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Design and Analysis When the Intercrops are in Different Classes

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SUMMARY

This paper introduces new designs using orthogonal arrays (ef. Raghavarao [8]) of strength 3 for conducting intercropping experiments when the intercrops are subdivided into classes (groups) based on agronomic, cultural, plant protection, economic considerations besides the main crop. The analysis of these designs considering specific effects and competing effects for main and intercrops is also presented.

Key words: Orthogonal array, Strength, Competing effect, Contrast.

1. Introduction

Intercropping is an important practice that a farmer uses to augment the income and/or to protect against natural calamities like drought, heavy rains, heavy infestation of pests and diseases, etc. The crops sown in the space between the main crop are called intercrops. When several crops are sown together, they compete for soil nutrients, sunlight, water and fertilizers. In this case, each crop may have a specific effect of its own and a competing effect on the other crops.

Another system of farming commonly used is mixed cropping. In this case there is no main crop and intercrops, but seeds of all the crops are mixed according to a specified proportion and sown at a time. In this situation also, the crops have specific and competing effects.

So far in the literature designs and analysis for intercrop or mixed crop experiments were considered assuming that the roles of all crops are same irrespective of main or intercrop. The fundamental issue addressed in this connection

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so far is the appropriateness of the response variable to compare crop combinations. Pearce and Gilliver [7] used bivariate methods; Wiley and Osiru [13] used Land Equivalent Ratio; Mead and Wiley [5] considered Effective Land Equivalent Ratio; and Jain and Rao [5] used Relative Net Return Index for the purpose of analysis of intercropping experiments. Mead and Riley [6] reviewed the statistical ideas relevant to intercropping research. For the literature on intercropping experiments, we refer to Federer [2].

Raghavarao and his coworkers considered designs for estimating specific and competing effects useful not only in agricultural setting, but also in marketing. Federer, Hedayat, Lowe and Raghavarao [12] presented a procedure to determine how much more (or less) effective a cultivar is in a blend than when grown alone. Raghavarao, Federer and Schwager [12] gave a general formulation of linear model with specific and competing effects and used it to distinguish balanced incomplete block designs with the same parameters and different support sizes. Federer and Raghavarao [4] gave minimal designs for mixtures of n of m varieties. Raghavarao and Wiley [12] conducted an experiment to study the competing effects of eight soft drinks. Raghavarao and Zhou [11] used unequal sized 3-designs (doubly balanced designs) to estimate the individual specific and competing effects.

In reality the intercrop and main crop are well defined and identified. The farmer likes to have the intercrops divided into groups and wants to use one representative variety from each group. The grouping may be done based on agricultural needs, practices and resistance to adverse weather conditions. For example Groundnut (peanut) can be taken as main crop whereas Sorghum, Pearl millet, Pigeonpea, Greengram, Sunflower, Castor, Cotton and Mesta as intercrops. These 8 intercrops can be grouped as S_1 {Sorghum, Pearl millet} as cereal crops, S_2 {Pigeonpea, Greengram} as pulse crops, S_3 {Sunflower, Castor} as oilseed crops and S_4 {Cotton, Mesta} as fibre crops.

Similarly grouping can also be done by taking Groundnut (peanut) as main crop and S_1 {Sorghum (cereal) Improved variety CSV-8R (High yield requiring high soil moisture, Hybrid variety CSH-11 with low grain yield requiring less soil moisture)}, S_2 {Pigeon Pea (Pulse) ICPL-87 short duration, LRG-30 long duration}, S_3 {Castor (Oilseed) Aruna low yield more susceptible to diseases, GCH-4 High yield tolerant to diseases}, S4 {Cotton (Fibre crop) MCU-5 susceptible to White fly, Varalakshmi, White fly tolerant}. Work in this direction has not so far appeared in the literature.

We provide suitable designs for these experiments using orthogonal arrays discussed by Raghavarao [8] in the next section and the analysis in the subsequent section.

2. Design

An orthogonal array [n, k, s, t] of index λ is a $k \times n$ matrix A with entries from a set of s (≥ 2) elements such that any $t \times n$ submatrix of A contains all possible $t \times 1$ column vectors λ times. Here n is called the size, k number of constraints, and t the strength of the array. For details and construction of orthogonal arrays, we refer to Raghavarao [8] and Mukerjee and Dey [1].

For constructing designs for experiments where each plot consists of main crop, m, and k intercrops, such that each of these intercrops is selected from a group of s intercrops, and to estimate the contrasts of specific effects and competing effects, we need orthogonal arrays of strength t = 3. The use of strength 3 is needed to account for bispecific combining abilities. We can definitely use asymmetric orthogonal arrays of strength three for the problem but it will have too many mixtures.

Consider the following orthogonal array (8, 4, 2, 3) of index 1 given in Illustration 2.3.2. of Raghavarao [8]:

$$\begin{matrix} 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 \end{matrix}$$

Let us consider an intercropping experiment using a main crop m and 8 intercrops where the intercrops are partitioned into four groups S_1, S_2, S_3, S_4 with 2 in each group, say $S_1 = \{1, 2\}$, $S_2 = \{3, 4\}$, $S_3 = \{5, 6\}$, $S_4 = \{7, 8\}$. We want to have designs where each plot consists of the main crop and 4 intercrops one from each of the sets S_1, S_2, S_3 and S_4. Identify the 0, 1 symbols of the first row of the orthogonal array with intercrops 1, 2 of S_1, second row with intercrops 3, 4 of S_2, third row with intercrops 5, 6 of S_3, and fourth row with intercrops 7, 8 of S_4. The arrangement of identifying the symbols within a group with the intercrops in that group is, however, arbitrary and does not affect the construction of the design. Consider the columns of the array as the plots of the intercrop experiment and augment the main crop to each plot. The resulting intercropping experiment will consist of the following 8 plots

(m, 1, 3, 5, 7) (m, 2, 3, 5, 8) (m, 1, 4, 5, 8) (m, 1, 3, 6, 8)

(m, 2, 4, 5, 7) (m, 2, 3, 6, 7) (m, 1, 4, 6, 7) (m, 2, 4, 6, 8)

It may be noted that this method gives intercropping design with 1 main crop and u = ks intercrops divided into k groups of s each. Though the number of intercrops becomes large it is possible to have so many combinations looking to the practicable example mentioned in page 2. The design may be repeated in the case if enough error degrees of freedom are not given by the basic design.

Remark. It may be worthwhile mentioning here that for $k \le 3$, an orthogonal array of strength three and index unity would amount to writing a complete factorial arrangement. In fact for $k = 1$ or 2, one would write all possible combinations that would not form an orthogonal array of strength three. However, for $k > 3$, the method would be useful as it would amount to reducing the number of mixtures to be run in the experiment. In other words, there would be four intercrops besides a main crop.

3. Analysis

Let m be the main crop and let there be $u = ks$ intercrops. These intercrops are divided into k disjoint groups $S_1, S_2, \ldots, S_k$ with $|S_i| = s$. Let the intercrops in group S_i be $(i - 1)s + 1, (i - 1)s + 2, \ldots, is$; $i = 1, 2, \ldots, k$.

We construct a design as discussed in the previous section with each plot consisting of the main crop and k intercrops one from each group. Let the plot with crops

$\{m, \alpha_1 \ldots, \alpha_k\}, \alpha_i \in S_i, i = 1, 2, \ldots, k$, be denoted by P_α for $\alpha = 1, 2, \ldots, n$.

We consider the linear model for representing the main crop response (say, net revenue) as

$$Y_m(P_\alpha) = \mu + \tau_m + \sum_{i=1} \gamma_{\alpha i(m)} + e_m(P_\alpha) \tag{1.1}$$

where $Y_m(P_\alpha)$ is the response on the main crop when it is sown in P_α th plot, μ is the general mean, τ_m is the specific effect of main crop, $\gamma_{\alpha i(m)}$ is the competing effect of intercrop α_i on the main crop m and $e_m(P_\alpha)$ are random errors on the main crop in the plot P_α assumed to be distributed independently $N(0, \sigma^2)$.

Similarly the linear model for the response on intercrop α_i from plot P_α is given by

$$Y_{\alpha i}(P_\alpha) = \mu + \tau_{\alpha i} + \gamma_{m(\alpha i)} + \sum_{\substack{j=1 \\ j \ne i}}^{k} \gamma_{\alpha j(\alpha i)} + e_{\alpha i}(P_\alpha) \tag{1.2}$$

where $Y_{\alpha i}(P_\alpha)$ is the response on the intercrop αi in the plot P_α for $i = 1, 2, \ldots, k$; μ is the general mean, $\tau_{\alpha i}$ is the specific effect of the ith intercrop, $\gamma_{m(\alpha i)}$ is the competing effect of main crop on αi, $\gamma_{\alpha j(\alpha i)}$ is the competing effect of αj on intercrop αi and $e_{\alpha i}(P_\alpha)$ are random errors on the intercrop αi distributed independently $N(0, \sigma^2)$.

Reparameterizing the specific and competing effects as follows

$$\tau_m^* = \tau_m + \sum_{i=1}^{k} \frac{1}{S} \sum_{j \in S_i} \gamma_{j(m)}$$

$$\tau_j^* = \tau_j + \gamma_{m(j)} + \sum_{\substack{i'=1 \\ i' \neq i}}^{k} \frac{1}{S} \sum_{l \in S_{i'}} \gamma_{l(j)},\ j \in S_i$$

$$\gamma_{l(j)}^* = \gamma_{l(j)} - \frac{1}{S} \sum_{\substack{l' \in S_{i'} \\ i \neq i'}} \gamma_{l'(j)},\ j \in S_i,\ l \in S_{i'}$$

$$\gamma_{l(m)}^* = \gamma_{l(m)} - \frac{1}{S} \sum_{l' \in S_i} \gamma_{l'(m)},\ l \in S_{i'}$$

such that $\sum_{\substack{l \in S_{i'} \\ i' \neq i}} \gamma_{l(j)}^* = 0$ for every $j \in S_i$, and $\sum_{l \in S_i} \gamma_{l(m)}^* = 0$, for every $i = 1, 2, ..., k$

Without loss of generality assume $s\tau_m^* + \sum_{j=1}^{t} \tau_j^* = 0$

The models given in (1.1) and (1.2) can be modified after reparameterization as

$$Y_m(P_\alpha) = \mu + \tau_m^* + \sum_{i=1}^{k} \gamma_{\alpha i(m)}^* + e_m(P_\alpha)$$

for the main crop m, and

$$Y_{\alpha i}(P_\alpha) = \mu + \tau_{\alpha i}^* + \sum_{\substack{j=1 \\ j \neq i}}^{k} \gamma_{\alpha j(\alpha i)}^* + e_{\alpha i}(P_\alpha)$$

for the intercrop αi.

Let T_i (T_m) be the total response on the intercrop i (or main crop), G be the grand total and P_{ij} (P_{mj}) be the total response on the intercrop i (main crop) when intercrop j is present.

The solutions of the normal equations are then given by

$$\hat{\tau}_m^* = \frac{T_m}{n} - \frac{G}{n(k+1)}$$

$$\hat{\tau}_i^* = \frac{T_i}{\lambda s^2} - \frac{G}{n(k+1)}$$

$$\hat{\gamma}_{i(m)}^* = \frac{P_{mi}}{\lambda s^2} - \frac{T_m}{n}$$

$$\hat{\gamma}_{l(j)}^* = \frac{P_{jl}}{\lambda s} - \frac{T_j}{\lambda s^2}, \quad j \in S_i, l \in S_{i'}, i \neq i'$$

By following the standard methods, the ANOVA table can be obtained as in Table 1.

If σ^2 is the error variance then the variances of the elementary contrasts of the specific and competing effects are given by

$$V\left(\hat{\tau}_m^* - \hat{\tau}_i^*\right) = \sigma^2\left(\frac{1}{n} + \frac{1}{\lambda s^2}\right) \qquad i = 1, 2, \ldots u$$

$$V\left(\hat{\tau}_i^* - \hat{\tau}_{i'}^*\right) = \sigma^2\left(\frac{2\sigma^2}{\lambda s^2}\right) \qquad i, i' = 1, 2, \ldots, u, i \neq i'$$

$$V\left(\hat{\gamma}_{l(m)}^* - \hat{\gamma}_{l'(m)}^*\right) = \frac{2\sigma^2}{\lambda s^2} \qquad l, l' \in S_{i'}$$

$$V\left(\hat{\gamma}_{l(j)}^* - \hat{\gamma}_{l'(j)}^*\right) = \frac{2\sigma^2}{\lambda s} \qquad l, l' \in S_{i'}, j \in S_i, i \neq i'$$

4. Concluding Remarks

It may be noted that in order to increase the error degrees of freedom the design can be replicated as indicated in Section 2. Following Raghavarao and Zhou [11], if the intercrops are not subdivided into groups (classes) UE-3 designs augmented with the main crop can be used from estimating individual specific and competing effects. If more than one main crop is to be tested the same design can be repeated with other main crops. If we want to test two different agronomic practices on each main and intercrop, methods and designs can be given following the lead of Raghavarao and Wiley [10] for one attribute in marketing setting.

Table 1. ANOVA

Source	d.f.	S.S.	M.S.	F
Specific effects	t	$\frac{T_m^2}{n}+\sum_{i=1}^{k}\frac{T_i^2}{\lambda s^2}-\frac{G^2}{n(k+1)}$	MS_S	$\frac{MS_s}{MS_e}$
Competing effects on main crop	k (s – 1)	$\sum_{i=1}^{t}\frac{P_{mi}^2}{\lambda s^2}-\frac{kT_m^2}{n}$	MS_{CM}	$\frac{MS_{CM}}{MS_e}$
Competing effects on jth intercrop for j = 1, 2, …, t, $j \in S_i$	(k – 1)(s – 1)	$\sum_{\substack{i'=1 \\ i'\neq i}}^{k}\sum_{l\in S_{i'}}\frac{P_{jl}^2}{\lambda s^2}-\frac{(k-1)T_j^2}{\lambda s^2}$	MS_{cl}	$\frac{MS_{cl}}{MS_e}$
Error	By Subtraction	By Subtraction	MS_e	
Total	n(k + 1) – 1	$\sum_{\alpha=1}^{n}Y_m^2(P_\alpha)+\sum_{\alpha=1}^{n}\sum_{i=1}^{k}Y_{\alpha i}^2(P_\alpha)-\frac{G^2}{n(k+1)}$		

REFERENCES

[1] Dey, A. and Mukerjee, R. (1999). *Fractional Factorial Plans.* John Wiley and Sons, New York.

[2] Ferderer, W.T. (1993). *Statistical Design and Analysis for Intercropping Experiments.* **1**, Springer, New York.

[3] Ferderer, W.T., Hedayat, A., Lowe, C.C. and Raghavarao, D. (1976). Application of statistical design theory to crop estimation with special reference to legumes and mixtures of cultivars. *Agronomy J.,* **68**, 914-919.

[4] Federer, W.T. and Raghavarao, D. (1987). Response models and minimal designs for mixtures of n of m items useful for intercropping and other investigations. *Biometrika,* **74**, 571-577.

[5] Jain, T.C. and Rao, G.N. (1980). Note on new approach to analysis of yield data in intercropping system. *Indian J. Agric. Sci.,* **50**, 570-572.

[6] Mead, R. and Riley, J. (1981). A review of statistical ideas relevant to intercropping research (with discussion). *J. Roy. Statist. Soc.,* **A144,** 462-509.

[7] Pearce, S.C. and Gilliver, B. (1978). The statistical analysis of data from intercropping experiment. *J. Agric. Sci.,* **91,** 625- 632.

[8] Raghavarao, D. (1971). *Constructions and Combinatorial Problems in Design of Experiments.* John Wiley and Sons, Inc, New York.

[9] Raghavarao, D. and Wiley, J.B. (1986). Testing competing effects among soft drinks brands in statistical design: Theory and Practice, *Proceedings of a Conference in Honor of Walter T. Ferderer.* Ed. C.E. McCulloch, S.J. Schwager, G. Caselk and S.R. Searle, 161-176, Cornell University Press, Ithaca.

[10] Raghavarao, D. and Wiley, J.B. (1994). Experimental designs for availability effects and cross effects with one attribute. *Comm. Statist.–Theory and Methods,* **23**, 1835-1846.

[11] Raghavarao, D. and Zhou, B. (1998). Universal optimality of UE-3 designs for a competing effects model. *Comm. Statist.–Theory and Methods,* **27,** 153-164.

[12] Raghavarao, D., Ferderer, W.T. and Schwager, C.J. (1986). Characteristics for distinguishing among balanced incomplete block designs with repeated blocks. *J. Statist. Planning and Inference,* **13**, 151-163.

[13] Wiley, R.W., Osiru, D.S.O. (1972). Studies on mixtures of maize and beans (*Phasoglus Vulgaris*) with particular reference to plant population. *J. Agric. Sci.,* **79**, 217-229.