Review

" Experimental Design and Analysis in Forest Research "

By J. N. R. JEFFERS

Stockholm, Almqvist & Wiksell (for the International Union of Forest Research Organisations), 172 pages, Sw. kr. 30.

THE object of this book is, according to the author's introduction : "to make statistical methods more available to foresters engaged in research." The first two chapters, comprising about one-third of the text, are devoted to the simpler forms of standard experimental design and the corresponding analyses. After a short chapter on experimental design in general, in which the standard designs are described, the second chaper gives detailed instructions for the analysis of results relating to randomised block, latin square, factorial and split plot designs. In each case an example is analysed in detail, and model worksheets are given in an appendix. In the case of incomplete block designs only a brief description is given and the reader is referred to other literature for methods of analysis, while more sophisticated types of design are given no coverage. Subsequent chapters deal with transformations, applications of chi-square, sampling, regression analysis and covariance analysis, and the final chapter is on the presentation of results. Some highly abridged statistical tables are given at the end of the book, and there is an English-French-German glossary of statistical terms (without definitions).

In spite of the very great detail with which methods of computation are described, it is unlikely that this book will be of much use to anyone who has had no previous contact with the concepts of modern statistical

theory or experimental design. Explanations are concentrated mainly on purely numerical aspects of the work and very little is said about its logical basis. Thus, for example, there is no adequate exposition of such concepts as "variance", "interaction" or "degrees of freedom", nor is there anything explicit about the role played by randomisation in ensuring the validity of the standard tests of significance. The book could, perhaps, be used as a working handbook by someone who already has a grounding in statistical theory, and who finds it an advantage to have the examples taken from the field of forestry research rather than from a wider range of biological applications, but any research worker is likely to encounter in practice many problems on which this book gives merely a reference to further literature. The absence of an index is an obstacle to its use as a work of reference.

A special feature of the treatment of the analysis of designed experiments is the "preliminary analysis" given with each example, in which assessments of significance are made using ranges obtained from the experimental results. It is doubtful if the use of this technique offers any worth while advantage. To a person having access to a fully automatic desk computer the saving of time as compared with the full analysis is small, and under present-day conditions it would surely be a highly uneconomic allocation of resources to have a research worker engaged on this type of work without adequate computing facilities. On the other hand, there are a number of points where shorter arithmetical methods might advantageously have been given. One instance is in the analysis of factorial experiments with factors at two levels where the use of differences to obtain mean squares is not mentioned; thus, on page 38 it would surely be easier, as well as giving better insight into the nature of the computation, to calculate the sum of squares for P as $(73.70 - 79.50)^2/48$ rather than as $[(73.70)^2 + (79.50)^2]/24 - 488.9633$, and to calculate the MP interaction sum of squares as $(30.05 + 45.95 - 43.65 - 33.55)^2/48$ instead of using the much longer expression given.

One noteworthy omission from the methods of analysis suggested is the partitioning of treatment sums of squares relating to quantitative factors into linear, quadratic, and higher-order components. Any experiment which is intended to give more than a qualitative result will need this technique if the data are to be adequately interpreted, and, as it happens, one of the examples in the book gives a good illustration of this point. In the example in Section 2b, when the "treatment" sum of squares is partially partitioned (Table 2b. 7), the "between composts" component is found to be non-significant, and the conclusion is drawn (on page 34) that "there were no significant differences between composts prepared at different dates." In fact, however, a slight further calculation will show that, of the sum of squares, 2.9021, found for the "between composts" effect, the portion due to the linear effect of date of composting is 2.0167, and that this gives an F-ratio significant at the 5% level. The conclusion is, therefore, that greater growth was

significantly associated with more recent preparation of the compost. The omission of this step in the analysis is particularly unfortunate in the present instance, as mere inspection of the summarised results suggests some relationship between date of preparation of the compost and growth, and no experienced worker would happily accept the negative conclusion drawn by the author.

Most of the material in section 2g (Combination of Experiments) could have been omitted if the nature of the so-called "error" components had been brought out more clearly in the earlier sections. Thus, if we recognise that in a randomised block experiment, "blocks" is in effect a second factor, and that "error" is actually the interaction between blocks and treatments, it will become obvious that when such experiments are to be combined, a further factor comprising "places" (or "years") will naturally appear, and that under certain circumstances the interaction of this additional factor with treatments will provide the appropriate error mean square. The approach adopted has led to some confusing and possibly misleading statements on page 54, where it appears to be implied that if the "places" form a random sample of all possible places, then the treatment mean square can be tested against the pooled error—even though a significant "places × treatments" interaction may have been found. In fact it is precisely in these circumstances that the interaction with places is the appropriate mean square for assessing the significance of the treatment effect. In the contrary case, (where the places do not constitute a sample) once a significant interaction effect has been found, the significance or otherwise of the treatment mean square becomes meaningless. Yet another hypothesis to be considered is that the selection of places forms a fully representative (not a random) sample of possible places; it is in this case that the pooled error mean square can be used, in spite of the existence of an interaction. A more unified approach to designed experiments in general would also have enabled a clearer account to be given of the analysis of split plot experiments; in particular the component labelled "Error (a)" in Table 2d.10 is actually the interaction blocks × gangs while "Error (b)" is the sum of the interactions blocks × tools and blocks × tools × gangs.

The inclusion of a chapter on transformations is to be welcomed, as the advantages of transforming certain kinds of data before analysis are often not sufficiently realised. However, the first seven pages of this chapter (Chapter 3) are of doubtful value. A method is given by which data with non-uniform variance can be analysed without the use of a transformation, at the expense of becoming involved in the rather thorny subect of comparing means from populations with different variances. In fact, a brief glance at the basic data in this example suggests that a logarithmic transformation should have been used, and this would have completely avoided the difficulty.

The chapter on sampling (Chapter 5) is also a very useful feature of the book, and much of the information given here on statistical aspects

of sampling should be of interest to workers in forestry even if not engaged in research. Some disappointment is felt that the author, whose experience in this field must be almost uniquely extensive, has little to say about the practical problems of sampling for forest data. For example, in an earlier chapter (page 71) data are given which were obtained by examining five branches at random in each of seventy plots. Logically this should have been done after first numbering every branch on every tree to provide a sampling frame, but in practice one would expect that some less laborious procedure could have been found, and it would have been of interest to know what procedure was adopted.

In the chapter on chi-square, the main example given (testing a sampling spear technique by means of coloured seeds arranged in layers) is an unfortunate one, as it is impossible to formulate a physically reasonable null hypothesis which gives rise to a chi-square distribution. The chapter in regression analysis gives an adequate account of the work of fitting a simple regression line and calculating the correlation coefficient, though some may find the notation confusing in that $\bar{x}$ is the mean value not of x but of X. A useful short-cut method of fitting a simple regression line is given later in this chapter. The reference to the probit transformation, however, is rather unhelpful; the use of probability paper (which is not mentioned) is likely to be the only aspect of this subject of much interest to the practical research worker. The suggested use of unweighted linear regression on empirical probits is not to be recommended, and the probit transformation is not likely to be of much use in cases where the saturation level has to be estimated from the data (as suggested on page 129).

The account given of covariance analysis has necessarily had to be drastically simplified in order to maintain conformity with the mathematical level of the earlier chapters. The usefulness of this chapter (Chapter 7) is marred by the fact that the example used is a rather special one. In a randomised block comparison of the working times involved in four different procedures for extracting thinnings, the volume of thinnings felled is used as a concomitant variable. In the preliminary variance analysis it is found that the volume of thinnings varied significantly between treatments (extraction procedures) but not between blocks. This result should immediately have caused the investigator to take a closer look at his data, and perhaps also at the sites involved, as it indicates that either the randomisation has not been properly done or that measured volume is in some way affected by the extraction procedure. If the former is the case then no valid statistical inferences can be drawn from the figures, while if the latter explanation is accepted then (as pointed out on page 139) covariance analysis will not be efficient. It is this rather special feature of the data that enables a straightforward result to be obtained. In a more typical case it would have been found that variation of the concomitant variable between blocks was as great as, if not greater than, that between treatments. For efficiency, estimation of the common regression coefficient would

then have to take into account the between blocks component of covariance and the analysis and interpretation would become appreciably more difficult. In any case it is hardly advisable to apply covariance analysis without including a check on the uniformity of the regression coefficient, and this aspect of the analysis is not covered.

The final chapter deals with presentation of the results of experiments. Its recommendations will be strongly endorsed by anyone with experience of this type of work.

The book could have been appreciably improved by more careful proof-reading. It is especially unfortunate that the first two worked numerical examples both contain printing errors; in Table 2a.1 the entry 1.91 under block 8 should read 0.91, while in Table 2b. 1 the entry 23.86 in the last column should read 25.86. The explanatory caption given under Table 2a. 6 actually belongs to Table 2b.1, three pages further on. On page 54, almost complete incomprehensibility is achieved by interchanging lines 21 and 23 and omitting two sections of tabular material. The printer is presumably responsible for the strange word "diagra" which appears in the caption to Figure 6.2; the same may possibly be true of "coveriate" on page 146 though the latter appears twice on this page.

In conclusion, this work may be of some value to a forestry research worker who already has some knowledge of statistical and experimental design theory and who wishes to have simple worked examples to follow relating specifically to his own field. The reader will soon find, however, that problems arising in practice will necessitate referring to a more advanced text. Moreover, even within the field covered, a critical attitude will need to be maintained.

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