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**PROCEEDINGS
OF THE
CARIBBEAN FOOD CROPS SOCIETY**



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EXPERIMENTAL DESIGN AND ANALYSIS UNDER LIMITED RESOURCES

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INTRODUCTION

In many territories in the Commonwealth Caribbean there is an active diversification programme, consequent upon an import substitution policy, where more emphasis is being placed on the production of food crops than hitherto. Research personnel in the region have embarked on extensive research programmes to determine optimal cultural operations for maize, grain legumes, root crops and vegetables. In many cases researchers have found that little or no work has been reported on these crops under ecological similar to their own, and that a major constraint on their work is the limitation of available experimental resources. Experimentation, under these circumstances, must necessarily be of an exploratory nature, at first, later becoming more sophisticated as knowledge and experience are gained.

The question of the experimental design that should be used often causes some concern. An experimenter may be tempted to proceed in cookbook fashion and may consult texts such as Cochran and Cox (1) or Le Clerg et al (4) for an appropriate recipe. The theme of this paper is that this approach might not be optimal for such a preliminary investigation, and the paper explores other avenues of approach.

THE PROBLEM

The problem, for the experimental situation which has been described, is the choice of an experimental design which has the following properties:

- (a) consideration of a number of factors simultaneously;
- (b) exploration of a wide range of levels for each factor;
- (c) non exploration of combinations of factor levels which are of little or no interest;
- (d) incorporation of the available general knowledge and experience of the experimenter;
- (e) efficient use of the experimental resources (land, labour, etc.) available;
- (f) ease of operation for field staff;
- (g) obtaining only information which is relevant to and consistent with the objectives of the experiment; and
- (h) determination of a second degree response surface over appropriate ranges of levels of each factor.

Two specific examples of investigations, which may arise in the experimental situation described above, will now be considered.

Example 1

The objective of this investigation is to determine the response of a crop to the nutrients, say, Nitrogen (N), Phosphorous (P) and Potassium (K) under different rainfall regimes and on soils with different physical and basic chemical properties. Experiments are laid down at several sites over a wide range of levels of rainfall and soil characteristics. The information from such an investigation may be useful in setting up a fertilizer advisory service for farmers growing this crop.

Example 2

The objective of this investigation is to determine the response of a crop to, say, N, P and K on a given soil type in a given region, where the experimenter may have prior knowledge with respect to the behaviour of the soil type. The farmers in this region may be operating well below what is estimated to be optimal efficiency and quick answers are needed which may result in, say a 50% increase in efficiency. In such a situation a general picture of the response behaviour may be required rather than a more precise estimate of the response for a specific combination of the ranges of factor levels.

An investigation with limited experimental resources implies that for a given plot size, the numbers of experimental units available is restricted and hence there is a limitation on the number of treatments which can be accommodated at a given site.

At the same time, since little information is available on the response of the crop to the nutrients, it is desirable to experiment over a wide range of levels for each nutrient. However, if treatments are considered in full factorial combination then the constraint on experimental resources is very quickly exceeded.

It seems apparent, therefore, that some of the treatments in the full factorial combination will have to be sacrificed to permit experimentation within the resources available and at the same time to permit relevant information to be gained.

SOLUTIONS TO THE PROBLEM

The conventional approach -

The recognized mechanism for solving the problem is to consider the use of (a) a fractional replication system of treatments, or (b) a composite system of treatments. In a full factorial system just enough observations are obtained for the estimation of all the main effects and interactions associated with the system. If factorial replication a subset of the factorial combinations from the full factorial system, is considered then the estimation of some of these main effects and interactions on the patterns of main effects and interactions which cannot be estimated Cox (2, p. 248) and these may or may not coincide with the main effects and interactions, information about which the experimenter is willing to sacrifice. However, in the case of preliminary survey involving a large number of factor fractional replication makes practicable investigations that could hardly be undertaken otherwise.

A composite system is usually a full factorial or a fractional replicate or a full factorial system, based on two levels for each factor, which supplemented specifically assigned central and peripheral treatment combinations to increase the number of levels for each factor in the investigation. Composite systems, Hill and Hunter (3) were originally designed to have desirable properties (orthogonality and rotatability) with respect to the estimation of a second degree response surface, and were conceived primarily for investigations involving industrial processes where experimental error is small. In agriculture, experimental error is seldom small (i.e. a coefficient of variation of 5 - 8%) and a second degree surface may be unrealistic or, in a preliminary investigation, a precise estimate of it not required and hence there may be no justification for the use of a composite system as conceived above. However, in looking for an economic optimum in fertilizer applications, usually the response surface is well approximated by a second degree polynomial in the region of the optimum and perhaps a composite system may be considered.

A modified approach -

A modification of the composite system is suggested. In the modified composite system freedom is exercised in the choice of nuclei of two-level factorial combinations and in the placement of the supplementary treatment combinations about these nuclei. However, this does not mean that these supplementary points are chosen at random but does permit any relevant knowledge and experience of the experimenter to be incorporated into the design. Hence, treatment combinations, which do not contribute or contribute little to the immediate objectives of the experiment, may be excluded.

A COMPARISON OF THE SYSTEMS

Table 1 indicates the status associated with fractional replication, a composite system and a modified composite system, with respect to the desirable properties for an experimental design, which were outlined above.

Table 1. - Indication as to Whether Each of the Three System Fully Satisfies the Prescribed Design Properties

Design Properties	System:	Fractional Replication	Composite	Modified Composite
(a)		Yes	Yes	Yes
(b)		No	Yes	Yes
(c)		No	No	Yes
(d)		No	No	Yes
(e)		No	No	Yes
(f)		Yes	No	Yes
(g)		No	No	Yes
(h)		Yes	Yes	Yes

Under these experimental conditions, the modified composite system, because of the additional freedom allowed in the choice of the design points to meet the experimenter's needs, fully satisfies the prescribed design properties. The fractional replication and composite systems appear to suffer from the disadvantage, in these particular experimental circumstances, that the structure of the systems was designed to facilitate a comprehensive factorial-type or response-surface type analysis, rather than to facilitate a greater input from the experimenter and to tolerate less of a formal analysis which gives the required information.

Property (h) is fully satisfied for all the systems and in this connection the work of Williams and Baker (5, 6) is relevant.

THE MODIFIED COMPOSITE SYSTEM

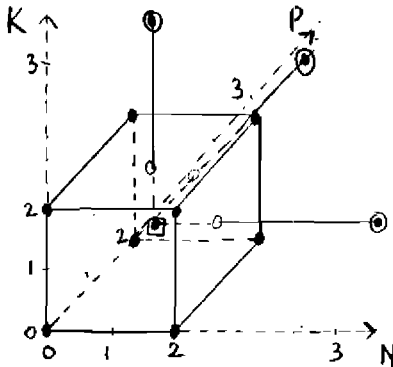
Two examples to illustrate the design and analysis of the modified composite system will now be given, and these are respectively associated with the two examples, given earlier in the paper, of investigations which may arise in the experimental situation described.

Example 1

At each site the same experimental design is used to standardize operations for the field staff. Four levels of the factors N, P and K are explored. One replicate of:

- (a) a full factorial system would require 256 experimental units;
- (b) a fractional replication system (say, one quarter replicate of a full factorial would require 64 experimental units, and
- (c) a composite or modified composite system would require approximately 18 experimental units.

Again, it is emphasized that the difference between the composite and modified composite systems is the greater freedom of choice of treatment combinations in the latter. One replicate of the modified composite system is demonstrated below:



- indicates one observation
- ⊙ indicates two observations
- ◻ indicates four observations.

Block 1			Block 2		
N	P	K	N	P	K
0	0	0	2	2	2
0	2	2	0	0	2
2	0	2	0	2	0
2	2	0	2	0	0
3	1	1	3	1	1
1	3	1	1	3	1
1	1	3	1	1	3
1	1	1	1	1	1
1	1	1	1	1	1

This system consists of a 2^3 factorial over levels 0 and 2 for each factor, the treatment combination (111) appears four times, the treatment combinations (311), (131) and (113) appear twice each, giving a total requirement of 18 experimental units per replicate. The design is a randomized blocks design with the NPK interaction confounded levels 0 to 2. In practice, the experimenter's judgement would be brought to bear on the choice of levels as follows:

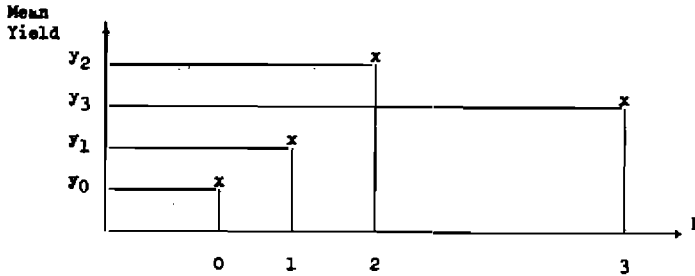
- (a) level 2 could be the experimenter's guess at the optimum level of each factor;
- (b) level 0 does not have to be zero application but could be such as to permit some growth of the crop, whereupon level 1 is chosen to be the mean of levels 0 and 2;
- (c) level 3 for each factor should not be too close to the corresponding level 2, but on the other hand should not be so great as to induce a toxic effect and inhibit growth. The choice of level 3 in this way is a departure from the composite system, where level 3 would have been prescribed and fairly close to level 2 to permit certain features in the analysis.

The first step in the analysis would be to tabulate the total yields for each treatment over the number of replicates that have been used. The analysis of variance table for a factorial-type analysis could then be presented as in Table 2.

Table 2. - Analysis of Variance Table for Example 1

ANOVA TABLE (2 replicates)			
Source of Variation		Degrees of freedom	SS
These main effects and interactions are over levels 0 to 2	Blocks	3	As usual
	N	1	
	P	1	
	K	1	
	NP	1	
	NK	1	
	PK	1	
Four orthogonal contrasts of interest associated with the mean of the 2^3 factorial treatments and the means of treatments (111), (311), (131) and (113).		4	Dependent on the four contrasts
Residual		22	As usual
Total		35	

If there are no significant interactions between N, P and K over levels 0 and 2 then we may look at the individual response curves for N, P and K for example:



y_0 is the mean of the observations from the treatments (000), (002), (020) and (022); y_1 is the mean of the observations from the treatment (111); y_2 is the mean of the observations from the treatments (200), (202), (220) and (222); y_3 is the mean of the observations from the treatment (311).

In this experiment the precision of y_0 , y_1 and y_2 is the same. The precision of y_3 is less, but the fact that the difference between levels 3 and 2 will be generally greater than the distance between levels 2 and 0 compensates for this, with respect to information about the response curve.

Since the factorial nucleus in this modified composite system is only at 2 levels, level 1 is useful in providing information between levels 0 and 2. Level 3 gives some indication of the behaviour of the response curve beyond level 2. The response curve for N given above may be regarded as the response of N averaged over P and K, each at level 1.

Similar response curves may be drawn for P and K.

At this stage the experimenter with the aid of significance tests, if necessary, should have a fairly good idea of the behaviour of his material and may be guided whether his choice of levels were satisfactory or whether some modifications should be made and further experimentation attempted.

If there are significant interactions then looking at individual response curves may lead to confusing results and a response surface-type analysis should be attempted.

Example 2

It is assumed that the prior knowledge of the experimenter is such that he is only interested in exploring the response to treatments as N increases, with P and K increasing in a constant ratio.

The system of treatments suggested in this situation is based on the module illustrated for Example 1 or on a similar, less expensive, module. One module may be located about the

treatment combination (111) and the other about the treatment combination, say, (444), where levels 1 and 4 for each factor are chosen by the experimenter subject to the constraint that P and K are in constant ratio. The information from each module may be analyzed separately, as in Example 1, or the results may be combined a response surface analysis. The flexibility of placing modules strategically in this manner, incorporates the experimenter's knowledge and experience into the design stage of the investigation and obviates the need for a full exploration of the experimental region.

The author is aware of the very heuristic approach in this paper and hopes that his optimism for the usefulness of a modified composite system approach, under the experimental situation described, will be shared by others.

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