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A STRATEGY FOR THE DESIGN AND LAYOUT OF FIELD EXPERIMENTS IN THE CARIBBEAN REGION

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SUMMARY

Nearly all field experiments on food crops which are conducted in the Caribbean region employ techniques of design and layout which have been developed by biometricians in temperate countries in North America and Europe.

These techniques have been very successful for field experimentation in the countries in which they were developed. However they have not been so successful in tropical regions. This is partly due to the fact that often the land used for experimentation in the tropics is not uniform which means that great care has to be taken to ensure that each block is laid down so as to eliminate most of the variations due to non uniformity of land. Again the type of factorial arrangements often chosen include treatment combinations which are not really of interest to the experimenter. Researchers are therefore urged to adopt a flexible approach to the design of their experiments so as to include only treatment combinations in which they are interested and also to give extra replication to treatments which are of special interest such as control treatments.

Another problem regularly faced by experimenters is to decide on the size and shape of their plots. Some suggestions are made to help in choosing the optimum plot size and the advantages of various plot shapes are also discussed.

INTRODUCTION

There has been a United Kingdom Ministry of Overseas Development funded biometrics project in existence in the Caribbean region since 1972, which has had as its objectives the development of more efficient statistical techniques for the conduct of field experiments in the region. This project was originally set up due to concern over the high variation which most experimenters in the region experienced in their field trials and it was hoped that the development of new techniques would help to reduce this variation to an acceptable level. This project is shortly due for completion and this paper has been prepared to present the findings of this project to the region's agricultural research personnel. The authors are confident that the implementation of their findings will lead to a realization of the objectives of the project. The findings amount to a fairly radical new approach to the problem of field experimentation in the region, involving a different strategy from that which is practiced in the main at present, and encompasses questions concerning the choice of treatments and their levels of replication, experimental design and analysis and field layout.

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CHOICE OF TREATMENTS AND NUMBER OF REPLICATIONS

The only treatments on which it is necessary to experiment are those which are likely to produce an optimum result plus one or more control treatments. An optimum result does not necessary mean the highest yield of a crop as economic considerations should be taken into account and the treatment which gives the highest yield may not be attractive to farmers if the cost of inputs is high. Control treatments are usually in the form of present farming practice or present recommended practice and should be included even if they are not likely to produce an optimum result as they provide a standard by which the other treatments can be judged. However, zero or null treatments need not be included unless these are present farming or recommended practice or in the unlikely event of being thought to be optimum. Thus in a fertilizer experiment a treatment of no fertilizer is not necessary unless it is present practice. In fact zero treatments of this kind can create problems. For example in an insecticide trial the infestation in an untreated plot can be so high as to spread to neighbouring plots.

If a factorial design with complete replication is chosen then all possible treatment combinations for the levels of factors chosen are included whether they are likely to produce optimum results or not. This approach is quite satisfactory if resources such as land and labour are plentiful, but in the limited resources conditions of experiments in the Caribbean it can be a very wasteful approach. Experiments with a factorial design in factional replication have the disadvantage that the treatment combinations are determined by the experimental design and not by the experience and knowledge of the experimenter.

Another popular misconception about experimental design is that all treatments must have equal replication. There is no need for this if experimental circumstances, such as the number of blocks available, make this difficult. Also some treatments may be in short supply and it is not possible to give them as many replications as other treatments. Again we are generally interested in comparing the control treatments with the other treatments and this is achieved with greater precision if the controls are given extra replications. As a general rule the greater the number of replicates of a treatment the more precisely can its effect be estimated. So treatments such as controls and any others in which there is special interest should be given extra replication. If a treatment is in short supply and we cannot give it many replications then we cannot estimate its effect with any great precision, but it is better to include it with a few replications rather than to leave it out entirely as this will not allow us to estimate its effect with any precision at all.

PURPOSE AND PRINCIPLES OF BLOCKING

Almost all field experiments employ the technique of blocking. The idea of blocking is to reduce error from factors other than those being investigated in the experiment and consequently each block should contain uniform experimental material. This means placing blocks on areas of uniform soil and environmental conditions and to achieve this aim the researcher must become familiar with the site on which the experiment is to be conducted, taking into account such factors as soil type, site history, topography and climatic conditions. Because of the layout of diagrams in text books on field experimentation, it is often thought that different blocks in an experiment must be equal in size and shape. This is only desirable however, if it achieves the aim of making the experimantal material within each block uniform. If not then blocks of different shapes and sizes will have to be employed. Blocks of very unequal sizes can cause problems in the statistical analysis because of the unequal variances of the treatment means and should only be used when experimental circumstances make it absolutely necessary. However, designs with blocks of slight or moderate inequality only lead to small differences in the variances of the treatment means and in many circumstances they lead to much better experiments than designs with equal block sizes. Again there is a misconception that blocks have to be geographically compact units, but again this is not a necessity. For example if two small areas in a field are badly drained and prone to flooding then if soil and climatic conditions are similar and the separate areas are individually too small for separate blocks without introducing very unequal block sizes, then it would make sense to use the two areas together as one block. If however, the two areas have different soil or climatic conditions then they will have to form two separate small blocks.

There is a growing tendency in the Caribbean to perform experiments on farmer's fields because findings in the idealised environment of an experimental station do not always apply to commercial crops grown on small farms. These farmers fields on which experiments are performed are frequently sloping and different parts of the field have sometimes been under different crops prior to the experiment. In cases like these if blocks of equal size and shape are laid down in geographically compact units then it is unlikely that each block will contain uniform experimental material. Even on research stations on flat, well drained land, different parts of a field chosen for an experiment sometimes have different soil types, climatic conditions and previous cropping history. Again uniform blocks will not be successful and the result will be a high coefficient of variation. Great care should be taken to choose blocks on uniform areas bearing in mind the principles outlined above.

BLOCK CONFIGURATIONS

It has been seen in the previous section that the primary purpose of blocking in field experimentation is to split the experimental area into "uniform" areas of land in which the plots within each area can be expected to perform in a similar manner. Uniform here has been put in inverted commas since it is obvious that there exists no such thing as a uniform area of land since this would imply, for instance, that identical clones of a species grown in such an area would all grow to the same height and yield exactly the same amount, and this of course never happens. What is actually meant by uniform is an area of land in which an experimenter, prior to planting out the experiment, cannot determine by observation or inference which portions of that land are likely to produce better or worse yields of the crop than others, except perhaps for knowledge that one particular direction of the land is likely to produce greater graduations in yield than other directions (directional variation). This may be inferred, for instance, from slopes in the land or a known fertility gradient. It is possible that the entire experiment is conducted on only one such area, though this can have disadvantages if the results of the trial are meant to apply to a range of conditions. Once these areas have been determined, there remains the problem of laying out plots and blocks within them.

We are greatly aided in this respect by knowledge of a property which is true of all such areas of land and was described in a paper presented at the previous meeting of this society (Brewer 1977) and this is that points of the land closer together are more similar than those further apart. This means that areas of land are in general more dissimilar the further they are away from each other. This is a direct result of the fact that the levels of the various environmental factors which influence the response of a crop are likely to be more closely related at points in the field that are near to one another. This effect can and has been investigated in a formal manner but it should be obvious that a direct result of this is that in order to form blocks of highly homogeneous land, these blocks should be both compact and small in size. Suitable arrangements of plots within them will be discussed in the next section.

Blocks are kept compact by making them square in shape, or nearly so, especially in the case where there is no directional variation present. There are far too many experiments in the Caribbean region laid down straight out of a text book with blocks formed as long strings of plots laid side by side.

Those are two ways of keeping down block size, firstly by using small sized plots which is discussed in the next section, and secondly by keeping the number of plots per block small. This second requirement is the source of one of the great disadvantages of the widely used randomized complete block (RCB) designs, which stipulates that the number of plots per block must necessarily be at least as large as the number of treatments in the experiment. The alternatives to this may be an unbalanced or partially balanced block design or confounded designs when the treatment structure is factorial, and these possible alternatives should be considered very seriously, especially when there are a large number of treatments involved. It should be pointed out that unbalanced or partially balanced designs can in these days be analysed just as easily as RCB designs once computer facilities are available. The best and most objective approach to experimental design is to form the blocking system in accordance with the nature of the land comprising the experimental site without any reference to the number of treatments to be investigated in the experiment. This may not lead to neat designs such as the RCB but if it leads to a highly accurate experiment, then we have achieved the whole point of the exercise.

A class of designs which have hitherto been somewhat underestimated in their usefulness is the row and column designs. By eliminating variation in two directions they often compensate well for the general property of field variation described earlier. The standard design of this class is the latin square which is not too often used because of its rigid structure, and it also suffers from the same kind of disadvantages as RCB designs. However, any contiguous grid of plots within the experiment can be used as a row and column structure, and this may lead to an experimental design which is unbalanced or partially balanced. These are again easy to analyse when computer facilities are available. Situations in which row and column designs can prove effective are listed below.

1. The classical situation in which they are used is when there are two factors likely to cause directional effects in the crop transverse to one another (e.g. a slope and a wind direction across the slope).

2. They can be used when contiguous grids of plots that are to form the experiment are not easily split into compact blocking units, e.g. if an area of land is used in an experiment on which it is convenient to place, for example, a 5 x 6 grid of plots, there may be no sensible way in which compact blocks can be defined on this area, and thus a row and column arrangement would be a superior design.

3. Even on land with no directional variation row and column designs of small dimension are often superior to block designs in eliminating environmental variation. In support of this contention, it has been generally observed, for instance, that latin squares of size 4 x 4 to 8 x 8 are often superior to an RCB design of the corresponding size. (Fisher 1942, p. 69).

4. In the situation where there is directional variation but for cultural reasons the plots have to be elongated transverse to this direction. This will be further explained in the next section.

It is thus evident that row and column designs are useful in a wide variety of situations. When plots in the experiment are arranged in rectangular grids then these designs should always be considered as one of the possible alternatives as long as the experiment is big enough to leave sufficient degrees of freedom for the estimation of experimental error.

When an experiment entails the use of an unbalanced design there are methods of determining a suitable or optimum allocation of treatments to the blocks or rows and columns. For reasons of length these cannot be included in this paper.

PLOT SHAPES AND SIZES

It has been shown in the previous section how the general property of "uniform" areas of land affect the best allocation of blocking systems upon it, and it will be seen here that it also determines the best arrangement of the plots within these blocks. Bearing in mind that it is the between plot variation which contributes the most to the experimental error, whilst within plot variation contributes relatively little, it is evident that plots within the same block should not be remote from one another, and individual plots should be spread out as much as possible to absorb the maximum amount of variation existing within the land which comprises the block. Although perhaps not quite as obvious as the implication on block shape, these desirable properties lead to the following optimum arrangements and plot shapes:

1. Where there is no directional variation, form long narrow plots side by side in any direction to form compact blocks.

2. With directional variation present form long narrow plots corresponding to this direction and lay them side by side to form blocks (form long narrow plots down a slope for instance).

3. When directional variation is suspected to be present but its actual direction is unknown, it is safest to form square plots in compact blocks to avoid laying long plots the wrong way.

4. Row and column designs allow the use of square plots since variation is eliminated in both directions.

5. When long plots have to be laid transverse to a direction of greater variation for cultural reasons, they should if possible be formed into a contiguous grid and a row and column design used. This enables the rows to eliminate the large variation in one direction, and the columns to correct for the remoteness of plots in the same row.

Of usually greater importance than plot shape is plot size. This is often the question which experimenters are uncertain about and sometimes ask biometricians for a solution. There is in fact a statistical method perporting to calculate the best plot size for any particular crop (Fairfield – Smith, 1939) and has been widely used in the past. However, the best plot size for any experiment is a function of the variability inherent in the crop itself (i.e. planting material), errors of observation, and the nature of the environmental variation of the land, and of these the latter is the most important factor. It is therefore erroneous to recommend a "best plot size" for a particular crop under any conditions, and preferable to set out general guidelines for determining a good plot size in any particular situation.

In essence this guideline is to keep to a minimum plot size, since this enables block size to be kept small and will also in many cases allow greater replication with the same resources. Viewing the choice as larger plots with less replication as against smaller plots with more replication the latter alternative is never worse than the former, and will normally be considerably better in terms of statistical precision, though of course it will generally require more work in general management and data recording. Indeed, it has been shown (Brewer,1977) that larger plot sizes even with the same amount of replication, can under certain conditions result in less precision due to the nature of the environmental variation. By minimum size is meant a size which is just large enough to allow the plot to give a representative reading of the treatment applied to it, and this is dependent upon the nature of the treatments and the objectives of the experiment. This allows for different plot sizes to be used for, say, a preliminary screening trial as opposed to an investigation of a treatment's performance in commercial practice.

The practice of planting guardl areas around a plot has an obvious modifying effect on every recommendation given in this section. Firstly a small experimental plot area has a greater ratio of guard plants to protect it, and secondly rectangular plots have a greater ratio of guard than do square plots. This creates conflicting objectives of optimizing the economics of a plot with its shape and size as opposed to gaining maximum statistical precision. An experimenter in this situation needs to assess the particular case on its merits, and should attempt to decide upon a minimum economic plot size based on what proportion of his planting material he is prepared to use as guard area.

CONCLUSION

Some of the methods described here have been recently developed and have not been extensively employed in field experimentation in the region whilst others have been used in experimental work. They are all, however, based upon statistical investigation and logical reasoning and each should help to produce more efficient field experiments. The methods are here brought together as an integrated approach and as such form a sound scheme for achieving greater efficiency. It remains to fully implement the approach in the research work of the region.

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