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Effect of rates and forms of nitrogen splitting on corn in the Brazilian Cerrado of Piauí State

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Zea mays **crop has been standing out in the Brazilian Cerrado of Piauí State, located in the Northeastern Brazil. However, despite the high technology level utilized, yield levels are still below the expectation, mainly due to the mismanagement of nitrogen (N). This experiment was conducted in field using single-cross hybrid 30F53 from Pioneer®. The experiment was conducted as completely randomized blocks design with nine treatments and four replications. The treatments consisted of five rates of N as urea, equivalent to 0, 60, 120, 180 and 240 kg N ha^{-1}. It was applied twenty kg N ha^{-1} at sowing and the rest as topdressing. The splits comprised the application of 50% at the four expanded leaf stage (V1) + 50% at the eight expanded leaf stage (V2) or total rates at four expanded leaf stage. Leaf N content, leaf relative chlorophyll content, plant height, ear height, stem diameter, yield, grains per ear and rows per ear, grains per row, 1000 grains weight and agronomic efficiency index were measured. Nitrogen significantly increased agronomic characteristics of corn and the highest grain yield was obtained with 190.65 kg ha^{-1} N. Plant height, relative chlorophyll content, leaf N content, plant biomass, stem diameter, thousand seed weight, yield and agronomic efficiency index were positively influenced by the rates of nitrogen. The split of topdressing in twice was not suitable in the dystrophic Yellow Latosol of the Piauí Cerrado. Plant height, relative chlorophyll content, ear insertion height, stem diameter, grains per ear and rows per ear, grains per row and agronomic efficiency index positively correlated with grain yield.**

Key words: Agronomic efficiency index, yield, relative chlorophyll content.

INTRODUCTION

The Brazilian Cerrado of Piauí has been standing out in the national scenario with an extensive acreage favorable to grain Yuction, in particular for the corn and *Glycine max* crops. In Piauí state, the corn crop in 2011/2012 had an area planted of 351.6 thousand ha, with estimated total Yuction of 787.2 M t and an average yield of 2,239 kg ha^{-1} (Conab, 2012).

In this region, most soils present flat relief and excellent physical conditions for agricultural expansion (Pragana et al., 2012). Nevertheless, they present low clay contents and low cation exchange capacity (CEC), mainly owing to low organic matter contents (OM), which for these soils

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may stand for up to 80% of the CEC. Owing to their low OM contents, they also present low N supply capacity for corn.

Corn crop presents varying demands for fertilizers, with an emphasis on N (Silva et al., 2012), which has its dynamics in soils conditioned by the management system, climatic conditions and soil characteristics, among others (Silva et al., 2005b). The importance of N as to its functions in the metabolism of plants, participating as a constituent of molecules of proteins, coenzymes, nucleic acids, cytochromes, chlorophyll etc., in addition to being one of the nutrients most relevant to the increased grain yield (Varvel et al., 1997; Ferreira et al., 2001). In corn, N is a nutrient absorbed in greatest amount, became it one of the greatest influence on yield, due to the several relevant functions in its physiological activities (Silva et al., 2005a, 2005c; Farinelli and Lemos, 2012) and the one which burdens the most on the Yuction cost of the crop.

The nitrogen fertilization management is one of the most complexes due to the nutrient possessing one of the greatest indices of losses, which may occur by leaching, erosion, ammonia volatilization and denitrification (Queiroz et al., 2011). The form of N management exerts a great influence on the use of this nutrient by corn (Silva et al., 2005a). Some studies demonstrate distinct responses as to the rate, the number of splits and its time of application (Silva et al., 2006; Duete et al., 2008), a fact conditioned to the N transformation in soil, which are mediated by microorganisms dependent on the edaphoclimatic conditions (Hurtado et al., 2009).

The nitrogen management should supply the plant demands in critical periods, maximize the percentage of N recovery (R%) and minimize the impact on the environment by the reduction of losses (Fernandes and Libardi, 2007). In this sense, the split and the time of application of the nitrogen fertilizer constitute alternatives to increase the efficiency of nitrogen fertilizers by corn, due to, among other factors, the reduction of the losses by the increased use of N, resulting from the timing between the applications and period of high demand of the nutrient (Silva et al., 2005a; Duete et al., 2008; Hurtado et al., 2009). Bastos et al. (2008) evaluating the effect of both rates and forms of N split for corn Yuction under no-till farming, observed the highest grain yield (7.74 t ha^{-1}) in the treatments in which N fertilizer was split into three times, obtained with the rate of 180 kg of N ha^{-1}.

In State of Piauí, there are shortage studies which aim to identify the effects of the combination between rates and forms of splits of nitrogen fertilization, which many times, limits the development of the plant. Also, is necessary to identify the right moment and at the adequate rate of N, it maximizes the expression potential of the crop. It was intended to verify the effect of the rates and splits of N in relation to the Yuction and yield components of corn in the Brazilian Cerrado of Piauí, northeastern region.

MATERIALS AND METHODS

The experiment was conducted on the Fazenda União, municipality of Currais - PI (09° 37 '27 of "latitude and 44° 40' of 52" longitude and altitude of 541 m) in January-May 2012. The climate of the region is of the Aw type according to Jacomine et al. (1986), with two well distinct seasons, one being dry which goes from May to September and a rainy season which goes from October to April. The average temperature of the region is 26.5°C (Viana et al., 2002). The data of rainfall during the period of the carrying out of the experiment are in Figure 1.

The predominant soil in the region is the Distrophic Red Yellow Latosol (Typic Haplorthox), characterized by presenting high acidity and low fertility, with appropriate physical conditions. It is situated on a flat to gently wavy relief, and it is suitable for agricultural activity (Pragana et al., 2012).

The chemical and textural characterization of the soil prior to the establishment of the experiment, and soil sampling in the second layer of 0-0.20 m (EMBRAPA, 1997) are shown in Table 1. Soil preparation was done by means of the passing of a heavy harrow and two light harrows to level the ground and eliminate weeds. The correction of the soil acidity was performed three months prior to the establishment of the experiment, using dolomitic limestone (RPTN = 90%) at the rate of 1.31 ton ha^{-1}.

Corn (single-cross hybrid 30F53 Pioneer®) was sown manually in January, 2012. This cultivar characterized as early, high yielding and capacity of adaptation to both the low and high lands of Central Brazil. At planting, the seeds were distributed with the help of a ruler, leaving every 0.3 m a seed, for the obtaining of a final population of approximately sixty-six thousand (66,000) plants per hectare.

Fertilizers (70 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} of K_2O) were applied in the furrow at sowing time according to the soil analysis (Table 1), using simple superphosphate and potassium chloride, respectively. In relation to the N fertilizer, urea was utilized, with the amount applied according to the treatments of rates and splitting of N (Table 2). Nitrogen topdressing (Table 2) was distributed manually on a band at 15 cm away from the seeds.

The disease control treatments such as weed and pest insect management were employed using Yucts recommended to the crop. Before sowing the corn, the herbicides glyphosate and 2,4-D were applied at rates of 1,440 and 806 g ha^{-1} ai, respectively. The weed control in post-emergence was conducted with corn in the stadium of five expanded leaves (V5), using the herbicide Atrazine (1,500 g ha^{-1}) ai. In the pre-blossoming period proceeded to application of the fungicides Epoxiconazole + pyraclostrobin (99.7 + 87.5 g ai ha^{-1}) and insecticides Methomyl (12.9 g ai ha^{-1}) and Imidacloprid + thiodicarb (45 + 135 g ai ha^{-1}).

The experiment was conducted as completely randomized blocks design with four replications. The treatments consisted of five rates of N (0, 60, 120, 180 and 240 kg ha^{-1}) as urea. Twenty kg ha^{-1} N were applied at sowing and the rest as split at topdressing. The splits comprised the application of 50% at the four expanded leaf stage (V1) + 50% at the eight expanded leaf stage (V2) or total rates at four expanded leaf stage. The experimental plot consisted of an area of 15 m^2 (3 × 5 m) with six rows of corn spaced 0.5 m and two central rows were considered.

For leaf N content (LNC), measured on the blossoming stage, the central third of 3 leaves of the base of the main ear was collected. Afterwards, the material was washed with tap and distilled water, dried in an oven with air forced circulation and air renewal at 60°C, and then ground into a Welley type mill for determination of N by Kjeldal method, according to the Malavolta et al. (1997). Simultaneously two plants of each plot were also collected for determination of plant biomass, which were dried at 60°C till constant weight. The reading of the relative content of chlorophyll (RCC) (SPAD index) at blossoming stage was obtained using a portable chlorophyll meter, three readings being obtained by plot,

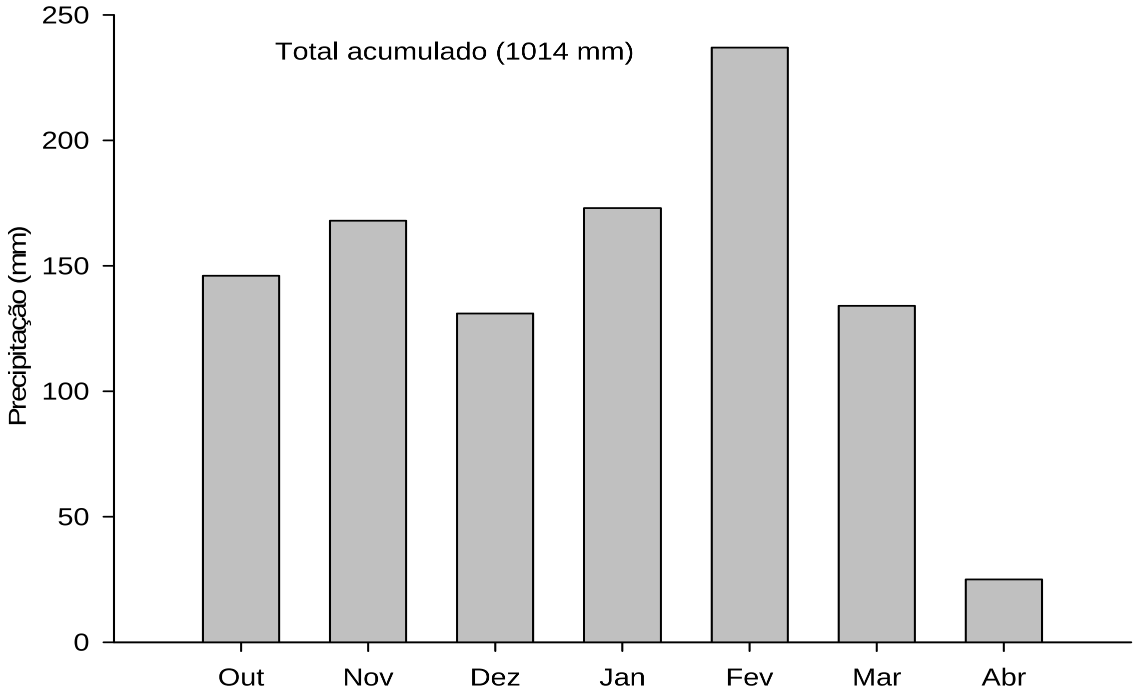

Figure 1. Average rainfall in the Farm União, Serra das Laranjeiras, municipality of Currais – PI, 2012. Accumulated total (1014 mm) precipitação = raiLNCall (mm) Oct, Nov, Dec, Jan, Feb, Mar, Ap.

Table 1. Contents of phosphorus (P), organic matter (OM), clay (Arg), silt (Sil), sand (Are), pH, exchangeable acidity (Al^{3+}), potential acidity (H+Al), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sum of bases (SB), cation exchaGPE capacity (CEC), base saturation (V) and aluminum saturation of Distrophic Red Yellow Latosol (Typic Haplorthox) on the Piauí Cerrado.

pH	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	CTC	V	m	MO	Are	Sil	Are
$CaCl_2$	**mg kg^{-1}**	**................................$cmol_c$ dm^{-3}..............................**							**.........%.........**		**g kg^{-1}**	**……..g kg^{-1}……..**		
4.6	53	0.19	2.10	1.0	0.2	3.10	3.29	6.39	51.49	5.73	15	790	50	160

pH em $CaCl_2$-Ratio 1: 2.5; P e K^+– Mehlich Extractor; Ca^{2+}, Mg^{2+} e Al^{3+} – Extractor: KCl 1 mol/L; H + Al – Calcium Acetate Extrator 0.5 mol/L– pH 7.0.

Table 2. Description of the treatments used: splitting rates and strategies of N.

Treatment	Rates of N (kg ha^{-1})			Total applied N (kg ha^{-1})
	Planting	4 leaves	8 leaves	
01	-	-	-	-
02	20	20	20	60
03	20	40	-	60
04	20	50	50	120
05	20	100	-	120
06	20	80	80	180
07	20	160	-	180
08	20	110	110	240
09	20	220	-	240

always performed in the central third of the opposite leaf and below the first ear, as the method proposed by Argenta et al. (2002). The evaluations of measurement of the plant height (H), height of ear insertion (EIH) and stem diameter (D) on three plants per plot were carried out at physiological maturity stage, using a measuring tape. Two central rows were harvested and the ears were threshed

Table 3. Table of contents of the descriptive and variance analysis for agronomic characteristics**,** Yuction and yield components of corn in response to nitrogen rates and splits in Distrophic Red Yellow Latosol (Typic Haplorthox) in the Piaui Cerrado.

Variable	**H**	**RCC**	**LNC**	**PB**	**EIH**	**D**	**RPC**	**GPE**	**GPR**	**TSW**	**Y**	**AEI**
	cm		**g kg^{-1}**	**g**	**cm**	**mm**				**g**	**kg ha^{-1}**	**%**
Treatment	*	***	***	***	ns	***	ns	ns	ns	*	*	*
CV (%)	5.77	3.98	8.37	11.24	10.22	7.50	4.73	12.01	12.48	4.51	19.19	66.04
Mean	2.16	64.18	24.34	196.44	90.94	20.09	14.89	416.25	27.95	265.10	6210	12.94

Subtitle: H: plant height; RCC: relative chlorophyll content, LNC: leaf N content; PB: plant biomass; EIH: ear insertion height; D: stem diameter; RPC: rows per cob; GPE: grains per ear; GPR: grains per row; TSW: thousand seed weight; Y: yield, AEI: Agronomic efficiency index, CV: coefficient of variation (%), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, and ns: non-significant.

Table 4. Table of contents of the analysis of variance for the agronomic characteristics, yield components and grain yield in response to different rates and splitting strategies of N in Distrophic Red Yellow Latosol (Typic Haplorthox) in the Piaui Cerrado.

Variable	**H**	**RCC**	**LNC**	**PB**	**EIH**	**D**	**RPC**	**GPE**	**GPR**	**TSW**	**Y**	**AEI**
	cm		**g kg^{-1}**	**g**	**cm**	**mm**				**g**	**kg ha^{-1}**	**%**
(Fc) Splits	2.62^{ns}	1.97^{ns}	1.39^{ns}	0.01^{ns}	2.68^{ns}	8.40**	1.72^{ns}	0.51^{ns}	0.05^{ns}	6.34*	0.18^{ns}	2.80^{ns}
(Fc) Rates	8.77***	12.83***	10.17***	23.91***	2.36^{ns}	11.61***	2.08^{ns}	2.15^{ns}	0.97^{ns}	3.45*	10.09***	7.59***
(Fc) Spli x Rate	1.06^{ns}	2.30^{ns}	1.87^{ns}	1.84^{ns}	0.67^{ns}	2.77*	0.71^{ns}	0.16^{ns}	0.20^{ns}	1.13^{ns}	2.40^{ns}	3.25*

Subtitle: H: plant height; RCC: relative chlorophyll content, LNC: leaf N content; PB: plant biomass; EIH: ear insertion height; D: stem diameter; RPC: rows per cob; GPE: grains per ear; GPR: grains per row; TSW: thousand seed weight; Y: yield, AEI: Agronomic efficiency index; Fc calculated F; Spli: Splitting; Rate: Rates, * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$, and ns: non-significant.

mechanically and standardized to 13% moisture. In each plot were also removed five ears to determine grains per ear and rows per ear, grains per row and thousand seed weight. From the yield data, the efficiency in the use of N was determined by using the following formula:

(AEI) = (PGcf - PGsf) / (QIn) in kg kg^{-1}

Where: AEI = agronomic efficiency index; PGcf = grain yield with N fertilizer; PGsf = grain yield without N fertilizer and QIn = amount of the nutrient applied (kg).

The data were at first subjected to analyses. And then, the variables were analyzed by simple descriptive statistics (mean, standard deviation and coefficient of variation) for further analysis of variance (ANOVA). In the ANOVA, the effects of treatments and blocks on the variables ($P < 0.05$) were analyzed. For comparison of the means of the different levels of the treatments, the Scott and Knott test (1974) at 5% probability was applied using the statistical program SISVAR 4.2 (Ferreira, 2011). To perform the Pearson correlation analysis, the SAS software (Statistics Analyst System) was used for Windows-NT, version 8.0 (Sas, 1999), by means of the PROC CORR command. The analyses of variance and Scott Knott test were conducted using the statistical program SISVAR 4.2 (Ferreira, 2011). For the effect of rates and splitting strategies, the data were subjected to regression analysis using also SISVAR 4.2 (Ferreira, 2011).

RESULTS AND DISCUSSION

The result of the analysis of variance of the different variables (Table 3) showed significant differences among the nine treatments for most traits evaluated except for ear insertion height (EIH), rows per cob (RPC), grains per ear (GPE) and grains per row (GPR). Such traits are mainly influenced by the genotype and followed by nutrient availability during the grain filling stage (Ohland et al., 2005).

There were significant effects of treatments (rates and splitting strategies of N) on plant height (H), relative chlorophyll content (RCC), leaf N content (LNC), plant biomass (PB), stem diameter (D), thousand seed weight (TSW), yield (Y) and agronomic efficiency index (AEI) (Table 3). There was an interaction between the rates and splitting strategies N for the variables D and AEI (Table 4). The distinct strategies of N splitting showed similar efficiency in H, RCC, LNC, PB, EIH, RPC, GPR, GPE and Y. According to Duete et al. (2008), possibly the little difference between the times of topdressing application of N is due to the coincidence between the time of N application and the stage of plant development in which linear absorption of nutrients occurs.

Rates of 0 and 60 kg ha^{-1} of N split into three times (T1 and T2, respectively) provided lower H. However, the rate of 60 kg ha^{-1} N applied at twice, 20 at planting and 40 at the 4 leaf stage showed behavior similar to the other rates (Table 5). According to Silva et al. (2005a), it should be taken into account that H is a characteristic of genetic heritability and less dependent on environment, unless the plant goes through a very severe nutrient deficiency, which may have occurred in treatments T1 and T2. The regression analysis stood out for H a quadratic PB (Figure 2a) on the basis of the rates of N applied. There was an increase in H with increased rate of N, reaching

Table 5. Means of agronomic **c**haracteristics, yield components and grain yield in response to different rates and splits of N in dystrophic Yellow Latosol of the Piauí. Cerrado.

TRT	H (cm)	RCC	LNC (g kg^{-1})	PB (g)	EIH (cm)	D (mm)	RPC	GPE	GPR	TSW (g)	Y (kg ha^{-1})	AEI (%)
T1	194.25^{b}	60.76^{c}	22.94^{b}	140.67^{c}	82.99^{a}	17.30^{b}	14.40^{a}	394.05^{a}	27.30^{a}	252.99^{b}	$4,504.33^{b}$	-
T2	201.92^{b}	57.94^{c}	18.89^{c}	176.10^{b}	81.41^{a}	18.42^{b}	14.65^{a}	384.05^{a}	26.02^{a}	261.23^{b}	$5,121.33^{b}$	10.28^{b}
T3	220.50^{a}	63.71^{b}	22.87^{b}	159.90^{c}	93.16^{a}	20.89^{a}	14.60^{a}	386.45^{a}	26.57^{a}	258.28^{b}	$6,394.50^{a}$	31.50^{a}
T4	216.25^{a}	63.34^{b}	25.58^{a}	188.42^{b}	93.83^{a}	18.83^{b}	14.90^{a}	419.85^{a}	28.25^{a}	269.18^{a}	$5,793.42^{b}$	10.74^{b}
T5	222.92^{a}	63.92^{b}	24.35^{a}	204.60^{a}	93.75^{a}	21.77^{a}	15.20^{a}	453.40^{a}	29.80^{a}	258.27^{b}	$6,507.08^{a}$	16.69^{b}
T6	222.42^{a}	66.64^{a}	25.79^{a}	239.03^{a}	89.91^{a}	21.08^{a}	14.80^{a}	440.85^{a}	29.75^{a}	284.09^{a}	$7,251.66^{a}$	15.26^{b}
T7	231.08^{a}	66.20^{a}	26.30^{a}	213.60^{a}	97.75^{a}	23.19^{a}	15.75^{a}	445.75^{a}	28.34^{a}	260.62^{b}	$7,249.66^{a}$	15.25^{b}
T8	220.50^{a}	67.78^{a}	25.93^{a}	211.85^{a}	91.08^{a}	20.13^{a}	14.75^{a}	403.55^{a}	27.50^{a}	276.07^{a}	$7,197.44^{a}$	11.22^{b}
T9	216.75^{a}	67.35^{a}	26.40^{a}	233.83^{a}	94.58^{a}	19.19^{b}	14.95^{a}	418.30^{a}	27.97^{a}	265.19^{b}	$5,825.58^{b}$	5.50^{b}

Means followed by the same letter in the column do not differ from each other at ($P < 0.05$) of probability by the Scott-Knott test. TRT: Treatment, H: plant height; RCC: relative chlorophyll content, LNC: leaf N content; PB: plant biomass; EIH: ear insertion height; D: stem diameter; RPC: rows per cob; GPE: grains per ear; GPR: grains per row; TSW: thousand seed weight; Y: yield, AEI: Agronomic efficiency index; T1 = 0 kg ha^{-1} (= 0 kg planting, 4 leaves = 0 kg , 8 leaves = 0 kg), T2 = 60 kg ha^{-1} (planting = 20 kg, 4 leaves = 20 kg, 8 leaves = 20 kg), T3 = 60 kg ha^{-1} (planting = 20 kg, 4 leaves = 40 kg), T4 = 120 kg ha^{-1} (planting = 20 kg, 4 leaves = 50 kg, 8 leaves = 50 kg), T5 = 120 kg ha^{-1} (planting = 20 kg, 4 leaves = 100 kg); T6 = 180 kg ha^{-1} (planting = 20 kg, 4 leaves = 80 kg, 8 leaves = 80 kg), T7 = 180 kg ha^{-1} (planting = 20 kg, 4 leaves = 160 kg), T8 = 240 kg ha^{-1} (planting = 20 kg, 4 leaves = 110 kg, 8 leaves = 110 kg); T9 = 240 kg ha^{-1} (planting = 20 kg, 4 leaves = 220 kg).

its peak (2.25 m) at a rate of 176.05 kg ha^{-1} of N. This rate is close to the one observed by Silva et al. (2012) who found the highest H at rate of 147.9 kg ha^{-1} N with application of different sources of slow release urea in corn crop, and Silva et al. (2005a) obtained the highest H with 171 kg ha^{-1} N at no-tillage on dystrophic Red Latosol (oxisol).

Increased RCC was obtained when the applied rates of 180 and 240 kg N ha^{-1} (T6, T7, T8, T9), regardless of the splitting strategy (Table 5). Sunderman et al. (1997) in evaluating the variability at the concentration of chlorophyll in corn hybrids determined the critical value of RCC in the flowering stage of 57.9. In the present study no treatment was obtained below this value. RCC increased linearly with higher N, obtaining maximum mean of 67.78 with the rate of 240 kg N ha^{-1} (Figure 2b). Hurtado et al. (2009) found that the metabolic potential of chlorophyll Yuction (point of highest response) in relation to the supply of N was achieved with 242 kg ha^{-1} N at the flowering stage (R1), with a mean of 62.6, a value equal to that of the present study for the highest chlorophyll synthesis (242 kg ha^{-1}) at flowering. Studies using the RCC as an parameter, indicating N in corn during the growing season, are still few in Brazil, however, the studies conducted in the country and worldwide have shown that the method is efficient to separate deficient plants from those with an adequate N level (Rambo et al., 2004). According to these authors, the method allows making a fast diagnosis of the crop and immediate decision-making on the application of topdressing. For the LNC, increased value was obtained from 120 kg N ha^{-1}, independent of the splitting strategy (Table 5). It was also found that for most N levels, the LNCs were lower than that reported as suitable for the cultivation of corn, the range of which lies between 27.5 and 32.5 g kg^{-1} of N according to Malavolta et al. (1997). Silva et al. (2005a) reported that lower LNC can be a characteristic of the hybrid utilized, since in the treatment in which grain yield above 7,000 kg ha^{-1} was achieved, the LNC has not reached the value regarded as adequate. In the present study, the one of the rates of N on the LNC proved linear (Figure 2c). Silva et al. (2005a) found an increase in the LNC content up to 145 kg ha^{-1}, while Silva et al. (2012) found a maximum value of 34.7 g kg^{-1} rate 114.4 kg ha^{-1}of N. According to Rambo et al. (2004), the LNC in general are able to detect deficiency in plant, but also shows luxury consumption, wherein the content of N continues to increase and the yield is stable with high rates of this nutrient.

Increased Yuction of PB was also obtained from 120 kg ha^{-1} N, when splitting twice (T5) (Table 5). Growing linear effect of the PB in relation to the rates of N was also found (Figure 2d). The increase was of 30.43% in relation to the lowest rate (T1 = 0 kg N ha^{-1}). Thus, the N required for higher yield of PB corresponds to the half of that found by Araújo et al. (2004) who obtained higher

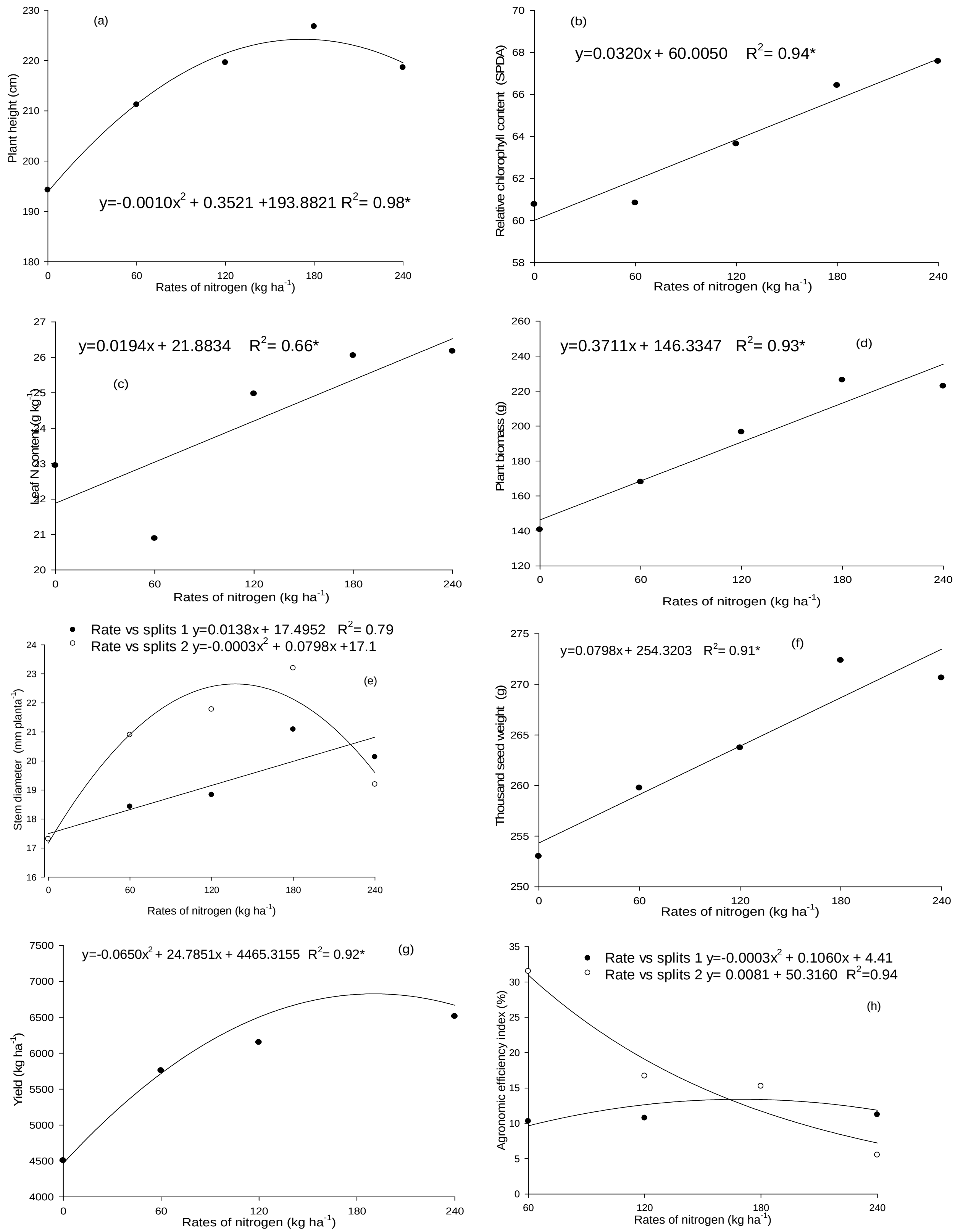

Figure 2. Plant height (a), relative chlorophyll content (b), leaf N content (c) plant biomass (d), stem diameter (e), thousand seed weight (f), yield (g) and agronomic efficiency index (h) in response to different rates and splits of nitrogen in corn in dystropheric Yellow Latosol of the Cerrado Piauí. Splits 1: 20 kg at planting and the rest divided into 50% at the four expanded leaf stage (V1) + 50% at the eight expanded leaf stage (V2); splits 2: 20 kg at planting and the rest at the four expanded leaf stage.

yield of shoot dry weight with 240 kg ha^{-1} N. The applications of 60 and 120 kg ha^{-1} N split in twice (T3 and T5, respectively), 180 kg ha^{-1} N, regardless of the split (T6 and T7) and 240 kg ha^{-1} N in splits in three times (T8), provided higher D (Table 5). According to Silva et al. (2005c), N acts on vegetative growth, directly influencing the cell division, expansion and photosynthetic process, combined with increase in D. The splitting strategy, 20 kg at planting and the remainder at 4 leaf stage enabled the obtaining of higher means (22.47) at the estimated rate of 136 kg ha^{-1} of N, but, the splitting of 20 kg at planting and the remainder divided in 50% at 4 expanded leaf stage + 50% at the 8 expanded leaf stage showed a growing linear effect in relation to rates N applied (Figure 2e). Cruz et al. (2008) studying the rates of N rates of the highest agronomic yield upon the morphological components of corn, found that rates above 85 kg ha^{-1} did not contribute to the increase of the D. Silva et al. (2012) also found, an increase in D with increasing rated, reaching higher value (17.39 mm) at the rate of 143.97 kg ha^{-1} of N.

Increased TSW was obtained when 120, 180 and 240 kg ha^{-1} N (T4, T6 and T8, respectively) were applied, these ones being split in twice, that is, 20 kg, at planting and the rest at four expanded leaf stage (Table 5). Linear effect was also found in relation to the rate tested for TSW, that is, as the rate of N was increased, there was a corresponding increase in grain weight (Figure 2f). A similar result was observed by Silva et al. (2005a), found the linear effect of TSW on different rates of nitrogem fertilizer in corn crop. Increased TSW due to the increase in the rates of N may have been determined mainly by the differences in the effective grain-filling period. Ferreira et al. (2001) observed that in the treatments without N and in those with lower rates, the lower leaves and ear straws presented themselves very dry, while in the treatments with higher N dosage, the plants were much more green, extending the period of sugar and N retranslocation to the grains, thereby increasing the final weight, a fact which was also observed in the present study.

For Y, the application of 60 kg ha^{-1} N split in twice (T3), 120 kg ha N split in twice (T5), 180 kg ha^{-1} of N independent of the splitting (T6 and T7) and 240 kg ha^{-1} N split three times (T8) provided greater means (Table 5). The difference between the Y provided by the application of 180 kg N ha^{-1}, split in three times and the control treatment was 2747.33 kg ha^{-1}, representing an increase of 60.99%. Duete et al. (2008) also obtained a 47% increase in Y in raising the rate of N from 0 to 135 kg ha^{-1} of N. Araújo et al. (2004) found that application of 240 kg ha^{-1} of N resulted in higher Y compared to the control, that is, 2,448 kg ha^{-1} (28%).

Higher Y with application of 60, 120 and 180 kg ha^{-1} of N split in twice, possibly, happened due to all N being applied till 40 days after sowing (DAS), demonstrating increased N supply in the early stage of crop growth, supported grain yield. In addition, the increase in Y provided by the application of N (Table 5) took place owing to this nutrient having supported an increase in the plant biomass (Figure 2d) and possibly leaf area, thus conditioning increased synthesis of assimilates, since N is a constituent of the chlorophyll molecule, acting in the processes of cell division and expansion (Ferreira et al., 2001). This assumption is confirmed by the lower amount of plant biomass of the control treatment and by its linear increase due to the increase in rate of N (Figure 2d). That took place also by the possible N mobilization and the high N requirement of corn, even in early stages, in which the full use of N contributes in yield in an advanced manner.

Data from Y (Figure 2g) responded quadratically to N rates. With the increase of the rate, one has an increase in the corn Y up to the estimated rate 190.65 kg ha^{-1}, that is, 6828 kg ha^{-1}. The quadratic effect of the rates of N on corn kernel yield is in agreement with the results obtained by Silva et al. (2005a) and Bastos et al. (2008). All those results allow stating that the N dynamics in the soil-plant system and, consequently, the efficiency of the use of this element by corn, is dependent on the amount and time of fertilizer application.

Highest AEI was obtained with application of 60 kg ha^{-1} N split twice (T3) (Table 5). The splitting strategy, 20 kg at planting and the rest at the 4 leaf stage yielded the highest AEI (23.29) at the estimated rate 114.43 kg ha^{-1} of N. but the split of 20 kg at planting and the rest divided into 50 % at the four expanded leaf stage +50% at the eight expanded leaf stage presented no significant effect (Figure 2h). Fernandes et al. (2005) studying the efficiency of N use in corn plants, using rates from 0 to 180 kg ha^{-1} N, reported that the use of N decreased with increase of rates applied, due to the supply of N exceeding the needs of the corn crop. For Farinelli and Lemos (2010), this reduction is coming from likely losses of ammonia and nitrate by leaching after the nitrification process, which increased with applied rate and this increase may be either linear or exponential.

The Pearson correlations among the characteristics were to a great extent significant, positive and low to moderate magnitude (Table 6). Among the variables which correlated with the Y were: H, RCC, EIH, D and GPE (Table 6), confirming that these components may be important in the Y of crop. Concerning H, these results corroborate with those observed by Silva et al. (2006). According to these authors, H is a parameter that determines the degree of development of the crop, having a positive correlation (0.50) with Y, therefore, for the same hybrid, larger plants tend to be more yielding, probably because they suffer less stress during their development and accumulate higher amounts of reserves in stem. Silva et al. (2005c), in another study on times and modes of N application also observed a positive correlation between H and Y of corn, with value of r of (0.87). Cruz et al. (2008) found a significant and positive

Table 6. Pearson correlation coefficients in response to different rates and splits of N on corn in dystrophic Yellow Latosol of the Piauí Cerrado.

Variable	H	RCC	LNC	PB	EIH	D	RPC	GPE	GPR	TSW	Y	AEI
H	1.00											
RCC	0.71***	1.00										
LNC	0.48**	0.71***	1.00									
PB	0.47**	0.52***	0.44**	1.00								
EIH	0.77***	0.60***	0.54***	0.36*	1.00							
D	0.66***	0.57***	0.21^{ns}	0.35*	0.46**	1.00						
RPC	0.44**	0.32^{ns}	0.39*	0.21^{ns}	0.33*	0.27^{ns}	1.00					
GPE	0.45**	0.44**	0.33^{ns}	0.17^{ns}	0.33*	0.46**	0.41*	1.00				
GPR	0.33*	0.36*	0.22^{ns}	0.10^{ns}	0.24^{ns}	0.39*	0.04^{ns}	0.92***	1.00			
TSW	0.34*	0.46**	0.32^{ns}	0.37*	0.25^{ns}	0.20^{ns}	0.04^{ns}	0.20^{ns}	0.22^{ns}	1.00		
Y	0.56***	0.42**	0.11^{ns}	0.25^{ns}	0.53***	0.54***	0.34*	0.54***	0.44***	0.31^{ns}	1.00	
AEI	0.47**	0.22^{ns}	0.01^{ns}	-0.05^{ns}	0.38*	0.53**	0.13^{ns}	0.27^{ns}	0.24^{ns}	0.06^{ns}	0.66***	1.00

H: plant height; RCC: relative chlorophyll content, LNC: leaf N content; PB: plant biomass; EIH: ear insertion height; D: stem diameter; RPC: rows per cob; GPE: grains per ear; GPR: grains per row; TSW: thousand seed weight; Y: yield, AEI: Agronomic efficiency index. * P <0.05, ** P <0.01, *** P <0.001, and ns: non-significant.

correlation between D and Y in Alagoas, Brazil. According to these authors, normally the D presents a correlation with Y due to being a storage organ of the plant. According to Fanceli and Dourado Neto (2000), the stem acts as the storage structure of soluble solids that are used later in the grain formation. But, the correlation between GPE and Y is explained by the fact GPE to be an explicative trait of the Y, corroborating with the value obtained by Silva et al. (2006) which was of 0.73.

Studies have also reported a correlation between the RCC and Y (Argenta et al., 2002, 2004; Hurtado et al., 2009). According to Argenta et al. (2002) the RCC in corn leaf is highly associated with Y, its being able this way to replace the determination of the N content in the leaf for diagnosis of this nutrient in plant.

Conclusions

Nitrogen significantly increased agronomic characteristics of corn and the highest grain yield was obtained with 190.65 kg ha^{-1} N. Plant height, relative chlorophyll content, leaf N content, plant biomass, stem diameter, thousand seed weight, yield and agronomic efficiency index were positively influenced by the rates of nitrogen. The split of topdressing in twice was not suitable in the dystrophic Yellow Latosol of the Piauí Cerrado. Plant height, relative chlorophyll content, ear insertion height, stem diameter, grains per ear and rows per ear, grains per row and agronomic efficiency index positively correlated with grain yield.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Araújo LAN, Ferreira ME, Cruz MCP (2004). Adubação nitrogenada na cultura do milho. Pesqui. Agropecuária Bras. 39(8):771-777. http://dx.doi.org/10.1590/S0100-204X2004000800007

Argenta G, Silva PRF, Mielniczuk J, Bortolini CG (2002). Parâmetros de planta como indicadores do nível de nitrogênio na cultura do milho. Pesquisa Agropecuária Brasileira. 37(4)519-527. http://dx.doi.org/10.1590/S0100-204X2002000400014

Argenta G, Silva PRF, Sangoi L (2004). Leaf relative chlorophyll content as an indicator parameter to predict nitrogen fertilization in maize. Ciênc. Rural 34(5):1379-1387. http://dx.doi.org/10.1590/S0103-84782004000500009

Bastos EA, Cardoso MJ, Melo FB, Ribeiro VQ, Andrade Júnior AS (2008). Rates e formas de parcelamento de nitrogênio para a Yução de milho sob plantio direto. Rev. Ciênc. Agron. 39(02):275-280.

Conab (2012). Companhia Nacional de Abastecimento - Prospecção para a safra 2011/2012 de milho.

Cruz SCS, Pereira FRP, Santos JR, Albuquerque AW, Pereira RG (2008). Adubação nitrogenada para o milho cultivado em sistema plantio direto, no Estado de Alagoas. Rev. Bras. Egpenharia Agrícola Ambiental 12(1):62-68.

Duete RRC, Muraoka T, Silva EC, Trivelin PCO, Ambrosano EJ (2008). Manejo da adubação nitrogenada e utilização do nitrogênio (15n) pelo milho em Latossolo Vermelho. Rev. Bras. Ciênc. Solo. 32:161-171. http://dx.doi.org/10.1590/S0100-06832008000100016

EMBRAPA (1997). Empresa Brasileira de Pesquisa Agropecuária -. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. 2ed. Brasília P. 212.

Fanceli AL, Dourado Neto D (2000). Yução de milho. Guaíba. Agropecuária P. 360.

Farinelli R, Lemos LB (2010). Yutividade e eficiência agronômica do milho em função da adubação nitrogenada e manejos do solo. Rev. Bras. Milho Sorgo 9(2):135-146.

Farinelli R, Lemos LB (2012). Nitrogênio em cobertura na cultura do milho em preparo convencional e plantio direto consolidados. Pesqui. Agropecuária Trop. 42(1):63-70. http://dx.doi.org/10.1590/S1983-40632012000100009

Fernandes FCS, Buzetti S, ARF O, Andrade JAC (2005). Rates, eficiência e uso de nitrogênio por seis cultivares de milho. Rev. Bras. Milho Sorgo 4(2):195-204.

Fernandes FCS, Libardi PL (2007). Percentagem de recuperação de nitrogênio pelo milho, para diferentes rates e parcelamentos do fertilizante nitrogenado. Rev. Bras. Milho Sorgo 6(3):285-296.

Ferreira ACB, Araújo GAA, Pereira PRG, Cardoso AA (2001). Características agronômicas e nutricionais do milho adubado com nitrogênio, molibdênio e zinco. Rev. Sci. Agric. 58(1):131-138. http://dx.doi.org/10.1590/S0103-90162001000100020

Ferreira DF (2011). Sisvar: a computer statistical analysis system. Ciênc. Agrotecnol. 35(6):1039-1042.

Hurtado SMC, Resende AV, Silva CA, Corazza EJ, Shiratsuchi LS (2009). Variação espacial da resposta do milho à adubação nitrogenada de cobertura em lavoura no cerrado. Pesqui. Agropecuária Bras. 44(3):300-309. http://dx.doi.org/10.1590/S0100-204X2009000300012

Jacomine PKT, Cavalcanti AC, Pessoa SCP, Burgos N, Melo Filho HFR, Lopes OF, Medeiros LAR (1986). Levantamento exploratório. Reconhecimento de solos do Estado do Piauí. Rio de Janeiro. EMBRAPA-SNLCS/SUDENE-DRN. P. 782.

Malavolta E, Vitti GC, Oliveira SA (1997). Avaliação do estado nutricional das plantas: Princípios e aplicações. 2.ed. Piracicaba, POTAFOS P. 319.

Pragana RB, Ribeiro MR, Nóbrega JCA, Ribeiro Filho MR, Costa JA (2012). Qualidade física de Latossolos Amarelos sob plantio direto na região do Cerrado piauiense. Rev. Bras. Ciênc. Solo. 36:1591-1600. http://dx.doi.org/10.1590/S0100-06832012000500023

Queiroz AM, Souza CHE, Machado VJ, Lana RMQ, Gaspar GH, Silva AA (2011). Avaliação de diferentes fontes e rates de nitrogênio na adubação da cultura do milho (zea mays). Rev. Bras. Milho Sorgo. 10(3):257-266.

Ohland RAA, Souza LCF, Hernani LC, Marchetti ME, Gonçalves MC (2005). Culturas de cobertura do solo e adubação nitrogenada no milho em plantio direto. Ciênc. Agrotecnol. 29(3):538-544, 2005. http://dx.doi.org/10.1590/S1413-70542005000300005

Rambo L, Silva PRF, Argenta G, Sangoi L (2004). Parâmetros de plantas para aprimorar o manejo da adubação nitrogenada de cobertura de milho. Ciênc. Rural 34(5):1637-1645. http://dx.doi.org/10.1590/S0103-84782004000500052

SAS/STAT (1999). User's guide, version 8.0, Cary: SAS Institute, Inc.

Scott A, Knott M (1974) Cluster-analysis method for grouping means in analysis of variance. Biometrics, Washington D.C. 30(3):507-512.

Silva EC, Buzetti S, Guimarães GLG, Lazarini E, SÁ ME (2005a). Rates e épocas de aplicação de nitrogênio na cultura do milho em plantio direto sobre Latossolo Vermelho. Revista Brasileira de Ciência do Solo. 29:353-362. http://dx.doi.org/10.1590/S0100-06832005000300005

Silva EC, Buzetti S, Lazarini E (2005b). Aspectos econômicos da adubação nitrogenada na cultura do milho em sistema de plantio direto. Rev. Bras. Milho Sorgo 4(3):286-297.

Silva EC, Ferreira SM, Silva GP, Assis RL, Guimarães GL (2005c). Épocas e formas de aplicação de nitrogênio no milho sob plantio direto em solo de cerrado. Rev. Bras. Ciênc. Solo. 29:725-733. http://dx.doi.org/10.1590/S0100-06832005000500008

Silva DA, Vitorino ACT, Souza LCF, Gonçalves MC, Roscoe R (2006). Culturas antecessoras e adubação nitrogenada na cultura do milho, em sistema plantio direto. Rev. Bras. Milho Sorgo 5(1):75-88.

Silva AA, Silva TS, Vasconcelos ACP, Lana RMQ (2012). Aplicação de diferentes fontes de ureia de liberação gradual na cultura do milho. Biosci. J. 28(1):104-111.

Sunderman HD, Pontus JS, Lawless JR (1997). Variability in leaf chlorophyll concentration among full-fertilized corn hybrids. Commun. Soil Sci. Plant Anal. 28(19):1793-1803. http://dx.doi.org/10.1080/00103629709369916

Varvel GE, Schpers JS, Francis DD (1997). Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meters. Soil Science Soc. Am. J. 61:1233-1239. http://dx.doi.org/10.2136/sssaj1997.03615995006100040032x

Viana TVA, Vasconcelos DV, Azevedo BM, Souza VF (2002). Estudo da aptidão agroclimática do Estado do Piauí para o cultivo da aceroleira. Rev. Ciênc. Agron. 33(2):5-12.