Jour. Ind. Soc. Ag. Statistics
Vol. XXXIX, No. 3 (1987), pp. 289-300

PRODUCTIVITY EQUIVALENT RATIO AND STATISTICAL TESTING OF ITS ADVANTAGE IN INTERCROPPING

M. K. JAGANNATH and N. SUNDERARAJ
University of Agricultural Sciences, GKVK, Bangalore

(Received : February, 1987)

SUMMARY

The basic objective in all intercrop experiments is to assess biological or agronomical advantage accruing in any intercropping system. The inherent defect of Land Equivalent Ratio in not bringing out such an aspect of intercropping has been analysed and an alternative ratio viz., Productivity Equivalent Ratio (PER) has been suggested. Further, a method has been devised for setting up fiducial limits for partial productivity equivalent ratio and thereform for partial LER to serve as a basis for drawing sound inference about intercropping schemes.

Keywords : Land Equivalent Ratio; Productivity Equivalent Ratio; Coefficient of Aggressivity; Competitive Ratio; Fiducial Intervals.

Introduction

Analysis of intercrop experiments is complex due to inclusion of two or more crops. The important types involved are : (i) screening of crops for compatibility (ii) genotype selection (iii) optimising of plant densities and/or row-ratios or fertilizer dose. There are two major aspects involved in the analysis of such experiments viz., Agronomic and statistical, besides the problems of constructing suitable experimental designs for such experiments. An excellent over-view of many aspects of analysis and designing of intercrop experiments is available in Willey [8] Mead and Riley [4], apart from Chetty and Reddy [1]. In substance, there is a plea for the need for development of a uniform methodology for analysis of intercrop experiments, although the present status indicates that there is no single straight forward method of analysis which is universally applicable.

Land Equivalent Ratio (LER) originally suggested by Willey and Osiru [9] is the one index most commonly used, despite its limitations, for the assessment of benefits from an intercrop scheme. In this article some of the limitations are examined (Sec. 2) and a modified ratio viz., Productivity Equivalent Ratio (PER) is advanced as an alternative index in place of LER, relating PER to LER and as a consequence to bring to forefront a few highlights of LER, possibly hitherto not explicitly expressed in the literature (Sec. 3). Then a method is suggssted for setting up fiducial limits for partial PER and therefrom on PLER (Sec. 4). This is followed by a method for setting up simultaneous fiducial intervals on several partial PER's (hence on PLER's) in an intercropping scheme (Sec. 5). Finally these are examined through an illustration from an intercrop experiment (Sec. 6).

2. Land Equivalent Ratio (LER)

Although various other indices of crop competition and combined yield have been suggested, the one considered most useful and meaningful is the land equivalent ratio (LER). It is also recognised by the users of LER's that comparing LER's for different crop combinations under different inrercrop schemes is not always straight forward. It is not hard to see the reason for this since the benefit of an intercrop scheme comes from two different sources viz., (a) land factor i.e., areas occupied by each crop in an intercrop scheme and (b) the biological/agronomic factor* due to geometry of arrangement of the two component crops in that scheme, although these two are intimately intertwined in an intercrop scheme. For instance the series 1 : 1, 2 : 2, 3 : 3 etc., different only in the geometry of the arrangement of the two intercrops but not in the land factor i.e., the ratio of areas occupied by the two crops. Hence any difference in the yields of the component crop i ($i = 1, 2$), apart from chance contribution due to experimental sources, is entirely due to biological factor as a result of differences in the geometry of the arrangements of component crops in an intercrop scheme. The same is true in the series 1 : 2, 4 : 2, 6 : 3 or in the series 3 : 1, 6 : 2, 9 : 3 etc. Thus any comparison of benefits between two intercrop schemes coming from two different series (e.g. 1 : 1 and 2 : 1 etc) via LER's meets with difficulties due to confounding of these two sources of benefits (biological factor and land factor) into one composite index of PLER and hence of LER.

*The term 'biological/agronomical' is implied by the single term 'biological' in the rest of this paper.

In the absence of any biological factor, yield differences between any two schemes would result solely from differences in land factor.

It is noted in Table 1 that PLER's are all larger than 0.50 for each component crop under each scheme and at first thought could be suggestive of beneficial effects for both the component crops in each scheme, the overall benefits being reflected by the LER values all being greater than one. Although there seems to be overall benefits from these intercrop schemes, (LER > 1), such benefits in the case of groundnut are only illusory and not real can be seen from Col. 9 and Col. 10 of Table 1, which display the expected yield of groundnut computed on the assumption of absence of biological factor contributing to the yield of groundnut in each intercrop scheme, for, under such an assumption, it is logical to expect the yield of groundnut to be equivalent to the yield under sole crop scheme, adjusted for the area occupied by the groundnut in an intercrop scheme.

Comparing the intercrop yields with the yields expected under sole crop environment on an equivalent area under intercrop scheme, it is immediately obvious that the groundnut crop has not derived any benefit from any of the intercrop schemes and at times its productivity levels are even quite low. The groundnut yield under intercrop is around 75 to 92% of the yield under sole crop grown on an equivalent area (Col. 10) of Table 1.

TABLE 1—YIELD, PLER AND LER FOR DIFFERENT INTERCROP SCHEMES OF GROUNDNUT (*G*) AND PIGEONPEA (*P*) ALONG WITH RESPECTIVE SOWN AREA

Intercrop scheme			*Yield in kgs per unit area*		*PLER*		*LER*	*Expected yield of*	*Col. 4/ Col. 9*
Scheme	*Area under*								
	G	*P*	*G*	*P*	*G*	*P*		*G*	
2 : 1	2/3	1/3	880	1670	0.54	0.84	1.38	1080@	0.82
3 : 1	3/4	1/4	980	1470	0.60	0.74	1.34	1215	0.81
4 : 1	4/5	1/5	970	1300	0.60	0.65	1.25	1296	0.75
6 : 2	3/4	1/4	1120	1150	0.69	0.58	1.27	1215	0.92
Sole crop			1620	1990					

@ 1080 –(Area 2/3) Yield per unit area 1620.

3. Productivity Equivalent Ratio (PER)

The important limitation of LER is its inability to reflect the relative contributions accruing from land source and from the geometry of arrangement (biological). Of these two sources of benefits, exploitation of the biological source in an intercrop scheme is of greater importance for obvious reasons, since increase in yield due to increase in area, may be derived even in the absence of biological effects, merely growing as sole crops in equivalent areas. So, what we need in an index which is a reflection of this biological component. One such appropriate index is the ratio of intercrop yield to the sole crop yield grown on an area equivalent to the area of component crop in the intercrop scheme; that is, we need an index based on productivity rather than on production, since productivity is independent of area of individual crops in the scheme. Later, the decomposition of LER into these two factors is shown (see equations 8, 9).

The recognition of importance of biological factor also raises issues in designing of intercrop experiments, requiring inclusion of atleast two schemes belonging to the same series, such as (1 : 1, 2 : 2 etc) or (3 : 1, 6 : 2 etc)—one possible such design being a nested classification of equivalent schemes with respect to ratios of areas, nested under selected levels of areas for component crops. Analysis of such experiments is expected to throw light on the relative magnitude of contributions from land and biological sources. Other treatments like N, P, K if any, bring in further problems of analysis.

For simplicity and to fix ideas with clarity, let us consider an intercrop scheme with equal row spacings for two components crops (e.g. G and P) and also the same row spacings in sole crop environment. Ignoring for the moment variations in yield due to experimental sources of errors, let the yields expressed in parametric values for the two component crops be μ_{I_1} and μ_{I_2} occupying respectively areas in the ratio a : $(1 - a)$, $(a < 1)$. Let μ_{S_1} and μ_{S_2} be the sole crop yields grown side by side in areas in the same ratio $a : (1 - a)$. We now define the two partial productivity equivalent ratios (PPER),

γ_1 and γ_2 for the two component crops as

$$\gamma_1 = \frac{\mu_{I_1}}{\mu_{S_1}} \quad \text{and} \quad \gamma_2 = \frac{\mu_{I_2}}{\mu_{S_2}}$$

and relate the same to PLER's (L_1, L_2) later. The two partial PER's, it may be seen, are similar to the components employed by Mcgilchrist and Trenbath [3] in defining their Coefficient of Aggressivity and Willey and Rao [10] in defining their Competitive Ratio.

It may further be noted :

(i) The partial PER γ_i ($i = 1, 2$) measures the effectiveness of an intercrop scheme accruing solely from a relatively more important source of contribution viz., biological source as γ_i is independent of land factor. This fact is particularly striking when the geometry of sole crops grown side by side (eg. *GGG ... GPPP ... P*) in the same ratio as $a : (1 - a)$ as component crops in the intercrop scheme (eg. *GGPGGP ... GGP*) is conceived as a degenerative form of an intercrop scheme with the property of total absence of biological source of influence on the component yields. Thus, μ_{s_1} and μ_{s_2} serve as appropriate base yield values solely due to land factor.

(ii) While $\gamma_i = 1$ implies rhe absence of biological factor on crop i, ($i = 1, 2$); $\gamma_i \lesseqgtr 1$, implies the presence of biological factor in the scheme, which may be beneficial either to only one crop (mutual compensation), both the crops (mutually cooperative) or to none of the two crops (mutually inhibitive).

While γ_1 and γ_2 could be individually evaluated as indices of intercrop benefits for the two component crops due to biological source, they can also be combined into one composite index in more than one way as γ_1 and γ_2 are essentially unit-less indices. These are :

a. *Productivity Equivalent Ratio (PER) : A Composite Index*

One may construct this composite index as a simple sum of γ_1 and γ_2 to measure the total benefit from an intercrop scheme. This composite measure γ could be either

$$\gamma = \gamma_1 + \gamma_2 \tag{3}$$

or alternatively

$$\gamma = \frac{\gamma_1 + \gamma_2}{2} \tag{4}$$

Then γ combines the two partial productivity ratios into one. In the form (3), a value of $\gamma > 2$ is indicative of an aggregate benefit of the intercrop scheme, while a value of $\gamma < 2$ is the lack of this benefit and $\gamma = 2$ being indicative of absence of any net benefit. In the form (4), the critical value for γ is 1 in place of 2.

Since γ measures the total benefit due to biological source one could be interested to know how this benefit is shared by the two component crops. This may be simply measured by the ratio $\gamma_1/(\gamma_1 + \gamma_2)$ and $\gamma_2/$

$(\gamma_1 + \gamma_2)$ for the component crops 1 and 2, respectively. If one desires, it could be expressed in percentage too. This measure may sometime be helpful for comparisons of different schemes, involving different component crops, as they all get reduced to a common percentage basis.

(b) *Measure of Aggressivity*

As mentioned earlier, γ_1 and γ_2 resemble very much the components used by Mcgilchrist and Trenbath [3] in defining their Coefficient of Aggressivity of one component crop over the other. In an analogous way the index defining this measure is

$$\alpha'(\gamma_1, \gamma_2) = \alpha' = \gamma_1 - \gamma_2 \tag{5}$$

Probably, a better measure is to free (5) from the total $(\gamma_1 + \gamma_2)$ so that aggressivity may be expressed as a fraction (or per cent) of this total benefit, viz.,

$$\alpha(\gamma_1, \gamma_2) = \alpha = (\gamma_1 - \gamma_2)/(\gamma_1 + \gamma_2) \tag{6}$$

This way it would facilitate comparison between different schemes. If $\alpha > 0$, component crop 1 is relatively more aggressive than component crop 2 and vice versa is the case when $\alpha < 0$, the two component crops stand on equal footing.

(c) *Competitive Ratio*

Competitive Ratio, similar to Willey and Rao [10] is similarly defined as

$$\rho = \rho(\gamma_1, \gamma_2) = \gamma_1/\gamma_2 \tag{7}$$

If $\rho > 1$, then component crop 1 derives better benefit than component crop 2 and vice versa is the case when $\rho < 1$; if $\rho = 1$, the two crops are on equal footing.

(d) *Relationships among PER and LER*

If μ'_{S1} and μ'_{S2} arr sole crop yields per unit area, than $\mu_{S_1} = a\,\mu'_{S1}$ and $\mu_{S_2} = (1 - a)\,\mu'_{S2}$

so that

$$L_1 = a\gamma_1, \quad L_2 = (1 - a)\gamma_2 \quad \text{and } L = a\gamma_1 + (1 - a)\gamma_2 \tag{8}$$

Alternatively, $\gamma_1 = L_1/a$ and $\gamma_2 = L_2/(1 - a)$

$$\gamma = L_1/a + L_2/(1 - a) \tag{9}$$

In this form of L_1, L_2 and L, the relative contributions from land factor and biological factor could be judged in a given scheme. Further, it will be readily apparent that for a given pair of γ_1 and γ_2 as fixed (e.g. different scheme with the same extent of biological advantages), L_i will be biased towards the component crop which gets greater area allotted to it. This might even confound a true picture since if area 'a' increases, $(1 - a)$ naturally decreases. For instance, consider two schemes which have the same amount of biological factor viz., $\gamma_1 = 0.6$ (not beneficial to crop 1) and $\gamma_2 = 1.5$ (beneficial to crop 2). If the first scheme has areas 0.75 and 0.25 for the two component cropsl and crop 2 respectively, then $L_1 = 0.450$, $L_2 = 0.375$, $L = 0.825$ indicating that the intercrop scheme is neither beneficial to either crop nor to the scheme as a whole. On the other hand, if the areas allotted were 0.25 and 0.75, instead, then $L_1 = 0.150$, $L_2 = 1.125$, $L = 1.275$, which throws up a different picture conflicting pictures although the two schemes are equivalent in respect of intercrop benefits. Thus, when $\gamma_1 + \gamma_2 > 2$, L could be less than 1. Likewise. when $\gamma_1 + \gamma_2 < 2$, L could be greater than 1.

Thus, use of γ_i's along with L_i's is therefore expected to shed more light in assessing intercrop scheme and may even prove a better substitute to LER.

(e) *PER and Effective LER*

The interpretative utility of LER as defined by Willey and Osiru relies upon the assumption that the "standardized" yield proportion $(L_1/(L_1 + L_2))$ obtained from an intercrop is exactly that required by the farmer. Sometimes two different LER's will meet with difficulty in comparison. Mead and Willey [10] described a method of producing an "Effective LER" for any predetermined (common) crop proportion.

This requires modifications of intercrop scheme in which intercrop scheme is sown on a certain proportion of area and of the balance with sole crop. A general method for obtaining the proportion of intercropping (K) for a required proportion (P) Effective LER is given by

$$\text{Eff. LER} = \frac{L_2}{(1 - L_1) + (L - 1)\,p}$$

The relationship between effective LER and PER is straight forward thus

$$\text{Eff. LER} = \frac{(1 - a)\,\gamma_2}{(1 - a\gamma_1)\,(1 - p) + p\,(1 \times a)\,\gamma_2}$$

(f) *Relationship between SLER and PER*

Reddy and Chetty [1] advanced yet another variation in LER and termed it Staple Land Equivalent Ratio (SLER) which takes account of the requirement that, in subsistence agriculture, it is important to maintain a certain minimum percentage of pure stand yield of staple crop. In this system, if P_{12} is the area allotted to intercropping and P_{11} to the main crop 1; then SLER may be shown to be

$$\text{SLER} = 1 + (L - 1)\left[\frac{P_{11} + P_{12} L_1}{L_1}\right]$$

which relates to γ_1 as

$$\text{SLER} = 1 + [a\gamma_1 + (1 - a)\gamma_2 - 1]\left[\frac{P_{11} + P_{12} L_1}{L_1}\right]$$

4. Interval Estimation of Partial PER

The method of setting up interval estimate on γ_i $(i = 1, 2)$ follows the method analogous to Fieller [2]. In case of γ_1 for instance, we construct a new random variable.

$$U_1 = \bar{y}_{I1} - \gamma_1 \bar{y}_{S1} \tag{10}$$

whose expectation is zero aad variance $V(u_1)$ is given by

$$V(u_1) = \frac{\sigma^2_{Si}}{n_1} + \gamma_1^2 \frac{\sigma^2_{Sr}}{n_2} \tag{11}$$

where n_1 and n_2 are independent observations from the intercrop and sole crop replications, respectively.
When it is reasonable to assume $\sigma^2_{I1} = \sigma^2_{S1} = \sigma^2$ then the variate

$$t = (\bar{y}_{I1} - \gamma_1 \bar{y}_{S1}) \Big/ \sqrt{s_1^2\left(\frac{1}{n_1} + \frac{\gamma_1^2}{n_2}\right)} \tag{12}$$

in which s_1^2 is an unbiased estimate of σ_1^2 based on $(n_1 + n_2 - 2)$ d.f., will follow students 't' distribution so that

$$P\left[\frac{(\bar{y}_{I1} - \gamma_1 \bar{y}_{S1})^2}{s_1^2\left(\frac{1}{n_1} + \frac{\gamma_1^2}{n_2}\right)} \leqslant t_1^2\right] = 1 - \alpha \tag{13}$$

where t_1 is $(1 - \alpha/2)$th percentile point of the t-distribution with $(n_1 + n_2 - 2)$ df.

Then the fiducial interval for γ_1 is defined by the set of all values of γ_1 for which (13) is valid. The limits themselves are given by solving the quadratic equation in γ_1 by replacing the inequality sign by the equality sign in (13). The limits may be shown to be (γ_{1L} = lower limit, γ_{1U} = upper limit)

$$(\gamma_{1L}, \gamma_{1U}) = \left[\bar{y}_{I1}\, \bar{y}_{S1} \pm t_1\, s_1 \sqrt{\frac{y_{I1}^2}{n_2} + \frac{y_{S1}^2}{n_1} - \frac{t_1^2 s_1^2}{n_1 n_2}} \right] \div \left[\bar{y}_{I1}^2 - \frac{t_1^2 s_1^2}{n_2} \right] \quad (14)$$

Similar expression for γ_2 may also be obtained. Fiducial interval on L_i follows directly from (8). The limits on L_1 are

$$[a\gamma_{1L}, a\gamma_{1U}] \text{ and on } L_2 \text{ are } [(1-a)\, \gamma_{2L}, (1-a)\, \gamma_{2U}] \quad (15)$$

If the equality $\sigma_{I1}^2 = \sigma_{S1}^2$ is not tenable, then Fisher-Behran's approach will be appropriate (Snedecor and Cochran [7]).

5. Simultaneous Fiducial Intervals on (γ_1, γ_2)

Setting up of exact confidence region on (γ_1, γ_2) needs joint distribution of ($\hat{\gamma}_1$, $\hat{\gamma}_2$) which is generally intractable. In the absence of this, simultaneous fiducial intervals with a composite error rate α may be set up using Bonferroni's technique (See Miller, R G [5]. In this technique simultaneous limits on γ_1 and γ_3 are set up as in (14) by employing t_1 value—not at $(1 - \alpha/2)^{\text{th}}$ percentile point, but—at $(1 - \alpha/4)^{\text{th}}$ percentile point. Then the resulting two intervals (γ'_{1L}, γ'_{1U}) and (γ'_{2L}, γ'_{2U}) will satisfy the probability statement.

$$P[(\gamma'_{1L} \leqslant \gamma_1 < \gamma'_{1U}) \cap (\gamma'_{2L} \leqslant \gamma_2 \leqslant \gamma'_{2U})] \geqslant (1 - \alpha)$$

Then the interpretation of (γ'_{1L}, γ'_{1U}) and (γ'_{2L}, γ'_{2U}) follows as in Section 3 for (γ_1, γ_2).

6. An Illustrative Example

The main purpose of this section is to demonstrate some of the ideas of the previous sections through an illustrative example partly reported in Sec. 2. Originally the experiment consisted of four intercrop schemes involving groundnut (*G*) and pigeonpea (*P*) in the ratios 2 : 1, 3 ; 1, 4 : 1 and 6 : 2 and the two sole crops *G* & *P* all tried in randomised complete block design (REBD) with three replications (Reddy and Chetty [6]. The spacing was same with 30 cms between rows for groundnut in each scheme, as well as in sole crop environment, while for pigeonpea it was 30 cms in each scheme and 60 cms between rows in sole crop environment. Since Partial PER's and hence PER required yields per equivalent areas under intercrop as well as under sole crop environments, analysis is restricted only to groundnut crop.

First individual fiducial intervals are set up for each γ_j ($j = 1, 2, 3$ and 4) for four schemes. This is followed by a set of four simultaneous fiducial intervals with a composite confidence coefficient of 95% using Bonferroni's approach (Miller R G. [5]. Since different schemes provide different areas for groundnut crop (see Table 2), the RCBD analysis was carried out on the transformed values all reduced to a common area equivalent to the area of the sole crop as reference plot. Table 2 sets forth the groundnut yield in kgs per plot all standardized to the sole plot size.

TABLE 2—ADJUSTED YIELD OF GROUNDNUT IN KGS/PLOT (PLOT SIZE-SOLE PLOT SIZE)

Scheme	*Area under*		*Replication*			*Mean*	
	G	*P*	*I*	*II*	*III*	$\bar{Y}_{I1}$	$\bar{Y}_{S1}$
Sole crop			6.56	8.18	6.20	—	6.98
2 : 1	2/3	1/3	5.67	5.96	5.54	5.72	—
3 : 1	3/4	1/4	5.03	7.00	4.96	5.66	—
4 : 1	4/5	1/5	6.09	5.72	3.84	5.22	—
6 : 2	3/4	1/4	7.28	6.35	5.72	6.45	—

RCBD analysis produced on error mean sum of squares $s^2 = 0.5257$ (kg)^2/plot. This value serves as s_1^2 value in expression (14) Bartlett test applied for s_1^2 ($i = 1$ to 5) for different schemes did not indicate wide variations. However, this assumption is necessary and is to be verified when in doubt as a result of change in geometry in different schemes.

Individual Fiducial Interv

Table 3 reports the individual fiducial intervals for four partial L_1's and PER's for groundnut crop for each of the four schemes using expression (14) and choosing relevant values from Table 2 and putting $s^2 =$ 0.5257 for 8 df. The same table also reports individual fiducial limits on partial LER's using (15).

For a significant biological effect of a scheme, the fiducial interval on γ_j should exclude $\gamma_j = 1$ which is the case for 4 : 1 scheme under partial PER and is indicative of deleterous effect on groundnut. For a significant biological effect of a scheme, the fiducial interval on partical LER (L_1) should exclude a value equivalent to the area occupied by the groundnut crop; which is the case for scheme 4 : 1 which allots 4/5th or 0.8 area for groundnut.

TABLE 3—INDIVIDUAL 95% fiducial intervals for partial PER'S AND PARTIAL LER'S FOR GROUNDNUT CROP

Scheme	*Partial PER* (γ_1)		*Partial (LER)*	
G : P	*Lower limit*	*Upper limit*	*Lower limit*	*Upper limit*
2 : 1	0.6541	1.0169	0.4361	0.6779
3 : 1	0.6461	1.0073	0.4846	0.7555
4 : 1	0.5259	0.9890*	0.4287	0.7912*
6 : 2	0.7510	1.1333	0.5633	0.8500

*Significant at 5% levels

TABLE 4—SIMULTANEOUS 95% FIDUCIAL INTERVALS FOR γ_i AND L_i'S

Scheme	*Area under groundnut*	*Partial PER* (γ_i)		*Partial LER* (L_i)	
		Lower	*Upper* (@)	*Lower*	*Upper* (@)
2 : 1	2/3	0.5935	1.1098	0.3957	0.7399
3 : 1	3/4	0.5857	1.0997	0.4393	0.8248
4 : 1	4/5	0.5281	1.0263	0.4225	0.8210
6 : 2	3/4	0.6882	1.2325	0.5162	0.9244

@ Footnote : All the formulae such as (14) are invariant with respect to the land area factor and hence may be employed for different schemes for determining fiducial intervals However, L_i's are not invariant in respect of land factor.

From the above table it may be noted that there is no evidence to show that an intercrop scheme had any significant biological effect on groundnut except for the scheme 4 : 1 where the effect is more deleterious to groundnut crop yield in comparison with sole crop yield on an equivalent area. Table 4 reports simultaneous fiducial intervals on all the four partial PER's with a composite 5% level using Bonferroni's approach. This has been done with an appropriate choice of t-value—not at 5% level, but—at 1.25% level for 8 df since there are four intervals. The t-value used in expression (14) for the present example for 8 df was interpolated at $t = 3.24$.

As expected from the individual fiducial intervals, none of the schemes showed any beneficial effect on groundnut. As pointed out earlier, such intervals could not be constructed for the pigeonpea crop as the spacings under sole crop were different. If this were possible, then each scheme as a whole could have been evaluated by considering simultaneous confidence interval on the partial PER for groundnut as well as for pigeonpea.

From the foregoing illustrative example, it would be possible to evaluate different intercrop schemes, although different schemes allot different areas under each crop.

REFERENCES

[1] Chetty, C. K. R. and Reddy, M. N. (1984) : Analysis of intercrop experiments in dryland agriculture, *Expl. Agric.*, **20** : 31-40.

[2] Fieller, E. C. (1940) : The biological standardization of insulin, *J. R. Statist. Soc. Suppl.*, **7** : 1-54.

[3] McGilchrist, C. A. and Trenbath, B. R. (1971) : A revised analysis of plant competition experiments, *Biometrics*, **37** : 659-671.

[4] Mead, R. and Riley, J. (1981) : A review of statistical ideas relevant to intercropping research, *J. R. Statist. Soc.* Series A, **144** : 462-509.

[5] Miller, R. G. (1966) : *Simultaneous Statistical Inference*, McGraw Hill Inc.

[6] Reddy, M. N. and Chetty, C. K. R. (1983) : Staple land equivalent ratio for assessing yield advantage, from intercropping *Expl. Agric.*, **20** ; 171-177.

[7] Snedecor, G. M. and Cochran, W. G. (1967) : *Statistical Methods*, Sixth Ed. Oxford and IBH Pub. Co., p. 115.

[8] Willey, R. W. (1979) : Intercropping—its importance and research needs. Part 1. Competition and yield advantages. *Field Crop. Abs.*, **32** : 1-10.

[9] Willey, R. W. and Osiru, D S. O. (1972) : Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population, *J. Agric. Sec. Camb.*, **79** : 519-529.

[10] Willey, R. W. and Rao, M. R. (1980) : A competitive ratio for quantifying competition between intercrops, *Expl. Agric.*, **16** : 117-125.