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Optimal economical dose of nitrogen and diagnostic leaf to assess the nutritional status of cowpea

Dose ótima econômica de nitrogênio e folha diagnóstica para avaliação do estado nutricional do feijão-caupi

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ABSTRACT

Considering that crop nutrition is essential to obtain high yields, the objective of this study was to determine the optimal economical dose of nitrogen (N) associated with maximum technical and economical yield. Additionally, to correlate cowpea cultivars with N contents and yield. The experiment was conducted under the edaphoclimatic conditions of Teresina, PI, Brazil, in Entisol (*Fluvic Neosol*), in the second half of 2017, in a randomized block design in a factorial scheme (2x2x5), whose factors were: (i) cowpea genotypes (BRS Imponente and BRS Itaim), (ii) form of application of N fertilization (basal + top-dressing or fully top-dressing) and (iii) N doses (zero, 10, 30, 50 and 70 kg ha^{-1} - urea as source). The variables measured were the total N content in the plant tissue, with a collection of leaves +1 and +3, and grain yield. When analyzing the effect of the interaction, there was significance only for the factors form of application and N doses. However, when the doses were further analyzed for each form of N fertilization, the best response model was the quadratic, whose point of maximum physical yield was verified with N doses of 34 and 44 kg ha^{-1} for basal + top-dressing and fully top-dressing applications, respectively. Furthermore, the most economical doses for basal + top-dressing and fully top-dressing N applications were 26.0 and 35.6 kg ha^{-1}, respectively. For N, the leaf that best represents the nutritional status for leaf diagnosis was +3.

KEYWORDS: *Vigna unguiculata*; basal fertilization; top-dressing fertilization.

RESUMO

Considerando que a nutrição da cultura é preponderante para obtenção de elevadas produtividades, objetivou-se determinar a dose ótima econômica de N associada à máxima produtividade técnica e econômica. Adicionalmente, realizar correlações entre cultivares de feijão-caupi com os teores de N e a produtividade. O experimento foi conduzido nas condições edafoclimáticas de Teresina, PI, em um Neossolo Flúvico, no segundo semestre de 2017, em delineamento em blocos casualizados em esquema fatorial (2x2x5), cujos fatores foram: (i) genótipos de feijão-caupi (BRS Imponente e BRS Itaim), (ii) época de aplicação da adubação nitrogenada (fundação+cobertura ou totalmente em cobertura) e (iii) doses de N (zero, 10, 30, 50 e 70 kg ha^{-1} – fonte ureia). As variáveis mensuradas foram a análise do N total do tecido vegetal com a coleta da folha +1 e +3, além da produtividade de grãos. Quando analisamos o efeito da interação houve significância somente para os fatores época de aplicação e doses de N, e quando desdobramos as doses para cada época de adubação nitrogenada o melhor modelo de resposta foi o quadrático, cujo ponto de máxima produtividade física foram verificados com as doses de 34 e 44 kg ha^{-1} de N para a aplicação na fundação+cobertura e totalmente em cobertura, respectivamente. Ainda, a doses mais econômica para a aplicação de N em fundação+cobertura e totalmente em cobertura foram de 26,0 e 35,6 kg ha^{-1}, respectivamente. Para o N a folha que melhor representa o estado nutricional para a diagnose foliar mostrou-se ser a +3.

PALAVRAS-CHAVE: *Vigna unguiculata;* adubação de fundação; adubação de cobertura.

INTRODUCTION

Cowpea (*Vigna unguiculata*) is a prominent crop in the Northeastern region of Brazil and has recently been expanded mainly in the Midwest region, with focus on grain exports. In recent years, cowpea has aroused the interest of farmers with higher technological levels due to the high profitability that this crop can provide (VALE et al. 2017).

Cowpea cultivation is often carried out in soils without proper fertilization, where the nutrients most extracted by the plant are K, N, and Ca, with variation of contents according to the cultivar and management system, contributing for the crop to not express its full production potential (VERA 2019, KYEI-BOAHEN et al. 2017). Therefore, the low grain yield of cowpea is mainly influenced by inadequate soil fertilization (MELO et al. 2018).

In cowpea crop, it is recommended to use inoculants (ALCANTARA et al. 2014, XAVIER et al. 2017), which stand out from mineral fertilizers due to low cost and lower environmental impact. However, there are reports of production increments with the use of nitrogen (N) fertilizers (NDOR & FARINGORO 2020, PEREIRA et al. 2018). MOREIRA et al. (2017) mention that the use of 60 kg ha^{-1} of N promoted better cowpea production responses than seed inoculation with *Bradyrhizobium elkanii* in the Cerrado of Roraima (Brazil). In this context, one may question whether, from an economic point of view, it would be advantageous to use N fertilizers, mainly due to the low levels of crop yield, so it is opportune to carry out economic analysis of production in response to the application of fertilizers.

In this context, for defining the nutrient dose to be applied, the goal should always be to use economical doses of the fertilizer, which will depend, in part, on the ratio between the prices of the agricultural product and the fertilizer, in addition to the type of response to the nutrient (PROCHNOW 2008).

It should be noted that the maximum technical yield generally differs from that considered economical, which is subject to the price of the nutrient, other production costs and sales prices of the obtained product (SOUZA et al. 2015).

According to RAIJ (1991), the law of diminishing returns serves as the basis for defining the most economical dose of an input because, when the value of the increment in production is equal to the cost of the fertilizer, one reaches the level of application above which the use of fertilizer does not translate into economic return, corresponding to the most economical or optimal dose (OLIVEIRA et al. 2009, NATALE et al. 2010).

In order to assess the nutritional status of a plant and, thus, to be able to plan the field actions, the diagnosis has been carried out. Although legumes share similar characteristics, especially common bean (*Phaseolus vulgaris*) with cowpea, it is still necessary to carry out studies with the latter, especially in order to indicate the diagnostic leaf for adequate nutritional assessment, optimize fertilization, and prevent possible negative environmental impacts resulting from the inadequate application of correctives, conditioners, and fertilizers.

In view of the above, the objective was to determine the optimal dose of N associated with maximum technical and economic yield and to indicate the diagnostic leaf in cowpea.

MATERIAL AND METHODS

Description of the study site and experimental design

The study was conducted under the edaphoclimatic conditions of Teresina, PI, Brazil, in an Entisol (*Fluvic Neosol*) (MELO et al. 2019), in the second half of 2017. The cultivars used were BRS Itaim and BRS Imponente, in an area with a mobile sprinkler irrigation system and fallow before cultivation. The air temperature and precipitation values during the experiments are shown in Figure 1.

Before the tests, ten single soil samples were collected (0.0-0.2 and 0.2-0.4 m) to form the composite sample for chemical and physical characterization, carried out according to TEIXEIRA et al. (2017), whose results are presented in Table 1. The sowing was carried out after operations with plowing harrow and leveling harrow, applying in each plot the equivalent to 40 and 30 kg ha^{-1} of P_2O_5 and K_2O, respectively.

The experimental design was in randomized blocks in a factorial scheme, in which the first factor was cowpea cultivars (BRS Itaim and BRS Imponente), the second factor was the form of application of N fertilizer (basal + top-dressing or fully top-dressing) and the third factor was N doses (0, 10, 30, 50 and 70 kg ha^{-1} of N), with four blocks. The plots were composed of 4 rows spaced by 0.5 m and 5 m length. The source used for N fertilization was urea (45% N), the two times of N application were: (i) part of N applied at planting (fixed N dose of 10 kg ha^{-1}) and the rest as top-dressing; (ii) entire N dose as top-dressing (applied 20 days after emergence of plants).

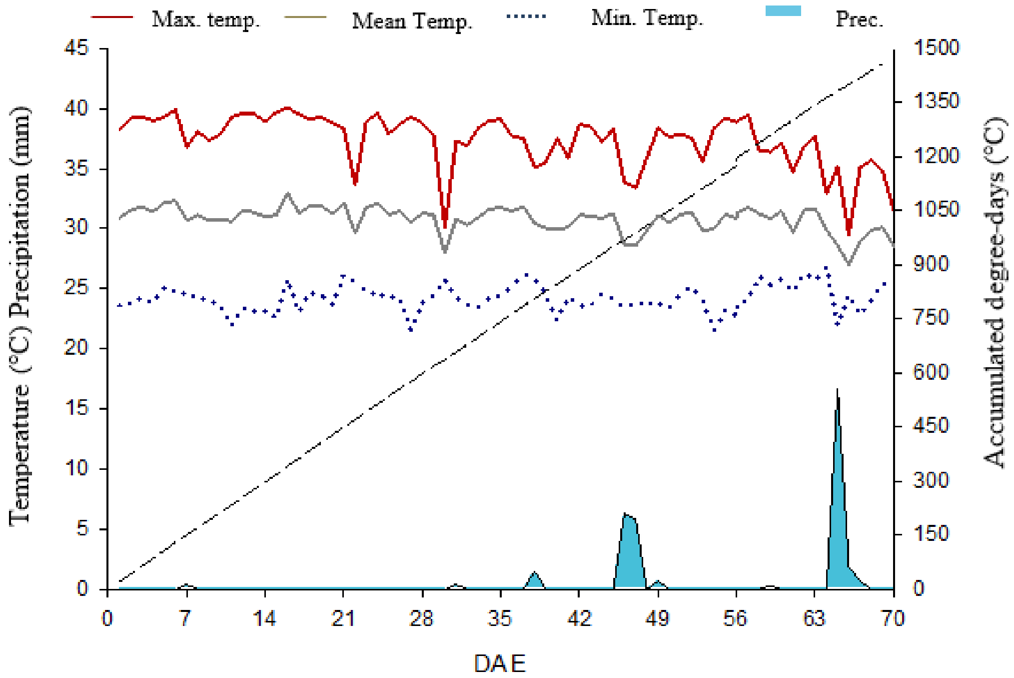

Figure 1. Temperature and precipitation variation along the experiment starting on 10/05/2017 (planting) and ending on 12/19/2017 (harvest). Source: INMET 2017.

Table 1. Chemical and physical characteristics of the soil of the experimental area, obtained in the 0.0-0.2 and 0.2-0.4 m layers.

Layers	pH	P	K	Na	Ca	Mg	Al	H+Al	SB	CEC pH 7	N	OM	BS
		mg dm-3	I------------------------cmolc/dm3-----------------------I								dag-1 kg-1		%
0.0-0.2 m	5.9	70.8	0.17	0.04	2.37	1.31	0.02	1.59	3.89	5.48	0.06	1.1	70.9
0.2-0.4 m	6.0	44.2	0.12	0.26	2.87	1.59	0.03	1.52	4.84	6.36	0.05	1.1	76.1
Layers	Sand	Silt	Clay	Textural Class									
	I-----------g/kg---------I												
0.0-0.2 m	407	139	453	Loam									
0.2-0.4 m	443	154	403	Loam									

OM - Walkley and Black (wet oxidation); P; K; Na – Mehlich-1 or double acid; Ca, Mg and Al - KCl; H+Al - Ca acetate; S-SO_4^{2-} - Turbidimetry/Barium Chloride; Sand, silt, clay – pipette method.

The cowpea cultivars tested have the following characteristics: BRS Imponente - indeterminate growth habit, semierect, with short lateral branches, early maturation cycle and insertion of pods above the foliage level, which promotes good resistance to lodging (DAMASCENO-SILVA et al. 2016); BRS Itaim - determinate growth habit, erect, high resistance to lodging, with average flowering of 35 days and a super-early maturation cycle of 60-65 days (FREIRE FILHO et al. 2009).

Data collected and analyses performed

Harvest of dry grains was quantified per each plot's usable area, and the data were adjusted to 13% moisture. The most economical N dose for cowpea grain yield was determined according to RAIJ et al. (1991) and NATALE et al. (2010), based on the exchange ratio of the input and dry grain production the plant.

The most economical doses were calculated based on the derivative of the regression equation ($y = ax^2 + bx + c$) between the production of cowpea grains and the doses of the N fertilizer, making it equal to the exchange ratio, that is: *dy/dx= a1+2.a2x* = exchange ratio. The most economical dose (x') is then calculated by (Eq. 1):

Equation 1: $$x' = \frac{b - exchange\ ratio}{2.(-a)}$$

The cost of the kilogram of N, whose source was urea, was obtained considering the average price practiced in Teresina, PI (R$ 3.93/kg). For cowpea, the average price per kilogram of grains established by MAPA ordinance no. 1577 of 07/17/2017 was considered, equal to R$ 0.88. Thus, the equivalence ratio was equal to R$ 4.47.

To determine the diagnostic leaf, the leaves +1 and +3 (matured leaves from the apex) were collected at the time of flowering, as recommended by MALAVOLTA et al. (1997). Also, one sample was collected in each treatment (2 cultivars x 2 forms of N application x 5 doses = 20 treatments), totaling 20 samples. Then, the leaves (+1 and +3) were washed in distilled water and dried in a forced air circulation oven at 65 ± 0.5 ºC, until reaching constant mass. N content was determined in the leaves by the Kjeldahl method (MALAVOLTA et al. 1997).

Statistical analysis

Analysis of variance was performed and, depending on the significance, means comparison test or regression analysis was applied using the statistical program SISVAR (FERREIRA 2014). With the results of plant tissue analysis and yield, Pearson's correlation between leaf content (+1 and +3) and cowpea grain yield was applied

RESULTS AND DISCUSSION

When analyzing the factors separately, there was no statistical difference for yield between cultivars and the form of N application, but for the doses factor the best response model was the quadratic, whose maximum point was reached with the N dose of 39 kg ha^{-1} ($y = -0.2752x^2 + 21.488x + 708.76$; $R^2 = 0.88$**) (Table 2).

Table 2. Mean values of cowpea yield as a function of cultivars, form of application and nitrogen doses.

Cultivar (C)	Yield (kg ha^{-1})
BRS Imponente	935
BRS Itaim	933
F test	ns
Form of application (FA)	
Basal + Top-dressing	905
Top-dressing	964
F test	ns
N doses (D), kg ha^{-1}	
0	725
10	845
30	1188
50	1027
70	885
F test	**[1]
C x FA	ns
C x D	ns
FA x D	*
C x FA x D	ns
CV (%)	27.5

[ns], * and ** - Not significant, significant at 5 and 1% probability levels. [1]Equation as a function of the doses factor: $y = -0.2752x^2 + 21.488x + 708.76$; $R^2 = 0.88$**.

When analyzing the effect of the interaction, there was significance only between the factors form of application and N doses (Figure 2), so the doses were further analyzed for each form of N application in both cases and the best response model was the quadratic, whose points of maximum physical yield were verified with N doses of 34 and 44 kg ha^{-1} for basal + top-dressing and fully top-dressing applications, respectively.

Calculation of the most economical dose according to Equation 1 indicated that the most economical N dose was equal to 26.0 kg ha^{-1} for basal + top-dressing application of the N fertilizer and to 35.6 kg ha^{-1} for fully top-dressing application (Table 3). Some studies may point out to lower doses as top-dressing or different management strategies to obtain better yield results; however, such techniques are employed during different phenological stages of the plant and/or with the use of inoculants, which may interfere in the final revenue (GALINDO et al. 2020, OMURA et al. 2020).

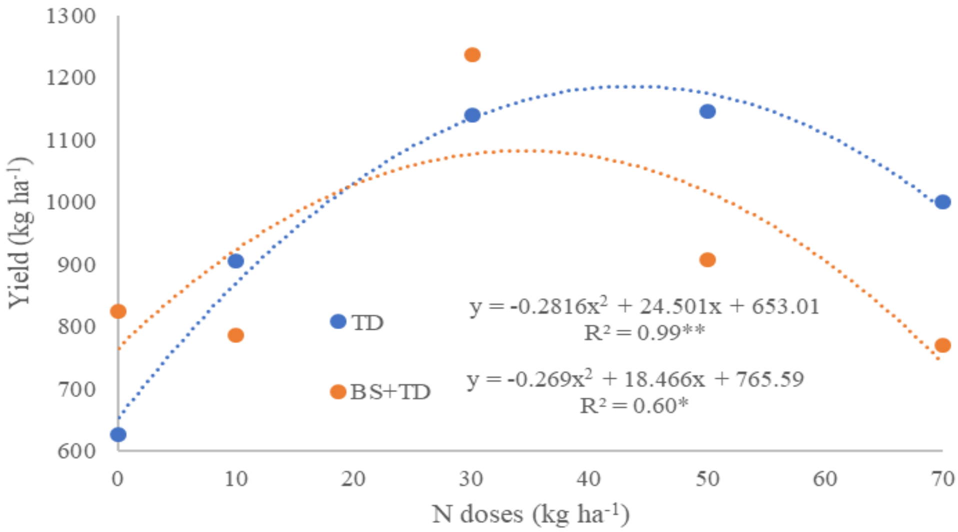

Figure 2. Cowpea yield as a function of doses and form of application of nitrogen fertilization (basal + top-dressing: BS+TD or fully top-dressing: TD).

It is also worth pointing out that the yields obtained with the most economical doses, for both fully top-dressing and basal + top-dressing applications, were close to the maximum yield possible (technical) (Table 3), being equal to 81% and 76%, respectively. This means that the application of optimal economical doses allowed savings in the application of the input, without significant reduction in the grain yield of cowpea.

Figure 2 shows that, in general, the N doses at which it was possible to obtain the maximum yield of the crop varied between 34 and 44 kg ha^{-1} regardless of the genotypes, so the variation was due to the form of application of N fertilizer. Thus, it differs from the behavior of common bean (*Phaseolus vulgaris*) in relation to the response to N, and each cultivar may show distinct responses (NASCIMENTO et al. 2021).

The expected profit due to N fertilization only as top-dressing can be determined by the increase in cowpea grain yield (515.2 kg ha^{-1}), which corresponds to grain yield with the most economical dose, equal to 1,168.2 kg ha^{-1}, minus the yield at the zero dose - absolute control, equal to 653.0 kg ha^{-1}; subtracting the cost of fertilizer in kilograms of cowpea grains (159.1 kg ha^{-1}) results in a profit of 356.1 kg ha^{-1} of cowpea grains (Table 3).

Table 3. Most economical nitrogen dose (urea as source) as a function of yield and costs of cowpea grains.

Fertilization	Most economical dose	Production increase	Cost of fertilizer	Profit	Yield[1]
	kg N ha^{-1}	------------------- kg grains ha^{-1}	---------------------		%
Top-dressing	35.6	515.2	159.1	356.1	81
Basal + Top-dressing	26.0	298.4	116.2	182.2	76

[1]Percentage of cowpea grain yield obtained at the most economical dose, relative to the maximum yield.

The expected profit due to basal + top-dressing N fertilization was also calculated based on the increase in the production of cowpea grains (298.3 kg ha^{-1}), which corresponds to grain production with the most economical dose, equal to 1,063.9 kg ha^{-1}, minus the production at the zero dose - absolute control, equal to 765.6 kg ha^{-1}, subtracting the cost of fertilizer in kilograms of cowpea grains (116.2 kg ha^{-1}) results in a profit of 182.2 kg ha^{-1} of cowpea grains (Table 3).

The results obtained for the economical dose of N in cowpea are close to the recommendation of MELO & CARDOSO (2017) and MELO et al. (2018). Both studies suggest 30 kg ha^{-1} of N for newly deforested areas, in sandy soils or with organic matter content lower than 1.0 dag kg^{-1}, and the values presented in Table 1 are close to these suggested values.

Regarding the evaluation of the diagnostic leaf, it is observed that leaf +1 did not have a significant correlation with grain yield ($p>0.05$; $r= 0.29$), which can be justified by the fact that it is not at the most appropriate stage or maturity, since there was no positive correlation between it and grain yield. In turn, leaf +3 proved to be the most appropriate for the evaluation of the nutritional status of cowpea ($p<0.01$; $r= 0.58$), considering that the correlation between the parameters evaluated was positive (N content in the leaf +3 x grain yield) (Figure 3).

As observed in Figure 3A, the line is neither parallel nor coincident with the points. On the other hand, Figure 3B presents a line that is parallel and coincident with the points. Thus, it can be observed that the choice of the most appropriate leaf for leaf diagnosis can be based on the graph that presents parallel lines that coincide with points, since it tends to have a higher correlation coefficient.

Although there are studies using the diagnostic leaf, there is no consensus on which is the most appropriate. Some studies follow the methodology adopted by MALAVOLTA (1989), while others adopt methodologies used for common bean, due to lack of recommendation for cowpea (PEREIRA JÚNIOR et al. 2015).

The result presented for the diagnostic leaf is important, because the recommendation of collection of cowpea becomes the same as that of common bean (SOUZA et al. 2011), and there is also a study in the literature with the suggestion of critical levels and sufficiency ranges considering the collection of the diagnostic leaf +3 for cowpea (MELO et al. 2020).

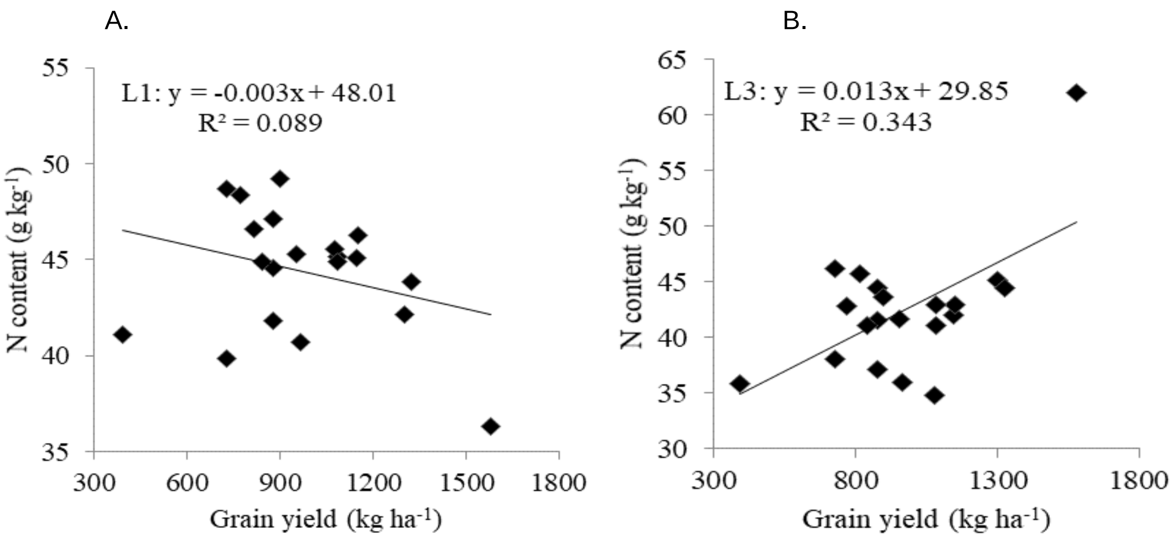

Figure 3. Equations, coefficients of determination (R^2) and correlations obtained between the nitrogen contents in Leaf +1 (A) and Leaf +3 (B) with grain yield. Teresina, PI, 2020.

In an experiment carried out by PEREIRA JÚNIOR et al. (2015) with the cowpea crop, under different N and P doses applied in the soil, the authors suggest that the increase in the doses of these nutrients promotes increments in mass of grains, grain yield and contents of these nutrients in the leaf. Also, the critical N level indicated by the aforementioned authors is 46.8 g kg^{-1}.

Top-dressing fertilization generates a higher profit than basal + top-dressing fertilization, which generated 356.1 kg ha^{-1} and 182.2 kg ha^{-1}, respectively. The diagnosis of the nutritional status of the cowpea plant can be performed by collecting the leaf +3 from the apex to the collar, with petiole, during flowering.

CONCLUSION

There was no difference between cowpea cultivars for doses and the form of N fertilizer application.

The maximum physical and economical yield was obtained when N was applied entirely as top-dressing. The maximum physical yield was obtained with doses of 34 and 44 kg ha^{-1} of N in basal + top-dressing and fully top-dressing applications, respectively. The most economical doses for basal + top-dressing and fully top-dressing applications were 26.0 and 35.6 kg ha^{-1} of N, respectively.

To evaluate the nutritional status of the cowpea plant, it is recommended to collect the leaf +3 from the apex to the collar, with petiole, during flowering.

The best form of application of N fertilization is top-dressing, at 20 days after the emergence of cowpea plants.

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