SPATIAL ARRANGEMENT AND DENSITY EFFECTS ON AN ANNUAL COTTON/COWPEA/MAIZE INTERCROP.
I. AGRONOMIC EFFICIENCY[1]

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ABSTRACT - Field experiments were conducted in Tucson, Arizona, to examine the effects of spatial arrangement and density on the agronomic efficiency of an annual cotton/cowpea/maize intercrop. The major results were: (1) the Land Equivalent Ratio (LER) for yield was higher in the spatial arrangement of single rows of cowpea and maize between single rows of cotton, (2) cowpea proportional LER for yield was higher in the spatial arrangements in which cowpea and maize were grown in separate rows, whereas maize proportional LER for yield was higher in the spatial arrangements in which cowpea and maize were grown in the same rows; (3) cotton and cowpea proportional LERs for yield decreased, whereas maize proportional LER for yield increased, as cowpea/maize density increased from 20,000 to 50,000 plants ha^{-1}; (4) LERs for biomass and yield were not affected as cotton density increased from 25,000 to 75,000 plants ha^{-1}, and (5) partial LERs for biomass and yield were higher than expected in the various treatments much more frequently for maize than for cotton or cowpea.

Index terms: intercrop system, single rows, separate rows, *Gossypium hirsutum* L., *Zea mays*, *Vigna unguiculata*.

EFEITOS DE ARRANJO ESPACIAL E DENSIDADE DE PLANTAS NO CONSÓRCIO ALGODÃO HERBÁCEO/CAUPI/MILHO.
I. EFICIÊNCIA AGRONÔMICA

RESUMO - Os efeitos de arranjo espacial e densidade de plantas na eficiência agronômica do consórcio algodão herbáceo/caupi/milho, foram examinados em Tucson, Arizona. Os principais resultados foram: (1) O índice de uso eficiente da terra (UET) foi mais alto no arranjo espacial de fileiras simples de caupi e milho entre fileiras simples de algodão. (2) O UET-proporcional do caupi foi maior nos arranjos espaciais onde o caupi e o milho foram plantados em fileiras separadas, enquanto que o UET-proporcional do milho foi maior nos arranjos onde o caupi e o milho foram plantados na mesma fileira. (3) Os UETs-proporcionais de caupi e algodão diminuíram com o aumento na densidade de caupi e milho (20.000 a 50.000 plantas/ha), enquanto, o UET-proporcional do milho aumentou. (4) Os UETs baseados tanto no rendimento como na biomassa não foram afetados com o aumento na população de algodão (25.000 a 75.000 plantas/ha). (5) Os UETs-parciais de cada cultura foram maiores do que os esperados na maioria dos tratamentos testados, com maior freqüência observada na cultura do milho.

Termos para indexação: consorciação de culturas, fileiras simples, fileiras separadas, *Gossypium hirsutum* L., *Zea mays*, *Vigna unguiculata*.

INTRODUCTION

Intercropping is the traditional means of producing fiber and food in tropical regions, where small farms and labor intensive operations predominate (Steiner, 1982; Gomez & Gomez, 1983; Francis, 1990; Bezerra Neto et al., 1991). For example, intercropping annual cotton with food crops, such as cowpea and maize, is a preferred practice among small farmers in the semiarid tropics of Northeast Brazil (Barreiro Neto et al., 1981; Zaffaroni & Azevedo, 1982; Morgado & Rao, 1985; Beltrão et al., 1986b). Among other potential benefits, intercropping appears to maximize land use and minimize the risk of losing the entire crop yield (Mercado, 1987).

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The productivity and efficiency of intercrops can be influenced by factors such as the spatial arrangement and densities of the component crops (Willey & Osiru, 1972; Willey, 1979; Rao, 1986; Ofori & Stern, 1987a, 1987b). Bezerra Neto et al. (1991) studied the effects of spatial arrangement and cowpea density on the efficiency of an annual cotton/cowpea intercrop in Northeast Brazil, and reported that the land equivalent ratio was highest for the intercrop in which double cotton rows alternated with single cowpea rows, with cowpea having a density of 40,000 plants ha^{-1}. Beltrão et al. (1986a) studied the effects of spatial arrangement on an annual cotton/sorghum intercrop in Northeast Brazil, and concluded that the intercrop in which double cotton rows alternated with single sorghum rows, with a 1 m spacing between cotton and sorghum rows, was the most efficient in terms of land use.

Several indices have been developed for evaluating the productivity and efficiency of intercrops, based on comparisons of absolute or relative yields (Mead & Riley, 1982; Steiner, 1982; Willey, 1985; Beltrão et al., 1986c). The most frequently used index is the land equivalent ratio (LER), which provides a measure of agronomic, or biological, efficiency (Francis, 1990). Several methods have been proposed for calculating LER that use different sole crop values as standardization factors. These include the sole crop yields in each block or replication (Fisher, 1977), the sole crop yields at each treatment level in studies involving graded levels of a factor such as fertilizer or herbicide (Mead & Willey, 1980), the average sole crop yields in the entire experiment (Mead & Stern, 1980; Oyejola & Mead, 1982; Federer & Schwager, 1983), and the best sole crop yields in the entire experiment (Huxley & Maingu, 1978; Mead & Willey, 1980). The most appropriate method depends, in part, on the aims of the experiment (Ofori & Stern, 1987a).

The objective of the present research was to analyze the effects of spatial arrangement and density on the agronomic efficiency of an annual cotton/cowpea/maize intercrop, measured in terms of biomass and yield. Intercrop efficiency was assessed in terms of LER, with component crop performances being evaluated in terms of proportional LER and partial LER. An additional objective was to compare methods for calculating LER using either the sole crop biomass and yield in each block or the average sole crop biomass and yield across blocks.

MATERIALS AND METHODS

Site and Cultivars

Two experiments were conducted at the West Campus Agricultural Center of the University of Arizona in Tucson, Arizona, USA (110° 57' W longitude, 32° 15' N latitude, and 726 m elevation). Both experiments were established in a Grabe fine loam (mixed [calcareous], thermic, typic torrifluvent). Physical and chemical soil analyses of a composite of seven samples, taken before sowing at two depths (0-20 and 20-40 cm), were performed for both experiments. Soil test values for the 0-20 and 20-40 cm depths were similar. The mean values for Experiment I were: 47% sand, 34% silt, and 19% clay texture, and 0.11% total N, 0.12% total P, 0.78% total K, 0.90% total C, 1.76% organic matter, 0.20 meq g^{-1} cation exchange capacity, and pH 8.0. The mean values for Experiment II were: 45% sand, 33% silt, and 22% clay texture, and 0.11% total N, 0.05% total P, 0.51% total K, 0.56% total C, 1.11% organic matter, 0.13 meq g^{-1} cation exchange capacity, and pH 8.2. Daily rainfall and maximal and minimal air temperatures during the cropping season, measured in a weather station about 40 m from the experimental plots, are shown in Fig. 1. The annual cotton (*Gossypium hirsutum* L.), cowpea (*Vigna unguiculata* (L.) Walp), and maize (*Zea mays* L.) cultivars were Deltapine 20 (a short season, bushy, smooth leaf cultivar), CB 46 (a short season, erect, bushy, white-seeded cultivar) and Pioneer Hybrid 3183 SX (a normal season, mid-tall, flaccid horizontal leaf cultivar), respectively.

Experimental Design

Experiment I

Experiment I analyzed the effects of spatial arrangement and cowpea/maize density on the efficiency of an annual cotton/cowpea/maize intercrop. The experimental design was a randomized complete block with 16 treatments and 3 replications. Treatments were combined in an unconfounded 4 x 4 factorial, which consisted of 4 spatial arrangements of cotton, cowpea, and maize crossed with 4 cowpea/maize densities (total densities of 20,000, 30,000, 40,000, and 50,000 plants ha^{-1}, with each total density consisting of 50% cowpea and 50% maize), according to the following scheme. Cotton density was

Single rows of cowpea and maize between single rows of cotton	Double rows of cowpea and maize between double rows of cotton
x c x m x c x m	x x c m x x c m
x c x m x c x m	x x c m x x c m
x c x m x c x m	x x c m x x c m
x c x m x c x m	x x c m x x c m
x c x m x c x m	x x c m x x c m
x c x m x c x m	x x c m x x c m
Single rows of cowpea--maize between single rows of cotton	**Double rows of cowpea--maize between double rows of cotton**
x c x c x c x c	x x c c x x c c
x m x m x m x m	x x m m x x m m
x c x c x c x c	x x c c x x c c
x m x m x m x m	x x m m x x m m
x c x c x c x c	x x c c x x c c
x m x m x m x m	x x m m x x m m

x = cotton; c = cowpea; m = maize.

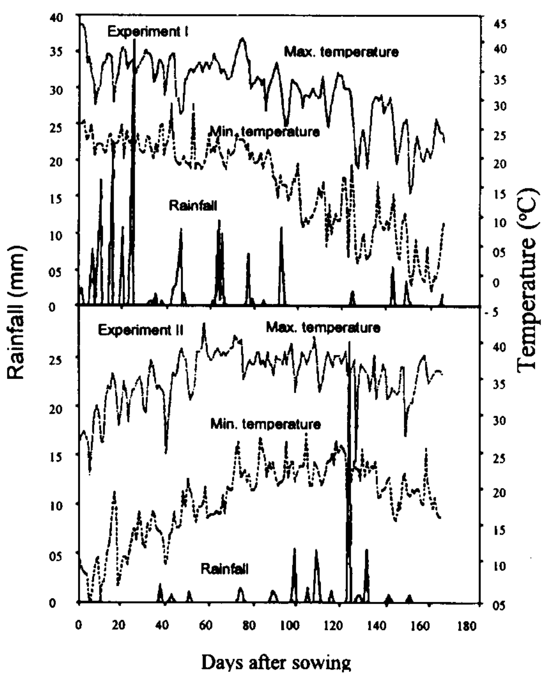

FIG. 1. Daily rainfall and maximal and minimal air temperatures during the cropping season in Experiment I (1990) and Experiment II (1991).

held constant at 50,000 plants ha^{-1}. The area occupied by cotton, cowpea, and maize in each intercrop was 50%, 25%, and 25%, respectively. Additionally, plots with cotton, cowpea, and maize in sole crop, at densities of 50,000, 40,000, and 40,000 plants ha^{-1}, respectively, were planted randomly in each block. Intercrop and sole crop densities were representative of those used in Northeast Brazil. The spacing between crop rows was 1 m. Within rows of cotton in intercrop and sole crop, the spacing between holes was 0.20 m. Within rows of cowpea and maize in intercrop, the spacing between holes varied with density; it was 0.50, 0.33, 0.25, and 0.20 m for densities of 20,000, 30,000, 40,000, and 50,000 plants ha^{-1}, respectively. Within rows of cowpea and maize in sole crop, the spacing between holes was 0.50 m. In the intercrops, cotton, cowpea, and maize had 2 plants $hole^{-1}$. In the sole crops, cowpea and maize had 2 plants $hole^{-1}$, and cotton had 1 plant $hole^{-1}$. Total and harvested plot sizes were 50 and 24 m^2, respectively.

All treatments in Experiment I were planted on 2 July 1990. At planting, a base fertilization of 45 kg ha^{-1} of N and 56 kg ha^{-1} of P_2O_5 was applied to all plots. Sowing was done by hand in dry soil and was followed by irrigation with enough water to reach field capacity. Three weeks later, all treatments were thinned to the desired population. The experiment received supplemental furrow-irrigations sufficient to fill the soil to field capacity 30, 39, 57, 91, 101, 111, and 124 days after sowing (DAS). The experiment was weeded by hand and sprayed whenever needed, maintaining it free of insects and diseases.

Biomass (above-ground vegetative and reproductive material) and yield of each crop were measured in each treatment. For cotton, the biomass of 10 plants $plot^{-1}$ was measured 120 DAS. The plants were cut at ground level, placed in large plastic bags, and oven-dried at 70°C until a constant weight was obtained. Dry weight biomass was calculated in t ha^{-1}. Cotton (60 plants $plot^{-1}$) was picked four times: 130-133, 141-144, 157-159, and 170-171 DAS. Seed yield was calculated in t ha^{-1}.

For cowpea, the biomass of 6 plants $plot^{-1}$ was measured 90 DAS. The procedure for harvesting and processing the plants was the same as described for cotton. Cowpea (12, 18, 24, and 30 plants $plot^{-1}$ for cowpea/maize densities of 20,000, 30,000, 40,000, and 50,000 plants ha^{-1}, respectively) was harvested for yield 81 and 87 DAS. The seed was oven-dried at 70°C, with yield being calculated in t ha^{-1} following correction to 13% moisture.

For maize, the biomass of 6 plants $plot^{-1}$ was measured 120 DAS. The procedure for harvesting and processing the plants was the same as described for cotton. Maize (12, 18, 24, and 30 plants $plot^{-1}$ for cowpea/maize densities of 20,000, 30,000, 40,000, and 50,000 plants ha^{-1}, respectively) was harvested for yield 120 DAS. The seed was oven-dried at 70°C, with yield being calculated in t ha^{-1} following correction to 14% moisture.

Experiment II

Experiment II analyzed the effects of cotton density and cowpea/maize density on the efficiency of an annual cotton/cowpea/maize intercrop. The experimental design was a randomized complete block with 11 treatments and 3 replications. Treatments were combined in an unconfounded 5 x 2 + 1 design. The 5 x 2 factorial consisted of 5 cotton densities (25,000, 32,500, 50,000, 62,500, and 75,000 plants ha^{-1}) crossed with 2 cowpea/maize densities (total densities of 30,000 and 50,000 plants ha^{-1}, with each total density consisting of 50% cowpea and 50% maize). The 1 additional treatment had a cotton density of 50,000 plants ha^{-1} and a cowpea/maize density of 50,000 plants ha^{-1}. In all treatments, the spatial arrangement consisted of single rows of cowpea and maize between single rows of cotton, which was the spatial arrangement giving the higher LER for yield in Experiment I. The area occupied by cotton, cowpea, and maize in each intercrop was 50%, 25%, and 25%, respectively. As in Experiment I, plots with cotton, cowpea, and maize in sole crop, at densities of 50,000, 40,000, and 40,000 plants ha^{-1}, respectively, were planted randomly in each block. The spacing between crop rows was 1 m. Within rows of cotton in all intercrops except the additional treatment, the spacing between holes varied with density; it was 0.20, 0.13, 0.10, 0.08, and 0.066 m for densities of 25,000, 37,500, 50,000, 62,500, and 75,000 plants ha^{-1}, respectively. Within rows of cotton in the additional treatment and in sole crop, the spacing between holes was 0.20 m. Within rows of cowpea and maize in intercrop, the spacing between holes was 0.33 and 0.20 m for densities of 30,000 and 50,000 plants ha^{-1}, respectively. Within rows of cowpea and maize in sole crop, the spacing between holes was 0.50 m. In the intercrops and sole crops, cowpea and maize had 2 plants $hole^{-1}$. In all intercrops except the additional treatment and in the sole crop, cotton had 1 plant $hole^{-1}$. In the additional treatment, cotton had 2 plants $hole^{-1}$, as in the intercrops in Experiment I. The additional treatment was thus a replicate of the intercrop in Experiment I whose spatial arrangement and cowpea/maize density resulted in the highest LER for yield. Total and harvested plot sizes were 50 m^2 and 24 m^2, respectively.

All treatments in Experiment II were planted on April 23, 1991. Fertilization, sowing, and thinning were the same as in Experiment I. The experiment received supplemental furrow-irrigations sufficient to fill the soil to field capacity 13, 20, 27, 34, 41, 48, 55, 62, 69, 76, 87, 94, 107, and 114 DAS. Weed, insect, and disease management was similar to that in Experiment I.

Biomass and yield of each crop were measured in each treatment as in Experiment I. For cotton, the biomass of 10 plants $plot^{-1}$ was measured 120 DAS. Cotton (30, 45, 60, 75, and 90 plants $plot^{-1}$ for cotton densities of 25,000, 32,500, 50,000, 62,500, and 75,000 plants ha^{-1}, respectively) was picked four times: 124-127, 134-137, 149--152, and 161-162 DAS.

For cowpea, the biomass of 6 plants $plot^{-1}$ was measured 90 DAS. Cowpea (18 and 30 plants $plot^{-1}$ for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1}, respectively) was harvested for yield 90 DAS.

For maize, the biomass of 6 plants $plot^{-1}$ was measured 120 DAS. Maize (18 and 30 plants $plot^{-1}$ for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1}, respectively) was harvested for yield 121 DAS.

Statistical Analysis

In both experiments, intercrop efficiency was assessed in terms of LER, where

$LER = I_{cotton}/S_{cotton} + I_{cowpea}/S_{cowpea} + I_{maize}/S_{maize}$,

with I and S being the biomass or yield of the component crops in intercrop and sole crop, respectively. Sole crop biomass and yield were standardized either by block (BB) or averaged across blocks (AB). Component crop performances were assessed in terms of proportional LER and partial LER. For each component crop, partial LER = I/S, and proportional LER = (I/S)/LER.

In both experiments, the effects of the treatment factors on LER and proportional LER were assessed with univariate analyses of variance (Oyejola & Mead, 1982; Oyejola, 1989). With respect to the assumptions of the analyses, the data were checked for: (1) the normality of residuals with residual plots and the K-S test through the SPSS package (Norusis, 1990), (2) the homogeneity of variances with the Bartlett-Box F test and Cochran's C test through the SPSS package (Norusis, 1990), and (3) the comparison precision with the coefficient of variation (Oyejola & Mead, 1982; Oyejola, 1989). In the analysis of variance in Experiment II, the additional treatment, in which cotton had 2 plants $hole^{-1}$, was contrasted with the treatment having the same cotton density (50,000 plants ha^{-1}) and cowpea/maize density (50,000 plants ha^{-1}), but in which cotton had 1 plant $hole^{-1}$. The latter treatment in this contrast is denoted the special treatment in the tables.

The effects of spatial arrangement in Experiment I were further assessed with pairwise multiple comparisons based on Duncan's new multiple range test (Pimentel-Gomes, 1987). The effects of cowpea/maize density in Experiment I and cotton density in Experiment II were further assessed with a least squares curve-fitting procedure through the Table Curve package (Jandel Scientific, 1991). Curve selection was based on: (1) the adjusted R^2, (2) the F-statistic of R^2, and (3) the parameters in the equation. The effects of cowpea/maize density in Experiment II were further assessed with t-tests.

In both experiments, observed and expected partial LERs for each crop were compared with t-tests (Jagannath & Sunderaraj, 1987).

RESULTS AND DISCUSSION

LER and Proportional LER

Experiment I

Spatial arrangement had a significant effect on LER for yield, and cowpea/maize density had significant effects on LERs for biomass and yield (Table 1). LER for yield was higher in the spatial arrangement SR cowpea & maize between SR cotton (Table 2). LERs for biomass and yield increased with increasing cowpea/maize density (Fig. 2). The effects of the treatment factors were similar for the two methods of standardizing sole crop biomass and yield (Tables 1 and 2, Fig. 2).

Spatial arrangement had a significant effect on cotton proportional LER for biomass, and cowpea/maize density had significant effects on cotton proportional LERs for biomass and yield (Table 3). Proportional LER for biomass was lower in the spatial arrangement SR cowpea-maize between SR cotton (Table 4). Proportional LERs for biomass and yield decreased with increasing cowpea/maize density (Fig. 3).

Spatial arrangement had significant effects on cowpea proportional LERs for biomass and yield, and cowpea/maize density had a significant effect on cowpea proportional LER for yield (Table 3). Proportional LERs for biomass and yield were higher in the spatial arrangements SR cowpea & maize between SR cotton and DR cowpea & maize between DR cotton (Table 4). Proportional LER for yield decreased with increasing cowpea/maize density (Fig. 4).

Spatial arrangement and cowpea/maize density had significant effects on maize proportional LER for yield (Table 3). Proportional LER for yield was higher in the spatial arrangements SR cowpea-maize between SR cotton and DR cowpea-maize between DR cotton (Table 4). Proportional LER for yield increased with increasing cowpea/maize density (Fig. 5). A significant interaction between spatial arrangement and cowpea/maize density existed for maize proportional LER for biomass (Table 3). In

TABLE 1. F-values from analyses of variance of LERs for biomass and yield in Experiments I and II.

Source of variation	df	LER[1]			
		Biomass		Yield	
		BB	AB	BB	AB
Experiment I					
Spatial arrangement	3	0.84	0.92	3.25*	3.30*
Cowpea/maize density	3	3.19*	3.61*	7.12**	7.31**
Interaction	9	0.62	0.86	1.34	1.32
CV (%)		12.4	12.8	13.8	13.9
Experiment II					
Cotton density	4	0.60	0.52	0.57	0.69
Cowpea/maize density	1	7.17*	7.49*	1.23	0.80
Interaction	4	0.74	0.57	0.42	0.39
Additional x Special treatment	1	0.00	0.00	0.02	0.00
CV (%)		14.2	11.9	13.2	13.6

[1] Sole crop biomass and yield were standardized either by block (BB) or averaged across blocks (AB).
* $P \leq 0.05$.
** $P \leq 0.01$.

TABLE 2. Effects of spatial arrangement on LER for yield in Experiment I.

Spatial arrangement[1]	LER for yield[2]	
	BB	AB
SR cowpea & maize between SR cotton	1.12a	1.12a
DR cowpea & maize between DR cotton	1.01b	1.01b
SR cowpea-maize between SR cotton	0.98b	0.97b
DR cowpea-maize between DR cotton	0.99b	0.98b

[1] SR = single row; DR = double rows.
[2] Within a column, means with different letters differ significantly at $P \leq 0.05$; sole crop biomass and yield were standardized either by block (BB) or averaged across blocks (AB).

TABLE 3. F-values from analyses of variance of cotton, cowpea, and maize proportional LERs for biomass and yield in Experiments I and II.

Source of variation	df	Proportional LER[1]					
		Cotton		Cowpea		Maize	
		Biomass	Yield	Biomass	Yield	Biomass	Yield
Experiment I							
Spatial arrangement	3	3.05*	1.86	23.99**	25.38**	16.97**	21.06**
Cowpea/maize density	3	41.13**	22.80**	2.04	3.92*	38.69**	51.90**
Interaction	9	2.06	1.00	0.71	0.23	2.51*	1.78
CV (%)		10.4	9.6	22.1	18.9	10.4	12.5
Experiment II							
Cotton density	4	2.86	0.83	1.43	0.84	1.67	3.68*
Cowpea/maize density	1	11.43**	10.00**	2.85	3.01	6.66**	12.00**
Interaction	4	2.85	0.51	2.85	1.33	1.67	1.00
Additional x Special treatment	1	0.21	1.85	0.49	0.15	0.16	1.42
CV (%)		12.0	13.8	23.3	13.4	15.1	13.6

[1] Sole crop biomass and yield were standardized by block (BB).
* $P \leq 0.05$.
** $P \leq 0.01$.

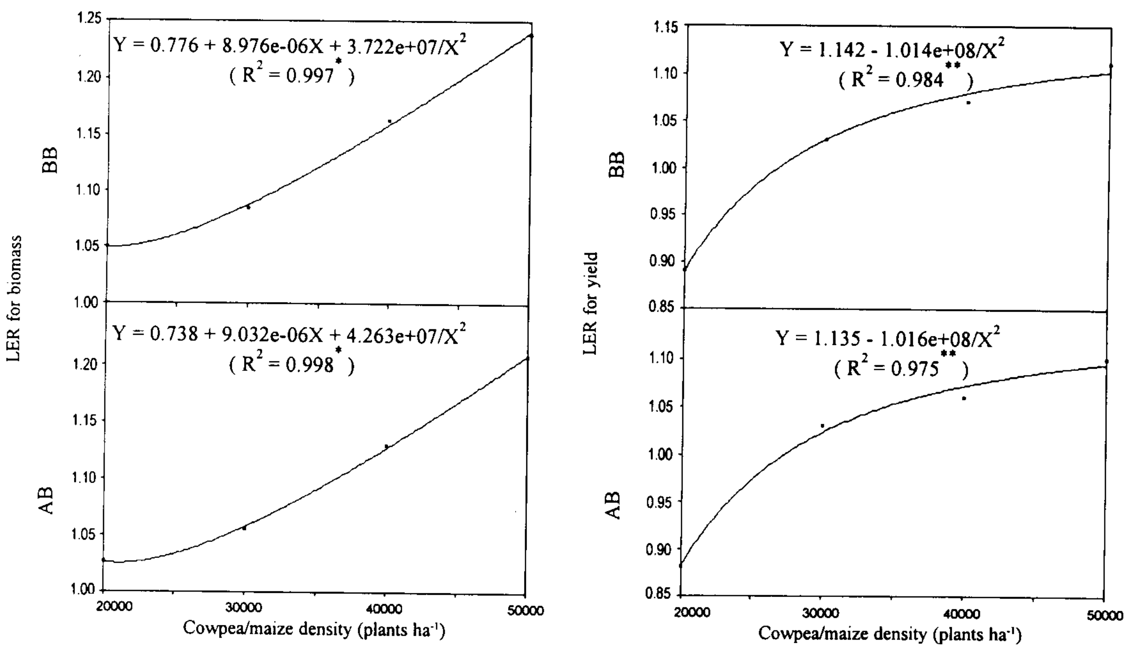

FIG. 2. Regressions of land equivalent ratio (LER) for biomass and yield on cowpea/maize density in Experiment I. Sole crop biomass and yield were standardized either by block (BB) or averaged across blocks (AB). * $P \leq 0.05$. ** $P \leq 0.01$.

the interaction partition, significant effects of cowpea/maize density occurred only within the spatial arrangements SR cowpea & maize between SR cotton and DR cowpea-maize between DR cotton. Proportional LER for biomass increased with increasing cowpea/maize density within these two spatial arrangements (Fig. 6).

TABLE 4. Effects of spatial arrangement on cotton proportional LER for biomass, cowpea proportional LERs for biomass and yield, and maize proportional LER for yield in Experiment I.

Spatial arrangement[1]	Proportional LER[2]			
	Cotton	Cowpea		Maize
	biomass	Biomass	Yield	yield
SR cowpea & maize between SR cotton	0.52a	0.17a	0.18a	0.31b
DR cowpea & maize between DR cotton	0.51a	0.16a	0.18a	0.32b
SR cowpea-maize between SR cotton	0.47b	0.12b	0.11b	0.41a
DR cowpea-maize between DR cotton	0.51a	0.09b	0.10b	0.40a

[1] SR = single row; DR = double rows.
[2] Within a column, means with different letters differ significantly at P≤ 0.05; sole crop biomass and yield were standardized by block (BB).

Experiment II

Cowpea/maize density had a significant effect on LER for biomass (Table 1), with LER for biomass being higher at the higher cowpea/maize density. Mean LERs for biomass for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 1.21 and 1.38, respectively, for the BB standardization method, and 1.18 and 1.35, respectively, for the AB standardization method. As in Experiment I, the effects of the treatment factors were similar for the two methods of standardizing sole crop biomass and yield (Table 1).

Cowpea/maize density had significant effects on cotton proportional LERs for biomass and yield (Table 3), with proportional LERs for biomass and yield being higher at the lower cowpea/maize density. Mean proportional LERs for biomass for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 0.53 and 0.43, respectively (for the BB standardization method). Mean proportional LERs for yield for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 0.43 and 0.36, respectively (for the BB standardization method).

Cotton density and cowpea/maize density had no significant effects on cowpea proportional LERs for biomass and yield (Table 3).

Cotton density had a significant effect on maize proportional LER for yield, and cowpea/maize density had significant effects on maize proportional LERs for biomass and yield (Table 3). Proportional

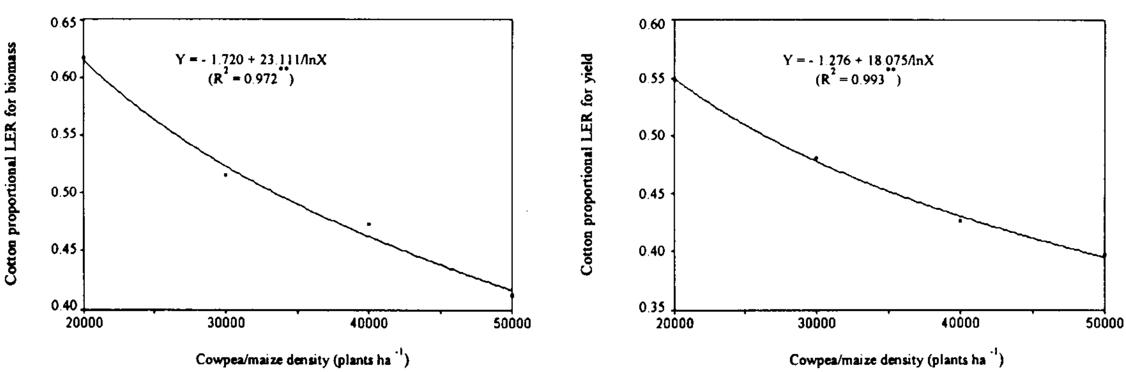

FIG. 3. Regressions of cotton proportional land equivalent ratio (LER) for biomass and yield on cowpea/maize density in Experiment I. Sole crop biomass and yield were standardized by block (BB). ** P ≤ 0.01.

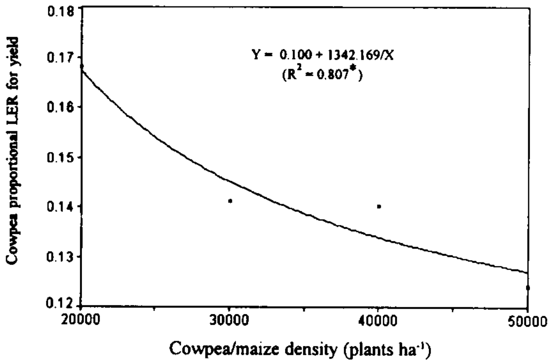

FIG. 4. Regression of cowpea proportional land equivalent ratio (LER) for yield on cowpea/maize density in Experiment I. Sole crop yield was standardized by block (BB). * P $\leq$ 0.05.

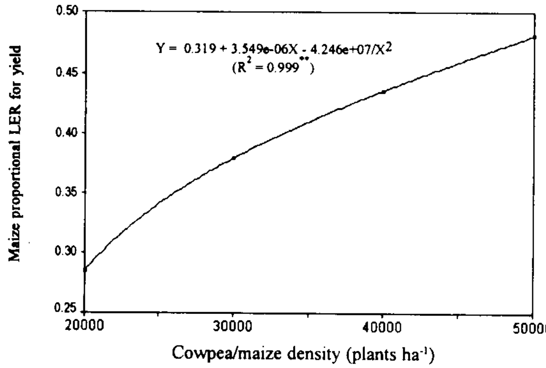

FIG. 5. Regression of maize proportional land equivalent ratio (LER) for yield on cowpea/maize density in Experiment I. Sole crop yield was standardized by block (BB). ** P $\leq$ 0.01.

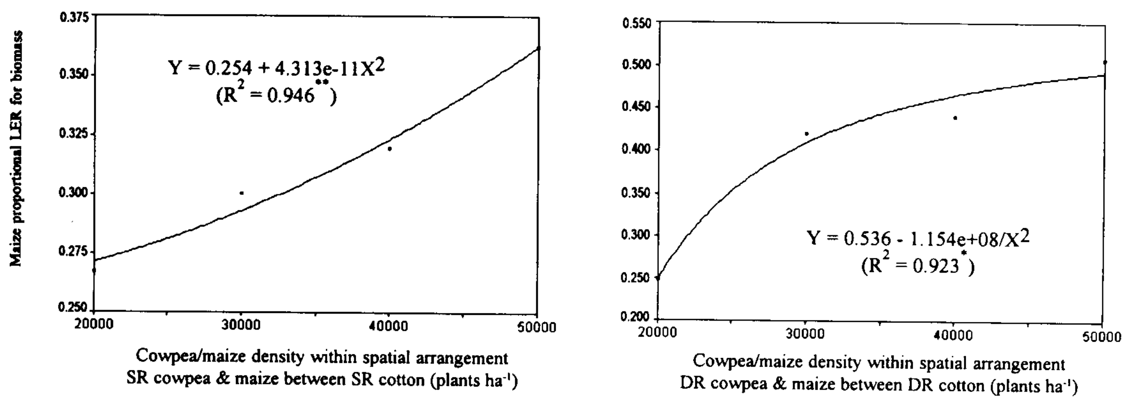

FIG. 6. Regressions of maize proportional land equivalent ratio (LER) for biomass on cowpea/maize density within two spatial arrangements in Experiment I. Sole crop biomas was standardized by block (BB). * P $\leq$ 0.05. ** P $\leq$ 0.01.

LER for yield was highest at intermediate cotton densities (Fig. 7). Proportional LERs for biomass and yield were higher at the higher cowpea/maize density. Mean proportional LERs for biomass for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 0.23 and 0.27, respectively (for the BB standardization method). Mean proportional LERs for yield for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 0.34 and 0.40, respectively (for the BB standardization method).

There were no significant differences in LERs and proportional LERs for biomass and yield between the additional treatment and the special treatment (Tables 1 and 3, Figs. 8 and 9).

Partial LER

Experiment I

Cotton partial LER for biomass was significantly higher than expected in the spatial arrangements SR cowpea & maize between SR cotton and DR cowpea & maize between DR cotton, and at a cowpea/maize density of 20,000 plants ha^{-1} (Table 5). Maize partial LERs for biomass and yield were significantly higher than expected in all spatial arrangements, and

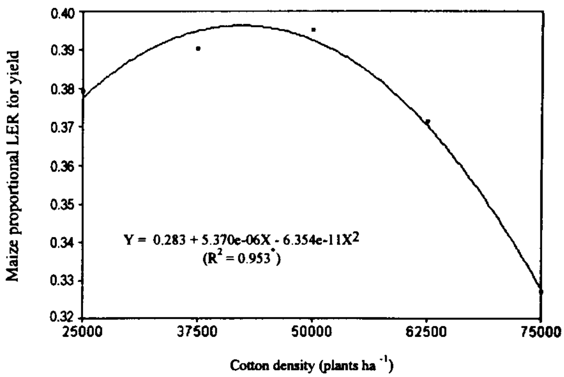

FIG. 7. **Regression of maize proportional land equivalent ratio (LER) for yield on cotton density in Experiment II. Sole crop yield was standardized by block (BB). * P ≤ 0.05.**

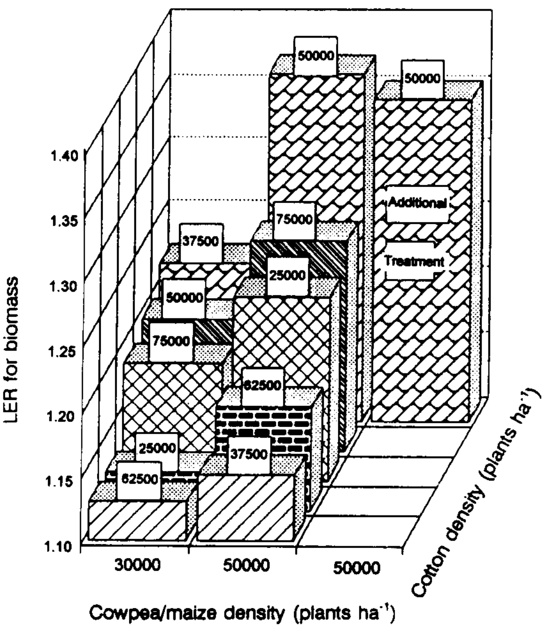

FIG. 8. **Responses of LER for biomass to cotton density and cowpea/maize density in Experiment II. Sole crop biomass was standardized by block (BB).**

at cowpea/maize densities of 30,000, 40,000, and 50,000 plants ha^{-1} (Table 5). In addition, maize partial LER for biomass was significantly higher than expected at a cowpea/maize density of 20,000 plants ha^{-1} (Table 5).

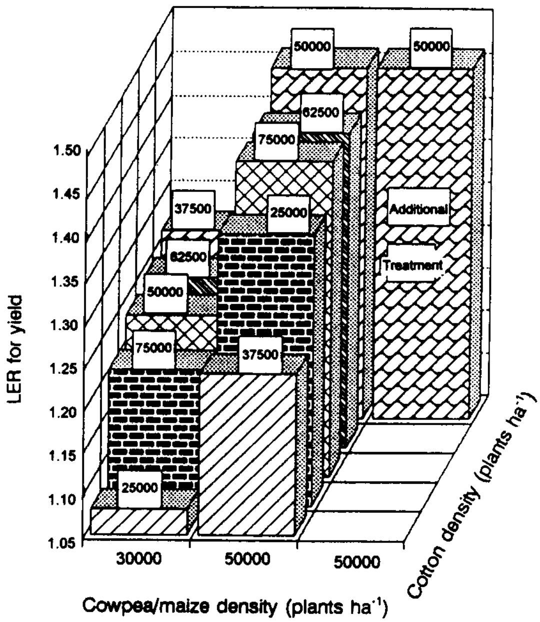

FIG. 9. **Responses of LER for yield to cotton density and cowpea/maize density in Experiment II. Sole crop yield was standardized by block (BB).**

Experiment II

Cotton partial LER for biomass was significantly higher than expected at all cotton densities except 25,000 plants ha^{-1}, and at both cowpea/maize densities (Table 5). Cowpea partial LER for biomass was significantly higher than expected at cotton densities of 25,000, 37,500, and 50,000 plants ha^{-1}, and at both cowpea/maize densities (Table 5). Maize partial LERs for biomass and yield were significantly higher than expected at all cotton densities and at both cowpea/maize densities (Table 5).

For this annual cotton/cowpea/maize intercrop, LER for yield was higher in the spatial arrangement of single rows of cowpea and maize between single rows of cotton. This arrangement may have minimized the effects of interspecific competition among the three crops. This result is similar to that of Bezerra Neto et al. (1991), who found that LER for yield in a cotton/cowpea/sorghum intercrop in Northeast Brazil was higher in the spatial arrangement of single rows of cowpea and sorghum between single rows of cotton.

TABLE 5. Effects of spatial arrangement, cowpea/maize density, and cotton density on cotton, cowpea, and maize partial LERs for biomass and yield in Experiments I and II.

Treatment	Partial LER[1]					
	Cotton		Cowpea		Maize	
	Biomass	Yield	Biomass	Yield	Biomass	Yield
			Experiment I			
Spatial arrangement						
- SR cowpea & maize between SR cotton	0.64**	0.54	0.20	0.20	0.38**	0.38**
- DR cowpea & maize between DR cotton	0.59*	0.45	0.19	0.18	0.37**	0.37**
- SR cowpea-maize between SR cotton	0.52	0.43	0.13	0.11	0.46**	0.45**
- DR cowpea-maize between DR cotton	0.57	0.46	0.11	0.09	0.44**	0.44**
Cowpea/maize density						
- 20,000 plants ha^{-1}	0.70**	0.49	0.14	0.15	0.28*	0.25
- 30,000 plants ha^{-1}	0.56	0.51	0.14	0.15	0.38**	0.38**
- 40,000 plants ha^{-1}	0.55	0.46	0.17	0.15	0.44**	0.46**
- 50,000 plants ha^{-1}	0.51	0.44	0.18	0.14	0.55**	0.54**
			Experiment II			
Cotton density						
- 25,000 plants ha^{-1}	0.53	0.45	0.36*	0.27	0.33*	0.46**
- 37,500 plants ha^{-1}	0.58*	0.50	0.35*	0.30	0.32*	0.38**
- 50,000 plants ha^{-1}	0.65**	0.49	0.36*	0.28	0.34*	0.51**
- 62,500 plants ha^{-1}	0.73**	0.44	0.31	0.26	0.30*	0.45**
- 75,000 plants ha^{-1}	0.67**	0.53	0.30	0.29	0.35*	0.40**
Cowpea/maize density						
- 30,000 plants ha^{-1}	0.64**	0.51	0.30*	0.29	0.28*	0.37**
- 50,000 plants ha^{-1}	0.62**	0.46	0.38**	0.28	0.38*	0.51**

[1] Sole crop biomass and yield were standardized by block (BB); expected partial LERs for biomass and yield were 0.50 for cotton, 0.25 for cowpea, and 0.25 for maize.
* Significantly higher than expected ($P \leq 0.05$).
** Significantly higher than expected ($P \leq 0.01$).

Cowpea proportional LER for yield was higher in the spatial arrangements in which cowpea and maize were grown in separate rows, whereas maize proportional LER for yield was higher in the spatial arrangements in which cowpea and maize were grown in the same rows. These patterns presumably reflected the relative importance of intraspecific and interspecific competition between the two food crops. With greater intraspecific competition, the proportional contribution of cowpea was enhanced and that of maize was reduced. With greater interspecific competition, in contrast, the proportional contribution of cowpea was reduced and that of maize was enhanced. Under the latter conditions, the taller cereal appears to have competed more successfully for light, as has been commonly observed in mixtures of legumes and cereals (Ofori & Stern, 1987a).

Cotton proportional LER for biomass was lower in the spatial arrangement of single rows of cowpea-maize between single rows of cotton. In this arrangement, every cotton row was bordered on both sides by rows containing maize, which may have maximized interspecific competition with the taller cereal, especially for light.

LERs for biomass and yield increased as cowpea/maize density increased from 20,000 to 50,000 plants ha^{-1}. Thus, the efficiency of this annual cotton/cowpea/maize intercrop was enhanced by higher densities of the food crops. With respect to yield, the enhanced efficiency was accompanied by decreases in cotton and cowpea proportional LERs, but an increase in maize proportional LER. Hence, the relative contribution of the cereal to intercrop efficiency was greater at higher food-crop densities.

Cotton density had no effects on LERs for biomass and yield, and no effects on cotton proportional LERs for biomass and yield. Thus, neither the efficiency of the intercrop nor the relative contribution of cotton was influenced by fiber-crop density, in sharp contrast to the influence of food-crop density.

Partial LERs for biomass and yield were higher than expected in the various treatments much more frequently for maize than for cotton or cowpea, suggesting that maize provided a much greater contribution to intercrop efficiency than did cotton or cowpea. The results also suggest that maize may have used environmental resources more effectively than cotton or cowpea. Willey & Osiru (1972) reported that when the component crops are present in approximately equal numbers, intercrop efficiency appears to be determined by the more aggressive crop, which is usually the cereal.

The alternative methods for calculating LER, using either the sole crop biomass and yield in each block or the average sole crop biomass and yield across blocks, gave similar results. As described in detail in Bezerra Neto (1993), this similarity existed not only for LER but also for proportional LER and partial LER. This similarity was presumably due to the small field variation among blocks. This result differs in part from that of Mead (1990), who showed that LERs within an analysis of variance are usually valid provided that a single set of divisors is used over the entire set of intercrop plot values.

With respect to recommendations, the results of these experiments suggest that consistently high LERs for biomass and yield may be obtained for annual cotton/cowpea/maize intercrops in which single rows of cowpea and maize alternate with single rows of cotton, and in which cowpea/maize density is 50,000 plants ha^{-1}. The degree to which these results may be generalized to different climates, soils, and cultivars remains to be assessed.

CONCLUSIONS

1. The biological efficiencies of cotton/cowpea/maize intercrops are influenced by the spatial geometry and densities of the component crops.

2. Intercrop density of plants and spatial geometry of the crops are important factors in minimizing interspecific competition for water, light and other resources.

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