Nitrogen fertilization regarding maize crop in a semi-arid region

Adubação nitrogenada nos parâmetros da cultura do milho em região Semiárida

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Abstract

The correct management of fertilization, with the use of adequate source and doses of nitrogen, allied to cultivars adapted to certain edaphoclimatic conditions, is essential to obtain high yields. Thus, the objective of this study was to evaluate the nutritional N status, the physiological status and the grain yield of maize as a function of the application of nitrogen fertilizer sources and doses in Sobral - CE, in the northeastern semi-arid region. The design was in randomized blocks, in the factorial scheme 5x3+1. The treatments consisted of the combination of five forms of urea: conventional urea; urea + enzyme inhibitor; urea + polymer; urea + enzyme inhibitor + B + Cu; and urea + coating with elemental S, in three doses of nitrogen: 30, 45 and 60 kg ha^{-1}, applied in coverage, in the V6 stage (six fully developed leaves), plus a control treatment without N. The maize variety studied was BRS Gorutuba. Nitrogen fertilization in maize coverage promoted greater increases in the content of leaf N, protein, SPAD index and grain yield, when compared to the control, without N. The highest grain yield of maize was obtained with the use of urea treated with urease inhibitor, at the dose of 47 kg ha^{-1}.

Additional keywords: improved fertilizers; leaf diagnosis; Z*ea mays L.*

Resumo

O correto manejo da adubação pelo emprego de fonte e doses adequadas de nitrogênio, aliados a cultivares adaptados a determinadas condições edafoclimáticas é essencial para obtenção de produtividades elevadas. Sendo assim, objetivou-se avaliar o estado nutricional em N, fisiológico e a produtividade de grãos de milho, em função da aplicação de fontes e doses de fertilizantes nitrogenados em Sobral-CE, no Semiárido nordestino. O delineamento foi em blocos ao acaso, no esquema fatorial 5x3+1. Os tratamentos consistiram da combinação de cinco formas de ureia: ureia convencional; ureia + inibidor enzimático; ureia + polímero; ureia + inibidor enzimático + B + Cu; e ureia + capeamento com S elementar, em três doses de nitrogênio: 30, 45 e 60 kg ha^{-1}, aplicadas em cobertura, no estádio V6 (seis folhas totalmente desenvolvidas), mais um tratamento controle sem N. A variedade estudada foi o milho BRS Gorutuba. A adubação nitrogenada em cobertura na cultura do milho promoveu maiores incrementos no teor foliar de N, proteínas, índice SPAD e produtividade de grãos, quando comparados ao controle, sem N. A maior produtividade de grãos de milho foi obtida com o uso da ureia, tratada com inibidor de urease na dose de 47 kg ha^{-1}.

Palavras-chave adicionais: diagnose foliar; fertilizantes de eficiência aprimorada; Z*ea mays L.*

Introduction

Maize, due to its high yield potential, chemical composition and nutritional value, plays an important role in the economy and social development of several regions of Brazil, being a source of food for humans and animals. Notwithstanding, its yield may be limited by the lack of technology use by small producers, especially those in the northeastern region (Santos et al., 2014). Therefore, studies that aim to evaluate the

efficiency of inputs and technologies are necessary, since they can contribute to increases in production.

In the Brazilian semi-arid, as maize is a subsistence crop, there is low use of inputs such as fertilizers, and there are few research that relates nutritional status and crop yield combined with the use of technologies. It is known, however, that the application of nutrients can guarantee satisfactory results, making its use feasible (Sampaio et al., 2004).

Among the essential elements for the growth and development of plants, nitrogen is highlighted, playing a key role as a constituent of proteins (many with enzymatic and regulatory functions in all plant metabolism), nucleic acids, phytochromes and chlorophyll. N also influences leaf initiation and expansion rates, leaf size and leaf senescence intensity (Malavolta, 2006), being the macronutrient that has the most complex management and fertilization recommendation (Raij, 2011).

Yield variability and increases in the content of chlorophyll, protein, nitrate reductase activity and dry matter as a function of the different amounts of nitrogen applied are observed by several authors (Lima et al., 2009; Soares et al., 2011; Frazão et al., 2014). Furthermore, plant characteristics such as nutritional status and chlorophyll content may be more adequate than soil parameters to predict N availability and maize grain yield (Vargas et al., 2012).

Thus, biochemical and physiological evaluations in the maize crop are important tools to correctly diagnose the nutritional status and, therefore, to make the most suitable fertilization recommendation (Argenta et al., 2001; Lima et al., 2009).

Among the nitrogen sources, urea is the most used in the country, due to its lower cost in relation to other N fertilizers; but it has a great loss potential due to NH^3 volatilization when applied to the soil without

incorporation (Silva et al., 2011), reducing N contents and, consequently, crop yield.

Currently, there are research studies comparing different forms of improved fertilizers, these being described as of slow or controlled-release, providing the nutrient for several days. Those of controlled release, associated with urease inhibitors and nitrification (Trenkel, 2010), as the name says, act in the inhibition of the enzyme urease, responsible for urea hydrolysis, increasing the use of N by plants (Mota et al., 2015). The use of these technologies may be a strategy to increase the nitrogen use efficiency by maize, mainly in conditions favorable to NH^3 volatilization.

The objective of this study was to evaluate the nutritional status and yield of the maize crop in the semi-arid region of northeastern Brazil by applying N rates in coverage, using several forms of urea with increased technology, measuring the grain yield, nitrogen content, chlorophyll content, protein content and SPAD index and their correlations.

Material and methods

The experiment was conducted in the experimental fields of Embrapa Caprinos e Ovinos, located in the municipality of Sobral - CE, at 3º41' S and 40º20' W. The climate of the region is BShw, according to the Köppen classification, with rainy season from January to June. The annual average temperature is 28 °C and the average rainfall is 759 mm per year.

The soil of the area was classified as lytic orthic chromic Luvisol, of medium texture, eutrophic, according to Ramos and Marinho (1980) and Santos et al. (2013). Chemical analyses regarding soil fertility were performed in the 0-0.2 m layer according to Silva (2009) and are shown in Table 1.

Table 1 – Soil chemical properties of the experimental area before experiment implantation.

pH	O.M.	P (resin)	K	Ca	Mg	H+Al	SB	CEC	V
(CaCl$_2$)	(g dm^{-3})	(mg dm^{-3})	--------------------------------- (mmol$_c$ dm^{-3}) ---------------------------------						(%)
5.3	12	5	1.5	31	19	25	51.5	76.5	67
B	Cu	Fe	Mn	Zn	S-SO$_4$	Al			
-- (mg dm^{-3}) --									
0.14	0.5	35	9.8	0.2	2	0			

O.M. = organic matter; SB = sun of bases; CEC = cation exchange capacity; V = base saturation

The maize variety used was BRS Gorutuba, with a super early cycle and adapted to the edaphoclimatic conditions of the northeastern semi-arid region. The trial was conducted in the 2010-2011 harvest. The average stand used was forty thousand plants per hectare. The rainfall during the experimental period that comprised the months of March, April, May, June and July were, respectively, 200, 233, 115, 61 and 84 mm.

The experimental design was a randomized complete block design with four replicates. The treat-

ments were distributed to the experimental units according to a 5 x 3 + 1 factorial arrangement (additional treatment without cover fertilization), resulting from the combination of five forms of urea: conventional urea (45% N); urea + urease enzyme inhibitor (NBPT) (45% N); urea + polymer (43% N); urea + + urease enzyme inhibitor + B + Cu (44.6% N + + 0.4% B + 0.15% Cu); and urea + coating with elemental S (37% N and 16% S), all applied through N rates in coverage in the V6 stage (six fully expanded leaves) of the crop: 100% (60 kg ha^{-1} N), 75% (45 kg ha^{-1} N) and

50% (30 kg ha^{-1} N). The plots consisted of six sowing rows with five meters of length, spaced 0.8 m apart, being considered as useful area the four central rows, excluding 0.5 m from each end.

The calculations of the yield expected for establishing the standard nitrogen dose were considered according to the history of the area (6-8 t ha^{-1} of grains), corresponding to 30 kg ha^{-1} at planting and 60 kg ha^{-1} N in coverage (100%), which were applied 10 cm next to the maize plants, in the phenological stage V6, without incorporation (Raij & Cantarella, 1997).

In the sowing fertilization, all the plots received 90 kg ha^{-1} P$_2$O$_5$ and 50 kg ha^{-1} K$_2$O, with triple superphosphate and potassium chloride as source, respectively. There was no need to perform correction of base saturation (V>60%) (Raij & Cantarella, 1997).

In the female flowering stage (Magalhães & Durães, 2006), the SPAD index was measured with the aid of a digital chlorophyll meter (Minolta SPAD 502); the readings were performed in the central third of the leaves in the ear base, in 10 plants of the useful area of the plot, during the morning. To evaluate the nutritional status, the central thirds of the same 10 plants were collected (Cantarella et al., 1997), being dried in a forced ventilation oven, ground and sent to the laboratory for determination of leaf N content, according to Silva (2009).

Total chlorophyll was evaluated by the method of Arnon (1949). The same leaves used for analysis of nitrogen and chlorophyll content were frozen in liquid nitrogen and macerated in a mortar with pestle. The protein content in the crude extract (1:3,w/v, 0.1 M Tris-HCl, pH 7.5, 1% PVPP, 0.005 M DTT, 0.005 M Na-

EDTA) was determined according to the methodology described by Bradford (1976), using bovine serum albumin as standard.

Grain yield was determined by manually collecting all the plant ears contained in the useful area of the plot. After collection, the ears were threshed, the grains were weighed, and the plot yield was calculated, being extrapolated to kg ha^{-1} and corrected to 13% moisture.

Having the data, the analysis of variance was performed by F test (p<0.05) and, when significant, regression analysis was performed for urea forms and doses, as well as their unfolding, in addition to the orthogonal contrast between treatments and control. N content, yield, SPAD index, proteins, chlorophyll *a*, *b* and total chlorophyll and carotenoids were also pooled for analysis of partial correlation and main components. The statistical software SAS was used.

Results and discussion

There was interaction for nitrogen content, SPAD index, protein content and grain yield (Table 2). In an isolated way, there was a significant result for chlorophyll *a* and total chlorophyll for the fertilizer factor, whose results were similar in both cases, that is, urea + urease inhibitor (NBPT) promoted lower values in relation to the other forms of urea, not providing, for these climatic conditions, the desired effect. For the contrast analysis, which is the comparison between the control treatment and the treatments that received coverage fertilization, there was a statistical difference (Table 2).

Table 2 - Summary of variance analysis for N content, SPAD index, protein content, chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl), carotenoids (Carot) and grain yield maize, as a function of nitrogen doses and sources.

Doses (D)	N content	SPAD index	Protein content	Chl *a*	Chl *b*	Total Chl	Carot	Grain Yield
(kg ha^{-1})	(g kg^{-1})	-	---------------------- (mg g^{-1}) ----------------------					(kg ha^{-1})
30	25.8b	28.5	8.4	1.0	0.4	1.4	418.9	4.762b
45	27.5a	31.8	8.7	1.1	0.4	1.5	456.3	5.374a
60	27.1ab	27.6	8.4	1.0	0.4	1.4	431.5	5.640a
F test	4.21*	0.51^{ns}	0.25^{ns}	1.71^{ns}	1.39^{ns}	1.64^{ns}	1.96^{ns}	8.25**
Equation	Q	-	-	-	-	-	-	L
Fertilizer (F)								
Urea	26.4b	26.9	7.8	1.0a	0.4	1.4a	432.8	4.514c
Urea + inhibitor	26.1b	24.3	8.3	0.9b	0.4	1.2b	405.7	7.110a
Urea + polymer	28.4a	27.1	8.8	1.1a	0.4	1.4a	449.9	4.702c
Urea + inhibitor (B+Cu)	26.7b	24.4	9.4	1.1a	0.4	1.5a	452.1	5.414b
Urea + S	26.4b	25.5	8.1	1.1a	0.4	1.4a	437.8	4.554c
F test	2.85*	2.42^{ns}	2.05^{ns}	3.41*	1.58^{ns}	2.81*	1.13^{ns}	29.37**
D x F (F test)	77.59**	3.28**	3.12*	6.38**	5.12**	6.18**	5.89**	19.09**
CV (%)	6.3	13.9	15.6	13.9	15.7	14.1	12.1	11.5
Control (C)	21.7	17.5	6.4	1.0	0.32	1.3	382.8	2.857
(D X F) vs C	8.46**	18.32**	6.74*	0.27^{ns}	0.01^{ns}	2.81^{ns}	2.81^{ns}	44.31**

^{ns}, * and ** - non significant, significant by the F test at 0.05 and 0.01 probability, respectively.

Considering that there was a difference regarding the grain yield, nitrogen content, SPAD index and protein content between the plants of the control treatment plot and those that received N in coverage, it can be stated that the direct measurement of chlorophyll (*a*, *b* and total), as well as of carotenoids, was not efficient in detecting these differences. This corroborates the results found by Argenta et al. (2001), who, when evaluating the correlation between N content and extractable chlorophyll in the maize crop in a management system with N coverage, did not observe significance when the readings were performed in the stage with 6-7 leaves, as in the present study. Figure 1 presents the unfolding of the regression analysis for leaf nitrogen content as a function of the fertilizers and the

doses used. It is verified that for the fertilizers urea + urease inhibitor and urea + coating with elemental sulfur, there was no difference between the doses; nonetheless, for urea + inhibitor + B + Cu, the best response model was the linear decreasing one, that is, there was a decrease in N contents as a function of the increase in the amount applied, probably due to the inhibition of urease by the bivalent cations promoted by this form of fertilizer, which causes that even at the lowest doses a higher N content occurs. In the case of urea + polymer and conventional urea, the second-degree equation better adjusted to the points, whose maximum nitrogen contents in the leaves were obtained at the doses of 50.1 and 53.7 kg ha^{-1} N, respectively.

◆ Ureia
$y = -0.0144x^2 + 1.4433x - 7.2$
$R^2 = 0.99$

■ Ureia + Urease Inhibitor
$y = 26.067$

▲ Ureia + S
$y = 28.433$

● Ureia + Urease Inhibitor + B + Cu
$y = -0.1467x + 33.267$
$R^2 = 0.98$

✻ Uréia + Polimer
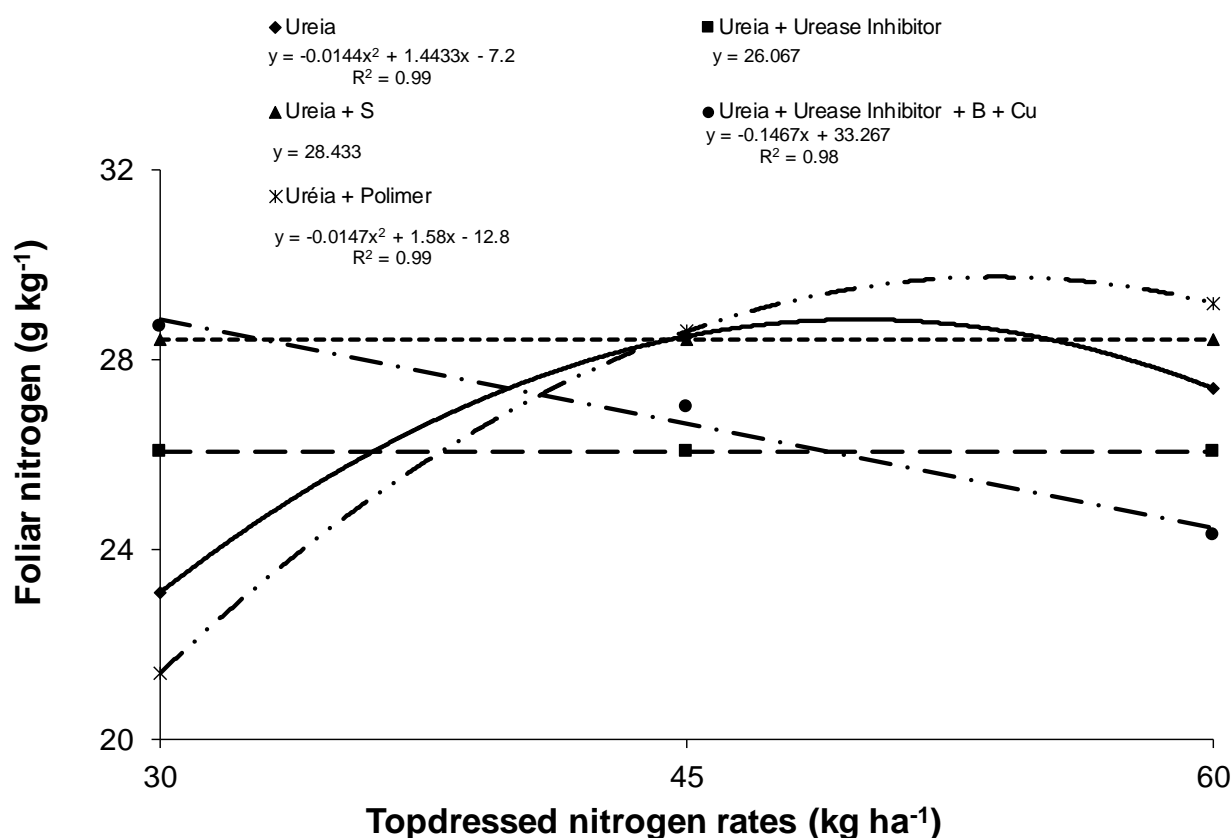$y = -0.0147x^2 + 1.58x - 12.8$
$R^2 = 0.99$

Figure 1 - Nitrogen content in maize crop as a function of sources and doses of N.

The N nutritional status was influenced differently by the urea forms, considering the appropriate ranges for evaluation of the nitrogen content, according to Cantarella et al. (1997), from 27 to 35 g N kg^{-1} dry matter, except for the control treatment that presented values well below the sufficiency zone.

In a study of the use of urea treated with nitrification inhibitor in the maize crop, Meira et al. (2009) found that the use of this fertilizer at the dose of 60 kg ha^{-1} N provided the highest nitrogen content when compared to untreated urea; in an analogous manner with urease inhibitor, Silva et al. (2011) verified

an increase in N content with increasing doses of the fertilizer.

The grain yield was influenced by the fertilizer sources and doses used (Figure 2), except for urea + coating with elemental S, which showed no difference between the amounts applied. In the case of urea without aggregate technology, there was a decrease in yield with increasing doses of N. As in the study by Maestrelo et al. (2014), one possible explanation is that urea without additional treatment may have provided the faster release of N due to the higher volume of rainfall recorded in the early stages of development.
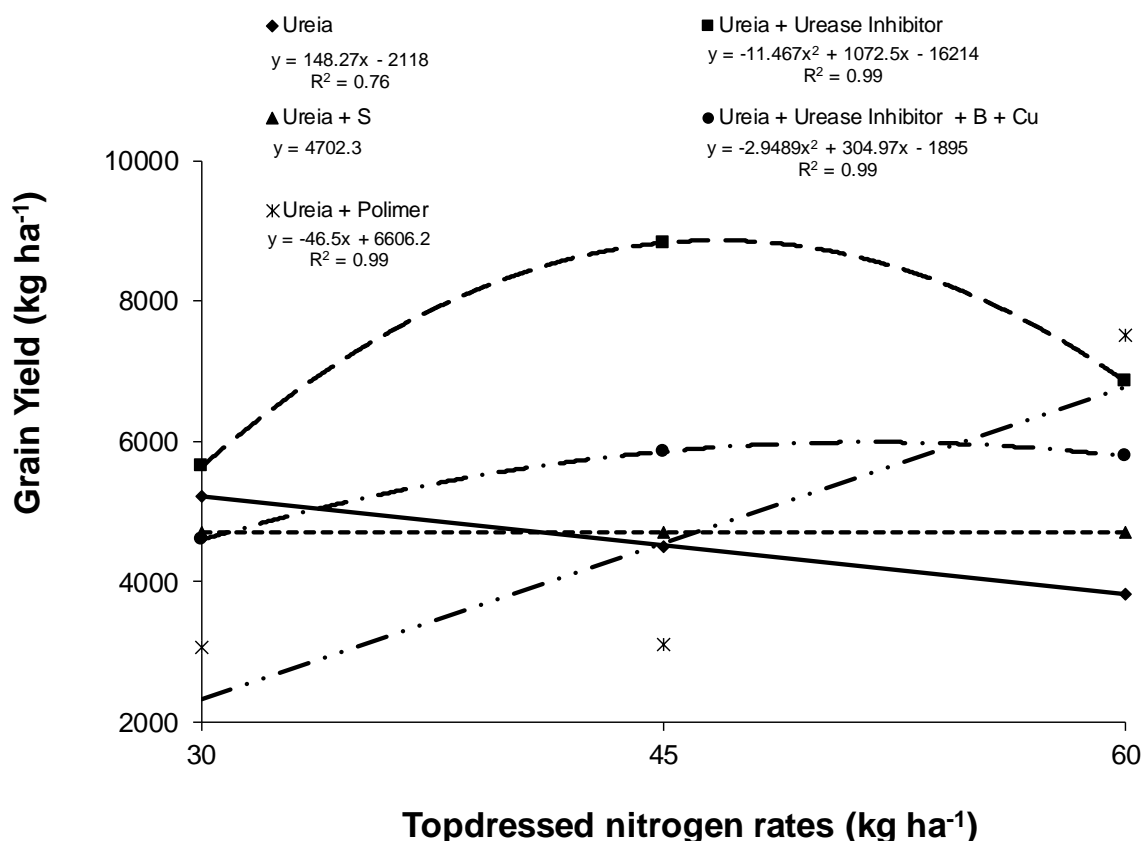
◆ Ureia
$y = 148.27x - 2118$
$R^2 = 0.76$

▲ Ureia + S
$y = 4702.3$

✳ Ureia + Polimer
$y = -46.5x + 6606.2$
$R^2 = 0.99$

■ Ureia + Urease Inhibitor
$y = -11.467x^2 + 1072.5x - 16214$
$R^2 = 0.99$

● Ureia + Urease Inhibitor + B + Cu
$y = -2.9489x^2 + 304.97x - 1895$
$R^2 = 0.99$

Figure 2 - Corn grain yield as a function of N doses and urea sources.

Ureas with urease inhibitor and urease + B + Cu inhibitor showed a quadratic response model, with maximum yields of 46.7 and 51.7 kg ha^{-1} N, respectively. The fertilizer urea + polymer showed an increase in grain yield with increasing N doses (Figure 2). When the yield values are verified considering the averages of the three doses applied (Table 2), it is observed that the urea with inhibitor promoted an increase of 157% in relation to the common urea. In work comparing common urea to urea treated with urease inhibitor, Silva et al. (2011) verified that both influenced positively the yield, where the model that best adjusted to the data was the quadratic and the linear, respectively, for common urea and urea treated with urease inhibitor.

The use of technologies added to urea increased the yield, especially with the use of doses greater than 30 kg ha^{-1} N in coverage. The possible explanation is the gradual release of the nutrient from the polymerized fertilizer, as well as the inhibition of urease (enzyme that promotes the volatilization of ammonia) in fertilizers with inhibitors. It is noteworthy that the maximum yield was obtained with the fertilizer urea + NBPT, with an observed yield of 7,110 kg ha^{-1} grains.

When evaluating the application of conventional urea and ureas treated with urease inhibitor and polymer in the Cerrado region, Pereira et al. (2009) observed that treatments with coated fertilizer and urease inhibitor reduced N volatilization by 50% in relation to the common urea; the authors also reported

that the sources were efficient in reducing the volatilization of N applied in coverage, which reflected in higher yields. However, Queiroz et al. (2011) did not verify differences in maize yield in the Cerrado region as a function of different forms of urea (treated with polymer and conventional). Kappes et al. (2009) observed differences between the nitrogen sources and the control (which did not receive N in coverage) for yield variables (ear length, cob diameter and grain yield) in the maize crop, but between sources there were no differences.

The average production of maize grains in the state of Ceará in the 2010/2011 harvest was about 1.200 kg ha^{-1} (Conab, 2012). In this experiment, considering the use of the variety Gorutuba, which is more tolerant to climatic inclemencies, the average yields obtained as a function of the treatments were 4.514, 7.110, 4.702, 5.414 and 4.554 kg ha^{-1} for urea, urea + + urease inhibitor, urea + polymer, urea + urease inhibitor + B + Cu and urea + coating with S, respectively, i.e., considering the average of these values, it is 338% higher than that obtained in the 2010/2011 harvest in the aforementioned state, however, it should be noted that the values obtained are under experimental conditions.

The potential economic gain using NBPT--treated urea is higher where the risk of ammonia loss is high and the crop responds to the nitrogen maintained in the soil by the inhibitor (Okumura & Mariano, 2012). Table 3 shows the unfolding of the regression

between fertilizer doses and sources for the variables SPAD index, protein content, chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids. It is observed for the SPAD index that there was significance for the fertilizers urea + urease inhibitor and urea + polymer;

for the former, the best response model was the quadratic one and, for the second, the linear one. A probable explanation would be that nitrogen may have been released more slowly due to climatic conditions.

Table 3 - Regression to the SPAD index, protein content, chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids as a function of nitrogen doses and urea sources.

Fertilizer	Equation	R^2	F
SPAD index			
Urea	$y = 26.9$		
Urea + Inhibitor	$y = 0.0277x^2 - 2.6007x + 81.16$	0.99	5.61*
Urea + Polymer	$y = 0.3113x + 13.077$	0.80	9.43**
Urea + Inhibitor + B + Cu	$y = 29.4$		
Urea + S	$y = 25.5$		
Protein content			
Urea	$y = 7.82$		
Urea + Inhibitor	$y = 8.27$		
Urea + Polymer	$y = 8.84$		
Urea + Inhibitor + B + Cu	$y = -0.119x + 14.735$	0.75	11.38**
Urea + S	$y = 8.13$		
Chlorophyll *a*			
Urea	$y = -0.0021x^2 + 0.182x - 2.62$	0.99	20.94**
Urea + Inhibitor	$y = -0.0097x + 1.3283$	0.57	6.12**
Urea + Polymer	$y = 1.07$		
Urea + Inhibitor + B + Cu	$y = 1.12$		
Urea + S	$y = 0.0143x + 0.4283$	0.99	12.69**
Chlorophyll *b*			
Urea	$y = -0.0007x^2 + 0.0587x - 0.81$	0.99	12.46**
Urea + Inhibitor	$y = 0.0005x^2 - 0.0473x + 1.41$	0.99	7.24*
Urea + Polymer	$y = 0.39$		
Urea + Inhibitor + B + Cu	$y = 0.41$		
Urea + S	$y = 0.006x + 0.0933$	0.94	12.39**
Total Chlorophyll			
Urea	$y = -0.0027x^2 + 0.2367x - 3.36$	0.99	19.02**
Urea + Inhibitor	$y = -0.013x + 1.815$	0.54	5.88**
Urea + Polymer	$y = 1.45$		
Urea + Inhibitor + B + Cu	$y = 1.52$		
Urea + S	$y = 0.018x + 0.6333$	0.99	13.15**
Carotenoids			
Urea	$y = -0.7207x^2 + 62.999x - 834.55$	0.99	19.12**
Urea + Inhibitor	$y = 0.4761x^2 - 44.615x + 1377.8$	0.99	8.34**
Urea + Polymer	$y = 449.9$		
Urea + Inhibitor + B + Cu	$y = 452.08$		
Urea + S	$y = 4.766x + 222.92$	0.99	11.14**

* and ** - significant by the F test at 0.05 and 0.01 probability, respectively.

The protein content was only significant for the fertilizer urea + inhibitor + B + Cu, with a decrease in the content as a function of the increase of the applied doses (Table 3), the opposite being observed by Lima et al. (2009) and Deuner et al. (2009), who observed increased protein content in maize plants using urea.

The pigments chlorophyll *a, b*, total chlorophyll and carotenoids were responsive to the technologies employed and presented the same model of response, that is, for urea without aggregate technology the second-degree equation; for urea + polymer and urea + inhibitor + B + Cu there were no differences between

doses; for urea + S the first-degree increasing equation; with the exception of chlorophyll *a* and total chlorophyll, which for urea + inhibitor and urea + S the best model was the linear increasing one; however, for chlorophyll *b* and carotenoids, with the fertilizer urea + + inhibitor, the best response model was the quadratic one.

These pigments are highly related to N content in plants, as they are responsible for the capture of the solar energy used in photosynthesis (Taiz & Zeiger, 2013). Thus, plants cultivated with inadequate N contents do not normally express their productive potential,

since, under such conditions, significant reductions in the net CO_2 assimilation rate may occur, since N is part of the main components of the photosynthetic system, such as chlorophylls and enzymes (Coelho et al., 2010).

Table 4 shows the correlation values between the evaluated variables. In general, correlation values greater than 0.6 are observed, which justifies the use of multivariate analysis between: nitrogen and protein content; SPAD index and total chlorophyll, chlorophyll b and carotenoids; total chlorophyll and the other photosynthetic pigments; chlorophyll a in relation to chlorophyll b and carotenoids; chlorophyll b with carotenoids.

Table 4 - Pearson correlation matrix between leaf nitrogen content (N), corn grain yield (Yield), SPAD index (SPAD), protein, total chlorophyll (Total Chl), chlorophyll a (Chl a), chlorophyll b (Chl b) and carotenoids (Carot).

	N	Yield	SPAD	Protein	Total Chl	Chl a	Chl b	Carot
N	1.00	-	-	-	-	-	-	-
Yield	0.18[ns]	1.00	-	-	-	-	-	-
SPAD	0.45[ns]	0.04[ns]	1.00	-	-	-	-	-
Protein	0.70*	0.09[ns]	0.52*	1.00	-	-	-	-
Total Chl	0.49[ns]	-0.08[ns]	0.64**	0.34[ns]	1.00	-	-	-
Chl a	0.44[ns]	-0.12[ns]	0.57*	0.30[ns]	0.99**	1.00	-	-
Chl b	0.60*	0.01[ns]	0.75**	0.43[ns]	0.96**	0.92**	1.00	-
Carot	0.58*	-0.01[ns]	0.68**	0.38[ns]	0.96**	0.93**	0.96**	1.00

* and ** - significant by the F test at 0.05 and 0.01 probability, respectively.

The chlorophyll content measured with digital chlorophyll meter showed correlation with extractable chlorophyll (a, b, total and carotenoids) (Table 4); a similar fact was presented by Argenta et al. (2001) when evaluating two maize hybrids in eight types of fertilization managements. The relative index of chlorophyll and the N content in the tissues are considered as the best predictors to evaluate the N availability to plants and the grain yield (Vargas et al., 2012). As N is an essential structural component of the chlorophyll molecule, when in appropriate levels, it promotes an increase in leaf area, providing better efficiency in the interception of solar radiation and photosynthesis, leading to higher grain yields (Fageria & Baligar, 2005).

The edaphoclimatic conditions of the northeastern semi-arid may have contributed to these results, because chlorophylls are responsible for the conversion of sunlight into energy, being related to the photosynthetic efficiency of the plants and, consequently, to their growth and adaptability to different environments (Neves et al., 2005). Furthermore, the variation in fertilizer composition can alter the molecular structure of plants, influencing the synthesis of these pigments (Taiz & Zeiger, 2013).

Table 5 shows the eigenvalues and the percentage of variance explained by the main components (MC), with MC1 and MC2 accounting for 63 and 17% of the variation, respectively; the sum of both represents 80% of the total variance of the studied characteristics.
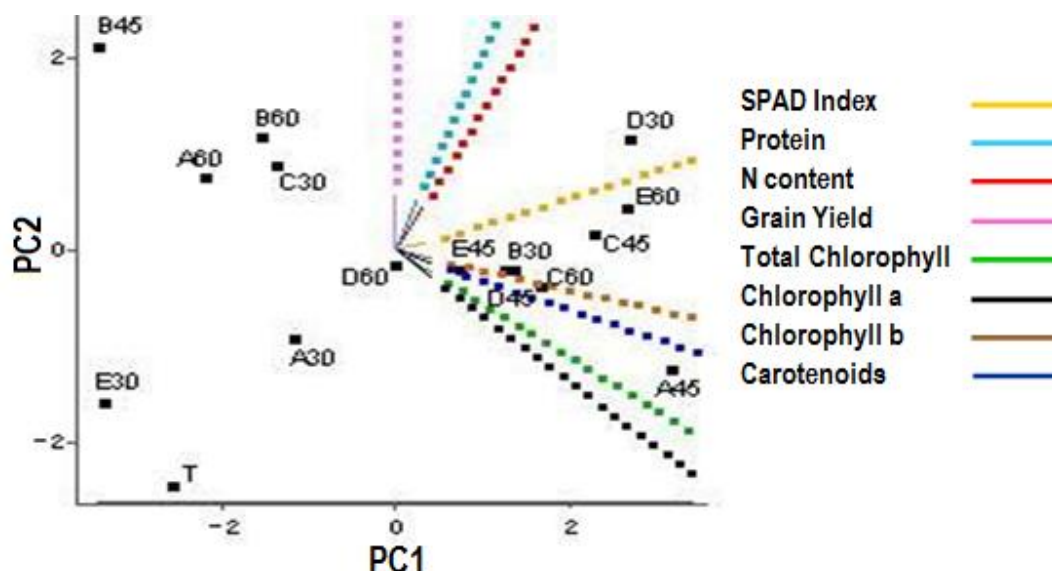
Table 5 - Principal component analysis (CP), eigenvalues (λi) and percentage of variance explained by the components (VEC) of nutritional, physiological and grain yield characteristics of maize.

Principal component	λi	VEC (%)	Accumulated VEC (%)
PC1	5.022	0.628	0.628
PC2	1.320	0.165	0.793
PC3	0.853	0.107	0.900
PC4	0.501	0.063	0.963
PC5	0.231	0.029	0.992
PC6	0.041	0.005	0.997
PC7	0.028	0.003	1.000

Note: PC1: N content: 0.69; Yield: 0.00; SPAD index: 0.77; Protein: 0.56; Total Chlorophyll: 0.94; Chlorophyll a: 0.91; Chlorophyll b: 0.97; Carotenoids: 0.96; PC2: N content: 0.52; Yield: 0.67; SPAD index: 0.11; Protein: 0.60; Total Chlorophyll: -0.26; Chlorophyll a: -0.32; Chlorophyll b: -0.10; Carotenoids: -0.15.

The "scores" of the main component 1 were positively correlated with N content (0.69), SPAD index (0.77), protein (0.56), total chlorophyll (0.94), chlorophyll a (0.91), chlorophyll b (0.97) and carotenoids (0.96) (Figure 3); for yield, the value was less than 1%.

For the main component 2, there was a positive correlation with N content (0.53), yield (0.67), protein (0.60) and SPAD index (0.11); and a negative correlation with total chlorophyll (-0. 26), chlorophyll a (-0.32), chlorophyll b (-0.10) and carotenoids (-0.15) (Figure 3).

Figure 3 - Biplot plot of the principal components (PC1 and PC2) of the physiological results, nutritional status and grain yield in corn (A - urea, B - urea + urease inhibitor, C - urea + polymer, D - urea + urease inhibitor + B + Cu, E - urea + S; 30, 45 and 60 kg ha^{-1} of N, respectively).

In the case of MC1, the treatments with positive values indicate high levels for the analyses of photosynthetic pigments (total chlorophyll, chlorophyll *a*, chlorophyll *b* and carotenoids); however, for MC2, fertilizations with positive values are characterized by high yield and high N and protein contents. It is worth mentioning that the SPAD index "score" was intermediate considering the nutritional status, grain yield and photosynthetic pigments in both components. Among the treatments used, the fertilizer containing urease inhibitor, at the dose of 45 kg ha^{-1} N, provided a high content of nitrogen and protein, in addition to high grain yield. The control treatment presented low values for yield and for nutritional and physiological indexes, since there were low levels of N (Figure 3).

Paiva et al. (2012) found that the dose of 60 kg ha^{-1} N was sufficient to provide maximum yield of green maize in Baraúna-RN. In a study carried out in Mauá da Serra - PR with urea + urease inhibitor, Okumura et al. (2013) found that the dose that provided the highest yield was 145 kg ha^{-1} N. In a study with Nitosol, Farinelli & Lemos (2010) obtained maximum yield of maize grains with the dose of 92 kg ha^{-1} in coverage. It is worth mentioning that in these studies the maize cultivars used were hybrids. Thus, in a similar way to the present study, it can be stated that the maize variety Gorutuba is responsive to nitrogen fertilization. Borges et al. (2006) also observed that the maize variety "Sol da Manhã" was also responsive to nitrogen fertilization when compared to hybrid maize.

Conclusions

For the maize crop, nitrogen fertilization in coverage promoted increases in leaf N content, protein, SPAD index and grain yield.

The highest grain yield of maize was obtained using the fertilizer urea + urease inhibitor at the dose of 47 kg ha^{-1} N.

High values of chlorophylls and carotenoids have no correlation with high grain yield.

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