

**SPACING EXPERIMENT ON MAIZE×MUNGBEAN
INTERCROPPING SYSTEM
USING A '3—WAY' SYSTEMATIC DESIGN**

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ABSTRACT

An experiment was carried out to investigate different levels of spacing of an inter-cropping system consisting of maize and mungbean using the "three-way parallel row design". The design independently evaluated the effects and interactions of three spacing factors: the intra-row spacings of the two component crops and the inter-row spacing between the two crops. It was found that the effects of inter-row spacing between maize and mungbean and those of intra-row spacing of maize, on the total inter-crop yield, were highly significant. The effect of changing mungbean intra-row spacing on yield was significant, but was of a lesser magnitude than varying maize spacing. The interaction effects were non-significant. The results showed that maize exerted a clear dominance over mungbean in the range of densities investigated. The optimum densities for a maximum inter-crop yield showed the requirement of a higher density of maize combined with a lower density of mungbean, relative to their respective monocropping densities.

KEY WORDS: Intercropping system, Inter-row spacing, Intra-row spacing, Maize, Mungbean, Three-way parallel row systematic design

INTRODUCTION

Intercropping experiments are complex because they involve a large number of treatment combinations due to the presence of two or more crops. Therefore appropriate experimental designs capable of evaluating a large number of treatments within a limited land area should be evolved. For spacing experiments systematic designs are of paramount importance, as conventional randomized block designs cannot handle large numbers of spacing combinations without wasting a high proportion of experimental area to guard rows.

Systematic spacing designs are basically of two types. They are fan designs and parallel row designs. A systematic spacing design consists of a grid of points, each representing a planting point. The grid for the fan

design (Nelder, 1962) is formed by the intersection of radii and arcs of concentric circles. Fan designs are more suitable for monocropping spacing experiments although Huxley and Mainu (1978) and Wahua and Miller (1978) used them for intercropping experiments.

In the parallel row design (Bleasdale, 1967) rows are laid out parallel to each other and the distance between adjacent rows are varied systematically. Parallel row designs have great potential as suitable designs for intercropping spacing experiments. Three different spacing factors are involved in a spacing study of intercropping, the intra-row spacings of the two component crops and the inter-row spacings between the two component crops. To find the optimum of each of these factors, a wide range of spacing levels of each have to be combined and evaluated.

Mead and Stern (1980) and Putnam *et al.* (1985) have used two way forms of the parallel row design, in which the intra-row spacings of the two crops were systematically varied within a factorial treatment structure while keeping the inter-row spacing constant.

Thattil (1985) proposed a three-way form of the parallel row design (Fig. 1) for an experiment with different intra-row spacings for each component crop together with varying inter-row spacings; each factor of spacing varied independently of the other factors.

The experimental area is divided into segments $S_1, S_2, S_3, \dots$. Within each segment the intra-row spacing for crop A ($D_{A1}, D_{A2}, \dots$) is the same, while it increases vertically between segments in a systematic manner. The inter-row spacing ($D_{11}, D_{12}, \dots$) increases systematically in the horizontal direction. The intra-row spacing for crop B ($D_{B1}, D_{B2}, \dots$) varies within each segment in a geometric progression.

Since these progressions run in opposite directions within adjacent segments, each succeeding segment is a mirror image of the preceding segment. This design enables, all the possible combinations of the three spacing factors to be laid out.

Harvest areas containing each specific spacing combination are denoted H_{ijk} in Fig. 1. Since spacing variations between adjacent harvest areas are very small and systematic, the plants could be considered as almost equally spaced. Therefore guard rows are not needed between different harvest areas.

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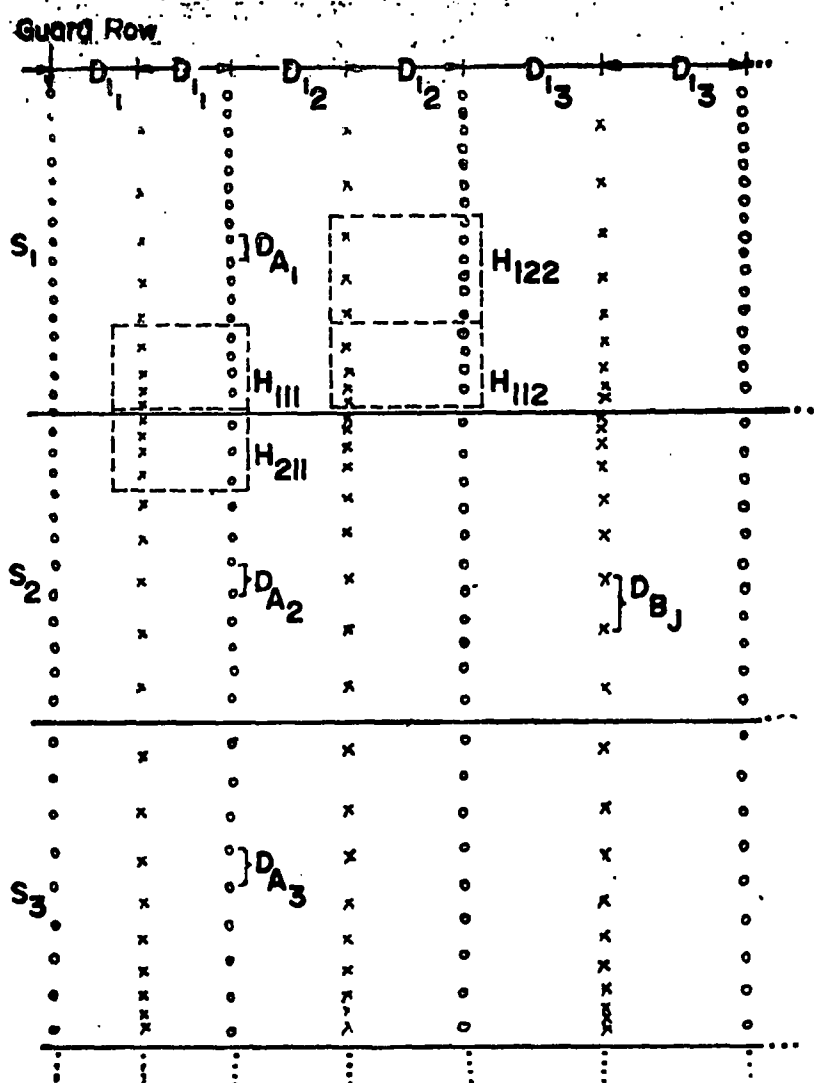


Fig. 1, Three-Way Parallel Row Systematic Design (Thattil, 1985)

Crop A = o Crop B = x S = Segments
 D_{A_i} = Intra-row spacing of crop A
 D_{B_j} = Intra-row spacing of crop B
 D_{1k} = Inter-row spacing.
 H = Harvest Area.
 H_{ijk} (i = level of intra-row spacing for crop A
 j = level of intra-row spacing for crop B
 k = level of inter-row spacing)

The present experiment is a preliminary investigation into the effects of different spacing levels of the Maize $\times$ Mungbean inter-crop mixture in 1:1 row arrangement, using the three-way parallel row design. The objective of this preliminary investigation was to evaluate a wide range of spacing combinations using the 3-way form of parallel row design proposed by Thattil (1985) and select a few promising combinations which could be studied further in conventional randomized block designs.

MATERIALS AND METHODS

Experimental site

The experiment was carried out from mid-July to mid-November, 1986 at the Agriculture Experimental Station of the University of Peradeniya located at Dodangolla on a sandy clay loam. The experimental site was situated at an elevation of about 367 m above mean sea level within the Mid-Country Intermediate Zone IM3 (Agro-ecological regions of Sri Lanka, 1979). The total rainfall at the experiment station during the period of the experiment was 812 mm. The two crops grown were maize (*Zea mays* var. Thai compositae) and mungbean (*Vigna radiata* (L) Wilczek var. type 77).

Experimental design

The experiment was laid out in two replicates on two separate long, narrow, parallel terraces. The arrangement of plants according to the 3-way parallel row systematic design for each replicate is shown Fig. 2.

The two crops were grown along alternate rows, i.e. 1:1 row arrangement. Four levels of each of the three spacing factors were chosen. The arrangement of the sixty four possible spacing combinations was as follows:

- (a) Inter-row spacing: The four levels chosen were 25, 30, 35 and 40 cm. Four pairs of rows of the two crops were systematically arranged at these inter-row spacings, along the horizontal axis of the design grid.
- (b) Intra-row spacing of maize: The four levels chosen were 20, 25, 30 and 35 cm. These spacings were systematically arranged in segments along the vertical axis of the design grid. Each segment contained 40 maize plants.

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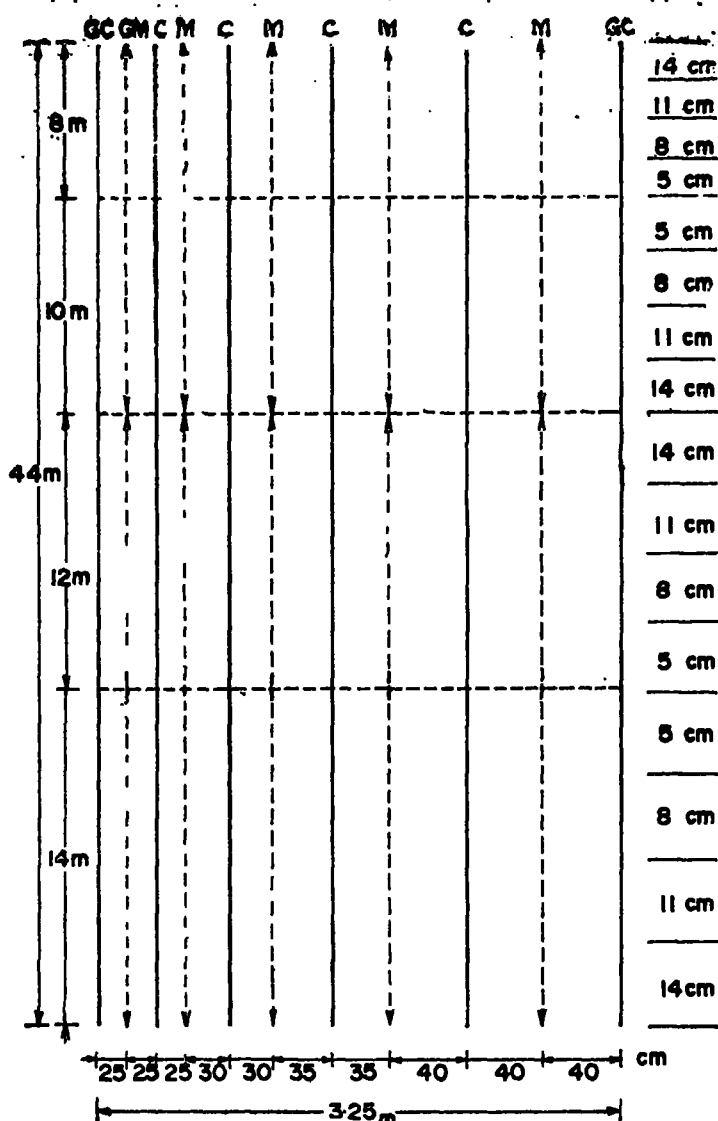


Fig. 2. Outline of the Three-Way Parallel Row Design
(As laid out in one whole systematic block)

----- Segment boundaries. GC = Guard Row (Maize) C = Maize Rows
GM = Guard Row (Mungbean) M = Mungbean Rows
↑ = Direction of the geometric progression of mungbean intra-row spacing.
5 cm = Mungbean intra-row spacing within the indicated segment

- (c) Intra-row spacing of mungbean: The mungbean plants were arranged so that the spacings increased in geometric progressions within each segment. These geometric progressions were so arranged that within the different harvest areas of each segment the four levels of average intra-row spacing of mungbean were approximately 5, 8, 11 and 14 cm. Two guard rows, one each of maize and mungbean were included along the outer boundaries of the design grid. For reasons given elsewhere, guard rows were not required within the design grid.

Cultivation practices

After a thorough land preparation and levelling, the seeds of the two crops were sown on 24th July, 1986. After two weeks from sowing, the plants were thinned out to the required spacings, with one plant for each planting point. Nitrogen (15 kg N/ha), phosphorous (20 kg P_2O_5 /ha) and potassium (25 kg K_2O /ha) fertilizers were applied just before seeds were sown. The rest of the N (45 kg/ha) was applied as a top dressing, 4 weeks after sowing. The field was irrigated uniformly at weekly intervals during the periods when there was no rain. Hand weeding and forking were done at one week from sowing and again at 4 weeks from sowing. Monocrotophos 60%, a broad spectrum insecticide was sprayed at a recommended dosage as a prophylactic measure at weekly intervals during the first 2 weeks and thereafter every fortnight. Marshall e.c. and Diazinon were applied to mungbean at the beginning of flowering to control pod-boring caterpillars.

Harvesting

The areas containing specific spacing combinations were harvested separately. There were sixty four (4³) such harvest areas, each containing at least 10 maize plants and a variable number of mungbean plants.

Mungbean was harvested in two picks at 60 and 75 days after planting (DAP). The seed yield was recorded at 13% moisture level.

Maize was harvested at 110 DAP. For yield evaluation, five randomly selected cobs were taken from each harvest area. The grain yield was calculated through yield component analysis. The reason for using yield component analysis in the estimation of maize yield was that earlier experiments on monocrop maize at the same site used this method. Since the

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average sole yield of maize is used in the computation of Land Equivalent Ratio (LER) the method of measuring yield has to be uniform. Another reason for using yield component analysis was to check if the yield components were affected at the higher and lower densities. In the present experiment, there were no marked differences in the yield components although there was a tendency for the grain size to be smaller at high densities. At higher densities than that used in the experiment, grain size can be seriously affected.

Evaluation of combined yield

The Land Equivalent Ratio (LER) (Mead and Willey, 1980) was used to measure the combined inter-crop yield in each harvest area. A single pair of constant divisors were used in the standardization of inter-crop yields. This was required to keep the distribution of the LERs approximately normal (Thattil, 1985). The pair of constant divisors were the sole crop yields of the two crops grown at their respective optimum monocropping spacing. As suggested by Mead and Stern (1980), these yields were obtained from the available yield data of previous experiments done at the same location. The average sole crop yields of past experiments conducted at Dodangolla were 6005 kg/ha for maize and 1391 kg/ha for mungbean. These values were used as the constant pair of divisors in the LER calculation.

Analysis of variance (ANOVA) was performed using the LER values as a measure of combined yield. Willey (1979) has argued that of the different indices of combined yield, LER based on a single pair of divisors is the most useful index with the additional advantage that it can be defined for any set of intercropping treatments. The other indices of combined yield such as relative crowding coefficient and aggressivity index can be used only for 'replacement series' experiment (Mead and Riley, 1981).

Although a conventional ANOVA may not be valid for systematic designs it can be used as a preliminary diagnostic tool of the significance or otherwise of the effects of the spacing factors (Willey and Rao, 1981). Furthermore Milne (1959) and Nelder (1962) point out that the risk from unsuspected periodic variation is negligible when using ANOVA if the land is chosen in such a way that avoids ridge—and—furrow land as is done for the present experimental site.

In order to find the optimum levels of the three spacing factors, a combined yield-density model developed by Thattil (1985) was used as the full model. Stepwise regression procedure was used to obtain the 'best' fitting model. The full model is given by

$$\text{LER} = b_0 + b_1 D_A + b_2 D_B + b_3 D_A^2 + b_4 D_B^2 + b_5 D_I + b_6 D_I^2 + b_7 D_A D_I + b_8 D_B D_I + b_9 D_A D_B + e$$

where, D_A = Level of intra-row spacing of maize; D_B = Level of intra-row spacing of mungbean; D_I = Level of inter-row spacing; $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8, b_9$, and e are regression coefficients and e = random error component.

RESULTS AND DISCUSSION

The LER values for each spacing combination are given in Table 1.

LER values greater than one and some even greater than two are shown for most of the spacing combinations. This indicates a greater efficiency of land utilization in intercropping when compared to monocropping. This advantage could either be due to the increased population pressure in the inter-crop as shown by Fisher (1977) or due to better and efficient use of resources by the inter-crop as shown by Willey and Osiru (1972). However, since the present study is a preliminary investigation of the response to spacing of a defined intercropping system, and not a comparison between sole and inter-crop performances, the above mentioned effects are not discussed in detail here.

Although an ANOVA is, strictly-speaking not appropriate for a systematic design, we can nevertheless perform one to use as a diagnostic tool for determining the importance of the different factors and interactions. The ANOVA of the yield data (using LER values as the index of combined yield) is shown in Table 2.

Significant differences exist for inter-row spacing and for intra-row spacing of maize, and intra-row spacing of mungbean. The interaction effects between spacing factors are non-significant,

The inter-row spacing controls the amount of light that comes into the canopy. When two morphologically dissimilar crops with different periods of maturity are inter-cropped, light is probably the most important factor that determines the yield (Willey, 1979). This explains the significant effect of inter-row spacing on total inter-crop yield.

Table 1. Total LER at different spacing combinations (Mean values of two replicates)

Inter-row spacing (cm)	Intra-row spacing (maize) (cm)															
	20				25				30				35			
	Intra-row spacing (mungbean) (cm)															
	5	8	11	14	5	8	11	14	5	8	11	14	5	8	11	14
25	1.98	1.88	1.60	1.58	2.55	2.31	2.29	2.16	2.03	2.03	2.03	1.97	1.66	1.61	1.53	1.54
30	2.29	2.09	1.85	1.92	2.17	1.82	1.74	1.83	1.75	1.46	1.28	1.37	1.53	1.34	1.11	1.22
35	2.07	1.95	1.76	1.77	1.57	1.43	1.24	1.28	1.48	1.32	1.14	1.19	1.29	1.04	0.93	0.91
40	1.61	1.41	1.19	1.25	1.27	1.05	1.00	1.06	1.33	1.09	1.00	0.90	1.13	0.98	0.87	0.85

Table 2. ANOVA of yield data (using LER values as the index of combined yield)

Source	D.F.	S.S.	M.S.	F
Replicate	1	0.001	0.001	
Treatment	63	23.076	0.366	
D _A	3	5.619	1.873	9.274***
D _B	3	2.154	0.718	3.555*
D _I	3	11.369	3.790	18.765***
D _A × D _B	9	0.075	0.008	0.042 ^{ns}
D _A × D _I	9	3.558	0.395	1.957 ^{ns}
D _B × D _I	9	0.134	0.015	0.074 ^{ns}
D _A × D _B × D _I	27	0.167	0.006	0.031 ^{ns}
Error	63	0.202	0.003	
Total	127	23.279		
C. V. (%)	3.70			

*** Significant at P=0.001

D_A =intra-row spacing for maize

** Significant at P=0.01

D_B =intra-row spacing for mungbean

* Significant at P=0.05

D_I =inter-row spacing between maize and mungbean^{ns} Not-significant

It is clear that maize because of its superior plant height and higher leaf area, largely determines the amount of light that the mungbean canopy receives. This makes maize the dominant crop in the present situation and as such the intra-row spacing has had a highly significant effect on the total inter-crop yield.

Mungbean being the other component crop in the system, does exert a significant effect on the total inter-crop yield when its intra-row spacing is varied. But this effect is not as marked as the effect of varying maize intra-row spacings and inter-row spacings. This is because of the fact that the contribution of mungbean to the total inter-crop yield is relatively small, as shown by Table 3.

The dominant effects of maize has been enhanced at higher densities, Normally, the optimum density for sole cropped maize is between 50,000 plants per hectare (pph) and 60,000 pph. But the present experiment involved maize densities up to 100,000 pph. Willey and Rao (1981) observed

Table 3. Contribution of mungbean to the total inter crop yield, calculated as the ratio of mungbean LER to the total LER

Inter-row spacing (cm)	Intra-row spacing (maize) (cm)															
	20				25				30				35			
	Intra-row spacing (mungbean) (cm)															
	5	8	11	14	5	8	11	14	5	8	11	14	5	8	11	14
25	0.25	0.24	0.16	0.12	0.21	0.20	0.13	0.15	0.27	0.27	0.19	0.22	0.34	0.27	0.23	0.27
30	0.30	0.17	0.14	0.16	0.31	0.26	0.18	0.14	0.42	0.34	0.22	0.26	0.45	0.37	0.28	0.25
35	0.22	0.24	0.10	0.12	0.29	0.29	0.15	0.14	0.44	0.31	0.24	0.22	0.44	0.33	0.22	0.17
40	0.32	0.28	0.15	0.12	0.34	0.30	0.21	0.16	0.45	0.35	0.31	0.22	0.41	0.33	0.28	0.17

with a chickpea/safflower inter-crop that, with the increase in plant density the dominant crop became more so. This has been the case with maize in the present situation. The other factor in favour of maize is the 1:1 row arrangement used in this experiment. As Huxley and Maingu (1978) argued, the effect of the dominant crop would be most significant at this row arrangement.

The 'best' fitting regression model is given below, with the standard errors in parenthesis.

$$\text{LER} = 3.983 + 0.047D_A - 0.14D_B - 0.0016D_A^2 + 0.0053D_B^2 - 0.053D_I$$

$$(0.516) \quad (0.036) \quad (0.036) \quad (0.0007) \quad (0.0018) \quad (0.0029)$$

The high adjusted R^2 value (0.81) indicates a good fit for the regression model. The optimum levels of the three spacing factors were obtained by taking partial derivatives of the estimated regression equation with respect to D_A , D_B and D_I .

It is seen that in the range of inter-row spacings tested, the total inter-crop yield has increased when the inter-row spacing is decreased. But as can be predicted, this trend would not go on continuously, because a point would be reached where the inter-crop competition would be so great that it would decrease the total inter-crop yield. Therefore the lowest inter-crop spacing tested which is 25 cm, could be recommended as the optimum. In terms of cultural practices too, it is not feasible to reduce inter-row spacing any further.

The estimated optimum intra-row spacing for maize is 14.53 cm which is less than the lowest spacing level tested (i.e. 20 cm). But due to intra-crop competition it is practically impossible to decrease the intra-row spacing for maize beyond 20 cm. Reducing beyond 20 cm may also lead to reduced size of cobs and grains. Therefore the optimum intra-row spacing for maize can be recommended as 18–20 cm.

The optimum plant density for maize based on the above estimates of optimum spacings is 100,000 pph. This is higher than the optimum density normally used in sole cropping. Putnam *et al.* (1985) obtained similar results with a maize-soybean inter-crop.

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The estimated optimum level of the intra-row spacing for mungbean (13.25 cm) is closer to the highest level tested (14 cm). The optimum plant density for mungbean on the basis of the above optimum spacing is 150,943 pph, which is lower than the density normally used in sole cropping. The above results indicate that a combination of low mungbean density and a high maize density is required to maximize the total inter-crop yield. This emphasizes the dominance of maize over mungbean in the range of densities investigated.

Practical significance of the results

As indicated elsewhere, this experiment is a preliminary screening of a wide range of spacing combinations with the objective of identifying a few favourable combinations. It actually has been a method of reducing the possible number of spacing combinations so that the few selected spacing combinations could be evaluated more thoroughly in conventional randomized block designs, in the next stage of the experimental programme. In the present maize $\times$ mungbean inter-crop, combinations of two levels of each of the spacing factors which are around the optimum levels estimated in this study could be chosen. The resulting eight (2^3) spacing combinations could be studied further in conventional block designs.

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