Effect of water regimes and plant densities on cowpea production[1]

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ABSTRACT

Cowpea has been cultivated in a rudimentary form in the main producing regions of Brazil, resulting in lower grain yields, when compared to the crop potential. The use of technologies such as water regimes, adequate plant density and soil management are alternatives to increase this crop yield. This study aimed at evaluating the effects of different water regimes and plant densities on the yield components of cowpea cultivated under conventional and no-tillage systems. A randomized block design in a split-plot factorial, with four replications, was used. The treatments consisted of five water regimes in the plots (157.00 mm, 189.00 mm, 234.00 mm, 274.00 mm and 320.00 mm) and five plant densities as subplots (12 plants m^{-2}, 16 plants m^{-2}, 20 plants m^{-2}, 24 plants m^{-2} and 28 plants m^{-2}). The evaluated variables were: number of pods per plant, number of pods per area, pod length and grain yield. The combination between 270 mm of irrigation water depth with a density of 280,000 plants ha^{-1} resulted in higher grain yield using the no-tillage system, while the combination between the density of 280,000 plants ha^{-1} and 320 mm of water depth favored the highest grain yields in the conventional growing system.

KEYWORDS: *Vigna unguiculata* (L.) Walp.; grain yield; irrigation.

RESUMO

Efeito de regimes hídricos e densidades de plantas na produção de feijão-caupi

O feijão-caupi tem sido cultivado de forma rudimentar nas principais regiões produtoras do Brasil, ocasionando baixas produtividades de grãos, em comparação ao potencial da cultura. A utilização de tecnologias como regimes hídricos, densidade de plantas e manejo adequado do solo são alternativas para aumentar os rendimentos dessa cultura. Objetivou-se avaliar os efeitos de regimes hídricos e densidades de plantas sobre os componentes de produção e produtividade de feijão-caupi, em sistemas de cultivo convencional e direto. Utilizou-se delineamento em blocos casualizados, em parcelas subdivididas, com quatro repetições. Os tratamentos foram cinco regimes hídricos nas parcelas (157,00 mm; 189,00 mm; 234,00 mm; 274,00 mm; 320,00 mm) e cinco densidades de plantas como subparcelas (12 plantas m^{-2}, 16 plantas m^{-2}, 20 plantas m^{-2}, 24 plantas m^{-2} e 28 plantas m^{-2}). As variáveis analisadas foram: número de vagens por planta, número de vagens por área, comprimento de vagens e produtividade de grãos. A combinação entre a lâmina de irrigação de 270 mm e a densidade de 280.000 plantas ha^{-1} promoveu maiores ganhos na produtividade de grãos no plantio direto, enquanto a combinação entre a densidade de 280.000 plantas ha^{-1} e a lâmina de 320 mm favoreceu os melhores rendimentos da produtividade de grãos no plantio convencional.

PALAVRAS-CHAVE: *Vigna unguiculata* (L.) Walp.; produtividade de grãos; irrigação.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp] is a crop with socioeconomic importance for the Northeast and North regions of Brazil, due to its low production cost and because it is an important source of protein for the low income populations of these regions, thus generating employment and income (Freire Filho et al. 2005). Due to its expansion in planted areas and in the consumption of this legume, in recent years, it has become an excellent income alternative for small growers and large farmers.

However, despite being a genetically improved crop, concerning size and architecture for mechanized cultivation, its growing is still rudimentary in the main producing regions of Brazil. As a result of the low level of technology applied, the average grain yield is low, reaching the national average of 400-500 kg ha^{-1} (Alves et al. 2009). In the Piauí state, the average yield is 256 kg ha^{-1}, lower than the crop

potential estimated at ~6,000 kg ha⁻¹. This low grain yield may be attributed to the water deficit and the low use of technologies, such as lack of adequate soil management, inadequate use of plant density and no irrigation management (Freire Filho et al. 2005).

Many authors (Bezerra et al. 2012 and 2014, Cardoso et al. 2015) have studied the plating density of cowpea in Brazil. Plant density significantly influences the cowpea grain yield, as it significantly alters the number of pods per plant or area, which is the main production component (Cardoso et al. 2005). In semi-prostrate growth habit cultivars, Cardoso et al. (2015) obtained quadratic responses for the number of pods per area, observing maximum values of 110.2 pods m⁻², 92.6 pods m⁻² and 92.9 pods m⁻², respectively at the plant densities of 12.8 m⁻¹, 13.0 m⁻¹ and 13.3 m⁻¹ (BRS Aracê).

Thus, it is very important to define an adequate plant population, especially considering the diversity of cowpea materials and cultivation systems. Typically, for erect varieties, a higher number of plants per area (180,000-220,000 plants ha⁻¹) is recommended, when compared to semi-prostrate or prostrate varieties (120,000-140,000 plants ha⁻¹).

When the irrigation is well conducted, it increases both cowpea yield and grain quality (Oliveira et al. 2011, Silva et al. 2013 and 2016, Locatelli et al. 2014). Silva et al. (2016) evaluated 20 genotypes under irrigation and observed an average grain yield 27 % higher than the same genotypes under no irrigation. These differences may be doubled or tripled in areas with severe water deficiency. The presence of straw on the soil surface during the cowpea development, combined with irrigation management, is an important tool, promoting a reduction in water evaporation (Locatelli et al. 2014). The crop residues on the soil act altering the soil-water relationship, thus reducing the transpiration rate of the crops, especially in the phases in which the soil is not covered by the crop itself, the irrigation frequency and operating costs (Stone et al. 2006).

The no-tillage system may be an advantageous alternative for a higher yield, when compared to the conventional system, because the straw on the soil surface of the no-tillage system reduces the water evaporation, thus saving water. There are few studies in the literature regarding the cowpea yield under no-tillage system and submitted to different population densities. This cropping system reduces

the drastic effects of climatic conditions unfavorable to the crop development (Simidu et al. 2010), such as water deficit and thermal stress. The crop residues act as an insulating agent, preventing abrupt fluctuations in the soil temperature and contributing to the lower water evaporation from the soil, with a better use of water by plants (Bizari et al. 2009).

This study aimed at evaluating the effects of water regimes and plant densities on the yield components of cowpea cultivated under conventional and no-tillage systems.

MATERIAL AND METHODS

Two experiments were carried out in the experimental field of the Embrapa Meio-Norte, in Teresina, Piauí state, Brazil (5º05'S, 42º29'W and 74.40 m of altitude), from June to August 2016, using conventional and no-tillage systems. The climate of the area, according to the Thornthwaite and Mather climate classification, is C1sA'a', and, considering the historical records from 1980 to 2014, presents an average annual temperature of 28.1 ºC and average annual precipitation of 1,342.4 mm (Bastos & Andrade Júnior 2015).

The soil of the experimental area is an eutrophic Yellow-Red Argisol, with a mild elevation relief and 0-3 % of slope (Melo et al. 2014). The soil granulometric and chemical analysis are presented in Tables 1 and 2, respectively.

Two experiments were carried out under conventional and no-tillage systems. For each experiment, a randomized block design in a split-plot factorial, with four replications, was used. The treatments were five water regimes (50 %, 75 %, 100 %, 125 % and 150 % of the crop evapotranspiration, corresponding to 157 mm, 189 mm, 234 mm, 274 mm and 320 mm, respectively) in the plots and five plant densities (12 plants m⁻², 16 plants m⁻², 20 plants m⁻², 24 plants m⁻² and 28 plants m⁻²) in the subplots. The experiment consisted of 100 subplots in each planting system. The plots consisted of 5 rows of 4 m, spaced

Table 1. Granulometric analysis of the soil of the experimental area.

Depth (m)	Granulometry (g kg⁻¹)			
	Coarse sand	Fine sand	Silt	Clay
0.0-0.2	451.8	190.4	164.5	193.3
0.2-0.4	471.3	180.2	168.0	178.7

Table 2. Chemical analysis of the soil from the experimental area.

Depth	OM	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^+ + Al^{3+}$	CEC	V
m	g kg^{-1}	H_2O	mg dm^{-3}				mmol dm^{-3}				%
0.0-0.2	7.7	6.1	34.4	0.2	0.04	2.2	0.5	0.05	1.4	4.5	66.8
0.2-0.4	8.5	6.0	25.1	0.2	0.04	2.1	0.5	0.05	1.9	4.9	60.0

at 0.5 m, totaling 10 m². The useful area of the plot totaled 4.0 m², being the two central rows.

The soil preparation in the conventional growing system consisted of cutting, plowing and harrowing. In the area under the no-tillage system, sorghum and brachiaria straw were used on the soil. The base fertilization was carried out according to the soil analysis and followed the crop nutritional requirements, with 50 kg ha^{-1} of P_2O_5 and 40 kg ha^{-1} of K_2O (Melo & Cardoso 2017). Seeding was performed on 24 June 2016, using the BRS Itaim cultivar for the two systems and 0.50 m between planting furrows, with the seeds at 0.03 m of depth.

The irrigations were carried out by a fixed conventional sprinkler system, with nozzle impact sprayers of 4.4 mm x 3.2 mm and flow rate of 1.59 m^{-3} h^{-1}, at a pressure of 3.0 x 105 Pa, spaced 12 m x 12 m. To verify the efficiency of the application of the irrigation depth in each treatment, at 6 days after sowing, 16 collectors were installed in each water regime, totalizing 80 collectors in the experimental area. The reference evapotranspiration was estimated based on the average daily climatic data of air temperature, relative air humidity, global solar radiation and wind speed obtained from an automatic meteorological station installed near the experiment. The water regime was applied restoring the crop evapotranspiration determined based on the reference evapotranspiration, estimated by the Penman-Monteith method, according to methodology proposed by Allen et al. (1998), and in the cowpea crop coefficient (Table 3) recommended by Andrade Júnior et al. (2000).

Table 3. Crop coefficients for cowpea according to the cycle phases used at the experimental area.

Cycle phase	Days after seeding	Crop coefficient
I	0-15	0.50
II	16-44	0.80
III	45-57	1.05
IV	58-65	0.75

Source: Andrade Júnior et al. (2000).

Up to 18 days after sowing, one daily irrigation was applied in the amount of 100 % of the crop evapotranspiration from the previous day. From the eighteenth day after sowing, water regimes defined in the treatments were applied. The maximum plant density (28 plants m^{-2}) was sown and, at 15 days after sowing, a thinning was carried out, in order to adjust the treatments proposed in this study.

Harvesting was carried out on 29 August 2016. The useful area of each plot was represented by the two central rows. From that, the following production components were obtained: number of pods per area, pod length (cm) and dry grain yield (kg ha^{-1}), corrected to 13 % of moisture.

Analyses of variance were performed to test the significance of the irrigation water depths, plant density and the interaction between these factors. Because the interaction between the two factors was significant, multiple regression analyses were performed, following the methods proposed by Custódio et al. (2000), Pimentel-Gomes (2009) and Zimmermann (2014). A reduced model was fit, consisting of nine parameters containing the isolated linear and quadratic effects, as well as the linear and quadratic interactions, as it follows: $Y = b0 + b1A + b2A^2 + b3B + b4B^2 + b5AB + b6AB^2 + b7A^2B + b8A^2B^2$, in which Y is the dependent variable, b0 the constant of regression, b1,...,b8 the regression coefficients and A and B the independent variables, consisting of the irrigation water depths and plant densities, respectively.

The best model was selected based on the t test for each parameter, accepting the significance of 15 % (Conagin & Jorge 1982). The statistical analyses were performed with the SAS software (SAS Institute 2015).

RESULTS AND DISCUSSION

Analyses of variance detected a significant effect of water regimes and plant densities for all the variables (number of pods per plant, number of pods per area, pod length and grain yield), for both

the conventional and no-tillage systems (Tables 4 and 5, respectively). The interaction between the factors was also significant for all the evaluated variables.

In the conventional system, the highest value was 2.3 pods per plant (corresponding to 5.3, with data transformation to $\sqrt{x}$), with the use of 318 mm of water depth and density of 12-14 plants m^{-2} (Figure 1A). Number of pods per plant is a variable that decreases with increasing plant density (Bezerra et al. 2012), due to an intraspecific competition compromising photosynthesis.

Bezerra et al. (2014), studying plant densities under irrigated regime, verified linear decreases in the number of pods per plant with an increase in plant density. It was observed a reduction of 66.48 %, from 100,000 plants ha^{-1} to 500,000 plants ha^{-1}, which resulted, on average, in 14.62 and 4.90 pods per plant, respectively.

From plants cultivated in the no-tillage system, the same pattern was observed for number of pods per plant, when compared to the conventional system. However, the highest value observed was 2.8, when a density of 12-13 plants m^{-2} was used with 282 of water depth (Figure 1B). This lower water depth value may be explained by the fact that the crop residues provide a higher water retention in the soil (Figure 1B). Bastos et al. (2011) evaluated the effect of water deficit on physiological and productive characteristics of cowpea, to select tolerant genotypes to water deficit, and observed that the water deficit, which was obtained by applying approximately half of the water amount required by the cowpea, reduced the average number of pods per plant by 175 % and the grain yield by 60 %.

The results obtained in this research, both for the conventional and no-tillage systems, show that the interaction between plant density and applied water depths is significant ($p \leq 0.01$), and it can be inferred that the higher the plant density and the lower the irrigation, the lower the number of pods per plant. On the other hand, it is possible to verify that the number of pods per plant is responsive to irrigation, a result also observed by Andrade Júnior et al. (2002), although with maximum values obtained

Table 4. Variance analysis of cowpea (BRS Itaim) for the number of pods per plant, number of pods per area, pod length and grain yield, for the conventional system.

Source of variation	DF	Mean square[1]			
		Number of pods per plant	Number of pods per area	Pod length (cm)	Grain yield (kg ha^{-1})
Block	3	0.0766[ns]	1.0770[ns]	0.4648[ns]	93,554.020[ns]
Water depth (WD)	4	2.9683**	58.9907**	10.8009**	2,361,409.99**
Error (a)	12	0.0628	0.8747	0.5258	112,063.676
Density (DENS)	4	1.1349**	5.2283**	3.5374**	49,712.866**
WD*DENS	16	0.1236**	1.8928**	1.5747*	34,651.654**
Error (b)	60	0.0113	0.1591	0.4534	22,517.64
CV(a) (%)		15.87	13.63	4.95	18.94
CV(b) (%)		6.72	5.82	4.59	13.88

[1] Data transformed to $\sqrt{x}$. * Significant at $0.01 < p \leq 0.05$; ** significant at $p \leq 0.01$; [ns] not significant ($p > 0.05$), by the F test.

Table 5. Variance analysis of cowpea (BRS Itaim) for the number of pods per plant, number of pods per area, pod length and grain yield, for the no-tillage system.

Source of variation	DF	Mean square[1]			
		Number of pods per plant	Number of pods per area	Pod length (cm)	Grain yield (kg ha^{-1})
Block	3	0.0073[ns]	0.1119[ns]	0.5106[ns]	6,632.83[ns]
Water depth (WD)	4	2.8578**	50.8047**	15.3268**	3,735,844.64**
Error (a)	12	0.0450	0.9553	0.2995	78,693.29
Density (DENS)	4	1.8513**	3.4373**	1.8223**	123,835.42**
WD*DENS	16	0.1122**	0.8550**	1.0283**	53,664.31**
Error (b)	60	0.0180	0.2946	0.1568	22,265.43
CV(a) (%)		10.82	11.38	3.56	23.89
CV(b) (%)		6.84	6.32	2.58	12.71

[1] Data transformed to $\sqrt{x}$. * Significant at $0.01 < p \leq 0.05$; ** significant at $p \leq 0.01$; [ns] not significant ($p > 0.05$), by the F test.

with different water depths, as those observed in the present study.

    For the number of pods per area, it was verified that the highest value observed in the conventional growing system was 8.8 (data transformed to √×), obtained in the highest plant density evaluated in this study (28 plants m^{-2}) and in the highest irrigation regime used (320 mm) (Figure 2A). For plants from the no-tillage system, the number of pods per area was 10.25 (transformed to √×), higher than the one observed for the conventional system. This maximum value was obtained with the same plant density and

(A) $Y = -0.5244 + 0.1769***D + 0.000029**L^2 - 0.0065***D^2 + 0.000015***LD^2 - 0.0000016***L^2D$

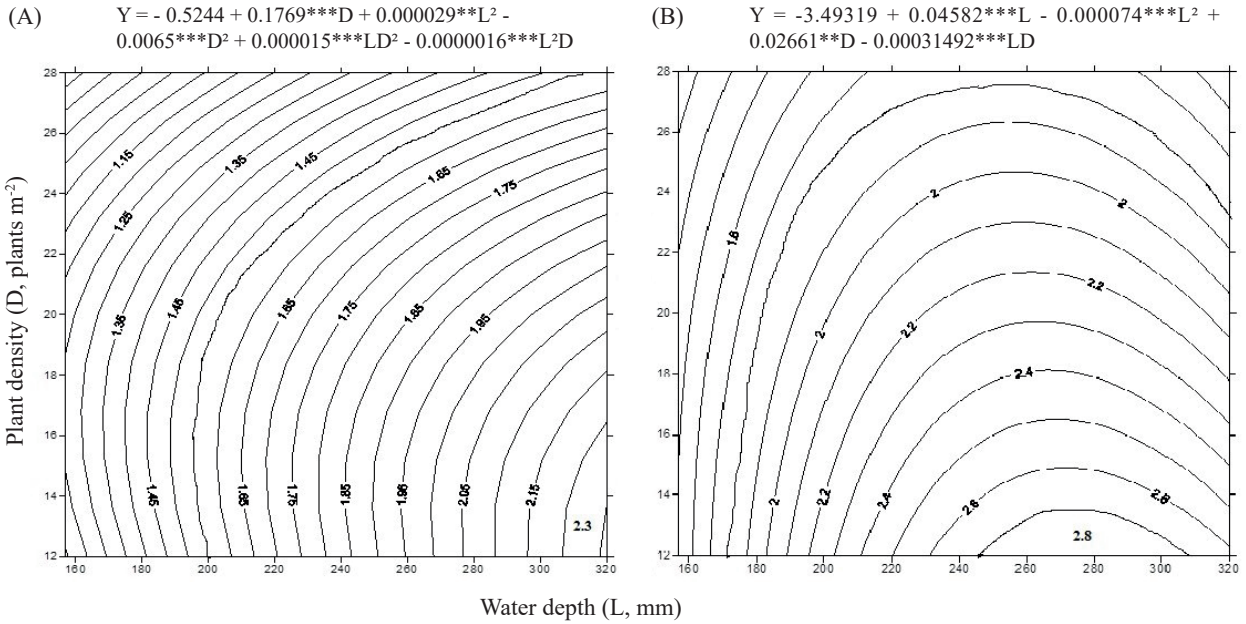(B) $Y = -3.49319 + 0.04582***L - 0.000074***L^2 + 0.02661**D - 0.00031492***LD$

Figure 1. Response surfaces for the number of pods per plant (data transformed to √×) of cowpea (BRS Itaim), according to water depths and plant densities, in the conventional (A) and no-tillage (B) systems.

(A) $Y = -0.5985 + 0.1320***D + 0.000056***L^2 + 0.0083***D^2 + 0.0025***LD - 0.0000056***L^2D$

(B) $Y = -13.55909 + 0.15682***L - 0.00027108***L^2 + 0.16650***D - 0.00045461**LD$
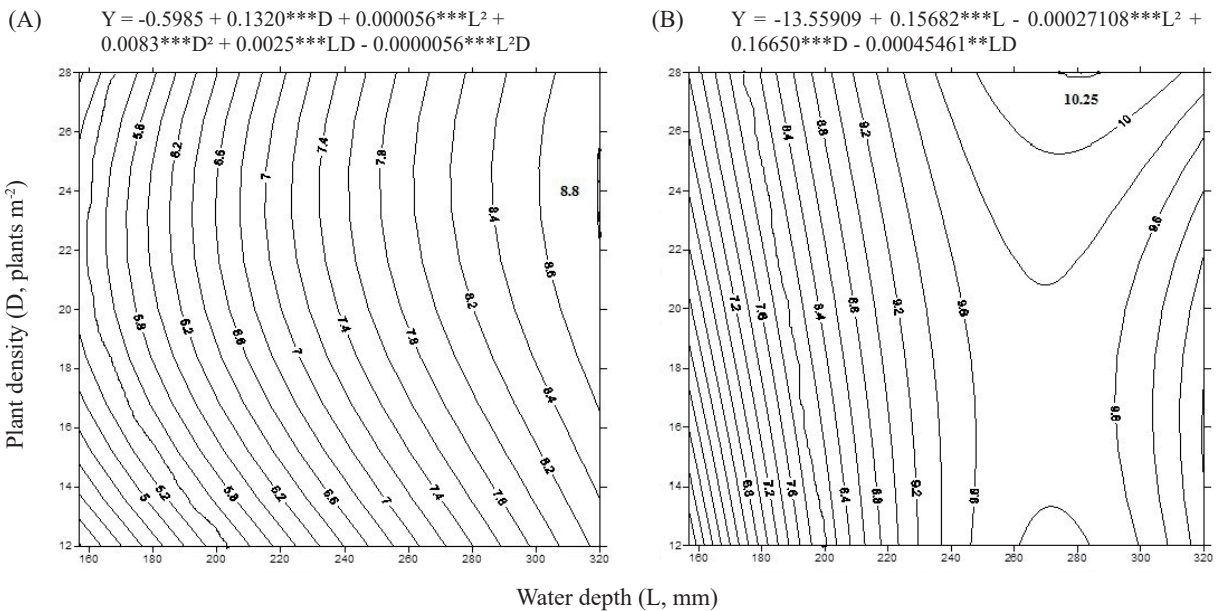

Figure 2. Response surfaces for the number of pods per area (data transformed to √×) of cowpea (BRS Itaim), with the application of water regimes and plant densities, under conventional (A) and no-tillage (B) systems.

265 mm of water depth, a decrease of 17.2 % in irrigation (Figure 2B).

It was observed a tendency to increase the number of pods per area with a higher number of plants per area (280,000 plants ha^{-1}) for both production systems. Although the greatest number of plants per area resulted in a reduction in the photo-assimilates production (intraspecific competition), there is a compensatory effect due to the higher number of plants per area. This result corroborates Shimada et al. (2000), who observed that the grain yield was favored by increasing the plant density.

The highest value for pod length in the conventional system was 15.74 cm, obtained with 312 mm of water depth and density of 17 plants m^{-2}, according to the response surface (Figure 3A). The results showed a significant quadratic effect for irrigation regimes and plant density for this variable under the conventional and no-tillage systems. Superior results were observed by Silva et al. (2013), evaluating the cowpea under irrigated regime, with 17.7 cm of pod length for the BRS Itaim cultivar.

In the no-tillage system, the highest pod length was 16.34 cm, when a density of 21 plants m^{-2} was used with 285 mm of water depth, which is lower, when compared to the one used in the conventional growing system. Silva et al. (2016) evaluated the dry grain yield and cowpea production components

under an irrigated system and observed increases in the pod length values (16-22 cm) with higher water depths (360 mm) than the ones tested in this study. Freitas et al. (2013) observed that the no-tillage and conventional systems may influence the following cowpea production components: pod length, number of grains per pod, number of grains per plant and grain yield.

The highest value for grain yield in the conventional system was 1,166.36 kg ha^{-1}, with a 320 mm depth and density of 28 plants m^{-2} (Figure 4A). The results indicate that there is a combination of irrigation depth and plant density that provides higher values for cowpea grain yield in this system. It is possible that the conventional growing system, by allowing a higher water evaporation from the soil, requires a higher water depth when irrigated. The density of 28 plants m^{-2} resulted in the highest number of pods per plant and, consequently, a higher grain yield.

Oliveira et al. (2015), evaluating the interaction between water depths and plant densities in the cowpea growth and yield, using a conventional production system, observed a grain yield of 1,668.86 kg ha^{-1}, using 390.88 mm of water depth and density of 24.1 plants m^{-2}, for the BRS Itaim cultivar. Souza et al. (2011) evaluated cowpea under a conventional production system and observed a grain yield of 1,376.9 kg ha^{-1}, with 449 mm of

(A) $Y = 1.7844 + 0.0594{***}L + 0.5341{***}D - 0.000080{*}L^2 - 0.0104{***}D^2 - 0.00055{**}LD$

(B) $Y = 5.33200 + 0.05925{***}L + 0.24021{***}D - 0.00012{***}L^2 - 0.00841{***}D^2 + 0.00041{**}LD$
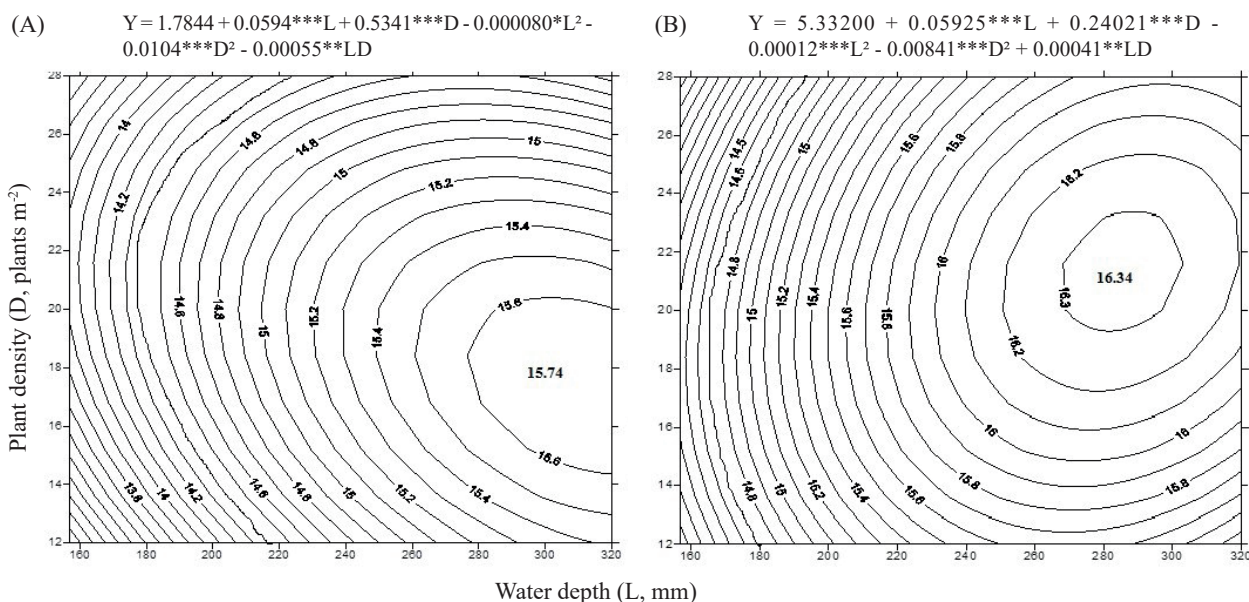

Water depth (L, mm)

Figure 3. Response surfaces for the cowpea (BRS Itaim) pod length, with the application of water regimes and plant densities, under conventional (A) and no-tillage (B) systems.
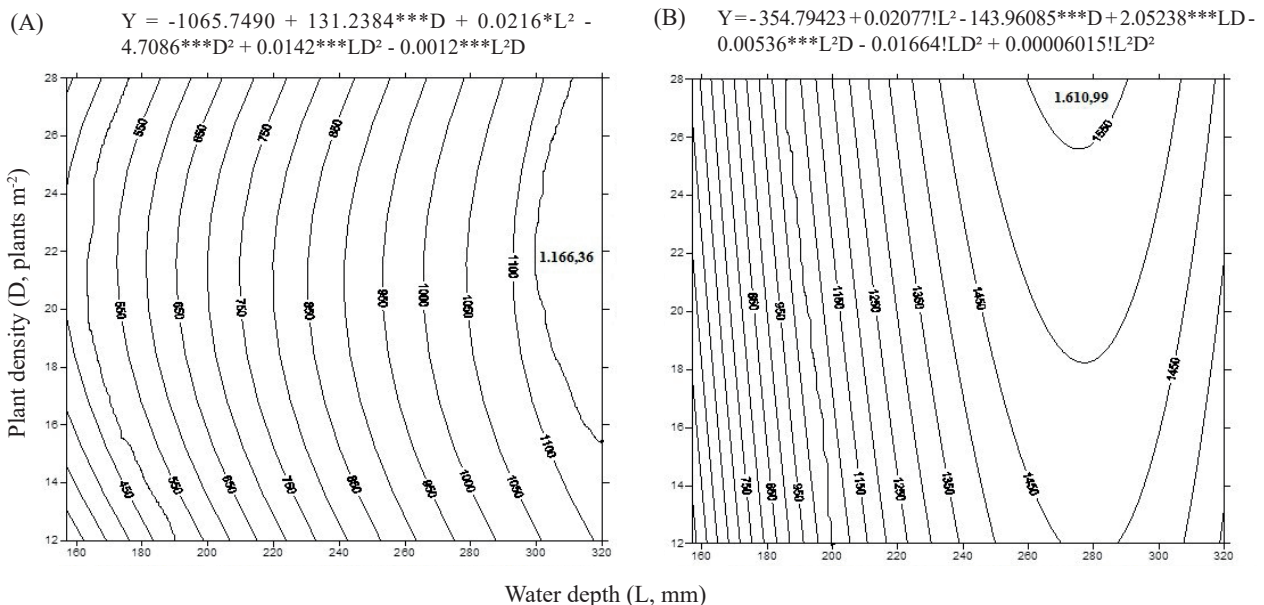
(A) $Y = -1065.7490 + 131.2384{***}D + 0.0216{*}L^2 - 4.7086{***}D^2 + 0.0142{***}LD^2 - 0.0012{***}L^2D$

(B) $Y = -354.79423 + 0.02077!L^2 - 143.96085{***}D + 2.05238{***}LD - 0.00536{***}L^2D - 0.01664!LD^2 + 0.00006015!L^2D^2$

Figure 4. Response surfaces for grain yield (kg ha^{-1}) of cowpea (BRS Itaim), with the application of water regimes and plant densities, under conventional (A) and no-tillage (B) systems.

water depth, being 29 % higher than the one used in this study.

Silva et al. (2016), evaluating the dry grain yield and cowpea production, observed increases of 30.4 %, with values ranging 886.72-1,274.06 kg ha^{-1}, with irrigation of 360 mm depth, under the conventional production system.

In the no-tillage system, the highest yield obtained was 1,610.99 kg ha^{-1}, when the density of 28 plants m^{-2} and irrigation with 270 mm of water depth were applied (Figure 4B). The results indicate that the increase in irrigation promoted an increase in grain yield, up to the maximum limit of 270 mm. The *Urochloa* (syn. *Brachiaria*) and sorghum crop residues used in the no-tillage system favored the reduction of water losses by evaporation. This resulted in a greater water efficiency in this system, so that the production component number of pods per area was the most influenced one, requiring a smaller water volume to reach a higher grain yield.

Tagliaferre et al. (2013) observed higher values for these variables in a study with cowpea (Guariba cultivar), according to water depths, and noticed a quadratic behavior reaching the maximum grain yield of 2,820.03 kg ha^{-1}, with 462 mm of water depth. These results are corroborated by Locatelli et al. (2014), who evaluated cowpea in a Yellow Latosol, under a no-tillage system, and observed an influence of the irrigation depth in the dry grain yield.

CONCLUSIONS

1. Irrigation with 270 mm of water depth, associated with a density of 280,000 plants ha^{-1}, resulted in a higher grain yield, under the no-tillage growing system;
2. The density of 280,000 plants ha^{-1} and 320 mm of water depth favored the best grain yields, when the conventional growing system was used.

ACKNOWLEDGMENTS

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