. Apart from the fact that the field trial always produces results *post festum*, *i.e.*, one year too late, we have the constant stream of brand new methods for evaluating experimental data. This indicates that one cannot treat as random variations those systematic errors, or rather those individual differences between control plots, which arise from variation of the soil within the experimental area, without reaching conclusions that are materially false. No serious investigator now supports the first enthusiastic claims which were based on the apparent precision of figures obtained by applying the theory of probability to plot technique, nor would he guarantee even his best experimental results as quantitative directions for practical manuring. In comparison with the information to be derived

from statistical examination of large scale trials he would regard his researches merely as the basis for fairly sound manurial recommendations. To arrive at such fairly sound recommendations by means of field experiments often entails a heavier outlay of time, labour and money than is justified by the result (p. 5.).

In a further passage Vageler refers to perennial crops thus:

"One can indeed readily understand that in patchy districts practically every tree stands on its own particular soil, probably differing from that of neighbouring trees. Besides, since the number of plants under observation is small, differences between individual trees have an unduly large effect and may occasionally give an entirely false impression. It is not surprising therefore, that manurial trials in small plots have seldom given satisfactory results in the case of perennial tropical crops. There is, then, urgent need for establishing as an alternative to field trials some rapid and reliable means of ascertaining manurial requirements. For this purpose soil analysis, or more generally, soil science is obviously the only safe guide."

The aims and methods of field experimentation are here again misconstrued. As has been mentioned previously, systematic soil variation is eliminated in modern experiments, whilst with regard to the representative character of field plots the error is in fact a measure of this representativeness. Whatever defects an experiment contains by reason of the fact that "Every tree stands on its own particular soil"; such defects are equally relevant to any system of nutrient requirement determination by soil analyses. Besides, no system of soil analysis can give information about those interactions of manures amongst themselves or with climatic or varietal factors, which represent one of the solid achievements of the present-day technique.

These examples have been quoted because they show that it is imperative to consider whether modern field experimental technique is a mere flash in the pan, destined to be discarded, or at any rate severely discounted. Our contention is that it is not. The plant itself is the best medium through which to derive information about environmental factors. It is a commonplace that investigations in the laboratory or the pot-culture house do not always give results concordant with those experienced in the field, so that the place of field experiments in agricultural research seems assured.

Nothing is more needed than some broad generalisation regarding the behaviour of crops under different conditions. The necessary technique is at hand, and one may envisage a time when standard experiments in varying climates and on different soils, will give some such information. Nothing could be more productive of good than that these experiments should go hand in hand with a detailed examination of the climatic and pedological conditions. The closer contact that research workers now have with one another through Imperial Bureaux, and the concentration of economic supplies of agricultural fertilisers in the hands of large combines, should help to make a scheme of this nature practicable. In the field of varietal response, work on these lines has been in progress for many years. Larsen [67] reports the results of a larger number of variety trials on oats, barley and potatoes, the latter being carried out for nine years on no fewer than 84 farms.

Examples of useful lines of development that can only be attempted with some assurance of success on the lines of this essay, are more numerous than can be mentioned. Yield is the integrated result of many factors, and the whole of the observational side of crop growth between seed time and harvest is as yet almost unexplored. The need of work on these lines is aptly stated in an editorial article in the Experiment Station Record for 1914 [68]:

"In too large a proportion of these experiments the main interest and reliance seems to be placed on weight or bulk of the harvested crop. This of course is the final measure, from an economic point of view, to determine whether a practice or treatment is profitable or advisable. But in investigation and in all experiments except those of the most rudimentary kind, the aim should be to learn not merely the economic result, but something of the way in which the result has been brought about, and the effect upon the plant to imposed conditions. The living plant must be studied quite as much as the final yield".

Agricultural research has the disadvantage of being carried out under conditions which are imposed on the worker whether he wills it or not, but this very fact brings with it a diversity of circumstance and outlook which hold promise of a rich experience. Nowhere is this more true than in the realm of field experimentation.

REFERENCES

1. Davy Humphery.—Elements of Agricultural Chemistry, London, 1813.
2. Boussingault, J. B.—Economie Rurale considerée dans ses Rapports avec la Chemie, la Physique, et la Meteorologie, 2nd. Edit., Paris, 1851.
3. Boussingault, J. B.—Annales de Chemie et Physique, 1841, **3**, 208.
4. Hall, A. D.—The Book of the Rothamsted Experiments, 2nd., Edit., London, 1917.
5. Gilbert, J. H.—Memoranda of the Origin, Plan, and Results of the Field and other Experiments, etc., 1898.
6. Lawes, J. B.—J. Roy. Agric. Soc., 1855, **16**. Roth. Mem., **1**, No. 7.
7. Gilbert, J. H.—Introduction to the Study of the Scientific Principles of Agriculture, 1884, Roth. Mem., **6**, No. 1.
8. Lawes, J. B. and Gilbert, J. H.—Report of Br. Ass., 1861, Roth. Mem., **1**, No. 16.
9. Lawes, J. B. and Gilbert, J. H.—J. Roy. Agric. Soc., 1864, **25**, 93 and 449.
10. Grey, E.—Reminiscences: Rothamsted Experimental Station, Harpenden, 1922
11. Rothamsted Experimental Station, Report for 1931.
12. Keen, B. A. and Haines, W. B.—J. Agric. Sci., 1925, **15**, 395.
13. Eden, T. and Maskell, E. J.—*ibid.* 1928, **18**, 163.
14. Woburn Field Experiments, Guide to, Roy. Agric. Soc., 1921.
15. Piper, C. V. and Stevenson, W. H.—Proc. Am. Soc. Agron., 1909, **2**, 70.
16. Egorov, M.—Russ. J. Expt. Landw., 1909, **10**, 502.
17. Wood, T. B. and Stratton, F. J. M.—J. Agric. Sci., 1910, **3**, 417.
18. Hall, A. D. and Russell, E. J.--J. Bd. Agric., Supplement, Nov., 1911.
19. Mercer, W. B. and Hall, A. D.—J. Agric. Sci., 1911, **4**, 107.
20. Kostecki, E.—Bul. Angew. Bot., 1912, **5**, 177.
21. Frohlich, O.—Mitt. Landw. Inst., 1913, **6**, 683.
22. Frischauf, J.—Landw. Jahrb., 1912, **43**, 501.
23. Lehn, D.—Bl. Zuckerrubenbau, 1913, **20**, 33 and 52.
24. Gregoire, A.—Rapports X^{e} Cong. Internat. Agric. Gand, 1913.
25. Miyake, C.--Ber. Chara Ins. Land. Forsch., 1916, **1**, 111.
26. Holtsmark, G. & Larson, B. R.—Tidsskr. Landbr. Planteavl., 1905, **21**, 330.
27. Leidner, R.—Landw. Jahrb., 1916, **49**, 105.
28. Carlton, M. A.—Proc. Soc. Prom. Ag. Sci., 1909, **30**, 55.
29. Pritchard, F. J.—J. Am. Soc. Agron., 1916, **8**, 65.
30. Kiesselbach, T. A.—Nebraska Sta. Res. Bull., No. 13, 1918.
31. Arny, A. C. & Garber, R. J.——J. Am. Soc. Agron., 1919, **11**, 33.
32. Arny, A. C. & Steinmetz, F. H.—J. Am. Soc. Agron., 1919, **11**, 81.
33. Hayes, H. K. & Arny, A. C.—J. Agric. Res., 1917, **11**, 399.
34. "Student", Biometrika, 1923, **15**, 271.
35. Harris, J. A.--J. Agric. Res., 1920, **19**, 279.
36. Maskell, E. J.—Rep. Imp. Bot. Conference, 1924.
37. Clapham, A. R.—J. Agric. Sci., 1929, **19**, 214.

38. Arny, A. C. and Hayes, H. K.—J. Agric. Res., 1918, **15**, 251.

39. Arny, A. C.—J. Am. Soc. Agron., 1922, **14**, 266.

40. Arny, A. C.—J. Agric. Res., 1921, **21**, 483.

41. Love H. H.—J. Am. Soc. Agron., 1928, **20**, 426.

42. Spragg, F. A.—*ibid.* 1920, **12**, 168.

43. Summerby, R.—*ibid.* 1923, **15**, 192.

44. Day, J. W.—*ibid.* 1920, **12**, 100.

45. Christidis, B. G.—J. Agric. Sci., 1931, **21**, 14.

46. "Student", Biometrika, 1908, 6, 1.

47. Fisher, R. A.—Metron, 1935, **5**, 3.

48. Beaven, E. S.—J. Min. Agric., 1922, Nos. 4 and 5.

49. Love, H. H.—J. Am. Soc. Agron., 1923, **15**, 217.

50. Fisher, R. A.—Statistical Methods for Research Workers, Edinburgh, 1925.

51. Irwin, J. O.—J. Roy. Stat. Soc., 1931, **94**, 285.

52. Irwin, J. O.—Sup. to J. Roy. Stat. Soc., 1934, **1**, 236.

53. Eden, T. and Fisher, R. A.—J. Agric., Sci., 1929, **19**, 201.

54. Fisher, R. A.—J. Min. Agric., 1926, 503.

55. Yates, F.—Emp. J. Exp. Agric., 1933, **1**, 235.

56. Tedin, O.—J. Agric. Sci., 1931, **21**, 191.

57. Salmon, S. C.—J. Am. Soc. Agron., 1924, **16**, 717.

58. Barclay, C. and Grantham, J.—Archief v. d. Rubbercultuur, 1933, **87**, 219.

59. Prillwitz, P. M. H. H.—Archief v. d. Thecultuur, 1929, 159.

60. Eden, T.—J. Agric. Sci., 1931, **21**, 547.

61. Engledow, F. L. and Yule, G. U.—The Principles and Practice of Yield Trials, Empire Cotton Growing Corp., 1926.

62. Fisher, R. A. and Mackenzie, W. A.—J. Agric. Sci., 1923, **13**, 311.

63. Gregory, F. G., Crowther, F. and Lambert, A. R.—J. Agric. Sci., 1932, **22**, 617.

64. Yates, F.—J. Agric. Sci., 1933, **23**, 108.

65. Salmon, S. C.—J. Am. Soc. Agron., 1923, **15**, 225.

66. Vageler, P.—An Introduction to Tropical Soils, London, 1933.

67. Larsen, B. R.—Aas. Agric. Coll. Report, 1912.

68. Editor, Experiment Station Record, 1914, **31**, 704.