academicJournals

Vol. 9(27), pp. 2132-2141, 3 July 2014
DOI: 10.5897/AJAR2013.7471
Article Number: F7C833245993
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of nitrogen rates and application time on popcorn

Luiz Fernando Pricinotto, Pedro Soares Vidigal Filho*, Carlos Alberto Scapim, Odair José Marques, Ricardo Shigueru Okumura and Deivid Lincoln Reche

UEM – Maringá University State (Universidade Estadual de Maringá), PGA - Post-graduation Program of Agronomy,(Programa de Pós-graduação em Agronomia), Av. Colombo, 5790, bloco J-45, CEP 87020-900, Maringá , Paraná, Brasil.

Received 11 June, 2013; Accepted 16 June, 2014

Among the various limiting factors in the production of Brazilian popcorn, paucity of information on cultural practices is highlighted, with emphasis on the management of fertilizer, especially nitrogen (N) topdressing. This mineral nutrient is of great importance in several agronomic characteristics of corn plants, mainly components of production. The aim of this study is to evaluate the effects of N management on popcorn (*Zea mays* L. subsp. *everta*) in two growing seasons (during 2007 and 2008 agricultural years) in Maringá, Northeast of Parana, Brazil. Experiment was conducted as a factorial arrangement in randomized complete blocks design with four replications. The treatments were a combination of five N rates (0; 45; 90; 135; 180 kg ha^{-1}), two seasons of topdressing applications (development stages V_4 and V_8) and two varieties of popcorn (BRS-Angela and IAC-125). The N topdressing rates increased plant height, leaf area index, and ear length, number of grains per row, thousand grain weight, and grain yield of popcorn. The highest yields (3.94 t ha^{-1} and 3.24 t ha^{-1}) were obtained with the estimated rates of 130.1 and 131.5 kg N ha^{-1} for the cultivars BRS-Angela in V_8 and IAC-125 at V_4, respectively. On the other hand, the economic rates of N topdressing were 73.76 and 78.42 kg N ha^{-1} for BRS-Angela and IAC-125 cultivars, respectively. The N rates and time of application did not influence the capacity for expansion, and only the effect in this genetic trait was observed.

Key words: Zea mays *L*., nutrient, corn, nutrient, productivity, fertilization.

INTRODUCTION

Among the various limiting factors in the production of Brazilian popcorn, paucity of information on cultural practices is highlighted, with emphasis on the management of fertilizer, especially N topdressing. N is of great importance in several agronomic characteristics of corn plants and can raise thousand grain weight and number of ears per plant (Melgar et al., 1991), ear length (Hanway, 1963), plant height and the weight of ears (Araújo et al., 2004), dry matter (Araújo et al., 2004; Duete et al., 2008) and grain yield (Mar et al., 2003; Araújo et al., 2004; Silva et al., 2005, 2006; Duete et al., 2008; Okumura et al., 2011).

It should be noted that good results seen in only one of these traits does not provide a good economic

*Corresponding author. E-mail: vidigalfilhop@gmail.com. Tel: +554430118955.

Table 1. Chemical and physical characteristics of soil in 0.00 - 0.20 m layer.

Solo	pH	C	*P	*K^+	**Ca^{+2}	**Mg^{+2}	**Al^{+3}	SB	CTC	V
	$CaCl_2$	(g dm^{-3})	(mg dm^{-3})			($cmol_c$ dm^{-3})				(%)
F	4.60	11.51	11.30	0.08	1.09	0.54	0.00	1.71	4.44	38.5
FN	5.00	21.96	8.20	0.58	3.34	1.60	0.00	5.52	10.48	52.6

Solo	Areia	Silte	Argila
		(g kg^{-1})	
F	760	10	230
FN	340	140	520

* Mehlich 1 (Mehlich, 1978). ** KCl 1 mol L^{-1} (Defelipo and Ribeiro, 1981).

productivity of the crop (Sawazaki et al*.,* 2000). Although the increase of productivity is always desired, it is the expansion capacity that plays a decisive role in commercial value of popcorn (Ceylan and Karababa, 2002); there is no information in the literature regarding the effects of N and its application forms on the expansion capacity index of popcorn.

Among the producers of popcorn, it is observed that it is common to use technical recommendations of fertilizer for common corn and popcorn. This is mainly due to the scant results on experimental results for the growing of corn. What has been made available, most of the time are technical data published by private companies, which are based on adaptations of the recommendations of the common corn for popcorn. However, due to potential differences in production between them, the doses of fertilizers used for popcorn may be overestimated and/or underestimated (Nunes, 2003).

The best timing of N application must be taken into consideration for the correct handling of topdressing N. According to Ritchie et al*.* (1993), it is within the 4 fully expanded leaves period (V_4 stage) that the plant has its production potential defined by the differentiation of the apical meristem, justifying the importance of N availability. At this stage, one can see the definition of the reproductive organs in the stem and leaves of the plant (Ritchie et al*.*, 1993), while in the V_8 stage (8 fully expanded leaves) the root system is already well developed, favoring the use of N by the plant (Ritchie et al*.,* 1993).

Based on these considerations, this work was developed with the aim of evaluating the response of popcorn to rates and timing of N topdressing applications in the cropping season of 2007/2008 summer harvest and 2008 interim-harvest.

MATERIALS AND METHODS

The experiments were conducted in the field at the Experimental Farm of Iguatemi (FEI), State University of Maringá (UEM), located in the Iguatemi District, in Maringa, Northeast of Parana, Brazil (23º21' S and 52°04' W, with an average altitude of 550 m). The climate is the Cfa type, according to the Köppen classification, that is, subtropical climate with average temperature below 18°C in spring months (mesothermal) and above 22°C in summer (warm), infrequent frosts and rainfall concentration during summer, but without dry season in the year.

The soils of the experimental areas were classified as Ferralsol and Ferralic Nitisol (Embrapa, 2006b) for the 2007/2008 summer harvest and 2008 Interim-harvest, respectively. The chemical and physical characteristics of soil from the experimental sites, 0.00 - 0.20 m layer, are shown in Table 1.

The experiments consisted of two crops of popcorn conducted during the summer harvest of 17th October, 2007, and the interim-harvest of 19th March, 2008. The spacing used between rows was o0.90 m, and of 0.20 m between plants, establishing a population of 55,000 plants ha^{-1}. The liming of the area, according to the need demonstrated by the result of the analysis of soil to increase the base saturation to 60% (Embrapa, 2006a), was carried out prior to the planting of each experiment. The sowing fertilization in the summer crop cultivation was of 24, 80 and 60 kg ha^{-1} and in the interim-harvest it was of 24, 50 and 50 kg ha^{-1} of N, P_2O_5 e K_2O, respectively, using ammonium sulfate (AS), triple superphosphate (TSP), and potassium chloride (K_2O).

Experiment was conducted as a 5 x 2 x 2 factorial arrangement in randomized complete blocks design with four replications. The treatments were a combination of five N rates (0; 45; 90; 135; 180 kg ha^{-1}), two seasons of topdressing applications (development stages V_4 and V_8) and two varieties of popcorn (BRS-Angela and IAC-125) (Ritchie et al*.,* 1993).

The plots consisted of five rows (6.0 m long) of plants. The evaluations were performed in 3 central rows of each plot, excluding the 2 border strips, and 0.5 m from each end of the plot, totaling 13.5 m^2 of useful area.

Initially, for the control of weeds, the vegetation of the experimental area was desiccated with application of the glyphosate herbicide, seven days before sowing, at a rate of 960 g of the active ingredient (a.i.) ha^{-1} (Andrei, 2005). Prior to sowing the seeds were treated with Imidacloprid (240 g a.i. per 100 kg) and Thiodicarbe (700 g a.i. per 100 kg) insecticides, according to Andrei (2005). This was done to control initial pests of crops.

Before sowing of the popcorn, the field was cultivated with black oat. Sowing was done manually using truncheons, and two seeds were placed in a hole. After seedling emergence, at V_2 stage (Ritchie et al*.,* 1993), thinning was performed, in order to eliminate the less vigorous plant. The weed control was carried out with the application of the Atrazine herbicide at a rate of 3.25 kg i.a. ha^{-1} in post-emergence, while for pest control, Methamidophos and Lufenuron insecticides were used (Andrei, 2005).

The following traits were evaluated in the field: plant height (PH), distance (m) between the ground level and the apex of the tassel; and the leaf area index (LAI), according to Francis et al*.* (1969). These traits were measured on ten plants in each plot. The harvest, performed manually, was conducted on the 29th of February, 2008

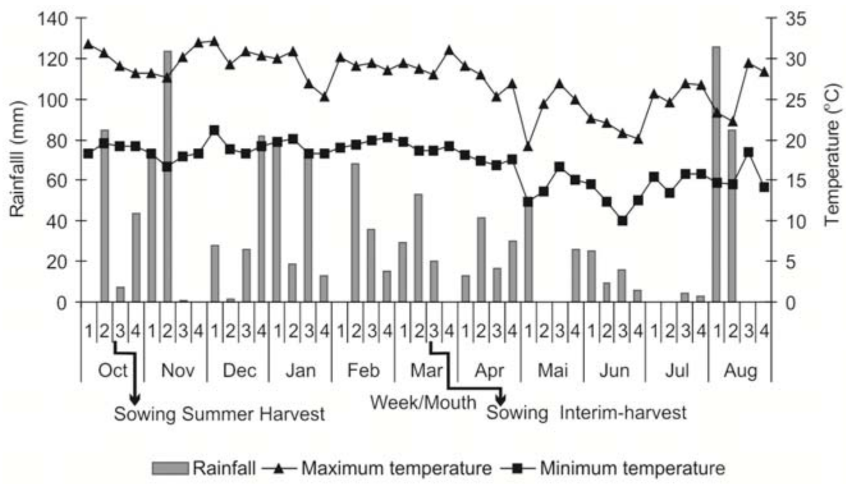

Figure 1. Rainfall and air temperatures for a week, from October, 2007 to August, 2008. Font: Laboratory of Seed Analysis from Iguatemi Experimental Farm – FEI/UEM.

for the summer crop and 30th August, 2008 for the interim-harvest. After harvesting, the samples were sent to the Laboratory of Crop Physiology of the Center for Research Applied to Agriculture (Nupagri). They were evaluated for ear length (EL) and number of grains per row (NGR), both evaluated using ten corn ears randomly chosen from the sample plot; thousand grains weight (TGW) according to Brasil (2009); grain yield (GY), and expansion capacity of the endosperm (ECE). The GY was determined by weighing the grain harvested from the useful area of the plot (13.5 m^2), correcting the moisture in the grain to 14% and subsequently transforming the data obtained for kg ha^{-1}.

The process of popping the kernels to obtain the ECE trait of the endosperm was initiated when the samples reached a grain moisture content of about 11.5%. Subsamples with a weight of 30 g of grains (bulk popcorn - BP) were subjected to a temperature of 280°C for two minutes and ten seconds under constant agitation (Roshdy et al*.,* 1984; Metzger et al., 1989; Song et al*.*, 1991.) It was then determined the amount of popcorn expanded volume (PEV, mL) with a 2000 mL beaker and the expansion capacity of the endosperm was calculated (ECE, mL $g^{-1)}$ by the expression: ECE = (VPE / BP) (Scapim et al., 2010).

The data obtained in the two experimental periods were subjected to the Levene test (Box, 1953) for homogeneity of variances and to the Shapiro-Wilk test (Shapiro and Wilk, 1965) for normality of errors. Once the basic assumptions of the analysis of variance were met, the data were subjected to an individual analysis of variance (Steel and Torrie, 1960). Then, the data were subjected to a joint analysis of variance, and the means of the effect of topdressing of N rates on the variables response were subjected to regression analysis (Cruz and Regazzi, 2001).

RESULTS AND DISCUSSION

The rainfall recorded during the cultivation cycle of popcorn of the 2007/2008 Summer Crop was 767.9 mm (Figure 1), sufficient for development of cultivation (Aldrich et al*.,* 1982; Matzenauer and Sutili, 1983). However, the culture went through drought periods between stages V_8 and V_T. When considering the period between the days from 16th November, 2007 to 20th December, 2007, the rainfall observed did not reach the mark of 30 mm, and the maximum drought period was 20 days, which occurred between the days from 16th November to 05th December (Figure 1). This fact, coupled with the soil texture of the experimental area (Table 1), compromised the development of the popcorn plants.

During the 2008 interim-harvest, due to the use of irrigation during scarcity of water (Figure 1) and increased water demand by plants due to differentiation of reproductive organs, tasseling and silking (Ritchie et al*.,* 1993), the crop did not suffer stress from lack of water. In turn, the cultivation suffered due to the occurrence of low temperatures in the first week of May and mid-June (Figure 1), a time when the temperatures were lower than the base temperature (10 ºC) for the growth and development of the popcorn plant (Tollenaar et al*.,* 1979).

The results of the analysis of variance for the PH, LAI, EL and NGR traits were significant for the N rate and cultivar factors; the agricultural year factor was not significant only for the EL trait and the stage of N application factor was not significant for any of the traits in question (Table 2). All interactions between factors were significant for PH, except the interaction cultivar x stage of N application. In relation to LAI, only the interaction of N rate x agricultural year was significant, as well as the agricultural year x cultivar interaction for EL. In the NGR trait, a significant interaction was observed between N rates x cultivar, cultivar x agricultural year and N rate x cultivar x stage of N application.

The PH for both cultivars was influenced by the use of N in topdressing applications, either application in the V_4 or V_8 stages, with quadratic regression adjustments being obtained in both cases (Figure 2a and b). The increase in PH is due to the fact that adequate nutrition of plants with

Table 2. Summary of variance analysis of the characteristics plant height (PH), leaf area index (LAI), ear length (EL) and number of grains per row (NGR) of popcorn plants.

Source of variations	DF	Mean squares							
		PH		LAI		EL		NGR	
N rate (N)	4	0.05160	*	0.23759	*	7.17097	*	65.56625	*
Cultivar (C)	1	0.56525	*	6.50039	*	5.61376	*	46.11756	*
Stage of N application (S)	1	0.00008	ns	0.10353	ns	0.16706	ns	0.06006	ns
Agricultural year (A)	1	2.43296	*	4.30008	*	1.75771	ns	166.66806	*
N x C	4	0.00623	*	0.00846	ns	1.18916	ns	13.95819	*
N x E	4	0.00381	*	0.01718	ns	0.21784	ns	1.94881	ns
N x A	4	0.00976	*	0.15581	*	0.96968	ns	3.17338	ns
C x S	1	0.00023	ns	0.10973	ns	1.82116	ns	0.66306	ns
C x A	1	0.02139	*	0.08696	ns	3.02225	*	64.64306	*
S x A	1	0.01040	*	0.00176	ns	0.00053	ns	7.70006	ns
N x C x S	4	0.00549	*	0.02358	ns	0.61285	ns	9.69213	*
N x C x A	4	0.00284	*	0.03663	ns	1.00699	ns	6.59619	ns
C x S x A	1	0.02003	*	0.15438	ns	0.04796	ns	5.14806	ns
N x C x S x A	4	0.00121	*	0.03537	ns	0.40416	ns	3.40400	ns
Block(A)	6	0.00013	ns	0.66907	*	1.53981	*	7.77965	*
Error	118	0.00044		0.06277		0.50254		3.78665	
MSE1		0.00011		0.07043		0.57008		5.05313	
MSE2		0.00059		0.05888		0.44783		2.65757	
>MSE/<MSE		5.26786		1.19615		1.27297		1.90141	
CV (%)		1.18		10.62		5.05		6.07	
General mean		17.92		23.58		140.41		32.05	

*:significant and [ns]: non -significant (P < 0.05) by F test.

N enables a greater vegetative development, since the nutrient directly influences cell division and expansion and photosynthetic process (Taiz et al., 2006). However, higher doses of N possibly provide the plant with luxury product consumption but reduce the PH (Melo et al., 2011).

The highest PH was observed for the BRS-Angela cultivar (Figure 2a). Similar results were observed by Gökmen et al*.* (2001) for popcorn crops. Mar et al*.* (2003), Silva et al. (2005), Cruz et al*.* (2008), Lana et al. (2009), Soratto *e*t al. (2010) and Okumura et al. (2011) also obtained response of PH for common corn with increased N rates.

On the other hand, Ferreira et al*.* (2001), Casagrande and Fornasieri (2002), Melo et al*.* (2011) and Biscaro et al*.* (2011) found no influence of N fertilization on PH of common corn. Magalhães and Jones (1990) claim that the stem serves as a reserve structure of photo-assimilated compounds that are translocated to the grains. This leads to larger plants, due to the larger size of the stem, which is usually associated with a higher filling of grains and productivity.

The LAI for the BRS-Angela cultivar was not influenced by N rates applied either at the V_4 or the V_8 growth stages, with mean values of 2.56. However, the LAI of the IAC-125 cultivar showed a growing linear response to the use of N in the V_4 stage (Fig. 2c). This suggests a better utilization of N for the formation of leaves of this cultivar at this stage, given that a positive response was not obtained when the N was applied at the V_8 stage, with mean values of 2.11. Similarly, Tomazela et al. (2006) and França et al*.* (2011) found a positive response of N rates on LAI of common corn.

The means of EL for the BRS-Angela cultivar adjusted in linear and quadratic forms the V_4 and V_8 stages, respectively (Fig. 2d). In turn, the IAC-125 cultivar showed EL with quadratic adjustment when the N was applied in the V_4 stage, but in the V_8 stage EL responded linearly to the use of N in topdressing applications (Figure 2e).Gökmen et al. (2001) observed that increasing rates

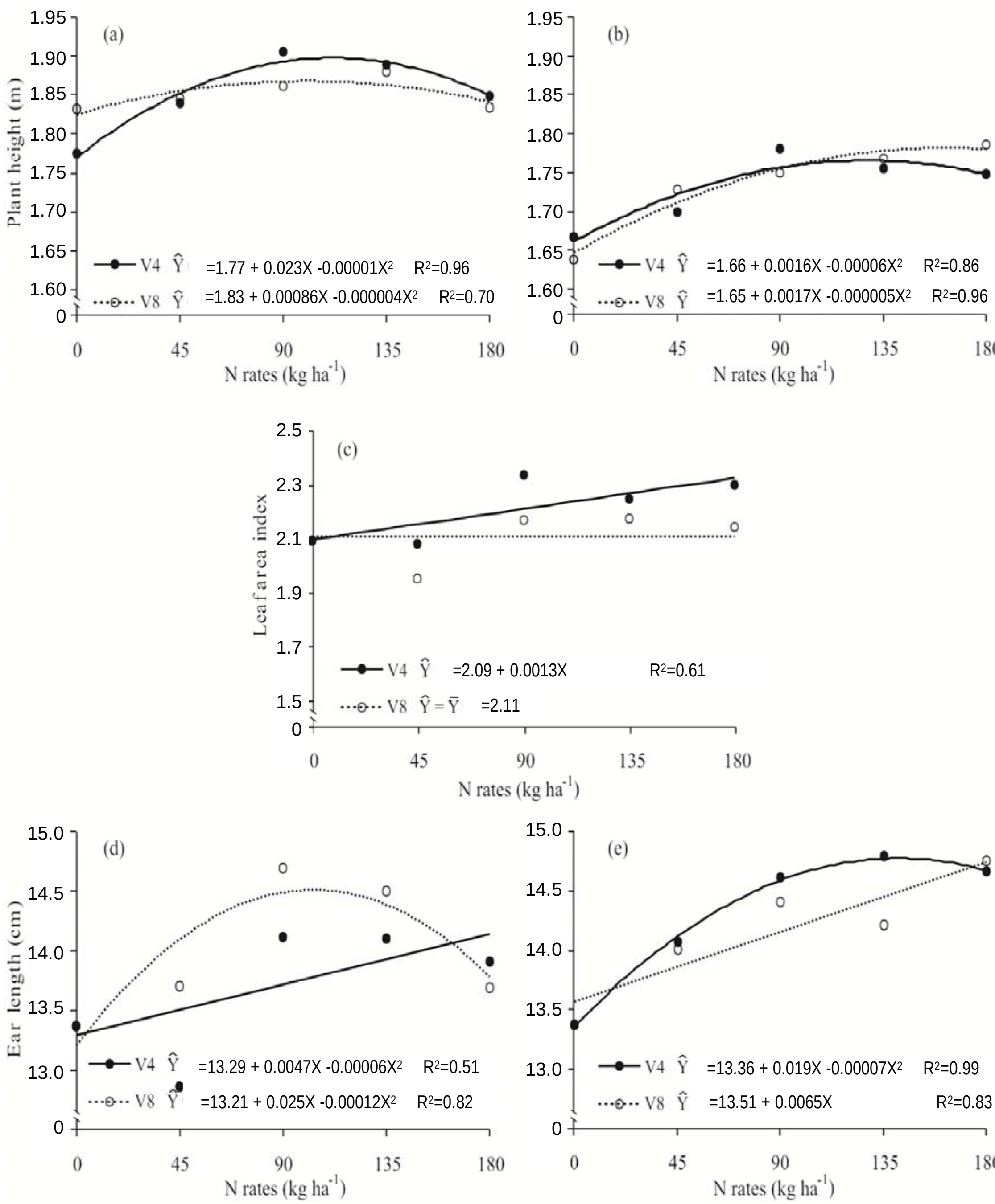

Figure 2a-e. Effect of N rates inside cultivars of popcorn and stage of N application for plant height of the cultivars (a) BRS-Angela and (b) IAC-125; (c) leaf area index of the cultivar IAC-125; ear length of the cultivars (d) BRS-Angela and (e) IAC-125.

of N used in popcorn crops provided the significant increase of the EL, and the highest values of EL were obtained with higher N rates used (250 kg ha^{-1}), while Lourente et al. (2007) observed a significant effect of N rates on the EL of common corn. However, Biscaro et al. (2011) pointed out that EL on common corn was not affected by increased levels of N. Nitrogen topdressing has also provided an increased NGR to the two cultivars of popcorn, and a quadratic regression adjustment has been observed, except for the IAC-125 cultivar when the N was applied at the V_8 stage (Figure 3a and b). At this time of applying N on the IAC-125 cultivar, it was noted an increasing linear regression adjustment in agreement with the results observed for the EL trait (Figure 2d and

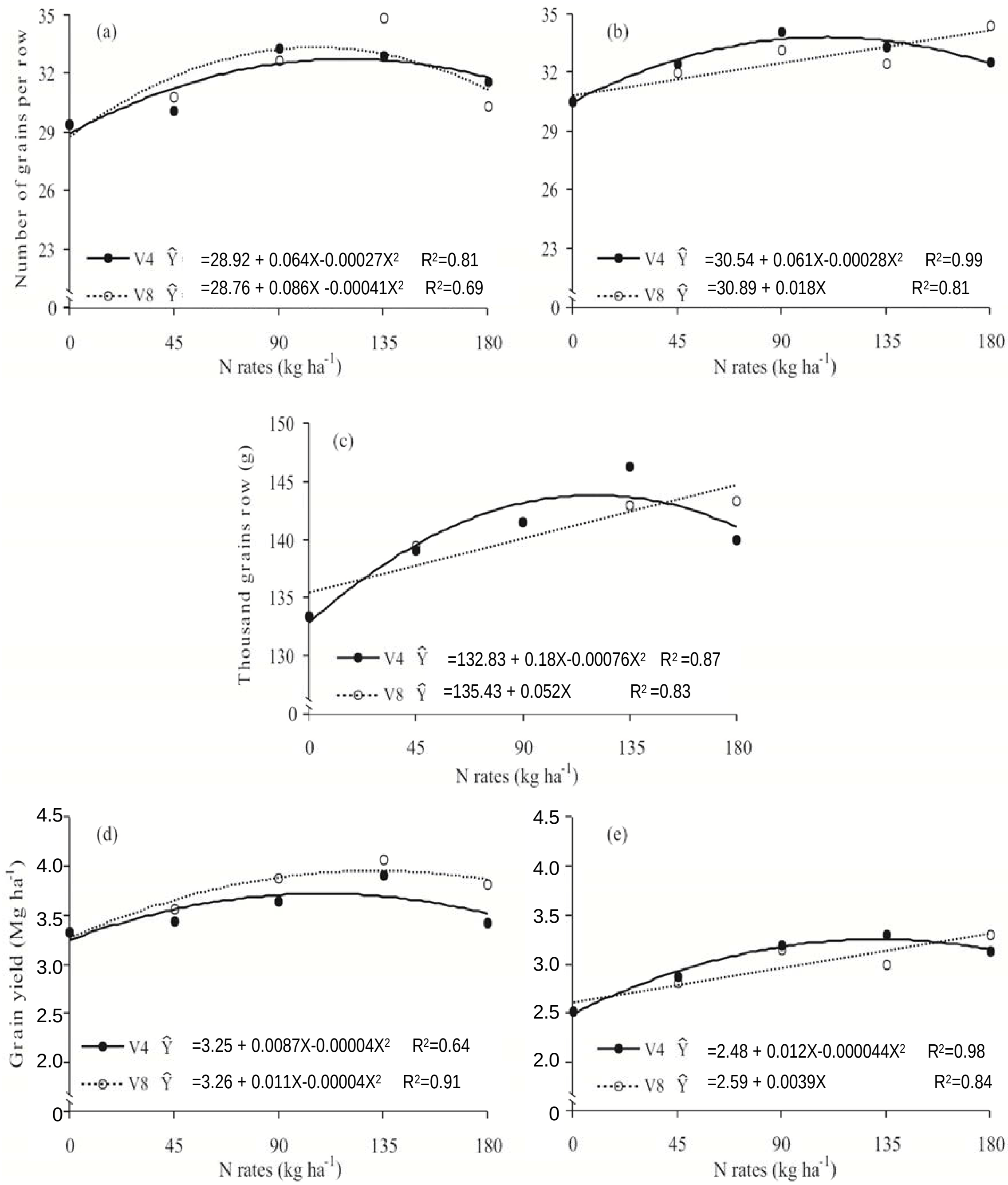

Figure 3a-e. Effect of N rates inside cultivars of popcorn and stage of N application for number of grains per row of the cultivars (a) BRS-Angela and (b) IAC-125; (c) thousand grain weight of the cultivar IAC-125; grain yield of the cultivars (d) BRS-Angela and (e) IAC-125.

2e). Similarly, Biscaro et al. (2011) observed a significant effect, with quadratic adjustment on the NGR common corn using N rates of 0, 90, 180, 270 and 320 kg ha^{-1}. On the other hand, Casagrande and Fornasieri (2002) found no effect of N rates in topdressing applications on NGR in field corn grown in the interim-harvest. The adequate supply of N in the initial stages of the corn plant development interferes with the process of floral differentiation and defines the yield potential of the crop; thus it can increase some production components, such as EL and NGR (Crawford et al., 1982; Bredemeier and Mundstock, 2000; Taiz et al., 2006).

The results of the analysis of variance for the TGW, GY and ECE traits were significant for the cultivar and crop

Table 3. Summary of analysis of variance of traits; thousand grain weight (TGW), grain yield (GY) and expansion capacity of the endosperm (ECE) of popcorn.

Source of variations	DF	Mean squares					
		TGW (g)		GY (Mg ha^{-1})		ECE (mL g^{-1})	
N rate (N)	4	106,40991	*	2,17689	*	0,54826	ns
Cultivar (C)	1	1.824,12036	*	17,86901	*	1.038,00438	*
Stage of N application (S)	1	1,91844	ns	0,17889	ns	1,85977	ns
Agricultural year (A)	1	2.900,20900	*	65,76147	*	963,48948	*
N x C	4	192,52197	*	0,24822	ns	2,81163	ns
N x E	4	70,83445	ns	0,14199	ns	14,47884	*
N x A	4	27,34857	ns	0,08819	ns	4,42002	ns
C x S	1	3,09136	ns	0,51438	ns	1,61002	ns
C x A	1	6.662,59344	*	31,67866	*	59,40188	*
S x A	1	12,45456	ns	0,22967	ns	12,42668	ns
N x C x S	4	2,96855	ns	0,05717	ns	4,44905	ns
N x C x A	4	84,95957	ns	0,27126	ns	4,62444	ns
C x S x A	1	40,88484	ns	0,01384	ns	15,09827	ns
N x C x S x A	4	4,87855	ns	0,03165	ns	3,51547	ns
Block(A)	6	84,58378	*	0,30672	ns	34,82106	*
Error	118	37,98142		0,16941		5,77634	
MSE1		37,61520		0,19789		4,52606	
MSE2		38,27805		0,13014		6,60397	
>MSE/<MSE		1,01762		1,52058		1,45910	
CV (%)		4,51		12,48		8,75	
General mean		136,70		3,30		27,47	

*: significant and ^{ns}: non significant (P < 0.05) by F test.

year factors, while the N rate factor was not significant only for the ECE trait, and the N application stage factor was not significant for all traits (Table 3). The interactions between cultivar and growing season were significant for all traits, and the N rate and cultivar interaction was also significant as well as the interaction for TGW trait and N rate x stage of N application for the ECE trait.

The regression analysis of the effects of N rates within combinations of cultivars and times of N application showed no significant adjustment regression of the TGW trait for the BRS-Angela cultivar; it has verified mean values of 133.57 and 133.07 g for applications in V_4 and V_8 stages, respectively. Regarding the IAC-125 cultivar, there was quadratic regression adjustment with a TGW maximum of 143.4 g obtained with the rate of 118.4 kg N ha^{-1}, when it was used in the V_4 stage (Fig. 3c). In turn, when N was applied at the V_8 stage, the adjustment was a linear increase, indicating that the application of the highest rate of N (180 kg ha^{-1}) was not sufficient to reach the maximum response of the TGW trait to N application (Figure 3c). The TGW response to only N for the IAC-125 cultivar was mainly attributed to the fact that this is a hybrid, which has better production characteristics, due to its genetic potential (Cruz et al., 2008), and the corn hybrid is typically more responsive to N fertilization practices.

The results observed for the BRS-Angela cultivar are in agreement with those obtained by Gökmem et al. (2001) for the popcorn crop and by Casagrande and Fornasieri (2002) and Gomes et al. (2007), who also found no effect of N rates on the TGW of common corn. Other authors such as Ferreira et al. (2001), Soratto et al. (2010) and Biscaro et al., (2011) observed that the averages of TGW showed a quadratic adjustment to the applications of N rates, as well as the results obtained with the application in the V_4 stage of this work. In turn, the adjustment of a growing linear regression of the TGW to rates of N obtained by Lana et al. (2009) was of 0, 30, 60 and 90 kg ha^{-1}, possibly due to lower doses. Nitrogen plays a key role in the formation of amino acids, the main components of proteins (Taiz et al., 2006). Thus, just like the grain formation is dependent on plant proteins, the grain weight is directly related to the supply of N (Crawford Junior et al., 1982; Bredemeier and Mundstock, 2000).

The BRS-Angela cultivar presented GY higher than the IAC-125 cultivar (Figure 3d and e). These results disagree with the statement by Cruz et al. (2008) that higher yields of corn are obtained with hybrids, in view of the genetic potential associated with these plants.

The results of GY adjusted in a quadratic form to the BRS-Angela cultivar in both times of application of N, whose maximum yield (3.94 Mg ha^{-1}) was obtained with the N estimated maximum rate of 130, 1 kg ha^{-1}, applied at the V_8 stage (Figure 3d). The higher N rates possibly provide the plant with a luxury consumption leading to an increase in leaf N content, but reducing grain yield (Melo et al., 2011).

In turn, the IAC-125 cultivar showed a quadratic regression adjustment and linear increase in the application of N at the V_4 and V_8 stages, respectively (Figure 3e). This cultivar had the highest yield (3.24 Mg ha^{-1}) with the application of maximum N rate of 131.5 kg ha^{-1} and at the V_4 stage. While the application of N at the V_8 stage provided an increase of 3.9 kg ha^{-1} in GY for each kg of N increased per hectare. The linear adjustment observed for the application of N at the V_8 stage followed the results of yield components observed in this study.

Gökmen et al. (2001) observed that the lower N rates (0, 50 and 100 kg ha^{-1}) resulted in significant increases in the GY of popcorn, while the higher rates of N (150, 200 and 250 kg ha^{-1}) did not significantly increase. In works with common corn, Mar et al. (2003), Silva et al. (2005), Lana et al. (2009), Biscaro et al. (2011) and Melo et al. (2011) obtained the quadratic adjustments of GY to top dressed N rates. Other studies developed by Araújo et al. (2004), Duete et al. (2008) and Soratto et al. (2010) verified increases in the production of common corn with the use of N in topdressing, but the results adjusted in an increasing linear form, not getting the maximum technical performance.

The positive effect of N on yield components and grain yield is possibly associated with the effect of N in the definition of the reproductive capacity of the plant, which occurs in early stages in corn crops (Ritchie et al., 1993), when cell division is intense (Taiz et al., 2006). The N supply to the plants provides increased levels of cytokinin in the aerial part, increasing cell division (Samuelson et al., 1992), positively influencing the formation of the reproductive organs (Ritchie et al., 1993). Nitrogen plays a fundamental importance as a constituent of amino acids; main components of proteins, with the formation of grains being dependent on them; therefore, the grain weight and productivity are directly linked to the supply of N (Taiz et al., 2006).

The lower productivity of the BRS-Angela cultivar observed with the application at the V_4 stage (Figure 3d) in relation to application at the V_8 stage may be attributed to the greater immobilization of N, due to the greater amount of crop residues present on the soil surface when the topdressing was performed (Basso and Ceretta, 2000; Lara-Cabezas et al., 2000; Lara-Cabezas and Couto, 2007). It is worth mentioning that in the summer crop at the experimental area the sequence of crops was oats-cassava-corn, while in the period following the interim-harvest the sequence of crops was oats-corn. On the other hand, Silva et al. (2005) observed that the use of N in topdressing applications between the V_4 to V_6 stages provided a higher GY of common corn than when N was applied between the V_8 to V_{10} stages, since, when the late application of N was performed, the culture had already defined their productive potential (Ritchie et al., 1993). Similar results were obtained by Silva et al. (2006), in which the authors observed higher productivity of common corn crops, when N was applied at the V_4 stage, compared to V_8.

Economically analyzing the results and using the values of R \$ 0.71 kg^{-1} grain, and U.S. \$ 3.62 kg^{-1} N (Seab, 2011) for popcorn and N, the economic rate of N in topdressing applications obtained was of 73.76 and 78.42 kg ha^{-1} for the BRS-Angela (V_8) and IAC-125 (V_4) cultivars, respectively.

Therefore, despite that the observed maximum N rates were 130.1 and 131.5 kg ha^{-1} for the BRS-Angela and IAC-125 cultivars, respectively, the financially recommended rates of N are much smaller, as they may provide higher returns from the crops to the farmer. Biscaro et al. (2011) obtained the highest N rate for common corn of 300 kg ha^{-1}, but the economic rate of N was only 90 kg ha^{-1}. Pavinato et al. (2008) observed similar higher rate of N (283 kg ha^{-1}) with Biscaro et al. (2011), but with higher economic rate of N (156 kg ha^{-1}). In this sense, it is worth emphasizing the importance of this study, since there is no information about the economic rate of N recommended for topdressing applications in popcorn crops.

The ECE did not show a significant response in relation to the doses of N, as well as to the stages of N application. There was only a significant effect of cultivars on the ECE trait, and the means obtained by the IAC-125 cultivar (ECE = 30.01 and 30.02 ml g^{-1}, respectively) were superior to the BRS-Angela cultivar (ECE = 24.71 and 25.13 ml g^{-1}, respectively). The means results of the ECE of popcorn were classified as: regular (26.77 ml g^{-1}) and good (33.08 ml g^{-1}), according to Green and Harris (1960), for the BRS-Angela and the IAC-125 cultivars, respectively.

The ECE presented by popcorn cultivars in this study was higher than the highest value in the results of the national popcorn test (20.8 ml g^{-1}), held in the 1991/1992 harvest (Sawazaki et al., 2000). In addition, the ECE was influenced by genetic difference between cultivars and not by rate or time of application of N, so that such differences have possibly been conditioned by the traits of each grain cultivar such as size, thickness, pericarp and water content (Sawazaki et al., 1986; Ruffato et al., 2000).

Conclusion

Plant height and leaf area index were influenced by N topdressing, with exception of the latter for the BRS-Angela cultivar. Nitrogen application in both V_4 and V_8 stages had significant effects on yield components: ear length, number of grains per row, thousand grains weight and grain yield of popcorn. The highest grain yields were obtained with estimated rates of 130.1 and 131.5 kg ha^{-1} of N for BRS-Angela and IAC-125 cultivars, respectively. On the other hand, the economic analysis indicated rates of 73.76 and 78.42 kg ha^{-1} of topdressing N, as that which will provide the greatest financial return for the cultivation of BRS-Angela and IAC-125, respectively. Despite the good expansion capacity index achieved by the cultivars, there was no significant effect of the application stages and rates of N, and only significant differences in the genetic order of cultivars used regarding the traits of popcorn were observed.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This study was made possible with financial support from CNPq and Capes-Brazil. We also appreciate them for their scholarship and support for this research work.

REFERENCES

Aldrich SR, Scott WO, Leng ER (1982). Modern corn production. 2. ed. Champaign: A & L Publication. P. 371.

Andrei E (2005). Compêndio de defensivos agrícolas. 7. ed. São Paulo: Andrei Editora. P. 1133.

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

Basso CJ, Ceretta CA (2000). Manejo do nitrogênio no milho em sucessão a plantas de cobertura de solo, sob plantio direto. Rev. Bras. Cienc. Solo 24:905-915.

Biscaro GA, Motomiya AYA, Ranzi R, Vaz MAB, Prado EAF, Silveira BLR (2011). Desempenho de milho safrinha irrigado submetido a diferentes doses de nitrogênio via solo e foliar. Revista Agrarian 4:10-19.

Box GEP (1953). Non-normality and tests on variances. Biometrika 40:318-335.

BRASIL. Ministério da Agricultura e Reforma Agrária (2009). Regras para analise de sementes. Brasília. P. 399.

Bredemeier C, Mundstock CM (2000). Regulação da absorção e assimilação do nitrogênio nas plantas. Cienc Rural 30:365-372. http://dx.doi.org/10.1590/S0103-84782000000200029

Brugnera A, Von Pinho RG, Pacheco CAP, Alvarez CGD (2003). Resposta de cultivares de milho-pipoca a doses de adubação de semeadura. Revista Ceres 50:417-429.

Casagrande JRR, Fornasieri Filho D (2002). Adubação nitrogenada na cultura do milho safrinha. Pesq. Agropecu. Bras. 37:33-40. http://dx.doi.org/10.1590/S0100-204X2002000100005

Ceylan M, Karababa E (2002). Comparasion of sensory properties of popcorn from various types and sizes of kernel. J. Sci. Food Agric. 82:127-133. http://dx.doi.org/10.1002/jsfa.1000

Crawford Junior TW, Rendig VV, Broadbent FE (1982). Sources, fluxes, and sinks of nitrogen during early reproductive growth of maize (*Zea mays* L.). Plant Physiol. 70:1654-1660.

Cruz CD, Regazzi AJ (2001). Modelos biométricos aplicados ao melhoramento genético. Viçosa: UFV. 390 p.

Cruz SCS, Pereira FRS, Santos Jr, Albuquerque AW, Pereira RG (2008). Adubação nitrogenada para o milho cultivado em sistema plantio direto, no Estado de Alagoas. Revista Brasileira de Engenharia Agrícola e Ambiental. 12:62-68. http://dx.doi.org/10.1590/S1415-43662008000100009

Defelipo BV, Ribeiro AC (1981). Análise Química De Solo: Metodologia. Viçosa: Ufv. Boletim De Extensão, 29:17.

Duete RRC, Muraoka T, Silva EC, Trivelin PCO, Ambrosano EJ (2008). Manejo Da Adubação Nitrogenada E Utilização Do Nitrogênio (^{15}n) Pelo Milho Em Latossolo Vermelho. Rev. Bras. Cienc. Solo. 32:161-171. http://Dx.Doi.Org/10.1590/S0100-06832010000400018

Embrapa. Empresa Brasileira De Pesquisa Agropecuária. Centro Nacional De Pesquisa De Milho E Sorgo (2006a). System For Producing Corn [Sistema De Produção De Milho], 2ª. Ed., Versão Eletrônica, Embrapa- Cnpms: Sete Lagoas. Available In: Http://Sistemasdeproducao.Cnptia.Embrapa.Br/Fonteshtml/Milho/Cultivodomilho_2ed/Index.Htm. [Accessed Sep 10, 2009].

Embrapa. Empresa Brasileira De Pesquisa Agropecuária (2006b). Sistema Brasileiro De Classificação De Solos. 2ª. Ed. Rio De Janeiro: Embrapa. P. 306.

Ferreira ACH, Araújo GAA, Pereira PRG, Cardoso Aa (2001). Características Agronômicas E Nutricionais Do Milho Adubado Com nitrogênio, molibdênio e zinco. Sci Agric. 58:131-138. http://dx.doi.org/10.1590/S0103-90162001000100020

França S, Mielniczuk J, Rosa Lmg, Bergamaschi H, Bergonci JI (2011). Nitrogênio Disponível Ao Milho: Crescimento, Absorção E Rendimento De Grãos. Revista Brasileira De Engenharia Agrícola E Ambiental. 15:1143-1151. http://Dx.Doi.Org/10.1590/S1415-43662011001100006

Francis CA, Rutger JN, Palmer AFEA (1969). Rapid method for plant leaf area estimation in maize (*Zea mays*). Crop Sci. 9:537-539.

Gökmen S, Sencar Z, Sakün MA (2001). Response of popcorn (*Zea mays Everta*) to nitrogen rates and plant densities. Turk. J. Agric. Forest. 25:15-23.

Gomes RF, Silva AG, Assis RI, Pires FR (2007). Efeito De Doses E Da Época De Aplicação De Nitrogênio Nos Caracteres Agronômicos Da Cultura Do Milho Sob Plantio Direto. Revista Brasileira De Ciência Do Solo. 31:931-938. Http://Dx.Doi.Org/10.1590/S0100-06832007000500010

Green JVE, Harris JED (1960). Popcorn quality and the measurement of popping expansion. Proc. Soil Crop Sci. Soc. Florida. 20:28-41.

Hanway JI (1963). Growth stages of corn (*Zea Mays*). Agron. J. 55:487-491.

Lana MC, Junior PPW, Braccini Al, Scapim CA, Ávila MR, Albrecht LP (2009). Arranjo Espacial E Adubação Nitrogenada Em Cobertura Na Cultura Do Milho. Acta Scientiarum-Agronomy. 31:433-438. http://Dx.Doi.Org/10.4025/Actasciagron.V31i3.788

Lara-Cabezas WARI, Couto PA (2007). Imobilização De Nitrogênio Da Uréia E Do Sulfato De Amônia Aplicado Em Pré-Semeadura Ou Cobertura Na Cultura De Milho, No Sistema De Plantio direto. Revista Brasileira de Ciência do Solo. 31:739-752. http://dx.doi.org/10.1590/S0100-06832007000400015

Lara-Cabezas WAR, Trivelin PCO, Kondörfer GH, Pereira S (2000). Balanço Da Adubação Nitrogenada Sólida E Fluida De Cobertura Na Cultura Do Milho Em Sistema Plantio Direto No Triângulo Mineiro. Revista Brasileira De Ciência Do Solo. 14:363-376.

Lourente ERP, Ontocelli R, Souza LCF, Gonçalves CC, Marchetti ME, Rodrigues ET (2007). Culturas Antecessoras, Doses E Fontes De Nitrogênio Nos Componentes De Produção Do Milho. Acta

Scientiarum-Agronomy. 29:55-61. http://Dx.Doi.Org/10.4025/Actasciagron.V29i1.66

Magalhães PC, Jones R (1990). Aumento De Fotoassimilados Na Taxa De Crescimento E Peso Final De Grãos De Milho. Pesq. Agropecu. Bras. 25:1747-1754.

Mar GD, Marchetti ME, Souza LCF, Gonçalvez MC, Novelino JO (2003). Produção De Milho Safrinha Em Função De Doses E Épocas De Aplicação De Nitrogênio. Bragantia. 62:267-274. http://dx.doi.org/10.1590/s0006-87052003000200012

Matzenauer R, Sutili VR (1983). Água Na Cultura Do Milho. Ipagro Informa. 26:17-32.

Mehlich A (1978). New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc. Commun.Soil Sci. Plant Anal. 9:477-492.

Melgar RJ, Smyth TI, Cravo MS, Sánchez PA (1991). Doses E Épocas De Aplicação De Fertilizantes Nitrogenado Para Milho Em Latossolo

Da Amazônia Central Revista Brasileira De Ciência Do Solo. 15:289-296.

Melo FB, Corá JE, Cardoso MJ (2011). Fertilização Nitrogenada, Densidade De Plantas E Rendimento De Milho Cultivado No Sistema Plantio Direto. Revista Ciência Agronômica. 42:27-31. http://dx.doi.org/10.1590/s1806-66902011000100004

Metzger DD, Hsu KH, Ziegler KE, Bern CJ (1989). Effect of moisture contente on popcorn popping volume for oil and hot-air popping. Cereal Chem. 66:247-248.

Nunes HV (2003). Comportamento De Cultivares De Milho-Pipoca Em Diferentes Épocas De Semeadura. Revista Ceres. 50:445-460.

Okumura RS, Takahashi HW, Santos DGR, Lobato AKS, Mariano DC, Marques OJ, Silva MHL, Oliveira Neto CF, Lima Junior JA (2011). Influence Of Different Nitrogen Levels On Growth And Production Parameters In Maize Plants. J. Food, Agric. Environ. 9:510-514.

Pavinato PS, Ceretta CA, Girotto E, Moreira ICL (2008). Nitrogênio E Potássio Em Milho Irrigado: Análise Técnica E Econômica Da Fertilização. Cienc. Rural. 38:49-54. http://dx.doi.org/10.1590/s0103-84782008000200010

Ritchie SW, Hanway JI, Benson GO (1993). How a corn plant develops. Special Report N. 48. Ames: Iowa State University of Science and technology. Coop. Ext. Ser. P. 26.

Roshdy TB, Hayakawa K, Daun H (1984). Time and temperature parameters of corn popping. J. Food Sci. 6:1412-1418.

Ruffato S, Correa PC, Martins JH, Mantovani Bhm, Silva JN (2000). Efeito Das Condições De Colheita, Pré-Processamento E Armazenagem Na Qualidade Do Milho Pipoca. Pesq. Agropecu. Bras. 35:591-597. Http://Dx.Doi.Org/10.1590/S0100-204x2000000300015

Samuelson ME, Eliasson L, Larson CM (1992). Nitrate-Regulated Growth And Cytokinin Reponses In Seminal Roots Of Barley. Plant Physiol. 98:309-315. Http://Dx.Doi.Org/10.1111/J.1399-3054.1995.Tb05309.X

Sawazaki E, Morais JFL, Lago AA (1986). Influência Do Tamanho E Umidade Do Grão Na Expansão Da Pipoca South American Mushroom. Bragantia. 45:363-370. Http://Dx.Doi.Org/10.1590/S0006-87051986000200014

Sawazaki E, Paterniani Meagz, Castro Jl, Gallo PB, Galvão JCC, Saes LA (2000). Potencial De Linhagens De Populações Locais De Milho Pipoca Para Síntese De Híbridos. Bragantia. 59:143-151. Http://Dx.Doi.Org/10.1590/S0006-87052000000200004

Scapim CA, Amaral Junior AT, Vieira RA, Moterle Lm, Texeira Lr, Viganó J, Sandoval Junior GB (2010). Novos compostos de milho pipoca para o Brasil. Semina: Ciências Agrárias. 31:321-330. http://dx.doi.org/10.5433/1679-0359.2010v31n2p321

Seab–Secretaria de Estado da Agricultura e Abastecimento do Paraná (2011). Sistema de informação do mercado agrícola. Seab. Available in:http://celepar7.pr.gov.br/sima/cotdia.asp. [Accessed July 06, 2011].

Shapiro SS, Wilk MB (1965). An analysis of variance test for normality (Complete Samples). Biometrika. 52:591-611.

Silva EC, Ferreira SM, Silva GP, Assis Rl, Guimarães Gl (2005). Épocas E Formas De Aplicação De Nitrogênio No Milho Sob Plantio Direto Em Solo De Cerrado. Revista Brasileira De Ciência Do Solo. 29:725-733. http://Dx.Doi.Org/10.1590/S0100-06832005000500008

Silva EC, Muraoka T, Buzetti S, Veloso MEC, Trivelin PCO (2006). Aproveitamento Do Nitrogênio (15n) Da Crotalária E Do Milheto Pelo Milho Sob Plantio Direto Em Latossolo Vermelho De Cerrado. Ciência Rural. 36:739-746. http://dx.doi.org/10.1590/s0103-84782006000300004

Song A, Eckhoff SR, Paulsen M, Litchfield JB (1991). Effects of kernel size and genotype on popcorn popping volume and number of unpopped kernels. Cereal Chem. 68:464-466.

Soratto RP, Pereira M, Costa Tam, Lampert VN (2010). Fontes Alternativas E Doses De Nitrogênio No Milho Safrinha Em Sucessão À Soja. Revista Ciência Agronômica 41:511-518. http://dx.doi.org/10.1590/S1806-66902010000400002

Steel RGD, Torrie JH (1960). Principles and procedures of statistics. New York : Mcgraw-Hill. P. 481.

Taiz L, Zeiger E, Bloom AJ (2006). Mineral Nutrition. In: Taiz L, Zeiger E. Plant Physiology. 4th Ed., Sundeland, Ma: Sinauer Associates. Inc.. 5th Chapter. pp. 74-93.

Tollenaar M, Daynard TB, Hunter RB (1979). Effect of temperature on rate of leaf appearance and flowering date in maize. Crop Sci. 19:363-366.

Tomazela Al, Favarin Jl, Fancelli Al, Martin TN, Dourado Neto D, Reis AR (2006). Doses de nitrogênio e fontes de Cu e Mn suplementar sobre a severidade da ferrugem e atributos morfológicos do milho. Revista Brasileira de Milho e Sorgo. 5:192-201.