SPATIAL ARRANGEMENT AND DENSITY EFFECTS ON AN ANNUAL COTTON/COWPEA/MAIZE INTERCROP.

II. YIELD AND BIOMASS[1]

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ABSTRACT - Field experiments were conducted in 1990 and 1991 in Tucson, Arizona, to examine the effects of spatial arrangement and density on yield and biomass of an annual cotton/cowpea/maize intercrop. In the 1990 experiment, treatments were combined in an unconfounded 4 x 4 factorial, which consisted of four spatial arrangements of cotton, cowpea, and maize crossed with four cowpea/maize densities. In the 1991 experiment, treatments were combined in an unconfounded 5 x 2 + 1 factorial, which consisted of five densities of cotton crossed with two densities of cowpea and maize, plus one additional treatment. The results of these experiments indicate that component-crop yield and biomass in an annual cotton/cowpea/maize intercrop can be significantly affected by the manipulation of spatial arrangement and density as management factors. The most appropriate arrangements and densities in particular circumstances depend on either the combined intercrop yield and biomass or the yield and biomass of a specific component crop that is more highly valued.

Index terms: *Gossypium hirsutum, Vigna unguiculata, Zea mays,* crop growth rate.

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

II. RENDIMENTO E BIOMASSA

RESUMO - Experimentos de campo foram conduzidos em Tucson, Arizona, USA, nos anos agrícolas de 1990 e 1991, visando estudar os efeitos de arranjo espacial e densidade de plantas no rendimento e na biomassa de um consórcio algodão herbáceo/caupi/milho. No experimento de 1990, estudaram-se quatro arranjos espaciais de algodão, caupi e milho, e quatro densidades de caupi e milho em um delineamento fatorial 4 x 4. No experimento de 1991, estudaram-se cinco densidades de algodão e duas densidades de caupi e milho, mais um tratamento adicional, em um delineamento fatorial 5 x 2 + 1. O rendimento e a biomassa das culturas componentes em um consórcio algodão herbáceo/caupi/ milho podem ser afetados de maneira significativa pelo manejo do arranjo espacial e da densidade de plantas. Os arranjos espaciais e as densidades de plantas mais adequadas dependem do rendimento e da biomassa total do consórcio ou do rendimento e da biomassa de uma cultura componente específica que tenha preço mais elevado.

Termos para indexação: *Gossypium hirsutum, Vigna unguiculata, Zea mays,* taxa de crescimento.

INTRODUCTION

In tropical regions, where small farms and labor-intensive operations predominate, fiber and food are traditionally produced by intercropping (Steiner, 1982; Gomez & Gomez, 1983; Francis, 1990; Bezerra Neto et al., 1991). Among small farmers in the semiarid

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tropics of Northeast Brazil, for example, annual cotton is commonly intercropped with food crops, such as cowpea and maize (Barreiro Neto et al., 1981; Zaffaroni & Azevedo, 1982; Morgado & Rao, 1985; Beltrão et al., 1986). Such intercrops are important sources not only of seed yield but also of biomass, which may be used as forage for animals.

Spatial arrangement and density are important management factors that can be manipulated to increase resource use in intercropping. Spatial arrangements in which the component crops alternate between rows rather than within rows often increase the production of the shorter-statured crop, typically the legume (Ofori & Stern, 1987). When the component crops are present in approximately equal densities, production is often determined by the more aggressive crop, usually the cereal (Willey & Osiru, 1972). Most crops become more competitive, however, as their proportional contribution to total intercrop density increases (Willey & Osiru, 1972).

The objective of the present research was to analyze the effects of spatial arrangement and density on yield and biomass of an annual cotton/cowpea/maize intercrop.

MATERIAL AND METHODS

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). Soil, climatic data and cultivars for the two experiments are described in Bezerra Neto & Robichaux (1996).

Experiment I analyzed the effects of spatial arrangement and cowpea/maize density on yield and biomass of an annual cotton/cowpea/maize intercrop. The experimental design was a randomized complete block with 16 treatments and three replications. Treatments were combined in an unconfounded 4 x 4 factorial, which consisted of four spatial arrangements of cotton, cowpea, and maize (as described in Bezerra Neto & Robichaux, 1996), crossed with four 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). Cotton density was held constant at 50,000 plants ha^{-1}. Intercrop densities were representative of those used in Northeast Brazil.

The area occupied by each crop, spacing, data on sowing, thinning, fertilizing, irrigating, and controlling weeds and insects are described in Bezerra Neto & Robichaux (1996).

Yield and biomass (above-ground vegetative and reproductive material) of each crop were measured in each treatment. Cotton (60 plants $plot^{-1}$) was picked four times: 130-133, 141-144, 157-159, and 170-171 days after sowing (DAS). Seed yield was calculated in t ha^{-1}. Cowpea and 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) were harvested for yield 81 and 87 DAS, and 120 DAS, respectively. The seeds were oven-dried at 70°C, with yield being calculated following correction to 13% moisture for cowpea and 14% moisture for maize.

Sixty (60) days after sowing (DAS), four plants of each crop were randomly harvested from each plot, and the leaves were separated from the remaining material. Leaf biomass and total biomass were measured following oven-drying at 70°C. Total biomass was also measured at the final harvest, which was 120 DAS for cotton (ten plants $plot^{-1}$), 90 DAS for cowpea (six plants $plot^{-1}$), and 120 DAS for maize (six plants $plot^{-1}$).

Experiment II analyzed the effects of cotton density and cowpea/maize density on yield and biomass of an annual cotton/cowpea/ maize intercrop. The experimental design was a randomized complete block with eleven treatments and three replications. Treatments were combined in an unconfounded 5 x 2 + 1 design. The 5 x 2 factorial consisted of five cotton densities (25,000, 32,500, 50,000, 62,500, and 75,000 plants ha^{-1}) crossed with two 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 one additional treatment had a cotton density of 50,000 plants ha^{-1} and a cowpea/maize density of 50,000 plants ha^{-1}. In each treatment, 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 (Bezerra Neto & Robichaux, 1996).

The area occupied by each crop, spacing, data on sowing, thinning, fertilizing, irrigating, and controlling weeds and insects are described in Bezerra Neto & Robichaux (1996).

Yield of each crop was measured in each treatment as in Experiment I. 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. Cowpea and maize (18 and 30 plants $plot^{-1}$ for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1}, respectively) were harvested for yield 86 and 121 DAS, respectively.

Leaf biomass and total biomass of each crop were measured in each treatment 60 DAS as in Experiment I. Total biomass was also measured at the final harvest, which was 120 DAS for cotton (ten plants plot^{-1}), 90 DAS for cowpea (six plants plot^{-1}), and 120 DAS for maize (six plants plot^{-1}).

For cotton, three plants were also randomly harvested from each plot at seven-day intervals from 25-81 DAS. Total biomass was measured according to the procedures described in Experiment I, and cotton growth rate (G) was calculated for each interval as: $G=(B_2-B_1)/P(t_2-t_1)$, where B=total biomass (g), P = ground area for which B was measured (m^2), and t=time (d), with the subscripts indicating the ending and beginning of the interval (Kvet et al., 1971).

In both experiments, Bartlett's test of sphericity (Norusis, 1990) was used to examine whether cotton, cowpea, and maize yields were correlated. The results of the test were not significant, implying that the yields of the three crops were independent. Thus, the effects of the treatment factors on yield and biomass were assessed with univariate, rather than multivariate, analyses of variance for the three crops. The data were checked with respect to the assumptions of the analyses according to the procedures in Bezerra Neto & Robichaux (1996). In the analyses of variance in Experiment II, the additional treatment, in which cotton had two 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 one plant hole^{-1}. The latter treatment in this contrast is denoted the special treatment.

Pairwise multiple comparisons and least squares curve-fitting procedure used in the experiments are described in Bezerra Neto & Robichaux (1996).

RESULTS AND DISCUSSION

Experiment I

Spatial arrangement had significant effects ($P<0.05$ by F test) on cotton seed yield, leaf biomass and total biomass (60 DAS) (Table 1), and cowpea/maize density had a significant effect on cotton total biomass (120 DAS) (Fig. 1). Seed yield was higher in the spatial arrangement SR cowpea & maize between SR cotton, and leaf biomass and total biomass (60 DAS) were higher in the spatial arrangements SR cowpea & maize between SR cotton and DR cowpea & maize between DR cotton (Table 1). Total biomass (120 DAS) decreased with increasing cowpea/maize density (Fig. 1). Spatial arrangement had no significant effect ($P>0.05$) on cotton total biomass (120 DAS). Cowpea/maize density also had no significant effects on cotton seed yield, leaf biomass and total biomass (60 DAS).

Spatial arrangement had significant effects ($P<0.05$ by F test) on cowpea yield, leaf biomass, total biomass (60 DAS), and total biomass (90 DAS) (Table 1), and cowpea/maize density had significant effects on cowpea leaf biomass and total biomass (90 DAS) (Fig. 2). Yield, leaf biomass, total biomass (60 DAS), and total biomass (90 DAS) were higher in the spatial arrangements SR cowpea & maize between SR cotton and DR cowpea & maize between DR cotton (Table 1). Leaf biomass and total biomass (90 DAS) increased with increasing cowpea/maize density (Fig. 2). Cowpea/maize density had no significant effect ($P> 0.05$) on yield and total biomass (60 DAS).

Spatial arrangement had significant effects ($P< 0.05$ by F test) on maize yield (Table 1), and cowpea/maize density had significant effects on maize yield, leaf biomass and total biomass (60 DAS) (Fig. 3). Yield was higher in the spatial arrangement SR cowpea-maize between SR cotton and DR cowpea-maize between DR cotton (Table 1). Yield, leaf biomass and total biomass (60 DAS) increased with increasing cowpea/maize density (Fig. 3). A significant interaction between spatial arrangement and cowpea/maize density existed for maize total biomass (120 DAS). In the interaction partition, total biomass (120 DAS) increased with increasing cowpea/maize density, but the nature of the relationship varied among spatial arrangements (Fig. 4). Spatial arrangement had no significant effect ($P>0.05$) on leaf biomass and total biomass (60 DAS).

Experiment II

Cotton density had significant effects ($P< 0.05$ by F test) on cotton leaf biomass and total biomass (60 DAS). Leaf biomass and total biomass (60 DAS) increased with increasing cotton density (Fig. 5). Cotton density had no significant effect ($P>0.05$) on yield and total biomass (120 DAS), and cowpea/maize density also had no significant effects on yield, leaf biomass, total biomass (60 DAS), and total biomass (120 DAS).

TABLE 1. Effects of spatial arrangement on cotton seed yield, leaf biomass and total biomass, cowpea yield, leaf biomass and total biomass, and maize yield in Experiment I[1].

Spatial arrangement[2]	Cotton			Cowpea				Maize
	Seed yield	Leaf biomass	Total biomass (60 DAS)	Yield	Leaf biomass	Total biomass (60 DAS)	Total biomass (90 DAS)	Yield
	(t ha^{-1})							
SR cowpea & maize between SR cotton	1.17 a	0.65 a	1.58 a	0.47 a	0.043 a	0.22 a	1.12 a	2.79 b
DR cowpea & maize between DR cotton	0.98 b	0.70 a	1.68 a	0.43 a	0.044 a	0.21 a	1.05 a	2.77 b
SR cowpea-maize between SR cotton	0.93 b	0.53 b	1.23 b	0.25 b	0.036 b	0.16 b	0.74 b	3.28 a
DR cowpea-maize between DR cotton	0.99 b	0.53 b	1.26 b	0.22 b	0.037 b	0.14 b	0.58 b	3.19 a
CV (%)	19.6	22.0	23.4	19.2	16.6	26.8	22.9	13.7

[1] Within a column, means with different letters differ significantly at $P \leq 0.05$ by DMRT.
[2] SR = single row; DR = double rows.

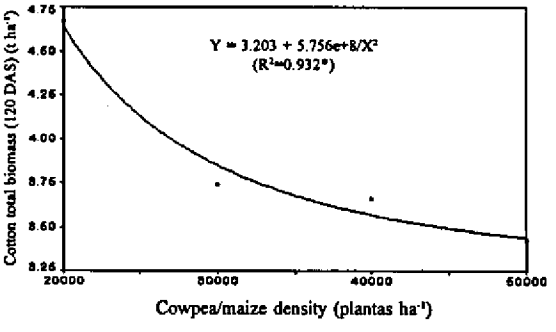

FIG. 1. Regression of cotton total biomass (120 DAS) on cowpea/maize density in Experiment I. *P ≤ 0.05.

Cowpea/maize density had a significant effect ($P<0.05$ by F test) on cowpea total biomass (90 DAS), with total biomass (90 DAS) being higher at the higher cowpea/maize density. Mean values of total biomass (90 DAS) for cowpea/maize densities of 30,000 and 50,000 plants ha^{-1} were 0.79 and 1.00 t ha^{-1}, respectively. Cotton density had no significant effects ($P>0.05$) on yield, leaf biomass, total biomass (60 DAS), and total biomass (90 DAS). Cowpea/maize density had no significant effects on yield, leaf biomass and total biomass (60 DAS).

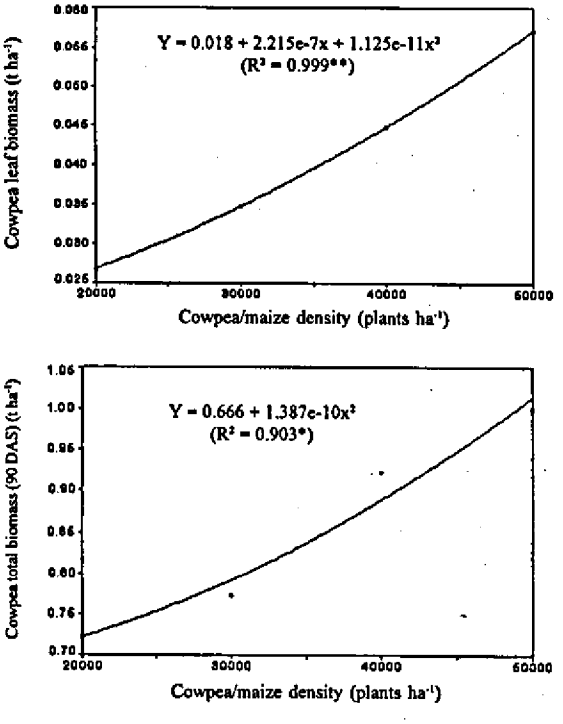

FIG. 2. Regressions of cowpea leaf biomass and total biomass (90 DAS) on cowpea/maize density in Experiment I. *P ≤ 0.05. **P ≤ 0.01.

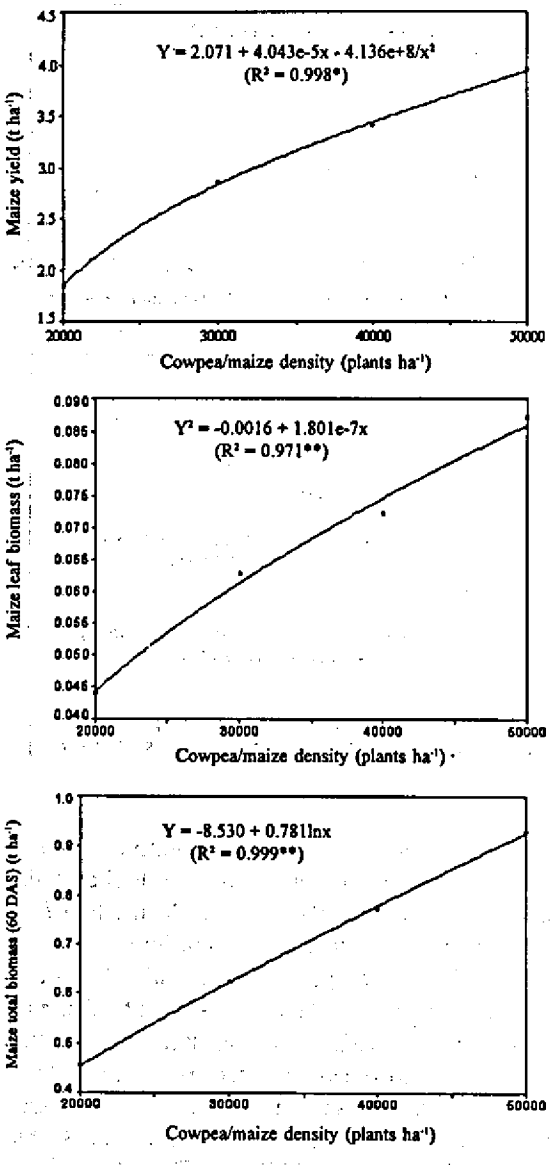

FIG. 3. Regressions of maize yield, leaf biomass and total biomass (60 DAS) on cowpea/maize density in Experiment I. *P ≤ 0.05. **P ≤ 0.01.

Cowpea/maize density had significant effects (P<0.05 by F test) on maize yield, leaf biomass and total biomass (120 DAS), with these parameters being higher at the higher cowpea/maize density. For cowpea/maize densities of 30,000 and 50,000 plants ha^{-1}, mean values of yield were 1.47 and 1.98 t ha^{-1}, of leaf biomass were 0.58 and 0.83 t ha^{-1} and of total biomass (120 DAS) were 3.89 and 5.28 t ha^{-1}, respectively. Cotton density had no significant effects (P>0.05) on yield, leaf biomass, total biomass (60 DAS), and total biomass (120 DAS). Cowpea/maize density had no significant effect on total biomass (60 DAS).

Cotton density had significant effects (P<0.05 by F test) on cotton growth rate for the intervals 39-46, 46-53, 53-60, 60-67, and 67-74 DAS. For each interval, growth rate increased with increasing cotton density, although the nature of the relationship changed during the season (Fig. 6). As the season progressed, the maximal growth rate was approached at progressively lower cotton densities. Cotton density had no significant effects (P>0.05) on cotton growth rate for the intervals 25-32, 32-39, and 74-81. Cowpea/maize density had no significant effects for all the intervals.

For all three crops, there was no significant difference in any parameter between the additional treatment and the special treatment.

In this annual cotton/cowpea/maize intercrop, cotton seed yield was higher in the spatial arrangement of single rows of cowpea and maize between single rows of cotton. This result agrees partially with that of Bezerra Neto et al. (1991), who found that cotton seed yield in an annual cotton/cowpea/sorghum intercrop in Northeast Brazil was higher when single rows of cowpea and sorghum alternated with single rather than double rows of cotton. In contrast to spatial arrangement, cowpea/maize density did not affect cotton seed yield. Thus, in terms of seed yield, the competitive effect of the two food crops on cotton may have been governed more by the spatial configuration of the intercrop than by the food-crop density.

Cotton density did not affect cotton seed yield. According to Burhan (1964), an increase in cotton density may be accompanied by a decrease in the number of flowers per plant and an increase in the amount of boll shedding. These changes could account for a reduced seed yield per plant, or yield compensation, at higher densities.

The effects of spatial arrangement on cowpea and maize yields differed significantly. Cowpea yield was higher in the spatial arrangements in which cowpea

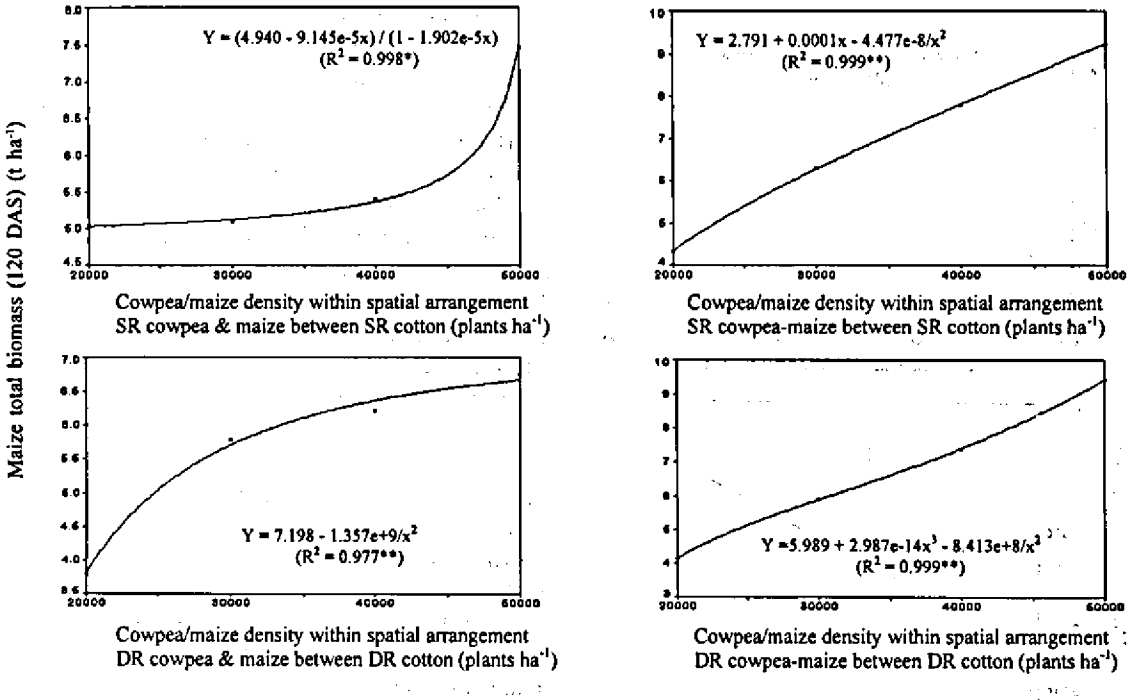

FIG. 4. Regressions of maize total biomass (120 DAS) on cowpea/maize density within four spatial arrangements in Experiment I. Notations for the spatial arrangements are in Table 1. *P ≤ 0.05. **P ≤ 0.01.

and maize were grown in separate rows, whereas maize yield was higher in the spatial arrangements in which cowpea and maize were grown in the same rows. Thus, cowpea yield was enhanced, and maize yield was reduced, under conditions of greater intraspecific competition. In contrast, maize yield was enhanced, and cowpea yield was reduced, under conditions of greater interspecific competition. The latter result may primarily reflect differences in the statures of the two crops, with the taller maize competing much more successfully for light. Similar results have been obtained for a wide variety of legume/cereal intercrops (Allen & Obura, 1983; Ofori & Stern, 1987).

The effects of cowpea/maize density also differed for the two food crops. Maize yield, but not cowpea yield, increased strongly with increasing cowpea/maize density. For maize, the yield response is similar to that reported by Fawusi & Wanki (1982) for cowpea/maize intercrops. For cowpea, any positive effect of higher cowpea densities on yield may have been offset by the negative effect of increased competition with maize at higher maize densities, given that the densities of the two food crops changed together in the experiments.

For all three crops in this annual cotton/cowpea/maize intercrop, total biomass at the final harvest varied with cowpea/maize density but not with cotton density. As cowpea/maize density increased from 20,000 to 50,000 plants ha^{-1}, total biomass increased for cowpea (90 DAS) and maize (120 DAS), but decreased for cotton (120 DAS). Thus, the increase in cowpea/maize density shifted the competitive balance toward the two food crops.

Cowpea total biomass (60 and 90 DAS) was higher in the spatial arrangements in which cowpea and maize were grown in separate rows rather than in the same rows. In the latter arrangements, interspecific competition with maize was presumably greater, especially for light, with the taller cereal shading the shorter legume. Ofori & Stern (1987) reported similar results for a wide variety of legume/cereal intercrops.

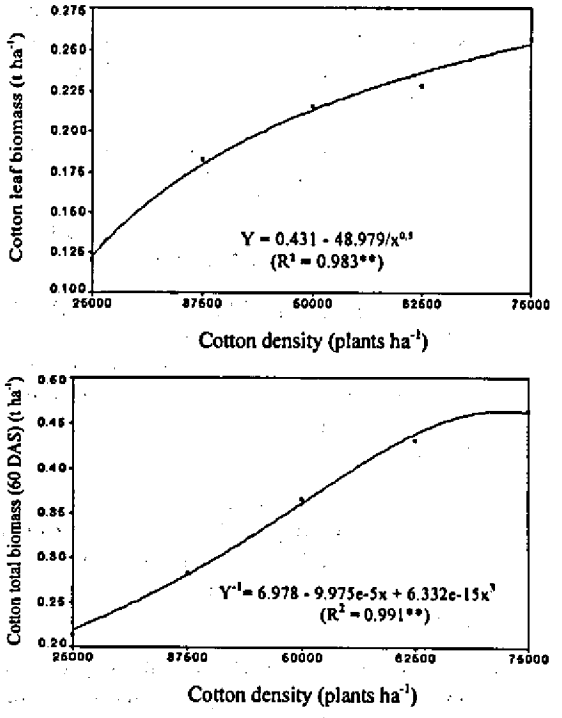

FIG. 5. Regressions of cotton leaf biomass and total biomass (60 DAS) on cotton density in Experiment II. *P ≤ 0.05. **P ≤ 0.01.

Patterns of biomass production late in the growth cycle of a crop may differ significantly from those earlier in the cycle (Brown, 1984). This was particularly evident for cotton in the two experiments. At the final harvest, total biomass (120 DAS) was affected by cowpea/maize density (between 20,000 and 50,000 plants ha^{-1}), but not by spatial arrangement and cotton density. In contrast, earlier in the season, total biomass (60 DAS) was affected by spatial arrangement and cotton density, but not by cowpea/maize density.

Cotton leaf biomass increased with increasing cotton density, and cowpea and maize leaf biomass increased with increasing cowpea/maize density between 20,000 and 50,000 plants ha^{-1}. Thus, for each crop, the pattern of leaf biomass production through 60 DAS followed the classical biomass/density relationship (Hardwick & Andrews, 1983). As discussed in Bezerra Neto (1993), the relationship between leaf area index and density for each crop paralleled that for leaf biomass and density.

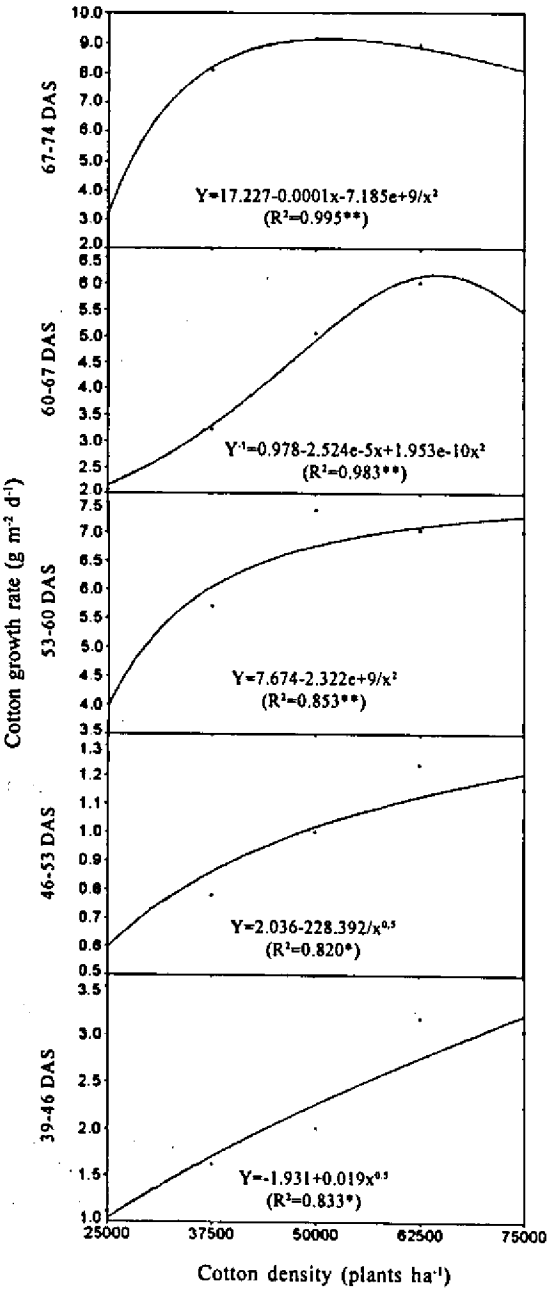

FIG. 6. Regressions of cotton growth rate on cotton density for five 7-day intervals in Experiment II. *P ≤ 0.05. **P ≤ 0.01.

The relationship between cotton growth rate and cotton density changed during the season, such that the maximal growth rate was approached at progressively lower cotton densities. The results suggest that the effects of intraspecific competition became more pronounced at higher densities later in the season. The results are similar to those of Mayilsami & Iruthayaraj (1981), who found that cotton growth rate varied with growth stage, or days after sowing, in cotton sole crops. As discussed in Bezerra Neto (1993), cotton density also affected cotton relative growth rate and net assimilation rate, but only from 46-53 DAS.

CONCLUSIONS

1. The component-crop yield and biomass in an annual cotton/cowpea/maize intercrop can be significantly affected by the manipulation of spatial arrangement and density as management factors.

2. The most appropriate arrangements and densities in particular circumstances depends on either the combined intercrop yield and biomass or yield and biomass of a specific component crop that is more highly valued.

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