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The effect of types and split of urea on yield indicators and yield components of maize

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Abstract

Maize is one of the most important cereals in the world. The productive potential of this crop is closely associated with nitrogen (N) fertilization, thus, studies focused on this subject are important in the development of cropping strategies. The aim of this work was to evaluate the effects of N split and different type of urea on important agronomic traits of the maize crop. A randomized complete block design in a 2×2+1 factorial treatment design with four replications was used. The factorial levels were composed of two types of urea (common and coated) and two nitrogen splits (V_3 and V_3+V_8), plus the control treatment (without urea application). Important agronomic traits such as grain yield, biological productivity, and yield components were assessed. It was verified that there is no difference between the common or coated urea on grain yield and its components. On the other hand, the split of nitrogen into V_3 and V_8 stages is an efficient strategy to improve grain yield as well as important features as the number of rows per ears and harvest index. Thus, by using this management system farmers can achieve a more efficient nitrogen use.

Key words: *Zea mays* L. nitrogen application; phenological stage; slow-release;
Abbreviations: N_ nitrogen; V3_ vegetative 3 stage; V8_ vegetative 8 stage; GY_ gain yield; BP_ biological productivity; SP_ straw productivity; HI_ harvest index; NRE_ number of rows per ear; NKR_ number of kernels per row; NKE_ number of kernels per ear; TKW_ thousand-kernel weight; KWE_ kernel weight per ear.

Introduction

Maize productivity is a complex trait dependent on several factors, mainly related to genetic characteristics of the cultivars, meteorological conditions during cultivation and use of the different fertilization managements. Modern maize genotypes are highly responsive to the use of nitrogen (N) and the time when N-fertilizer is available. This has a direct impact on yield components and maize productivity indicators (Rizzardi et al., 2008; Queiroz et al., 2011).

Nitrogen presents a great dynamic in the soil due to numerous chemical and biological reactions (Cantarella and Duarte, 2004) that result in a complex management of N-fertilization Schiavinatti et al., (2011). Only a part of the N applied is absorbed by the plants, the remainder is lost in the soil-plant-atmosphere system by leaching, volatilization, erosion and denitrification processes, with a fraction remaining in the soil in the organic form (Dhital and Raun, 2016). Thus, the domain of knowledge related to N fertilization is essential to increase the efficiency of N use by plants, maximize productivity and reduce their excess in the environment (Hurtado et al., 2009; Cui et al., 2010; Prando et al., 2013).

There are some management techniques that make possible to increase the effectiveness of N-use by plants. The N splitting, the use of different sources and the definition of the time of application are the main alternatives for increasing nitrogen use efficiency and mitigating its losses to the environment (Cantarella, 2007; Schiavinatti et al., 2011). Thus, knowing how these techniques influence maize productivity is vital since N-fertilization is one of the most expensive steps in maize production (Gramig, Massey, Yun, 2016).

In maize cropping, there are two primordial vegetative stages to carry out the N splitting: V_3 and V_8. In these stages occur the definition of the productive potential, being crucial regarding N availability. The V_3 stage is characterized by the plants presenting three fully developed leaves. In that stage, all the leaves and ears that the plant will eventually produce are being formed. Therefore, the establishment of the maximum number of kernels, and consequently, the potential of production, is defined at this stage. In the V_8 stage, the plants have eight fully developed leaves and there is a definition of the number of kernel rows per ear (Silva et al., 2005). Thus, the synchronism between N fertilization and plant's demand is vital for mitigating the losses by leachate, runoff, and denitrification (Scharf, 2015).

In addition to N splitting and N supply at the ideal moment of plant need, there is another alternative for mitigating N losses, such as the use of slow-release urea, a recent technology in production of polymer-coated urea reported in several studies (Cahill et al., 2010, Civardi et al., 2011; Almeida and Sanches, 2012). Despite the higher cost of its acquisition, coated urea is able to reduce N losses, providing a gradual release of this nutrient to the plants throughout the growing cycle. This process reduces the losses to the environment and brings benefits from the environmental point of view (Drinkwater and Snapp, 2007, Cantarella, 2008, Valderrama et al., 2009, Valderrama et al., 2011). According to Vitti and Reirinchs (2007), this gradual release is the result of the slower dilution process in the soil compared to common urea, in addition to meeting the N requirement of the crop over the time, avoiding waste, reducing the environmental contamination and guaranteeing higher economic returns (Zheng et al., 2017).

Several studies have been carried out in the maize crop focusing on the use of different sources of N (De Souza et al., 2006; Guedes et al., 2017) as well as N splitting (Portela et al., 2016, Guedes et al., 2017). However, there is a gap regarding the effects of the application of coated urea at different vegetative stages of maize crop on grain yield, biological productivity, and yield components. Understanding this dynamic is essential for making the correct decision in choosing the best vegetative stage and type of urea to be used in N fertilization of maize.

For filling this gap, the aim of this study was to evaluate the effect of the splitting of different types of urea (conventional and coated urea) on biological productivity, grain yield and yield components of maize.

Results and discussion

Rainfall and temperature

During the maize crop cycle, between September and January, rainfall was 1225 mm, below the historical average of the last 20 yr. (1550 mm) with a minimum average temperature of 18ºC and maximum of 36ºC (Figure 1). These temperatures are close to the ideal temperature for maize growing, between 24ºC and 30ºC (Maldaner et al., 2014). However, there were several days with a temperature higher than ideal, which could cause a decrease in corn grain yield. At the time of N fertilizer, the soil presented adequate moisture conditions due to the accumulation of rainfall from previous days (Figure 1). At the period that includes the flowering and beginning of grain filling, critical period of greater sensitivity to water deficit to maize plants (Bergamaschi et al., 2006), it was verified that there was an interval of 16 days without rainfall. Except for this interval, there were no other periods of water deficit or excessive rainfall (Figure 1). In maize, the expression of productivity potential is directly related to the interaction of climatic factors, mainly solar radiation (Junior, 2013), precipitation and temperature (Maldaner, 2014).

Response of maize to types of urea and N splitting

The ANOVA revealed significant differences (p < 0.05) for grain yield, number of kernels per row, number of kernels per ear and kernel weight per ear. For grain yield, both main effects (splitting and type of urea), as well as the interaction between these factors were statistically significant. However, for the variables number of kernels per row, number of kernels per ear and kernel weight per ear, the meaningful effect was only for the splitting.

When observed the contrasts, there was only a significant effect on the number of kernels per row and kernel weight per ear (Table 1). This fact may be associated with the amount of N Fertilizer available to the plants both by the addition of N-fertilization in the base and by the decomposition of the residues of the predecessor crop, the forage turnip. This cruciferous species presents a low C/N ratio in its straw, rapidly providing a high amount of N in the soil solution (Souza, 2014).

Decomposing the interaction between the factors (splitting and type of urea) through orthogonal contrasts (C), it is observed that the C_1 does not have a significant effect on the yield and yield components. Several studies also reported that the use of coated urea does not bring benefits in terms of increase grain yield (Meira et al., 2009; Kappes et al., 2009; Soratto et al., 2010; Cardoso et al., 2011; Soratto et al., 2011). The NH_4^+, synthesized by the hydrolysis of the urea molecule might present volatilization rates that can achieve up to 30%, mainly under conditions of low precipitation and high temperatures in the first days after fertilization (Chen et al., 2014). A suitable soil moisture condition at the time of application of urea at the V_3 stage (Figure 1) was a factor that might have favored the rapid incorporation of N into the soil solution, regardless of the type of urea (common or coated), thus, providing a N supply to the plants even when the second application in the V_8 stage was not carried out.

In the contrast 2, comparing the N splits with the common urea, a significant effect was observed for the number of rows per ear and thousand-kernel weight. The N splitting in two stages (V_3 and V_8) increases the number of rows per ear whereas the application in V_3 increases the thousand-kernel weight. On the other hand, when the N splits with coated urea (C_3), a significant effect was observed for grain yield and harvest index, where the N splitting in the stages V_3 and V_8 provided the best response. Thus, it was noticed that the N split into the stages that maize has the higher N demand, is an efficient method to improve grain yield. Recent studies have reported that split applications improve the utilization of N and increase grain yield in several crops such as maize (Maharjan et al., 2016), wheat (López-Bellido et al., 2005; Olivoto et al., 2016) and garden pea (Sharma et al., 2016). Thus, split N application might be a strategy to be recommended from the standpoint both of the environment and of farmer gains.

Comparing factorial levels with control

Comparing the contrast between the treatments and control (without N application) it was observed significant differences wherein the coated urea split into the stages V_3 and V_8 provided higher grain yield (+1732.50 kg) and higher kernel mass per ear (+38.88 g). This can be explained due to the application of urea only in V_3 as well as the split of common urea in V_3 and V_8 stages, does not provide an adequate N provision in most advanced stages of maize development. The coated urea, however, due its slower volatilization provided a slow and continuous N liberation, which associated with its split, provided an adequate N supply to plants. Thus, it was proved that in conditions of soil moisture, both types of urea provide the same benefits to plants. The split of N, however, increase grain yield and important yield components, such as number of rows per ear and harvest index.

Materials and methods

Site description and soil classification

The experiment was carried out in the 2014/2015 growing season, in the municipality of Augusto Pestana, Rio Grande do Sul, Brazil (S 28°26'30"; W 54°00'58", at 390 masl). The soil of the experimental area is classified as Oxisol (Oxisol) (Streck et al., 2008) and the climate as Cfa, according to Koppen's classification (Alvares et al., 2013).

A soil analysis was performed 30 days before sowing, obtaining the following results: pH = 6.5; P = 34.4 mg dm^{-3}; K = 262 mg dm^{-3}; MW = 2.9%; Al = 0 c^{molc} dm^{-3}; Ca = 6.6 cmolc dm^{-3} and Mg = 3.4 cmolc dm^{-3}.

Table 1. Analysis of variance for the biological productivity (BP), grain yield (GY), straw yield (SY), harvest index (HI), number of rows per ear (NRE), number of kernels per row (NKR), number of kernels per ear (NKR), thousand-kernel weight (TKW) and kernel weight per ear (KWE).

Source of variation	DF	Mean square								
		BP (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})	HI (kg kg^{-1})	NRE (nº)	NKR (nº)	NKE (nº)	TKW (g)	KWE (g)
Block	3	2533258	237617	1756550	0.00012	2.32	16.32	12104	0.00368	332.91
Treatments	4	1551830^{ns}	3411659*	3243561^{ns}	0.00309*	3.82^{ns}	25.07*	12008^{ns}	0.0034^{ns}	883.16*
Factorial	3	970200^{ns}	4518997*	2833537^{ns}	0.000395*	5.08^{ns}	21.73*	13182^{ns}	0.00452^{ns}	809.44*
Split (S)	1	2822400^{ns}	3296040*	18360^{ns}	0.00160^{ns}	9.00^{ns}	0.0625^{ns}	6561^{ns}	0.00076^{ns}	371.62^{ns}
Type (T)	1	44100^{ns}	7072940*	6000050^{ns}	0.00722^{ns}	4.000^{ns}	60.0625*	31862*	0.00331^{ns}	1543.11*
S x T	1	44100^{ns}	3188010*	2482200^{ns}	0.00303^{ns}	2.25^{ns}	5.0625^{ns}	1122^{ns}	0.00951^{ns}	513.59^{ns}
Factorial x control	1	3296720^{ns}	89646^{ns}	4473634^{ns}	0.00050^{ns}	0.05^{ns}	35.11*	8487^{ns}	0.00003^{ns}	1104.32*
Error	12	1130267	229042	1620494	0.00033	2.36	5.94	4157	0.0026	169.56
Mean		31462	9737	21725	0.31	12.87	35.81	455.50	0.38	169.47
CV (%)		3.37	4.91	5.85	11.77	20.65	6.80	14.15	13.44	7.68

DF: degrees of freedom; CV: coefficient of variation; *significant at 0.05 probability error; ^{ns} not significant

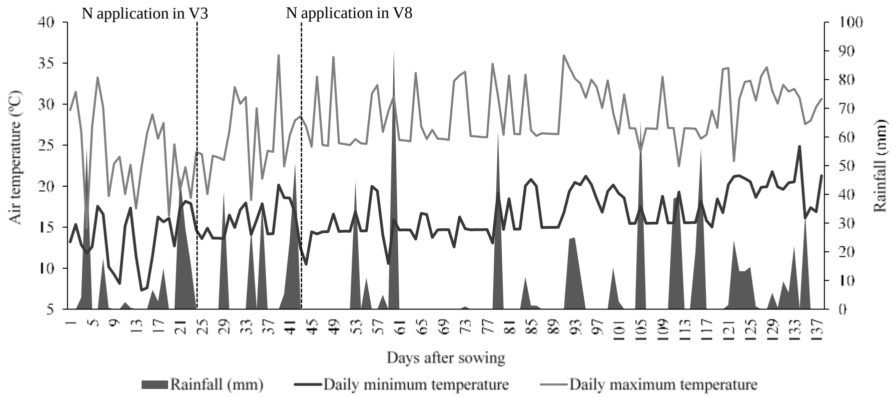

Fig 1. Rainfall and maximum temperature in maize crop cycle.

Table 2. Results of orthogonal contrasts for biological productivity (BP), grain yield (GY), straw yield (SY), harvest index (HI), number of rows per ear (NRE), number of kernels per row (NKR), number of kernels per ear (NKR), thousand-kernel weight (TKW) and kernel weight per ear (KWE).

	Contrast 1 (C1)			Contrast 2 (C2)			Contrast 3 (C3)		
	Mean 1	Mean 2	Significant	Mean 1	Mean 2	Significant	Mean 1	Mean 2	Significant
BP (kg ha^{-1})	62085	63765	ns	31043	31043	ns	31778	31988	ns
GY (kg ha^{-1})	18567	20383	ns	9065	9502	ns	9080	11303	*
SY (kg ha^{-1})	43518	43383	ns	21978	21541	ns	22698	20685	ns
HI (kg kg^{-1})	0.60	0.64	ns	0.29	0.31	ns	0.29	0.35	*
NRE (nº)	24.13	26.63	ns	11.13	13.00	*	13.25	13.38	ns
NKR (nº)	71.83	71.19	ns	34.39	37.44	ns	33.33	37.86	ns
NKE (nº)	870.23	951.27	ns	382.09	488.14	ns	439.37	511.90	ns
TKW (g)	0.77	0.74	ns	0.43	0.35	*	0.36	0.38	ns
KWE (g)	329.30	348.57	ns	160.49	168.80	ns	158.80	189.77	ns

C_1: Mean 1: V3 common + V3+V8 common -vs- Mean 2: V3 coated + V3+V8 coated; C_2: Mean 1: V3 common -vs- Mean 2: V3+V8 common; C_3: Mean 1: V3 coated -vs- Mean 2: V3+V8 coated *significant at 0.05 probability error according to orthogonal contrast test; ^{ns} not significant.

Table 3. Differences between factorial combinations and control treatment (without nitrogen application) for biological productivity (BP), grain yield (GY), straw yield (SY), harvest index (HI), number of rows per ear (NRE), number of kernels per row (NKR), number of kernels per ear (NKR), thousand-kernel weight (TKW) and kernel weight per ear (KWE).

Treatments	BP (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})	HI (kg kg^{-1})	NRE (nº)	NKR (nº)	NKE (nº)	TKW (g)	KWE (g)
V_3 common	-1435.00^{ns}	-505.00^{ns}	-930.00^{ns}	-0.005^{ns}	-1.50^{ns}	1.86^{ns}	-21.86^{ns}	44.50^{ns}	9.61^{ns}
V_3 coated	-700.00^{ns}	-490.00^{ns}	-210.00^{ns}	-0.012^{ns}	0.75^{ns}	0.80^{ns}	35.42^{ns}	-18.20^{ns}	7.91^{ns}
V_3V_8 common	-1435.00^{ns}	-68.00^{ns}	-1367.00^{ns}	0.010^{ns}	0.25^{ns}	4.91^{ns}	84.19^{ns}	-32.20^{ns}	17.91^{ns}
V_3V_8 coated	-490.00^{ns}	1732.50*	-2222.50^{ns}	0.057^{ns}	1.00^{ns}	5.34^{ns}	107.95^{ns}	1.00^{ns}	38.88*
Mean of control	32477.50	9570.00	22907.50	0.290	12.75	32.50	404.00	380.75	150.89

*significant at 0.05 probability error by Dunnett's test; ^{ns} not significant.

Plant material and experimental design

The experimental design was a randomized complete block with five treatments (2×2+1 factorial treatment design), with four replications. The factorial levels were composed of two types of urea (common and coated) and two application stages (V3 and V3 + V8), plus the control treatment, without urea application. The corn hybrid was BG7046, with a 137-day growing cycle, high productive potential and high management responsiveness. Corn sowing was performed manually on September 8, 2014, on a cultural precedent of *Raphanus sativus* L., which presents a low C/N ratio. The plant density was adjusted to 70,000 ha^{-1} final plants. Each plot was composed of four 5-m long rows spaced at 0.50 m between lines, forming a 10-m^2 experimental unit. At the sowing, 20 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5 and 80 kg ha^{-1} of K_2O were applied in the base fertilization. During the execution of the study, there was no need of fungicide and insecticide application. The control of weeds was done with manual weeding, whenever necessary.

The total amount of N to be applied in top-dressing fertilization (156 kg ha^{-1}) was defined according to the soil analysis. This amount of N was applied in one only application in the V3 stage or split into two applications in V3 and V8 stages with two types of urea (i) Common urea [$CO (NH_2)_2$], with 45% of N; and (ii) coated urea commercially called *Kimcoat N®*. This type of urea has the same formulation and N concentration than common urea, but presents a polymer-coat around the granules, allowing a slow-release of N. Both types of urea were applied under the same conditions of soil moisture considering each vegetative stage. The applications were manually carried out, distributing the equivalent dose homogeneously in the plots.

The harvest was performed on January 22, 2015, when the kernels presented approximately 20% moisture. The following variables were assessed: a) Grain yield (GY, kg ha^{-1}), obtained by harvesting the ear of two central lines of each plot; The ears were threshed with a stationary harvester and directed to the laboratory for correction of grain moisture to 13% and subsequent weighing. B) Biological productivity (BP, kg ha^{-1}), obtained by the close soil-cutting the plants of two central lines of each plot at the stage of harvest maturity; The collected material was directed to a forced air oven at a constant temperature of 65 °C up to constant weight. C) Straw productivity (SP, kg ha^{-1}), estimated by PB-PG; D) Harvest index (HI, kg ha^{-1}) obtained by the PG/PB ratio. In ten randomly-collected ears per experimental plot the following traits were assessed: a) number of rows of grains; B) number of kernels per row; C) number of kernels per ear; D) thousand-kernel weight (g); E) kernel weight per ear (g) determined by an analytical balance.

Statistical analysis

The homogeneity, normality of the residual variances and the additivity of the model were tested. Once the assumptions have complied, a two-way ANOVA with additional treatment was performed ($p \leq 0.05$). As the effects of pairs of combinations in the factorial design are independent of on the effect of additional treatment, for each trait, the following models were considered: $y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$ and $y_h = \mu + \tau_a + \varepsilon_h$; where y_{ijk} is the response trait related to the *i*th level of first factor (i = 2) with *j*th level of the second factor (j = 2); μ is the overall mean ; α_i is the effect of the *i*th level of the first factor; β_j is the effect of the *j*th level of the second factor; γ_{ij} is the effect of the interaction of *i*-th level of the first factor with the *j*th level of the second factor; and ε_{ijk} is the experimental error associated with the y_{ijk} observation where ε_{ijk} ~N(0, σ^2); y_h is the response trait associated to the *h*th observation (h = 1, 2, 3, 4) of the additional treatment; τ_a is the effect of the additional treatment; and ε_h is the experimental error associated with additional treatment, considering ε_h ~N(0, σ^2).

In order to compare the means of the factorial combinations orthogonal contrasts (C) were used (Nogueira, 2004). The three contrasts planned had specific aims as can be seen following: C1: [V3 common + V3+V8 common -vs- V3 coated + V3+V8 coated]. This contrast has tested if there is a difference between common and coated urea, independently of the stage of application; C2: [V3 common -vs- V3+V8 common]. This contrast has tested if the common urea provides best responses if applied in split or in one fertilization only; C3: [V3 coated -vs- V3+V8 coated]. This contrast has tested if the coated urea provides best responses if applied in split or in one fertilization only. The means of each combination of the factorial design were compared with control by the Dennett's test. All statistical procedures were performed in Genes software (Cruz, 2013).

Conclusion

Our results suggest that there is no difference between the common or coated urea on grain yield and yield components of maize. On the other hand, the split of nitrogen into stages that maize has the higher demand is an efficient method to improve grain yield as well as important features as number of rows per ears and harvest index. Thus, farmers can achieve a more nitrogen uptake by using this management.

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