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Influence of amount and parceling of nitrogen fertilizer on productivity and industrial revenue of sweet corn (*Zea mays* L.)

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Abstract

Brazil's potential to produce sweet corn is very high, but due to lack of research, the sweet corn crop fertilization is strongly based on fertilization performed to the common corn (mature grain). Among the nutrients, the nitrogen has important effect upon sweet corn productivity and industrial revenue. We conducted an irrigated field experiment in Guaira, São Paulo, Brazil from 22 April to 15 August 2013 in an acric and eutrophic Latosol soil to verify the effects of nitrogen (N) fertilization on sweet corn (GSS 41243) productivity and industrial revenue. The treatment replicates were distributed in a 6 × 2 factorial randomized complete block design at six dose levels of N (0, 60, 120, 180, 240, and 300 kg ha^{-1}) and two dose-parceling procedures, P1 and P2. The doses of N fertilizer were applied in P1 0, 7, 14, 21, 28, 35, 42, and 49 days after sowing and in P2 0, 14, 28, and 42 days after sowing. The dose of 300 kg N ha^{-1} produced the highest total yield of sweet corn and marketable ears. The dose of 188 kg N ha^{-1}, however, produced the highest industrial revenue of 0.239 g of grains kg^{-1} of ears. The parceling of the N doses in eight or four applications did not affect the productivity or the industrial revenue of the sweet corn.

Keywords: industrial processing; nitrogen fertilization; *Zea mays.*
Abbreviations: CP_commercial strawless ears productivity; DAS_days after sowing; ED_ear diameter; EL_ear length; FN_foliar nitrogen; GP_grain productivity; GY_grain yield; IY_industrial yield; NME_number of marketable ears; PME_percentage of marketable ears; TP_productivity of ears.

Introduction

Sweet corn (*Zea mays*) is a horticultural plant of the highest economic importance. Globally in 2012, the cultivated area was 1 125 916 ha, production was 9 764 006 t of ears, and productivity was 8.7 t ha^{-1}. The USA, Mexico, Nigeria, Indonesia, Hungary, South Africa, and Peru were the largest producers (FAO, 2014). The area cultivated with sweet corn has been increasing every year with an almost total consumption by the agroindustry. Farmers grow it as an alternative to conventional corn because it can be sold directly for human consumption at good prices. Adequate technical information, though, is not available for the growing of sweet corn, unlike for common corn (Sunitha and Reddy, 2012). Among several other management factors, the application of fertilizers to crops not only increases productivity, but also increases the number of properly shaped ears for facilitating industrial processing. Productivity is currently evaluated by the number of harvested ears necessary to produce 1 kg of grains (Barbieri et al., 2005; Albuquerque et al., 2008). Nitrogen (N) has the largest effect on the productivity and industrial revenue of sweet corn (Carmo et al., 2012; He et al., 2012). The nutritional status of N in plants affects the number of marketable ears, the length and diameter of the ears, and the productivity of ears and grains (Pöttker and Wiethölter, 2004; Carmo et al., 2012). N has a structural function and influences physiological processes such as ion absorption, photosynthesis, respiration, and cell multiplication and differentiation (Taiz and Zeiger, 2010). Corn demands high amounts of N (Barker and Bryson, 2007; Alimohammadi et al., 2011), and its productive potential is defined at the phenological stage V_4, which may extend to V_6 when the apical meristem differentiates and the number of leaves is defined. The highest ear growth rate with the application of N fertilizers is verified at stage V_8, when the number of grain rows is defined (Fancelli and Dourado Neto, 2004; Fornasieri Filho, 2007). The number of ovules and the ear size are defined at stage V_{12} and are negatively affected by a deficiency of N (Fancelli and Dourado Neto, 2004; Carmo et al., 2012). In addition to the reduction in revenue due to the higher production costs, however, an excess of N also increases the plant cycle, plant height, and protandry, in which fertile pollen is released before the stigmas are receptive, thus leading to sterility or ill-formed pollen grains (Amanullah et al., 2009). The efficiency of N fertilization is dependent on climatic conditions, edaphic proprieties (physical, chemical, and biological), crop management (mainly spacing and irrigation), and genotype (Fageria and Baligar, 2005; Fernandes et al., 2005; Carmo et al., 2012). Sweet corn is often cultivated in large regions with atypical characteristics, so regional studies are necessary for optimizing N fertilization that could increase profits and mitigate the environmental impact of groundwater contamination with nitrates (Fernandes et al., 2005; Hawkesford et al., 2012). Further studies of fertilization for sweet corn are also needed because Opazo et al. (2008) and

Bhatt et al. (2012) have reported maximum productivity with 240 kg N ha^{-1}, but Amanullah and Shah (2010), Oktem et al. (2010), Alimohammadi et al. (2011), and Carmo et al. (2012) have reported that doses of 180, 320, 90, and 150 kg N ha^{-1}, respectively, were the most efficacious. No information is available about the dose and parceling of N fertilizers for the cultural practices and climatic conditions of our study area. This area is the most important area for the production of sweet corn in the state of São Paulo and one of the most important areas in Brazil, with 170 ha sown every week, but the recommended N doses vary widely. Cantarella et al. (1997) recommended 170 kg N ha^{-1} (at sowing and then three subsequent applications) for a productivity of 16-20 t ha^{-1} of ears in soils with a high response to N. Sweet-corn farmers, however, are applying 240 kg N ha^{-1}, with doses at sowing and four subsequent doses during plant growth. The differences in recommendations are probably related to the new cultivars in use, which are more productive and more responsive to N than the older cultivars. In addition to determining the most efficient dose of the N fertilizer, further studies should also examine how N is distributed during plant growth. As a general rule, higher numbers of applications are better; because N losses are significantly lower (Coelho, 2006). The objective of this study was to evaluate the influence of N dose and dose parceling on the productivity and industrial revenue of the sweet-corn cultivar 'GSS 41243'.

Results and Discussion

Foliar N content

The influence of N dose was verified by a significant linear relationship with foliar N (FN) content (Table 1). Foliar N contents were 21.2 and 24.4 g kg^{-1} at N doses of 0 and 300 kg ha^{-1}, respectively (Fig. 1). The FN contents are considered low, because adequate values tend to be between 27 and 35 g kg^{-1} (Cantarella et al., 1997). No visible signs of N deficiency, such as reduced growth, small leaves, thin stems, V-shaped chlorosis, or necrosis (Barker and Bryson, 2007; Alimohammadi et al., 2011), however, were observed. The FN content was not affected by parceling (four or eight applications) (Table 1). The number of ovules and ear size are defined at stage V_{12}, so that N deficiency at that phase has a negative effect on both characteristics (Magalhães et al., 2002; Fancelli and Dourado Neto, 2004; Carmo et al., 2012). A delay of seven days in N application in P1 49 DAS, when the plants were at V_{14}, relative to P2 42 DAS, when the plants were at V_{12}, did not affect foliar N content.

Number and percentage of marketable ears

The number of marketable ears (NME) and N dose were also significantly linearly correlated (Table 1). The NMEs were 43 537 and 52 335 ears ha^{-1} at 0 and 300 kg N ha^{-1}, respectively (Fig. 2). Ear formation improved at higher N doses, which is better for industrial processing. Opazo et al. (2008) reported higher NMEs of 71 138 and 63 191 ears ha^{-1} at 240 kg N ha^{-1} for the hybrids 'Jubileu' and 'Rodeo', respectively. A significant adjustment to a quadratic equation was verified for the percentage of marketable ears (PME) and N dose (Table 2). A dose of 182.3 kg N ha^{-1} produced the highest PME (86.4%), but PME was 80% at 300 kg N ha^{-1} (Fig. 3). Ears had to be discarded at a dose of 300 kg N ha^{-1} due to diseases that deteriorated the grains, perhaps caused by reductions in the production of phenolic compounds at excessive N doses. These compounds (such as lignin) have fungistatic activity that reduces the damaging effects of fungi (Huber et al., 2011).

Length and diameter of ears

The doses and parceling of N did not influence ear length (EL) or diameter (ED), whose means were 19.3 and 4.7 cm, respectively (Table 1). These means were larger and smaller, respectively, than those reported by Carmo et al. (2012) at N doses of 0-150 kg ha^{-1} but were similar to those reported by Ohland et al. (2005) of 19.7 and 5.0 cm, respectively, in an experiment where N fertilization at 0-200 kg ha^{-1} had no significant effect on EL or ED. Oktem et al. (2010), however, reported significant effects and higher mean EL and ED of 21.8 and 5.15 cm, respectively, at doses of 0-360 kg N ha^{-1} applied at sowing and at stage V_6.

All ears were equally accepted by the processing industry, independent of the influence of dose and parceling on EL and ED, and exceeded the limits for EL and ED established by Albuquerque et al. (2008) of 15 and 3.0 cm, respectively. N fertilization can thus contribute to an increase in the number of marketable ears. EL, ED, and number of ears are characteristics that determine the productive potential of this crop (Ohland et al., 2005).

Total, commercial, grain and industrial productivities

A significant adjustment of a linear equation was verified between productivity of ears with straw (TP) and the productivity of marketable ears without straw (CP) (Table 2). A dose of 300 kg N ha^{-1} produced the highest TP (19 417 kg ha^{-1}) and CP (9919 kg ha^{-1}) (Fig. 4). Oktem et al. (2010) also reported increased TP at increasing doses of N. The highest TP and CP were 25 and 33%, respectively, higher than those obtained when no N was supplied to the plants. The TP in this study was superior to that reported by Sunitha and Reddy (2012) of 16 180 kg ha^{-1} at 180 kg N ha^{-1} and to that reported by Bhatt et al. (2012) of 14 159 kg ha^{-1} at 240 kg N ha^{-1}. The CP in our study was larger than that reported by Souza et al. (2013) of 6186 kg ha^{-1} at 110 kg N ha^{-1}.

An adjustment to a quadratic equation for grain productivity (GP) was verified (Table 2). A dose of 240 kg N ha^{-1} produced the highest GP (5294 kg ha^{-1}), and higher doses up to 300 kg N ha^{-1} produced lower GPs (Fig. 4). The GPs were 38 and 97% of the estimated maximum at doses of 0 and 300 kg N ha^{-1}, respectively. The GP was higher than that reported by Amanullah et al. (2009) of 5170 kg ha^{-1} at 180 kg N ha^{-1} applied at sowing, V_3, V_8, V_{12}, V_{16}, and R_1. The higher TP, CP, and GP at higher doses of N may have been due to the higher foliar N contents and numbers of marketable ears. GP has been positively correlated with the N nutritional status of plants (Bertin and Gallais, 2000; Amanullah et al., 2009). An adequate supply of N increases chlorophyll content and the synthesis of nitrogenous compounds that increase photosynthetic capacity and carbon assimilation (Wolfe et al., 1988), delay foliar senescence, and maintain high photosynthetic rates, especially during ear growth, which lead to increased grain size and number of grains per ear and thus higher TP, CP, and GP (Lee and Tollenaar, 2007; Bhatt et al., 2012). As with the other characteristics, TP, CP, and GP were not affected by N parceling. This lack of difference between four and eight applications of N may be attributed to the irrigation after the application of N, the low amount of precipitation (107 mm), and/or the high clay content of the soil (519 g kg^{-1}) that may have minimized the loss of N and increased its availability.

Table 1. Summary of the analysis of variance and means of foliar nitrogen (FN) content, number of marketable ears (NME), ear diameter (ED), and ear length (EL) of sweet corn 'GSS 41243' influenced by N doses and parceling.

Sources of variation	FN	NME	ED	EL
Doses of N (D)	1.25 ns	1.60 ns	2.04 ns	0.61 ns
Parceling of N (P)	1.68 ns	0.01 ns	0.00 ns	0.02 ns
D × P	0.36 ns	1.18 ns	0.63 ns	0.65 ns
CV (%)	13.91	16.13	3.53	4.76
Doses of N (kg ha^{-1})	Means			
	g kg^{-1}	ears ha^{-1}	cm	cm
0	21.2	41 587	4.58	19.53
60	21.4	44 444	4.72	19.52
120	23.3	49 524	4.67	19.03
180	23.4	51 746	4.65	19.17
240	24.0	50 476	4.74	19.53
300	24.4	40 841	4.63	18.87
Parceling of N	g kg^{-1}	ears ha^{-1}	cm	cm
P1	21.4	47 830	4.69	19.25
P2	23.4	48 042	4.70	19.29
1st degree regression	10.48**	5.43*	0.12 ns	1.23 ns
2nd degree regression	1.03 ns	2.19 ns	0.09 ns	0.00 ns
3rd degree regression	0.16 ns	0.05 ns	3.28 ns	0.26 ns

ns, *, and ** indicate no significance in an F test at 5% probability, significant at 5% probability, and significant at 1% probability, respectively.

Table 2. Summary of the analysis of variance and means of percentage of marketable ears (PME) relative to the total, productivity of total (TP) and marketable ears (CP), grain productivity (GP), grain yield (GY), and industrial yield (IY) of sweet corn 'GSS 41243' influenced by N doses and parceling.

Sources of variation	PME	TP	CP	GP	GY	IY
Doses of N (D)	1.42 ns	2.40 ns	3.40*	7.95**	1.98 ns	4.47**
Parceling of N (P)	1.31 ns	0.83 ns	0.82 ns	0.01 ns	1.76 ns	2.19 ns
D × P	0.56 ns	0.75 ns	0.79 ns	1.11 ns	1.80 ns	0.44 ns
CV (%)	10.34	16.12	16.95	15.10	11.74	11.2
Doses of N (kg ha^{-1})	Means					
	%	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	%	kg kg^{-1}
0	76.30	14226	6747	3111	47.10	0.22
60	80.34	16504	7774	4419	56.86	0.27
120	88.17	16788	9050	4925	54.65	0.29
180	84.81	17826	9114	4942	55.67	0.29
240	80.51	18490	9134	5201	56.86	0.28
300	80.81	19139	9666	5263	54.29	0.27
Parceling of N	%	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	%	kg kg^{-1}
P1	83.43	16744	8374	4645	55.65	0.28
P2	80.21	17580	8787	4642	52.83	0.26
1st degree regression	0.47 ns	11.14**	14.21**	30.00**	2.89 ns	8.07*
2nd degree regression	4.50*	0.41 ns	1.90 ns	7.95*	4.06 ns	10.79**
3rd degree regression	0.56 ns	0.18 ns	0.37 ns	1.84 ns	0.83 ns	1.60 ns

ns, *, and ** indicate no significance in an *F* test at 5% probability, significant at 5% probability, and significant at 1% probability, respectively.

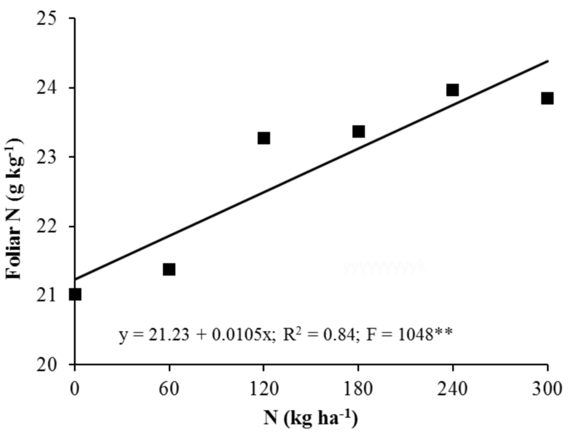

Fig 1. Content foliar nitrogen (N) of sweet-corn 'GSS 41243' in function of N doses.

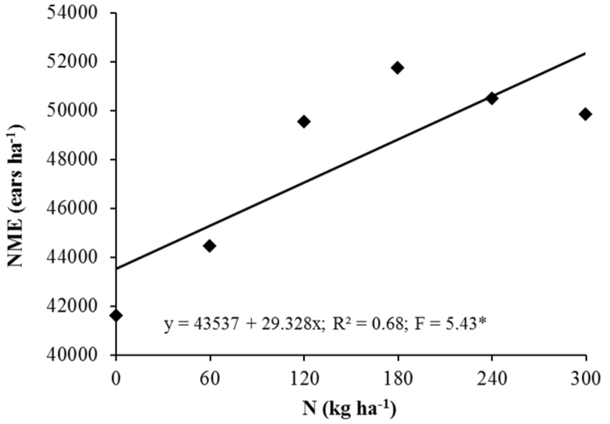

Fig 2. Number of marketable sweet-corn ears (NME) of sweet-corn 'GSS 41243' in function of N doses.

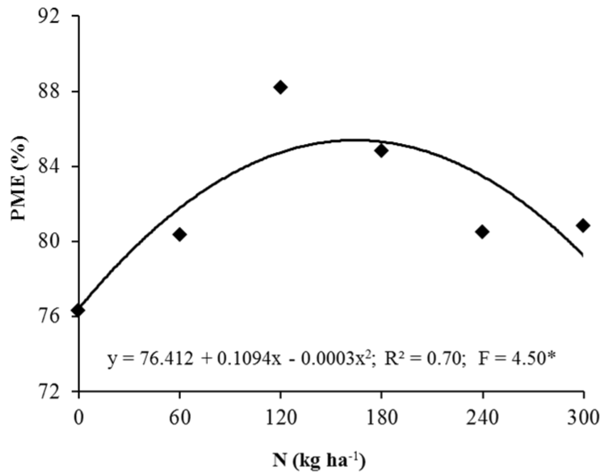

Fig 3. Percentage of marketable sweet-corn ears (PME) of sweet-corn 'GSS 41243' in function of N doses.

Grain yield (GY) was not significantly influenced by N dose or parceling (Table 2). Increasing the N dose thus promoted similar alterations (r = 0.83**) between grain and ear masses. Doses of 0 and 300 kg N ha^{-1} produced variations of 47.1-56.9% (Table 2) in GY, which are above the 30% considered to be satisfactory for industrial processing (Maggio, 2006). Our mean GY (54.2%) was superior to that reported by Barbieri et al. (2005) of 49.1% at 100 kg N ha^{-1}.
The industrial yield (IY) of ears was significantly influenced only by dose, and a significant adjustment of a quadratic equation for the observed means was detected. As with the other characteristics, IY was not affected by parceling or by interactions among the factors (Table 2). A dose of 0 kg N ha^{-1} produced the lowest IY of 0.22 kg of grains from 1.0 kg of ears. IY increased to a maximum of 0.239 kg of grains for each 1.0 kg of ears at 188 kg N ha^{-1} (Fig. 5). A dose of 300 kg N ha^{-1}, which maximized the total and marketable ear productivities, contributed to an increase in the cost of producing canned sweet corn. This dose produced more ears and thus more income for the farmer, but the ears had fewer grains per kg relative to the ears produced at 188 kg N ha^{-1}.

Materials and Methods

Growing conditions

The experiment was carried out from 22 April to 8 August 2013 in the municipality of Guaíra (20º12′45.41″S, 48º26′57.71″W; 528 m a.s.l.), state of São Paulo, Brazil. During the experiment, the mean temperature was 28 °C, and 107 mm of rain fell. The soil at the study site is classified as an acric and eutrophic Latosol. The corn was sown in soil covered with dry soybean straw. The chemical attributes of the soil (clayish texture) were determined before the experiment at depths of 0-20 cm following the procedure proposed by Raij et al. (2001). The values obtained were: pH($CaCl_2$) of 5.4, organic-matter content of 28 g dm^{-3}, P(resin) of 34 mg dm^{-3}, base soil saturation of 56%, and 29, 3.9, 22, 11, 36.9, and 65.9 $mmol_c$ dm^{-3} of H^+, Al^{3+}, K^+, Ca^{2+}, Mg^{2+}, and cation-exchange capacity, respectively.

Treatments and experimental design

The experimental design had complete randomized blocks with 12 treatments in a 6 × 2 factorial scheme with three replicates. The factors evaluated were N dose (0, 60, 120, 180, 240, and 300 kg ha^{-1}) and dose parceling (P1 and P2). The N fertilizer was applied 0, 7, 14, 21, 28, 35, 42, and 49 days after sowing (DAS) in P1 and 0, 14, 28, and 42 DAS in P2. These periods corresponded to the sowing date and phenological stages V_E, V_3, V_5, V_7, V_9, V_{12}, and V_{14} in P1 and the sowing date and stages V_3, V_7, and V_{12} in P2. The experimental plots had areas of 12.5 m^2. Urea with 45% N was used as the source of N. The N fertilizer was applied alongside the plant rows, except at sowing when the N was mixed with the other fertilizers (see below) and applied inside the rows.

Plant material and crop management

The seeds of the hybrid supersweet corn 'GSS 41243' were manually planted in the rows on 22April 2013 at a depth of 0.04 m with 0.25 m between plants in a row and 0.50 m between rows. The plants were irrigated with a total of 460 mm of water at various developmental stages.

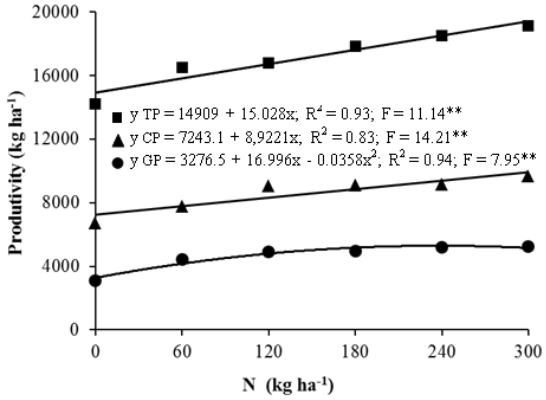

Fig 4. Ear total productivity (y TP), productivity of marketable ears (y CP), and grain productivity (y GP) of sweet-corn 'GSS 41243' in function of N doses.

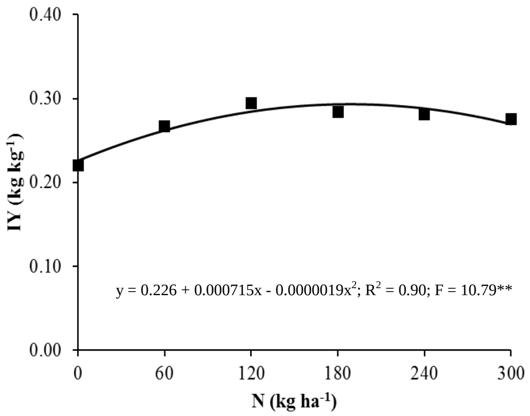

Fig 5. Industrial yield (IY) of sweet-corn ears of sweet-corn 'GSS 41243' in function of N doses.

At sowing, the rows were fertilized with 160 kg P_2O_5 ha^{-1} (as simple superphosphate) and 150 kg K_2O ha^{-1}. The sides of the rows were dressed with 50 kg K_2O ha^{-1} 10 and 22 DAS, 40 kg S ha^{-1} 15, 24, and 30 DAS (as magnesium sulfate), and 15 kg Zn ha^{-1} (as zinc sulfate) 12 DAS. All products used for the control of weeds, diseases, and pests were registered chemicals. Harvest was 112 DAS when the grains had a moisture content of 70%, i.e. at stage R_3.

Measurements

Foliar N was measured when 50% of the plants had reached the tasseling stage. The medial third of a leaf at the base of an ear was collected from 10 plants per plot, as recommended by Cantarella et al. (1997). The material was washed in running water and a 1% detergent and dried in a forced-ventilation oven at 65 °C. The dried material was ground in a Wiley mill and then digested for the determination of N concentrations, as described by Malavolta et al. (1997).

Number of marketable ears (ears ha^{-1}), ear length, and ear diameter were recorded. Productivity was determined based on the weight of ears with straw (TP kg ha^{-1}), commercial strawless ears (CP kg ha^{-1}), and grains (GP kg ha^{-1}). The percentage of marketable ears (PME) relative to the total number of ears was also determined. Grain yield (GY) was calculated by dividing grain productivity by the productivity of marketable ears (Barbieri et al., 2005). Industrial yield (IY) was determined as the weight of grains from 1 kg of ears (kg kg^{-1}).

Statistical analysis

The experimental data were analyzed for variance, and the N-dose data were adjusted by regression analysis, using AgroEstat (Barbosa and Maldonado Júnior, 2011).

Conclusions

Four or eight applications of N did not differentially affect productivity or the industrial yield of supersweet corn 'GSS 41243'. A dose of 300 kg N ha^{-1} provided the highest productivities of total and marketable ears, but a dose of 240 kg N ha^{-1} provided the highest grain productivity. A dose of 188 kg N ha^{-1} provided the highest industrial yield of 0.293 kg of grains from 1.0 kg of ears.

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