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Morpho-physiological and productive biometry in semi-erect cultivars of the cowpea under different plant populations[1]

Biometria morfofisiológica e produtiva em cultivares semieretas de feijão-caupi sob diferentes populações de plantas

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ABSTRACT - The aim of this study was to evaluate morpho-physiological and productive characteristics in four semi-erect cultivars of the cowpea under five plant populations. The experiment was conducted in the experimental area of Embrapa Meio-Norte in Teresina in the State of Piauí, Brazil (PI). The experimental design was of randomised complete blocks with four replications, in a 4 x 5 factorial scheme, for evaluating four cultivars (BRS Guariba, BRS Novaera, BRS Potengi and BRS Tumucumaque) and five plant populations (10^5, $2x10^5$, $3x10^5$, $4x10^5$ and $5x10^5$ plants ha^{-1}). There were significant differences between cultivars for primary branch length (PBL), number of lateral branches (NLB), 100-grain weight (HGW), and dry-grain yield (GY). The maximum PBL of 58.5 cm was obtained with 300 thousand plants ha^{-1}, corresponding to an increase of 11.5% when compared to 100 thousand plants ha^{-1}. However, there was a reduction of 91.2% in NLB when compared to the populations of 100 and 500 thousand plants ha^{-1}. The increases of 188% obtained in the leaf area index (LAI) in the range of 100 to 500 thousand plants ha^{-1} explain the linear increase in the crop growth rate (CGR) as being due to the greater production of leaf area; also, the decreases seen in the net assimilation rate (NAR), especially in the range of 100 to 300 thousand plants ha^{-1}, are explained as due to the consequent self-shading, which was intensified in the larger populations. LAI, light interception, and CGR in the cultivars increase in response to higher densities. HGW and GY are not significantly affected by the different populations.

Key words: *Vigna unguiculata*. Growth. Production. Plant density.

RESUMO - Objetivou-se avaliar características morfofisiológicas e produtivas em quatro cultivares semieretas de feijão-caupi submetidas a cinco populações de plantas. O experimento foi conduzido no campo experimental da Embrapa Meio-Norte, em Teresina-PI. Utilizou-se o delineamento experimental de blocos completos casualizados com quatro repetições, em arranjo fatorial 4x5 sendo avaliadas quatro cultivares (BRS Guariba, BRS Novaera, BRS Potengi e BRS Tumucumaque) e cinco populações de plantas (10^5, $2x10^5$, $3x10^5$, $4x10^5$ e $5x10^5$ plantas ha^{-1}). Houve diferenças significativas entre as cultivares para o comprimento do ramo principal (CRP), número de ramos laterais (NRL), massa de cem grãos (MCG) e rendimento de grãos secos (REND). O CRP máximo de 58,5 cm foi obtido com 300 mil plantas ha^{-1}, correspondendo a um aumento de 11,5% quando comparado com 100 mil plantas ha^{-1}. Entretanto, houve redução de 91,2% no NRL quando comparadas às populações de 100 e 500 mil plantas ha^{-1}. Os aumentos de 188% obtidos no índice de área foliar (IAF) no intervalo de 100 e 500 mil plantas ha^{-1}, explicam o aumento linear da taxa de crescimento da cultura (TCC) em função da maior produção de área foliar, bem como, os decréscimos obtidos na taxa de assimilação líquida (TAL), notadamente no intervalo de 100 a 300 mil plantas ha^{-1}, devido ao consequente autossombreamento, que foi intensificado nas maiores populações. O IAF, a interceptação de luz e a TCC das cultivares aumentam em resposta às maiores densidades. O MCG e o REND não são afetados significativamente pelas diferentes populações.

Palavras-chave: *Vigna unguiculata*. Crescimento. Produção. Densidade de plantas.

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INTRODUCTION

The cowpea [*Vigna unguiculata* (L.) Walp], due to its nutritional potential together with its ease of production and accessibility, is the most important food legume, especially for populations in the north and northeast of Brazil, which have been characterised historically by protein-energy and mineral deficiencies (BEZERRA *et al*., 2014).

Modern cultivars, with a higher potential for grain yield and responsive to cropping technology, have helped expand the cowpea to areas of the Cerrado and the Central-West region, as the main or off-season crop. However, expression of the production potential of the crop depends on the favourable combination of a set of factors, noteworthy among them being population density, which directly influences the use of technological, environmental and management resources.

Leaf-area development is fundamental to the interception of light, and is strongly related to physiological processes, such as the addition, expansion and senescence of the leaves, and consequently the accumulation of biomass (RICAURTE *et al*., 2016). According to Oroka and Omoregie (2007), sufficient increases in the population density of the cowpea can significantly enhance the interception of solar radiation and efficiency in its use. Mendes *et al*. (2005), working with cowpea, found that the percentage of intercepted light and the leaf area index increased by 50% and 206.5% respectively, comparing populations of from 41,666 to 166,666 plants ha^{-1}.

Determining the ideal plant density for a minimum of intraspecific competition is essential to optimise the use of water and nutrients per unit area, resulting in increased productivity (EWANSIHA *et al*., 2015; HELMY; HASSAN; IBRAHIMET, 2015).

General recommendations for spacing, without considering the different characteristics of cultivars and production systems, may contribute to low grain yields in the cowpea (KAMARA *et al*., 2014). Thus, with the development of modern cultivars for technified and/or traditional systems, there is a need for more precise information about imputed changes in the morphological and productive characteristics of these cultivars when submitted to different planting densities.

The aim of this study was to evaluate the morpho-physiological and productive characteristics of four modern, semi-erect cultivars of the cowpea under five planting densities.

MATERIAL AND METHODS

The experiment was carried out from May to August 2013 in the experimental area of Embrapa Meio-Norte in Teresina, in the State of Piauí, Brazil (05º02’17’’ S and 42º47’83’’ W, at an altitude of 75 m), using a sprinkler irrigation system with at average application rate of 9 mm and irrigation frequency of two days. The climate of the region, according to Thornthwaite and Mather (1955), is C1sA’a’, characterised as dry sub-humid, megathermal, with a moderate water surplus in the summer.

The soil of the experimental area is classified as a Dystrophic Red-Yellow Argisol (SANTOS *et al*., 2013) and presented the following chemical attributes in the 0-20 cm layer: pH ($CaCl_2$) 5.9; MO, 9.2 g kg^{-1}; P, 12.6 mg dm^{-3}; K, 117 mg dm^{-3}; Ca, 2.62 cmol$_c$ dm^{-3}; Mg, 0.65 cmol$_c$ dm^{-3}; Al, 0.02 cmol$_c$ dm^{-3}; H+Al, 2.06 cmol$_c$ dm^{-3}; CEC 2,92 cmol$_c$ dm^{-3} and base saturation of 2.94 cmol$_c$ dm^{-3}. The experimental area was prepared by harrowing twice and levelling, with no chemical fertiliser being applied.

Five plant populations (10^5, $2x10^5$, $3x10^5$, $4x10^5$ and $5x10^5$ plants ha^{-1}) were evaluated, corresponding respectively to 5, 10, 15, 20 and 25 plants m^{-1}, and four improved varieties (BRS Guariba, BRS Potengi, BRS Novaera and BRS Tumucumaque), whose main characteristics are shown in Table 1.

A randomised complete block design was used in a 5 x 4 factorial scheme, with four replications. One experimental plot of 12.5 m^2 consisted of five rows of 5.0 meters in length, spaced 0.5 m apart, for a working area of 6.0 m^2.

Manual sowing was carried out in holes, using labelled string for the pre-established plant populations. Each hole was 2.0 to 3.0 cm in depth, and contained two seeds to ensure the initial stand. Thinning was performed 15 days after planting, when the surplus plants were cut below the cotyledon node, to avoid sprouting and damage to the root system of the remaining plant.

The control of invasive plants was by the pre-emergent application of the herbicide S-Metolachlor (960 g L^{-1}), at a dose of 1.25 L of commercial product per hectare. Insect pests were controlled with Thiamethoxam (250 g kg^{-1}), at a dose of 150 g of commercial product per hectare, for whitefly (*Bemisia tabaci race B*), thrips (*Frankliniella schultzei*), and the green leafhopper (*Empoasca kraemeri*); for control of the cotton aphid (*Aphis gossypii*), dimethoate (400 g L^{-1}), at a dose of 600 mL of commercial product per hectare, was used.

The following characteristics were evaluated: primary branch length (PBL, in cm), distance from the

Table 1 - Main characteristics of the four semi-erect cultivars of cowpea [*Vigna unguiculata* (L) Walp]

Cultivar	Comercial Class	Recommended Population1 (plants ha^{-1})	Maturation Cycle (days)	Grain Yield (kg ha^{-1})
BRS Guariba	White	200,000	65-70	1,475
BRS Potengi	White	160,000	70-75	922
BRS Novaera	White	200,000	65-70	1,074
BRS Tumucumaque	White	200,000	65-70	1,098

[1]Embrapa Meio-Norte

root collar to the apex of the main stem; number of lateral branches (NLB), count of the primary lateral branches; leaf area index (LAI), ratio of plant leaf area to the area of ground occupied by the plant; light interception (LI, as a %), reading carried out between 1100 and 1300, using an LDR-225 digital lux meter; crop growth rate (CGR, in g m^{-2} day^{-1} - Equation 1); net assimilation Rate (NAR, in g m^{-2} day^{-1} - Equation 2); 100-grain weight (HGW, in g), grain randomly chosen per plot, with 13% moisture; and grain yield (GY), total grain yield in the working area of the plot, with 13% moisture, converted to kg ha^{-1}.

$$CGR = \frac{MS_2 - MS_1}{S} \times \frac{1}{t_2 - t_1} \quad (1)$$

$$NAR = \frac{MS_2 - MS_1}{t_2 - t_1} \times \frac{\ln AF_2 - \ln AF_1}{t_2 - t_1} \quad (2)$$

where: MS_1 and MS_2 - the mean value for shoot dry matter of four plants per plot at 25 and 35 DAS respectively; S - area of ground occupied by the plant; ln AF_1 and ln AF_2 - Neperian logarithm of the leaf area (LA) at 25 and 35 DAS respectively; and t_1 and t_2 - time in days corresponding to 25 and 35 DAS respectively.

The data were submitted to analysis of variance ($p<0.05$) with polynomial regression for plant population, and Tukey's test ($p<0.05$) to compare the mean values for the cultivars. For the statistical analysis, the ASSISTAT 7.6 Beta software (SILVA; AZEVEDO, 2009) was used.

RESULTS AND DISCUSSION

In relation to the cultivars, significance was found by F-test for PBL, NLB, HGW and GY only, showing variability between the cultivars relative to these variables. There was no interaction between factors for the variables under analysis, demonstrating that the four cultivars respond similarly to the effects of the different populations (Table 2).

The cultivar BRS Guariba had the highest value for PBL (70.9 cm) and the lowest for HGW (19.0 g) and GY (981.0 kg ha^{-1}). The highest value for HGW (23.0 g) and GY (1,240.0 kg ha^{-1}) were obtained with the cultivar BRS Novaera, which did not differ statistically ($p>0.05$) from BRS Potengi, where GY was 1,230 kg ha^{-1} (Table 3). High values for GY, and large grains (HGW ≥ 20 g), meet the requirements of producers and the preferences of the domestic and especially the international market, thus increasing the export potential of the product.

Table 2 - Summary of the analysis of variance for primary branch length (PBL, in cm), number of lateral branches (NLB), leaf area index (LAI), light interception (LI, as a %), crop growth rate (CGR, in g m^{-2} day^{-1}), net assimilation rate (NAR, in g m^{-2} day^{-1}), 100-grain weight (HGW, in g), and grain yield (GY, in kg ha^{-1}) in four semi-erect seedlings of cowpea [*Vigna unguiculata* (L) Walp] submitted to five plant populations

SV	DF	F-Test							
		PBL	NLB	LAI	LI	CGR	NAR	HGW	GY
Blocks	3	24.6**	6.8**	2.9*	22.4**	4.8**	3.5**	2.4^{ns}	30.3**
Cultivars	3	34.0**	14.6**	0.9^{ns}	1.3^{ns}	1.3^{ns}	1.2^{ns}	55.0**	15.4**
Populations	4	1.8^{--}	38.4^{--}	19.1^{--}	4.1^{--}	2.7^{--}	1.7^{--}	0.3^{--}	1.1^{--}
Interaction	12	0.8^{ns}	1.2^{ns}	0.7^{ns}	0.9^{ns}	0.6^{ns}	0.7^{ns}	0.5^{ns}	1.1^{ns}
Overall mean		2.94	0.85	1.52	66.9	10.2	5.3	20.8	1130.5
CV%		16.9	33.3	14.3	20.9	30.0	26.1	4.7	12.7

$^{ns, *\ and\ **}$ Not significant, significant at 5% and 1% respectively by F-test. $^{--}$ Study of polynomial regression

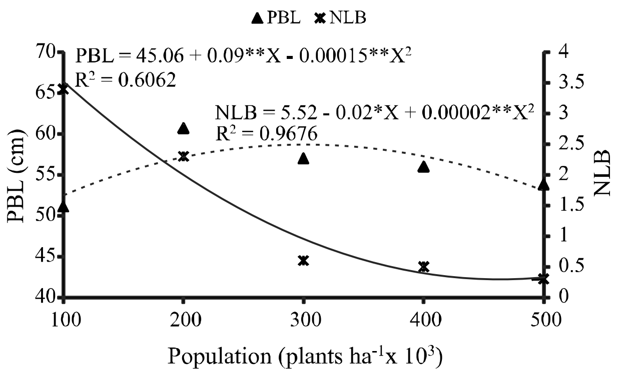
Table 3 - Mean values for primary branch length (PBL, in cm), number of lateral branches (NLB), 100-grain weight (HGW, in g) and grain yield (GY, in kg ha^{-1}) in four semi-erect seedlings of cowpea [*Vigna unguiculata* (L) Walp] submitted to different plant populations

Cultivar	Mean[1]			
	PBL (cm)	NLB	HGW (g)	GY (kg ha^{-1})
BRS Guariba	70.9 a	1.4b	19.0d	981b
BRS Potengi	38.8 d	1.9a	20.0c	1230a
BRS Novaera	51.4 c	1.3b	23.0a	1240a
BRS Tumucumaque	61.9 b	0.9c	21.0b	1069b
l.s.d	8.8	0.4	0.82	120.3

[1] Mean values followed by the same letter in a column do not differ by Tukey's test ($p<0.05$)

The regression analysis showed a quadratic fit for PBL and NLB in response to the increases in plant population (Figure 1). PBL had a maximum of 58.5 cm for 300 thousand plants ha^{-1}, corresponding to an increase of 11.5% in PBL when compared to 100 thousand plants ha^{-1}. However, there was a 91.2% reduction in NLB when compared to the populations of 100 and 500 thousand plants ha^{-1}, with 82.4% of this reduction occurring in the range of 100 to 300 thousand plants ha^{-1}. Kumar *et al*. (2012) and Helmy, Hassan and Ibrahimet (2015) obtained greater lengths for the primary branches and a smaller number of lateral branches in cowpea cultivars when subjected to higher plant densities. Nwofia, Nwanebu and Agbo (2012), studying populations in 12 varieties of cowpea, concluded that PBL shows a significant and negative correlation with grain yield.

Figure 1 - Primary branch length (PBL, in cm) and number of lateral branches (NLB) in four semi-erect cultivars of cowpea [*Vigna unguiculata* (L) Walp] submitted to five plant populations



A drastic reduction in NLB due to the increase in plant population has a negative impact on leaf area, impairing photosynthetic capacity and grain production per plant, considering that the greatest number of pods per plant in these cultivars are found on the lateral branches. According to Choudhary and Bordovsky (2001), the number of pods per plant is an important regulator of grain production. Mendes *et al*. (2005), Kumar *et al*. (2012), Bezerra *et al*. (2009, 2014) and Rezaeei *et al*. (2013) saw reductions in NLB in cowpea cultivars submitted to higher plant densities.

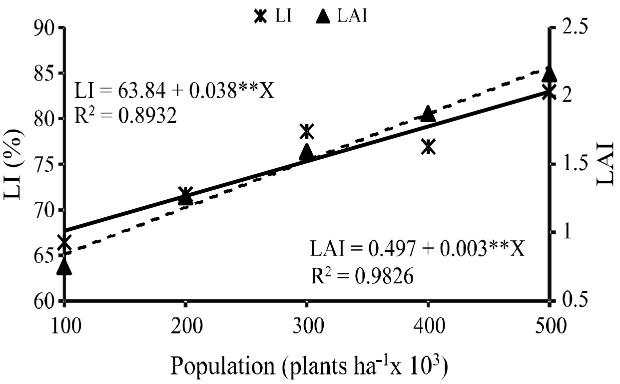
PBL and NLB are important in determining plant architecture and have an influence on the lodging resistance and yield of cultivars. Thus, the response of the cultivars when at higher densities in relation to these two variables can directly influence their potential adoption in technified systems, which use higher densities than those recommended.

When the populations of 100 and 500 thousand plants ha^{-1} were compared, light interception (LI) by the canopy increased from 66.4% to 82.9%, and LAI from 0.75 to 2.16 (Figure 2). It can be seen that for this population range, the increases in LAI (188%) were much more expressive than the increase in LI (24.9%), showing that in the largest populations, only 13.2% of the increase in LAI was converted into increments in light interception by the canopy. This result can be explained by the higher level of self-shading that occurred in the larger populations, which can reduce net photosynthesis and consequently dry-matter accumulation.

Greater light interception at the larger populations may favour greater control of invasive plants and less evaporation of available water, especially in the most superficial layer of the soil, and this joint effect may help to boost productivity in the cultivars.

The capacity to produce dry matter from a crop under satisfactory conditions will ultimately depend on the degree of solar radiation utilised (BEZERRA *et al*., 2014); according to Taiz and Zeiger (2009), only 5% of

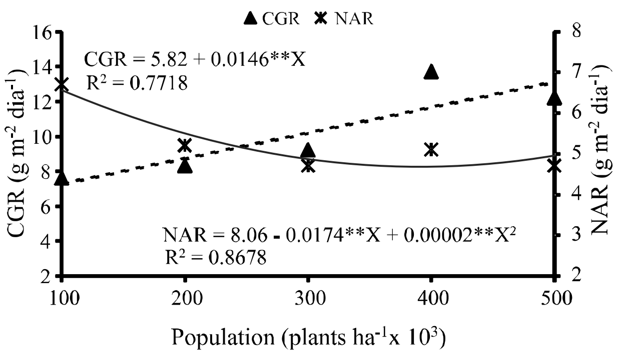
Figure 2 - Light interception (LI) and leaf area index (LAI) in four semi-erect cultivars of cowpea [*Vigna unguiculata* (L) Walp] submitted to five plant populations



the incident solar radiation is converted into carbohydrates by the leaf. Mendes *et al*. (2005) and Kamara *et al*. (2016), working with different plant densities in the cowpea, found significant increases in LI and LAI with increased plant populations per hectare. Kuapata, Hall and Madore (1990), found differences in light interception between two cowpea cultivars, however, higher percentage light interception was seen at the higher plant densities. Ricaurte *et al*. (2016), working with three cultivars of the common bean, obtained values for light interception close to 100% and less than 70% for each cultivar at 50 DAS, for densities of 35 and 5 plants m^{-2} respectively.

For CGR, there was adjustment of the linear model, with an increase of from 7.6 to 12.2 g cm^2 day^{-1}, and of the quadratic model for NAR, which was reduced from 6.7 to 4.7 g cm^2 day^{-1}, considering the populations of 100 and 500 thousand plants ha^{-1}, representing a 60.5% increase in CGR and a 29.9% reduction in NAR (Figure 3).

Figure 3 - Crop growth rate (CGR) and net assimilation rate (NAR) in four semi-erect cultivars of cowpea [*Vigna unguiculata* (L) Walp] submitted to five plant populations



In the range of 100 to 300 thousand plants ha^{-1}, NAR was reduced by 29.9%, but remained stable in the range of 300 to 500 thousand plants ha^{-1}. The increases of 188% obtained in the LAI in the range of 100 to 500 thousand plants ha^{-1} explain the linear growth of the CGR as being due to the greater production of leaf area; these increases also explain the decreases seen in NAR, especially in the range of 100 to 300 thousand plants ha^{-1}, due to the consequent self-shading, which was intensified with the increase of LAI in the largest plant populations.

There was no adjustment ($p<0.05$) of the tested models for HGW or GY. Bezerra *et al*. (2009, 2014) and Bisikwa *et al*. (2014), in studies of cowpea populations, found similar results for HGW.

The independence of GY in relation to the increasing plant densities shows that the positive effects of the rises in plant population on LI, LAI and CGR may have offset the negative effects on NLB and NAR, thereby making it possible to maintain the productivity of the cultivars.

CONCLUSIONS

1. The cultivars BRS Guariba, BRS Potengi, BRS Novaera and BRS Tumucumaque respond similarly to different plant densities;
2. The leaf area index, light interception, and growth rate of the cultivars increase in response to higher densities;
3. The 100-grain weight and grain yield are not significantly affected by plant population.

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