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Some Statistical Concepts and Constructs in Intercrop Experiments

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Summary

Intercrop experiments are gaining greater importance in modern concept of crop production. Difficulties in respect of designing and analysing data from intercrop experiments are well known. In the previous publications little or no attention is paid for defining and quantifying an intercrop environment. The major focus of this paper is to generate some new statistical concepts and constructs in intercrop experiments and include definition and grading of an intercrop environment and ways and means of designing experimental designs which admit the conventional assumptions about them in analysing such data.

Keywords: Intercrop environment; grading; SLER; Intensity; Response Curve..

Introduction

Intercrop experiments have engaged attention of agronomists and statisticians alike in recent times. During the last decade a good number of papers have been published highlighting inherent difficulties in analysing such data and pleading for a more satisfactory method of analysis. As a common ground, majority of such methods make land equivalent ratio (LER) and its varied forms as their focus. An excellent status review of this area of research is available in Mead and Riley [2]. A few of the most recent ones in the last ten years are Willey [6], Mead and Willey [3], Willey and Rao [7], Willey and Reddy [8], Ready and Chetty [5], Pearce and Edmundson [4], and Jagannath and Sundararaj [1].

In this paper major focus is on developing some new concepts and constructs related to intercrop experiments, which have received little or no attention in earlier publications. The assumptions of normality and ANOVA which are basic to many statistical methods of analysis are always in question, in respect of methods involving LER. In the present conceptualization many of these difficulties are tide over by defining new concepts of intercrop environment and indexing its intensity in a scheme like piq by a grading method. Also such grading and cataloguing of schemes hopefully usher in new concepts in designing of intercrop experiments, to admit the usual conventional methods of analysis.

2. *Two Basic Parameters*

In an intercrop scheme involving two component crops we may recognize two basic sources of influences viz., proportion of physical areas occupied by the two component crops in a scheme, which we may call Land Factor and the other Biological factor which influences crop response in a complex way. This biological factor comes into operation as a result of nature and degree of intercrop environment to which the two component crops in the scheme get 'exposed' and which itself is a result of many factors like relative densities of the two component crops, their spatial arrangements, their 'affinity' etc., all generated by geometry of arrangement of the two component crops in that scheme.

Contribution of land factor is directly proportional to areas under two crops. While effect of biological factor is not so simple since it depends upon nature of biological affinity between the two crops., viz., mutually cooperative, mutually inhibitive to use Willey's terminology [6]. By way of illustration consider, for instance, an intercrop scheme 1:1 with two component crops A & B, with proportion of area a for A and (1–a) for B (a<1) depending upon their row spacings. Consider the schemes in the series (1:1), (2:2), (3:3) which are alternate single row, alternate two row and alternate three row system of intercropping respectively. These systems allot the same proportion of area 'a' for A and (1–a) for B, but differ from one another in their geometry of arrangements of the two component crops, thus, affecting the nature and degree of intercrop environment to which the two component crops get expressed. And thus any difference in the yield of crop A (or B) between the two schemes say, (1:1) and (2:2), is purely due to this biological factor and not due to the land factor. On the other hand a scheme like (2:1) which allots greater area to crop A than the scheme (1:1), higher yield for crop A in (2:1) could be entirely due to land factor only, even in absence of any biological factor due to intercropping being operative.

Thus, there is indeed a necessity for devising some ingenious but pragmatic way of isolating land factor and biological factor. Towards this end we need to define an intercrop environment embedded in a scheme as a *treatment factor* and to devise a scientific basis for grading the intensity of this intercrop environment; and to examine ways of incorporating the same in designing intercrop experiments to isolate and estimate contributions from the two factors land and biological. This will be the focus of the subsequent sections.

3. *Defining Intercrop Environments as a Treatment Factor*

Concept of intercrop environment which is a constituent part of biological factor is not easily amenable for a unique definition, acceptable from all view points - agronomical, physiological or other biological view points. All the same a definition needs to be devised with its foundation/rooted in its inherently intuitive nature of crop environment generated in an intercrop scheme.

For evolving one such definition we first note that in a sequence (AA..AA) or (BBB..BB), when grown as a sole crop, intercrop environment is totally absent and hence intensity of intercrop environment is zero or same as sole crop environment is 100%. In contradistinction with this, at the other end, the sequence (ABAB..ABAB) of the 1:1 scheme, intercrop environment is complete for both the crops and hence its intensity is 100%, while sole crop environment is zero. The two sequences could thus serve as two end points for grading an intercrop environment a basis for devising a scale for measuring intensity of other intermediary schemes like 3:2 viz., B/AAABB/A.. etc.

Also in an intercrop environment one may identify three fundamental types of segments which we may call Primary (P), Secondary (S) and Tertiary (T) types of environment. These three types would determine nature and degree of intercrop environment embedded in a scheme. In a segment like BAB in a scheme intercrop environment for crop A is complete since it is flanked by the intercrop B on either side. We may define such an environmental segment as of primary degree since it provides maximum intensity of intercrop environment. On the other hand in a segment like BAAB, the intercrop environment for crop A could be defined as of secondary degree since each A is flanked by the intercrop B only on one side and monocrop of its own species A on the otherside. The intensity of intercrop environment in respect of each A is thus only 50% of the primary type. Likewise for B in ABBA. A third type of segment — the tertiary type — is experienced by the central row of

A in BAAB since the central row A is flanked by its own species A on its either side and only obliquely by the intercrop B. Obviously this tertiary segment may be of varied length as, for instance, segments like BAAAAB and BAAAAAAB have two and four central rows of A respectively under tertiary influence of B, each successive row possibly providing different degree of such intensity depending upon how far away that row is from the flanking rows of B. Likewise for B in ABBBBA or ABBBBBBA etc.

A simple device for enumeration of primary (P), secondary (S) and tertiary (T) numbers in a scheme is to consider a run of three consecutive letters in succession and identify each type in them. For instance, for the scheme 3:2, adding the last letter B of the previous row as a prefix and the first letter A of the succeeding row as a suffix resulting in ...B/AAABB/A... runs of three successive letters are BAA, AAA, AAB, ABB, BBA which readily facilitate identifying primary, secondary and tertiary types of segments in this scheme. Thus 3:2 scheme contains, for crop A, zero segment of primary type, two secondary types one each in BAA and AAB, one tertiary type in AAA; and for crop B, zero primary type, two secondary types one each in ABB and BBA and zero tertiary type. Thus this simple devise may be used for enumerating different types of segments in a given scheme.

For grading the three types of segments for intensity of intercrop environment, it may be desirable to base it on simplicity and intuitive operations. Since a primary segment provides maximum intensity we may assign a score of one. By borrowing analogy from crop competition we may grade a secondary type equivalent to half the intensity of a primary type and assign a score of half or equivalently two secondary types may be considered equivalent to one primary type. For grading a tertiary type of segment, one needs to be a bit careful, since there is no simple way for grading it. For instance, if one could assume, as it is sometime done in crop competition, that an intercrop environment would not percolate beyond one neighbouring row to an appreciable degree, then every tertiary row, for example as in ...B/AAAAAABBB/A.. could be assigned score of zero as such rows are treated like monocrop rows; in which case, under this simplistic assumption, the total intensity of intercrop environment comes solely from primary and secondary segments only. If this assumption is in doubt, this could be tested by comparing average yields of such tertiary segments in different schemes with monocrop rows.

Other grading devices for tertiary types may also be examined.

For instance, extending the analogy that a secondary type is half of a primary type and numbering the positions of tertiary rows as in ...B/AAAAAABB/A.. of 6:2 scheme symmetrically from their ends, the weights could be $(1/2)^2$, $(1/2)^3$ etc., for positions 1, 2 etc. in that scheme. Or a score equivalent to exp (–v) where v is the position of the tertiary row under consideration could also be examined if one could assume the intensity to decrease exponentially as the tertiary row moves away from the intercrop row. There could be other considerations too like a linear decline in a regression fashion.

Thus for grading a scheme for intensity of intercrop environment, it is crucial to take decision in respect of tertiary rows in a scheme. However it is also possible to devise schemes involving only primary and secondary types thus eliminating the problem of tertiary segments. In section 5 grading total intensity in respect of conventional intercrop schemes is discussed, while in section 6 we discuss non-conventional new schemes involving only primary and secondary types of segments.

4. *Grading a conventional Intercrop Schemes (p:q)*

Total intensity of intercrop environment in a unit plot depends upon two parameters; numbers of P, S, T segments embedded in a basic schemes S (p:q) and number of such schemes that could be accommodated in a unit plot of given size. For simplicity and clarity we shall, at first instance, assume equal spacings for the two component crops and a unit plot of 100 rows to facilitate expressing intensity on a percent scale. In practice this figure could be adjusted for any plot size. And later comments will be offered for suitable modifications when row spacings are different component crops. Also by convention schemes, we mean here that layout of scheme S (p:q) requires p row of A, followed by q rows of B; this sequence being to cover the entire plot of 100 rows.

Table-1 gives the computational steps for determining the total intensity in the entire plot. The information about numbers P, S, T segments embedded in a basic scheme as computed from the enumeration method described in the previous section is shown in Col. 5; the number of basic set in a unit plot of 100 rows at the rate of (p+q) rows per set in Col. 6; total numbers of P, S, T segments in this unit plot in Col. 7; intercrop intensity as measured by (P + 1/2S) for each crop in Col. 8; total intensity in the plot along with total tertiary number of rows in Col. 9. Since there are multiple possibilities for scoring tertiary rows, they are shown as such with freedom to employ any grading method and add the resulting score

Table 1. Procedure for grading total intensity of intercrop Environment in a unit plot of 100 rows with equal spacings for the two componemt crops A and B in conventional schemes S (p : q)

Sl. no.	Scheme S (p : q)	Scheme (p:q) layout	Crop	No. of P, S, T in Basic Set P	S	T	No. of sets per 100 100/(p:q)	Total no. of P, S, T in unit plot P	S	T	Crop Intensity in unit plot cropwise (P+½S)	Total (P+½S)	T
1	2	3	4	5			6	7			8	9	
1.	S (1:1)	..B/AB/A..	A	1	0	0	50	50	0	0	50	100	0
			B	1	0	0		50	0	0	50		
2.	S (3:2)	..B/AAABB /A..	A	0	2	1	20	0	40	20	20	40	20
			B	0	2	0		0	40	0	20		
3.	S (3:3)	..B/AAAB BB/A..	A	0	2	1	100/3	0	33⅓	16⅔	16⅔	33⅓	33⅓
			B	0	2	1		0	33⅓	16⅔	16⅔		
4.	S (8:4)	..B/AAAAAA AABBBB/A..	A	0	2	6	100/12	0	16⅔	50	11⅓	22⅔	66⅔
			B	0	2	2		0	16⅔	16⅔	11⅓		

to (P + 1/2S) to obtain the final score for the total intensity in the plot as a whole.

In the Table-1 only a few schemes to serve as illustration of the new concepts proposed are presented. The method could be employed for any arbitrary scheme too. It may be noted that, except in 1:1 scheme, there is no primary intercrop segment at all in a scheme which will result only in increased tertiary lengths as p : q increases and thus such rows are likely to behave more like sole crop rows. One could see from table-1 that the percentage of tertiary rows increases from zero for S (1:1) scheme to 66 2/3 % for the Scheme S (8:4) *at the expense of intensity of intercrop environment.*

It is thus strikingly obvious that such conventional schemes in general do not seem to incorporate the very vital sinews of intercrop environment as a treatment factor to isolate and exploit the crucial beneficial effects in full measure for component crops; and p:q seems to be determined mostly to achieve desirable densities for the two component crops to meet needs of farmers from economic view point for an assured area for main crop.

As such some alternative approaches are desirable to ensure not only realizing densities p:q for the two component crops but at the same time to achieve desirable intensity of intercrop environment.

5. *Designing Schemes for Higher Degree of Intensity of Intercrop Environment as a Treatment Factor*

In any intercrop scheme we have already identified that primary and secondary types of segments offer high degree of intercrop environment. By selective integration of these segments in a scheme it is not only possible to achieve higher degree of intensity but also achieve any preselected density for the ratio p:q for the two component crops. Only a few illustrative examples are presented in Table-2. The guiding principle for this is to integrate proper ratios of primary and secondary segments in the required scheme p:q, if necessary to add monocrop rows for marginal adjustments in a fashion, as is sometimes suggested to achieve Staple Land Equivalent Ratio suggested by Reddy and Chetty [5].

Table-2 attempts to do this for p:q schemes by integrating segments P and S in different permutations and combinations as displayed in Col. 3 resulting in non-conventional types designated as S′ (p:q) to distinguish it from the conventional types S (p:q) of Table-1. For this purpose the first four schemes of Table-2 are designated as *fundamental* schemes. They are terminated so

Table 2. Procedure for grading total intensity of intercrop Environment in a unit plot of 100 rows with equal spacings for the two component crops A and B in *non-conventional* schemes S′ (p : q)

Sl. no.	Scheme S′ (p : q)	Scheme S′ (p:q) layout	Crop	No. of P, S, T in Basic Set			No. of sets per 100 100/(p:q)	Total no. of P, S, T in unit plot			Crop Intensity in unit plot cropwise (P+½S)	Total	
				P	S	T		P	S	T		(P+½S)	T
1	2	3	4	5			6	7			8	9	
1.	S′(1:1)	..B/AB/A..	A	1	0	0	50	50	0	0	50	100	0
			B	1	0	0		50	0	0	50		
2.	S′(1:2)	..B/ABB/A..	A	1	0	0	100/3	33⅓	0	0	33⅓	66⅔	0
			B	0	2	0		0	66⅔	0	33⅓		
3.	S′(2:1)	..B/AAB/A..	A	0	2	0	100/3	0	66⅔	0	33⅓	66⅔	0
			B	1	0	0		33⅓	0	0	33⅓		
4.	S′(2:2)	..B/AABB/A..	A	0	2	0	100/4	0	50	0	25	50	0
			B	0	2	0		0	50	0	25		
5.	S′(3:2)	..B/ABAAB/A..	A	1	2	0	100/5	20	40	0	40	80	0
		S′(1:1)+S′(2:1)	B	2	0	0		40	0	0	40		
6.	S′(3:3)	..B/ABBAAB/A..	A	1	2	0	100/6	16⅔	33⅓	0	33⅓	66⅔	0
		S′(1:2)+S′(2:1)	B	1	2	0		16⅔	33⅓	0	33⅓		

Contd

Contd. Table 2.

Sl. no.	Scheme S′ (p : q)	Scheme S′ (p:q) layout	Crop	No. of P, S, T in Basic Set			No. of sets per 100 100/(p:q)	Total no. of P, S, T in unit plot			Crop Intensity in unit plot cropwise (P+½S)	Total	
				P	S	T		P	S	T		(P+½S)	T
1	*2*	*3*	*4*	*5*			*6*	*7*			*8*	*9*	
7.	S′ (2:3)	..B/ABABB/A.. S′ (1:1)+S′ (1:2)	A B	2 1	0 0	0 0	100/5	40 20	0 40	0 0	40 40	80	0
8.	S′ (4:6)	..B/ABBABBAA BB/A.. S′(1:2) + S′(1:2) + S′(2:2)	A B	2 0	2 6	0 0	100/10	20 0	20 60	0 0	30 30	60	0
9.	S′ (5:5)	..B/ABAABBAA BB/A.. S′(1:1) + S′(2:2) + S′(2:2)	A B	1 1	4 4	0 0	100/10	10 10	40 40	0 0	30 30	60	0
10.	S′ (5:5)	..B/ABABABAA BB/A.. S′(1:1) + S′(1:1) + S′(1:1) + S′(2:2)	A B	3 3	2 2	0 0	100/10	30 30	20 20	0 0	40 40	80	0

because S′ (1:1) provides primary type of environment with maximum intensity for both the component crop A & B, S′ (1:2) providing primary for crop A only but secondary type for crop B, S′ (2:1) its vice-versa and lastly S′ (2:2) providing only secondary types for both the crops. A derived scheme, for instance, S′ (3:3) may then be generated in more than one way viz., S′ (1:1) + S′ (2:2) or S′(1:2)+S′(2:1), in which the symbol + stands for the operation of integration of S′ (1:1) and S′ (2:2) to yield the pattern...B/ABAABB/A.. with an intensity of 66 2/3 % and S′ (1:2) and S′ (2:1) to yield the pattern ...B/ABBAAB/A... with an intensity of 66 2/3 % (Table-2).

The computation of intensity of intercrop environment embedded in a scheme in Table-2 could follow the same procedure as laid out for Table-1. However, one could also compute this from the knowledge of the intensities of the two fundamental schemes which enter this derived scheme. For instance, if the scheme S′ (3:3) requiring six rows is achieved by integrating the two scheme S′ (1:1) with two rows and S′ (2:2) with four rows, it is, readily seen that the intensity of the resulting scheme is a weighted average of the two intensities viz., {(2/6)th of [Intensity of S′ (1:1)] plus (4/6)the of [(Intensity of S′ (2:1)]} which is equal to {(2/6) × (100) + (4/6) × (50)} = 66⅔. In general if two schemes A′ (p:q) and S′ (p:q) with intensities I_1 and I_2 are integrated to result in a new scheme S′ (p+p′ + q+q′), then the intensity I of this scheme is given by

$$I = \frac{P+Q}{(p+q)+(p'+q')}(I_1) + \frac{P'+Q'}{(p+q)+(p'+q')}(I_2)$$

From this Table it may be noted that the degree of intensity of intercrop environment gets increased to varying degrees in a p:q scheme although such resulting non-conventional schemes may apparently appear to offer layout difficulties in field conditions and likely, at first instance, to be less attractive at farmer's level. Nevertheless one cannot fail to admit the merit of such schemes at least at experimental stage and the potentialities they carry with them in incorporating the very vital concept of intercrop environment to understand the underlying phenomenon of biological factor in intercrop experiments. Such schemes will be helpful in indentifying compatible crops for selection to serve as companion crops; also to design experiments with specific objectives. Some of these are considered in the next section.

As a point of merit, it may be noted that none of the schemes has the problem of tertiary rows, although if need be, one could incorporate such rows in a measured way by ensuring their number to be constant in every scheme to study their behaviour in different schemes.

New schemes could also be generated by integrating, say, m sets of scheme S′ (p:q) and n sets of another scheme S′ (p′:q′) subject to the constraint m (p+q) + n (p′+q′) = 100 rows to yield a new scheme S′ {(mp + np′) : (mq + nq′)}. The resulting intensity I of this new scheme is easily computed by noting down the numbers of P & S segments for S: (p:q) and P′ & S′ for the scheme S′: (p′ : q′) and combining them in the form I = m (P+½S) + n (P′+½S). Then in a plot of 100 rows 'I' will yield the percent intensity in the resulting new scheme. In a similar way one may extend this principle for integrating, say, of m sets of S′ (p:q), n sets of S′ (p′+q′) and t sets S′(p″+q″) to yield a new scheme S′ {(mp+np′+tp″) : (mp+nq′+tq″)}, with a lot of flexibility to realize any density level l:m in the new scheme.

Other variations could also be introduced in generating new schemes. For instance, in a plot of 100 rows a scheme S′ (p:q) could be sown in only 'r' rows (r < 100) and filling the remaining (100–r) rows with monocrop rows of either component crop A or B or both. This will not only ensure a plot with preselected intensity but will also provide flexibility to achieve Staple Land Equivalent Ratio (SLER) for the component crops.

Before quitting this section a word about the case when the two component crops do not have the same row spacings and the unit plot provided is of area, say M. Since the row spacings are not the same as assumed for all the previous discussions, there is now need to take this into account while determining the intensity of intercrop environment in the basic scheme S′ (p:q) and in the unit plot of area M. While information in Table-1 from Col. 1 to Col. 5 remains same, whether row spacings for the two component crops are same or not, the number of basic sets of Col. 6 which needs to be determined, should take into consideration area occupied by a basic set. For instance if α and β are the row spacings for A & B respectively in S: (p:q) with p rows of A and q rows of B, the area per set will then be ({$\alpha p + \beta q$), so that the number of sets that could be accommodated in unit plot of area M is $M/(\alpha p + \beta q)$. This will be the multiplying factor in Col. 6 to compute P, S, T segments in Col. 7 from Col. 5. With this necessary modification, further computations in the Table-1 or Table-2 remain unaltered.

In summary, we have so far introduced a new concept of defining an intercrop environment as a treatment factor, on a scientific basis - intuitively appealing too . . . operationally defined to measure its intensity embedded in a scheme so as to facilitate indexing such schemes for further statistical use. In the next section we may examine the ways of utilising this information on designing intercrop experiments with optimum properties satisfying the usual assumptions about ANOVA etc.

6. *Some design considerations for Intercrop Experiments.*

With a background of indexing explained in the foregoing section, it is purported to explain ways of devising intercrop experiments to isolate and estimate the land and biological factors. Although one could think of many illustrations and novel ways of demonstrating some of these, we shall content ourselves with three major types of common interest. These are :

I. Factorial set-up, to isolate and estimate contributions from land and biological factors in an intercrop experiment.

II. Nested classification designs : nesting intensity factors into land factors and vice-versa.

III. Response curve designs to study responses of component crops A & B with a view to assess their biological affinity or disaffinity for screening a suitable companion crop.

I. *Factorial Set Up* : In this set up levels of land factor and levels of intensity factor are combined in a factorial fashion to facilitate separation of their effects due to each of them and their interaction effect from observed responses like yield from the component crops. In Table-2, for instance, we note that the two schemes S′ (5:5) and S″ (5:5) allot the same proportion of area viz., 50 to the component crop A (hence 50% for B too) but contain different levels of intensity viz., 60% and 80% respectively. Likewise the two schemes S′ (4:6) and S′ (2:3) allot the same but slightly lower percent area viz., 40% to component crop A (hence 60% to B) but contain, as before, intensity levels of 60% and 80%. In otherwords if we denote the area a_0 = 40% and a_1 = 50% and the intensity levels I_0 = 60% and I_1 = 80%, we readily recognize that the treatment combination a_0I_0 is embedded in the scheme S′ (4:6), a_0I_1 in S″ (2:3) a_1I_0 in S′ (5:5) and a_1I_1 in S″ (5:5) resulting in a factorial set up of treatment

Table 3. A 2 × 2 factorial combination of treatments for the two factors Land and Intensity

FACTOR : LAND		FACTOR : INTENSITY	
		I_0 (60%)	I_1 (80%)
Area to Crop A	a_0 (40%)	S′ (4 : 6) (a_0 I_0)	S′ (2 : 3) (a_0 I_1)
	a_1 (50%)	S′ (5 : 5) (a_1 I_0)	S′ (5 : 5) (a_1 I_1)

combinations as in Table-3.

If these treatment combinations (schemes) are tried in an RCBD with r replications, the resulting data for yield or some other response variable for each crop may be subjected to customary ANOVA under the usual linear model response (yield) appropriate to Randomized Complete Block Design. The final ANOVA table would then show contributions to total variability in response variate from different sources viz., Land Intensity (Biological) and their interaction effect. In the ANOVA table if the Intensity source turns out to be non-significant, it would only support the hypothesis that there would be no special advantage in growing the two crops in an intercrop environment due to lack of biological effects and such rows would behave just like monocrop rows with yields proportionate to the areas sown under each crop. On the other hand if this F-test turns out to be significant, it may have an interesting story to say about the advantages of growing the two crops as intercrops; and comparison of cell means would then directly reflect such advantages. If the interaction component turns out to be non-significant, the two factors viz., land and biological are contributing independently and in this case schemes with higher load of intercrop intensity but with same proportions of areas for component crops in the two schemes would prove advantageous. If the interaction component turns out to be significant then a detail study of cell means is desirable to effect judicious choice of a particular scheme.

In summary, the present approach to intercrop analysis facilitates a means for apportionment of contributions along with their interaction accruing separately from the land and the biological factors and facilitates judgement about the relative importance of these two factors in increasing the yield of a crop.

Another striking advantage to be expected is about the assumptions of normality etc., so much essential for meaningful statistical analysis, it is more likely to be satisfied in the present analysis as only linear combinations of observations are involved rather than ratios as in the case of LER. Lastly, any scheme picked up by this analysis should be expected to yield higher LER score to reflect the same.

II. *A Nested Set up* : In this set up levels of intensities of different schemes may be nested within a selected levels of land factor or vice-versa. For instance, schemes S (1:1), S (2:2), S (3:3), S (4:4) ... all share a common proportion of land for each component crop, say, a_0 for crop A with different levels of intensities. Likewise the series S (2:1), S (4:2), S (6:3). . . allot the same but higher proportion say, a_1 of area to crop A, ($a_1 > a_0$), but vary in respect of their intercrop intensities. These schemes may then be nested under a_0 & a_1 respectively. The resulting treatment combinations may be replicated in RCBD. The data on yield realized from such an experiment may then be subjected to appropriate analysis of variance suitable to the hierarchal classification.

If one desires, such data obtained either from factorial set up or from nested set up, may also be subjected to a Bivariate ANOVA with necessary assumptions for MANOVA.

III. *Response curve analysis* : In intercrop experiment it is always desirable to select a companion crop to the main crop which provides mutual benefit to each other. In such studies response curve analysis seems to be particularly appropriate. For a meaningful response curve analysis, yield responses for component crops are to be generated for different degrees of intensities varied in a measured way; which means schemes are to be designed specially to meet this objective in view. Although it has been conceptualized that two secondary segments are equivalent to one primary segment, it may be instructive to vary intensities using one pattern only.

For instance if one likes to study crop responses under primary type of intensity for both the crops A and B, plots may be constructed with required number of AB types of intercrop segments, to achieve desired intensity level and filling the balance part of the plot with mono crop rows of A land B since they contribute zero score to the intercrop intensity in the plot. Then a plot of 100 rows may look like this:

Intercrop	*Monocrop A*	*Monocrop B*
..AB.. type	..AA.. type	..BB.. type
r_1 sets	r_2 rows	r_3
$= 2r_1$ rows		

with $2\ r_1 + r_2 + r_3 = 100$ rows contributing to a total intercrop intensity of $2\ r_1\%$, since r_2 monocrop rows of crop A, r_3 monocrop rows of crop B totally contributing zero to intensity.

The setting $(r_1, r_2, r_3,)$ = (50, 0, 0), (40, 10, 10) (30, 20, 20), (20, 30, 30), (10, 40, 40), (0, 50, 50) will successively lead to plots of 100, 80, 60, 40, 20 and 0 percent intensity. The data may then look like:

Plot Intensity (%)	0	20	40	60	80	100
Yield : Crop A (X)	x_1	x_2	x_3	x_4	x_5	x_6
Crop B (Y)	y_1	y_2	y_3	y_4	y_5	y_6

And the same may be analysed graphically as well as analytically by fitting appropriate response curves for A and B.

A similar experiment may be planned with secondary types of segments only like (AABB) for both the crops; or mix-up AB and AABB types too. Such experiments may bring out qualitative as well as quantitative differences, not otherwise obvious, to identify whether crops are mutually cooperative, mutually compensatory or mutually inhibitive.

In brief: This paper proposes a few new concepts and constructs in intercrop experiments as a treatment factor, which hopefully overcome many difficulties of interpretation encountered in LER analysis.

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