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# Corn yield as a function of amounts of nitrogen applied in bands

**Mauricio Gruzska[1], Silvana Ohse[1], André Belmont Pereira[2]* and Carlos Tadeu Dos Santos Dias[1]**

[1]Departamento de Fitotecnia e Fitossanidade, Universidade Estadual de Ponta Grossa, UEPG, 84030-900, Ponta Grossa, PR, Brasil.
[2]Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, UEPG, Brasil.

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**The aim of the current paper is to study the effect of different amounts of nitrogen applied in bands of corn hybrids on variables related to corn plant growth and its yield components. The experiment was carried out under no-tillage system at Guarapuava, PR, Brazil, throughout the period of October 1st 2009 to March 20th 2010. The treatments resulted in the combination of two simple hybrids of corn (P30R50 and AG8025) and six doses of nitrogen applied in bands (0; 75; 150; 225; 300 and 375 kg N ha$^{-1}$ in urea form). The treatments were 12 arranged in a 2x6 factorial design of randomized blocks in four replications. The corn hybrid AG8025 had a small number of leaves, smaller rows of grains per stalk and insertion height of primary stalk compared to the hybrid P30R50. However, with a greater plant height, higher overall dry phytomass and productivity point out the influence of genetic variability on the crop. Nitrogen doses influenced significantly biological variables, such as plant height at the phenological stages $V_9$ and $R_1$, insertion height of the primary stalk, branch diameter, number of photosynthetically active leaves at $R_1$, stalk diameter, one thousand grains weight and productivity. 295 kg de N ha$^{-1}$ dose provided estimated yield of 13,032.93 kg ha$^{-1}$. Factors, such as hybrids and N doses, did not affect harvest index, whose average value corresponded to 0.52. Yield was positively correlated to most of the variables in the study, outstanding yield components, such as dry phytomass of grains per stalk and overall phytomass of the aerial part per plant. It is concluded that knowing the effect of N on corn plant physiology makes the characterization of yield possible and helps in the selection of corn plant as a parameter for N management in bands.**

**Key words:** *Zea mays* L., yield component, nitrogen, harvest index.

## INTRODUCTION

Corn (*Zea mays* L.) belongs to the Poaceae family, and has $C_4$ mechanism for carbon fixation. Such a feature,

*Corresponding author. E-mail: abelmont@uepg.br. Tel: +55 42 3220 3089. Fax: + 55 42 3220 3071.

associated with its leaf area, makes it utilizes global solar radiation for the conversion of mineral carbon into organic one. Thus, among the cereals of economic importance, corn has the greatest potential to produce phytomass which makes it to give a high productivity at a given site (Sangoi et al., 2007).

Nevertheless, the productivity potential of the crop is highly dependent on essential nutrients. Among them, nitrogen (N) is considered as the nutrient required by plants in great amounts. It leads to high yield (Fontoura and Bayer, 2009; Holland and Schepers, 2010); its appropriate dose and right time application make the crop to yield well. Corn yield might be affected in high or low intensities in the phenological stage (Subedi and Ma, 2005).

Knowledge of the effect of N on corn crop physiology under different environments and management systems, whether by means of variables related to the crop growing season, yield components, as well as the accumulation of dry phytomass (Shanahan et al., 2008), contributes to knowing the right moment to apply N in bands, rationalize nitrogen fertilization in bands so as to reduce the environmental impact of the N applied in the soil and water, mainly as a nitrate form (Alcântara and Camargo, 2010).

The aim of the current study is to scrutinize the effect of N doses applied in bands in corn hybrids on biological variables related to growth and development of corn plants, yield components and overall dry phytomass of the aerial part. It also aims to examine whether there is correlation of such variables with yield to establish a feasible N management for corn plants at Guarapuava, PR, Brazil.

## MATERIALS AND METHODS

The field experiment was conducted under no- tillage system at the region of Entre Rios, in the municipality of Guarapuava, PR, Brazil [latitude 25º32'S, longitude 51º28'W and altitude of 1,126 m] between October 1st and March 20th of 2010. The climate of the site, according to Köppen's classification, is humid subtropical bereft of dry season and with frequent severe frosts (Peel et al., 2007). Mean annual rainfall at the region is 1.942 mm. Monthly mean air temperature is 16.8°C with maximum and minimum values corresponding to 23.1°C and 12.4°C, respectively (Simepar, 2011).

Throughout the crop growing season the overall amount of rainfall was above 35 year historical average, along with variations of 5.1 mm for the month of November and of 114.7 mm for the month of January. There was crop rotation over the last years at the experimental area for winter/summer year season as follows: wheat/soybean (2006), oat/maize (2007), barley/soybean (2008), and in 2009 oat preceded maize crop. The type of soil prevailing in the experiment area is latosol with a depth of roughly 2 m, good physical conditions, and with a high potential for agricultural use. The chemical characteristics of the soil are seen in Table 1.

Treatments that resulted from the combination of two simple hybrids were classified as precocious cycle for maize - Pioneer 30R50 and Agroceres 8025 (P30r50 and AG8025) - and 6 doses of N applied in cover (0, 75, 150, 225, 300 and 375 kg of N $ha^{-1}$ in the form of urea). The treatments comprise a 2x6 factorial design of randomized blocks with four replications. Plots consisted of 8 lines of 5 m long and space of 0.75 m, occupying a total area of 30 $m^2$. Sowing was performed manually on October 1st of 2009 shortly after the incorporation of 8-30-20 fertilizer formula plus 0.4% of Zn to reach a plant population of 69.722 plants $ha^{-1}$. Cultural practices were adopted in the crop according to its occurrence and recommendation for the crop in the field.

N doses were applied once manually in the total area on November 9th, 2009 with the plants at $V_5$ stage. Under the $V_3$ stage, out of the two central lines, 4 plants per $plot^{-1}$ were selected and identified for determination of the following variables: plant height, branch diameter, insertion height of the primary stalk, number of photosynthetically active leaves, number of grain rows per stalk, number of grains per row, number of total expanded leaves, length of stalk, diameter of stalk, one thousand grain weight, dry phytomass of grains per stalk, overall dry phytomass of the aerial part per plant, and harvest index.

The determination of initial plant population was preformed at V1 stage and the final one at harvest. This was done by taking into accout all the plants along 5 meter from the four central lines in order to obtain a mean number of plants per linear meter, which was extrapolated to plants per hectare.

Final productivity was assessed by means of the manual harvest of the ears from a useful area of 13.5 $m^2$, mechanical threshing, determination of dry phytomass of grains per stalk and extrapolation of the values for kg $ha^{-1}$, correcting it to a water content of 13%.

Experimental data obtained from each variable were subjected to analysis of variance through the SAS statistical program (SAS, 2008). Whenever the interaction between the hybrids and N doses was significant, and when effect of N doses was observed, a study of regression was carried out by means of illustrations provided by graphs made by the Excel program. The degree of correlation and agreement between the variables measured herein was expressed by the coefficient of Pearson correlation.

## RESULTS AND DISCUSSION

The AG8025 corn hybrid (56.52; 159.04 and 243.47 cm) demonstrated the highest plant heights (PH) at all phenological stages assessed ($V_5$, $V_9$ and $R_1$) in relation to the P30R50 hybrid (46.51; 141.12 and 238.25 cm). Fluctuations on the PH among corn hybrids at the $R_1$ stage were also observed by Subedi and Ma (2005), showing values between 187 and 232 cm, with lower values for the P30R50 and AG8025 hybrids at $R_1$ stage. Probably such discrepancies observed between the hybrids might reflect the variation on its genetic origins regardless of the N doses applied in bands.

The PH at $V_9$ stage increased with the N application up to the dose of 285 kg $ha^{-1}$, determined as the dose of a maximum technical efficiency, which corresponded to an estimated height of 159.52 cm (Figure 1a). The PH at $R_1$ stage increased up to the dose of 285 kg $ha^{-1}$, corresponding to 247.36 cm (Figure 1b) and revealing a high N requirement between the stages $V_9$ and $R_1$. In the

**Table 1.** Chemical characteristics of the soil at the experimental area classified as Brume Latosol. Ponta Grossa, PR, Brazil. 2012.

| Attributes | Unities | Depth (cm) | | |
|---|---|---|---|---|
| | | 0-10 | 10-20 | 20-40 |
| pH in $CaCl_2$ | | 5.4 | 4.7 | 4.7 |
| H + Al | $cmol_c\ dm^{-3}$ | 5.35 | 8.36 | 9.01 |
| Al changeable | $cmol_c\ dm^{-3}$ | 0.0 | 0.3 | 0.4 |
| Ca changeable | $cmol_c\ dm^{-3}$ | 6.9 | 4.0 | 3.1 |
| Mg changeable | $cmol_c\ dm^{-3}$ | 2.4 | 1.5 | 1.3 |
| K changeable | $cmol_c\ dm^{-3}$ | 0.57 | 0.38 | 0.25 |
| P | $mg\ dm^{-3}$ | 22.9 | 6.0 | 2.4 |
| C-organic | $g\ dm^{-3}$ | 32 | 21 | 19 |
| CTC at pH 7 | $cmol_c\ dm^{-3}$ | 15.22 | 14.24 | 13.66 |
| CTC effective | $cmol_c\ dm^{-3}$ | 9.87 | 6.18 | 5.05 |
| Sat. per bases (V) | % | 64.8 | 41.3 | 34.0 |
| Sat. per Al (m) | % | 0.0 | 4.9 | 7.9 |
| Sat. per Ca | % | 45.3 | 28.1 | 22.7 |
| Sat. per Mg | % | 15.8 | 10.5 | 9.5 |
| Sat. per K | % | 3.7 | 2.7 | 1.8 |
| Ratio Ca/Mg | | 2.9 | 2.7 | 2.4 |
| Ratio Ca + Mg/K | | 16.3 | 14.5 | 17.6 |

H + Al: Buffer solution SMP; Al, Ca and Mg changeable: KCl 1 mol $L^{-1}$; P and K: Mehlich-1 and C-organic: Walkley-Black. Source: Laboratory of Soil Fertility of the State University of Ponta Grossa.

work idealized by Silva et al. (2005), the corn PHR1 responded up to the dose of 171 kg of N $ha^{-1}$, reaching 223 cm. However, Gomes et al. (2007) observed a linear increase of PH for corn as a function of N doses, reaching 222 cm with an application of 150 kg de N $ha^{-1}$ in bands.

The PH of the P30F33 hybrid assessed by Tomazela et al. (2006) under the dose of 100 kg of N $ha^{-1}$ corresponded to 260 cm at $R_1$ stage. This makes it viable to characterize the genotypic differences among corn hybrids for PH, since in the current study, P30R50 and AG8025 hybrids at $R_1$ stage with an estimated dose of 285 kg de N $ha^{-1}$, that is, 185 kg of N $ha^{-1}$ less, showed a lower value of PH (247.36 cm). The correlation among $PHV_5$, $PHV_9$, $PHR_1$ and yield was significant (p<0.01) and increasing (r=0.52; 0.77 e 0.80$^{**}$, respectively). The $PHR_1$ showed also a high correlation with branch diameter at $R_1$ stage ($BDR_1$), number of photosynthetically active leaves ($NPALR_1$), number of grains per row (NGR), dry phytomass of grains per stalk (DPGS), overall dry phytomass of the aerial part per plant (ODPAP), corresponding to 0.77, 0.72; 0.69; 0.67 and 0.66$^{**}$, respectively. Such associations indicate that an increase in PH was accompanied by the number of photosynthetically active leaves, and as a result by the overall dry phytomass of aerial part, culminating in a high net photosynthesis and yield.

The corn hybrid P30R50 revealed a higher insertion height of the primary stalk (IHPS) compared to the AG8025 hybrid (125.17 against 117.31 cm), differing by 6.7%. With regard to the variable identification of the leaf of the primary stalk (ILPS), the primary stalk of the P30R50 hybrid has been located on average a leaf above (at leaf 13) in relation to the position of the stalk of the AG8025 hybrid. Such variations might be ascribed to the genetic variability among hybrids. In the same way, Subedi and Ma (2005), by analyzing three corn hybrids, also found the influence of genetic variability for the variables IHPS (88.0; 97.0 and 76.0 cm) and ILPS (11, 12 and 10). The correlation between IHPS and yield was of 0.43**, although no correlation was found between ILPS and corn yield. The estimated dose in 285 kg of N $ha^{-1}$ in bands was the one that promoted the highest IHPS, corresponding to 127.22 cm (Figure 1c). Silva et al. (2005) obtained responses up to the dose of 158 kg of N $ha^{-1}$, allowing for the estimation of the IHPS in 122.69 cm.

The branch diameter (BD) was influenced by the corn hybrids and N doses applied in bands at $V_9$ ($BDV_9$) stage, as well as only by the N doses at the $R_1$ stage ($BDR_1$). The $BDV_9$ of the P30R50 hybrid (26.34 cm) was 2.8% higher than the $BDV_9$ of the AG8025 hybrid (25.63 cm), a

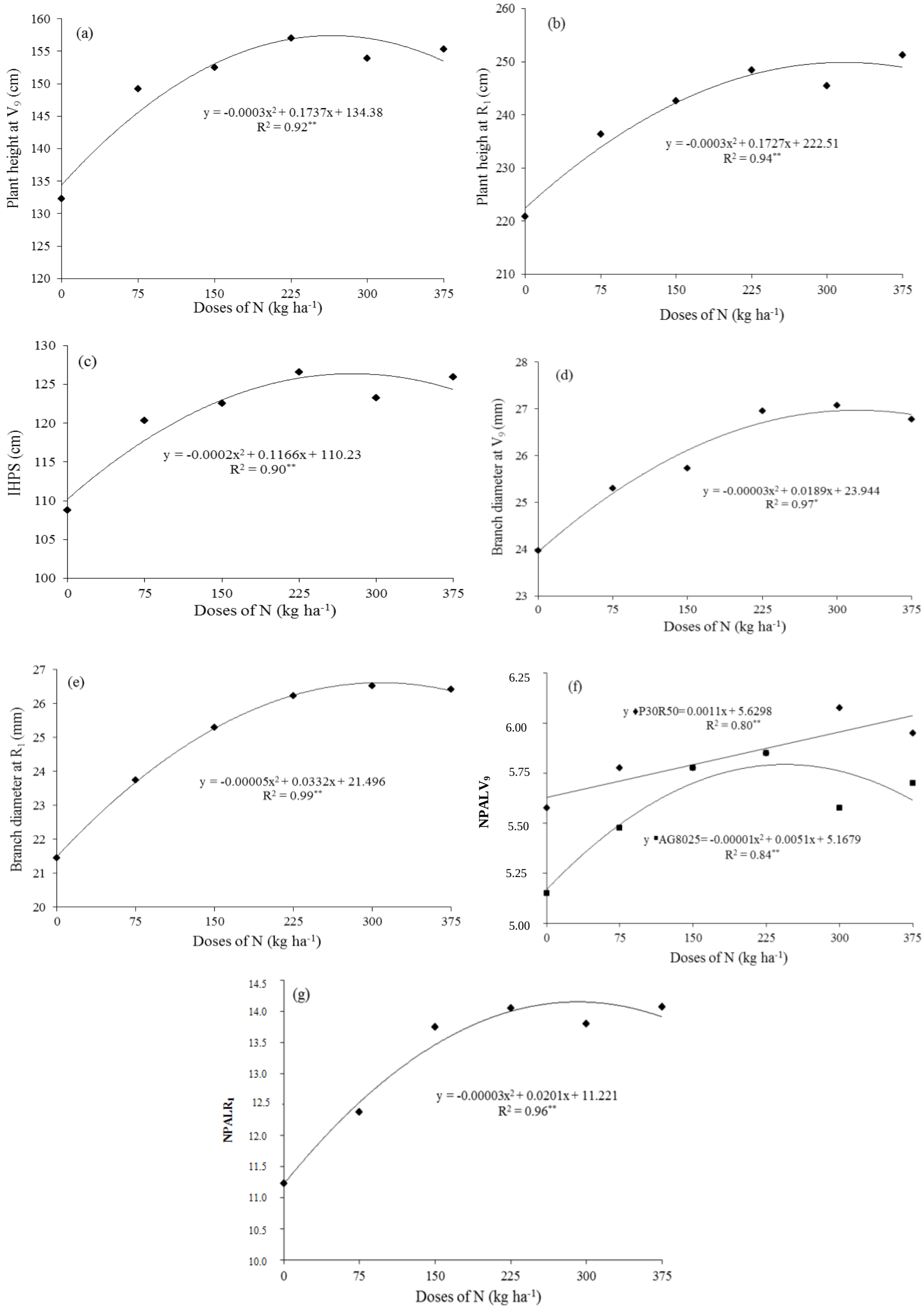


**Figure 1.** Height of corn plant at the phenological stage $V_9$ (a), height of corn plant at the phenological stage $R_1$ (b), insertion height of the primary stalk (IHPS) (c), diameter of corn plant branches at the phenological stage $V_9$ (d), diameter of corn plant branches at the phenological stage $R_1$ (e), number of photosynthically active leaves per plant at the phenological stage $V_9$ ($NPALV_9$) (f), number of photosynthically active leaves per plant at the phenological stage $R_1$ ($NPALR_1$) (g) as a function of corn hybrids and N doses applied in bands. $^{*}$ $p<0.05$ and $^{**}$ $p<0.01$. Ponta Grossa, PR, Brazil. 2012.

difference not observed at the stage $R_1$; its average BD was 24.97 mm. Dourado Neto et al. (2003) found an average value of $BDR_1$ of 30.8 mm for the hybrids AG1051, AG7575 and DKB911, whereas Tomazela et al. (2006) obtained a BD of 22.5 mm for the P30F33 hybrid at the same stage, with values higher and lower than the average.

Regression analysis studies resulted in estimated 26.92 and 27.01 mm. Maximum values of $BDV_9$ and $BDR_1$ corresponded, respectively, to the doses of 305 and 330 kg of N $ha^{-1}$ applied in bands (Figures 1d and e). The difference between BD estimated as the peak at $V_9$ and $R_1$ stages was minimum (0.09 mm), but the consumption at the $R_1$ stage was 25 kg of N $ha^{-1}$ higher at the $V_9$ stage, a fact that demonstrates a BD stabilization for the corn hybrids from $V_9$. The correlation between $BDV_9$, $BDR_1$ and yield was 0.50** and 0.71**, respectively. The $BDR_1$ also showed a high correlation with $NPALR_1$, NGR, DPGS and ODPAP (r= 0.88; 0.72; 0.67 and 0.66**, respectively).

P30R50 hybrid was superior in the number of photosynthetically active leaves per plant (NPAL) at $V_5$ (3.36), $V_9$ (5.83) and $R_1$ (13.48) stages as opposed to AG8025 for the same stages, with increases of 6.33% (3.16); 4.29 % (5.59) and 4.01% (12.96), respectively. P30R50 also demonstrated a large number of total expanded leaves (NTEL) in relation to AG8025 (18.50), with a 4.05% difference for both hybrids. The outcomes indicate that P30R50 had a higher NPAL per plant than that obtained for AG8025.

Subedi and Ma (2005) also found significant differences for NTEL with fluctuations of 16 to 20 leaves per plant. Sangoi et al. (2007) obtained for the simple hybrid DKB909 after three years of evaluation a NTEL of 20.7; 19.2 and 19.1 - values roughly similar to that of the simple hybrids P30R50 and AG8025 (19.25 and 18.50, respectively). By comparing NTEL with NPALR1 we evidenced that there was a significant reduction in NPAL along all its extension. Faced with such a fact we might infer that there was N remobilization (Seebauer et al., 2004), as well as carbonic skeletons (Taiz and Zeiger, 2013) to the stalks and/or roots of the corn plants. The number of senescent leaves was of 5.77 leaves for the P30R50 hybrid and 5.54 for the AG8025 hybrid.

The NTEL was not influenced by the N doses in bands. This is likely owing to N amounts applied at the sowing date, as well as the available N in the soil which met the initial crop needs, since the differentiation of the leaves takes place up to the $V_6$ stage (Ritchie et al., 2003). And also due to the fact that up-dated corn hybrids absorb less than 15% of the total N up to the $V_7$ stage (Shanahan et al., 2008). Such an up take of N corresponds to the phenological stage where there is an accumulation of about 5% of the overall dry phytomass.

For the variable $NPALV_9$ there was an increasing linear response of the crop to the N doses applied in bands for the P30R50 hybrid and a quadratic response for the AG8025 hybrid (Figure 1f). N doses significantly affected $NPALR_1$; however both corn hybrids performed in the same fashion and revealed a similar behavior (Figure 1g). Sangoi et al. (2007), applying bands of 100 kg of N $ha^{-1}$ at $V_5$, obtained after 3 years of assessment for the simple hybrid DKB909 an $NPALR_1$ of 13.6; 13.7 and 10.9, corresponding to yields of 11,750; 11,760 and 9,500 kg $ha^{-1}$, respectively. In the current work the maximum estimate of $NPALR_1$ was 1.86 times the mean value obtained throughout a three year evaluation by Sangoi et al. (2007). However, N requirement of the crop was much higher (230 kg of N $ha^{-1}$). The correlation between yield and NPAL was positive at $V_9$ and $R_1$ stages (r= 0.33** and 0.70**, respectively). There were also positive correlations for $NPALR_1$ and NGR, DS, DPGS, ODPAP and HI with r Pearson coefficients of 0.68**, 0.58**; 0.59**; 0.53** and 0.41**, respectively. $NFTER_1$ correlated only with NFG (r= 0.29**).

For both initial (IPP) and final plant populations (FPP) there was neither effect of the studied factors nor interaction among them on the variables assessed herein. Mean IPP was of 73,958.44 and FPP was of 69.722,25 plants $ha^{-1}$, corresponding to a 5.73% reduction in yield. For the FPP evaluation only plants with stalks were taken into account. Nevertheless the difference of 4,236.19 plants $ha^{-1}$ between the IPP and FPP might be attributed mainly to a delay of emergence of the seedlings, which certainly did compromise growth of the aerial part and root system of the crop.

The intraspecific competition effect existing among the corn plants in the field might have been intensified within plants with delaying emergence. A reduction in the number of stalks per area or an increase in the occurrence of plants bereft of stalks is an indication of competition that takes place during the vegetative stage (Merotto et al., 1999). Sterility in corn, according to Sangoi (2000), might occur even in hybrids of precocious cycle that result in low plant height, low NPAL, more erected leaves, small corn tassels along with a small variation amplitude (expressed in days) between the development of male and female inflorescences. IPP correlated positively only with FPP (r= 0.72**) and FPP with yield (r= 0.35**).

Sangoi et al. (2009), making use of a population of 75,000 plants $ha^{-1}$ for the simple hybrid P30F53, obtained a dry phytomass of grains per stalk (DPGS) of 181.18 g and a yield of 12,634 kg $ha^{-1}$. Comparing to a FPP of 69,722.25 plants $ha^{-1}$ found in the current study, this corresponded to a DPGS of 202.47 g and a yield of 11,684 kg $ha^{-1}$. This indicates that an increase in FPP might cause a reduction in DPGS, but an increase in yield.

Corn hybrids impinged significant effects on variables such as number of grain rows per stalk (NGRS), number of grains per row (NGR), length of stalk (LS), one thousand grain weight (1000GW) and stalk diameter (SD). However, the factor N doses had a significant effect on the variables NGR, LS, 1000GW and SD along with interactions only for the NGR and SD variables.

The NGRS was higher for the P30R50 hybrid (15.35) in comparison to the AG8025 (14.69), with a difference of 4.5%. However, for the variables 1000GW and SD there was a superiority of the AG8025 hybrid in relation to the P30R50 (358.08 g and 50.87 mm), a 33.86 g and 0.58 mm difference corresponding to 9.46 and 1.14%, respectively. Though the NGRS has been lower for the AG8025 hybrid, the SD and HI (Figure 2b) were high, resulting in a higher 1000GW and an increase in crop yields. There was no positive association between NGRS and yield, since NGRS was not influenced by the N doses applied in bands.

In order to estimate the number of grains per stalk (535.76), it is necessary to multiply NGR (35.67) by NGRS (15.02), which corresponded to a 1000GW of 375.01 g. Similar results were also obtained by Tomazela et al. (2006) for the P30F33 hybrid, whose mean number of grains per stalk (NGS) was 522.75, corresponding to a 1000GW of 346.95 g. Nevertheless, Sangoi et al. (2007) found throughout a three year assessment for the DKB909 hybrid 447, 397 and 400 grains per stalk, corresponding therefore to a mean 1000GW of 333; 324 and 300 g, respectively.

Fernandes et al. (2005) obtained for the simple hybrids AG9010 and DKB333B, triple hybrid CO32, double hybrid XB8010, cultivars BR106 and Sol da Manhã a NGR of 482.89; 506.41; 534.35; 523.31; 459.39 and 466.88, corresponding to a 1000GW of 275.10; 277.70; 272.70; 285.90; 233.90 and 269.10 g, respectively. The 1000GW were all lower than those obtained for the simple hybrids P30R50 and AG8025, whereas the triple hybrid CO32 and double hybrid XB8010 did show similar calculated values for NGS (535.76). The discrepancies at stake were ascribed possibly to genetic basis of the hybrids and also to environmental factors.

A regression study revealed a quadratic response of the crop to the N doses applied in bands either for the P30R50 or AG8025 hybrids (Figure 2a) as a function of the maximum doses estimated in 185 and 335 kg of N $ha^{-1}$, respectively, corresponding to 36.04 and 38.38 grains per stalk (Figure 2a). There was great variation amplitude of crop response to N doses between hybrids for NGR. Silva et al. (2005) did obtain for such variable a lower dose (154 kg of N $ha^{-1}$ in bands), demonstrating therefore a quite similar value of NGR (38.55).

Discrepancies noted between the maximum doses for technical efficiency estimated for NGR, compared to the outcomes obtained by Silva et al. (2005), evidenced that there are different responses of the crop to N demand for the hybrids that lead to distinct yield estimates. Silva et al. (2005) obtained by means of the estimated dose 166 kg of N $ha^{-1}$ a yield of 6,709.37 kg $ha^{-1}$ against a 13,032.93 kg $ha^{-1}$ yield found in the current work with the estimated dose of 295 kg of N $ha^{-1}$ (Figure 2g). Data on the productivity potential are rather dependent on N availability, other productivity components, as well as the accumulation of dry phytomass at each environment. Owing to the favorable meteorological conditions of Guarapuava, PR, along with cultural practices adopted in the corn crop which were conducive to increase productivity potential, we drew the conclusion that the responses of the crop to the highest N doses applied in bands were justifiable for NGR of both P30R50 and AG8025 hybrids - an observation that might be confirmed by the high correlation between NGR and yield (r= 0.70**). The NGR also showed a high correlation with DPGS (r= 0.84**) and ODPAP (r= 0.76**).

Maximum stalk length (SL) for the P30R50 corn hybrid was estimated to be 17.64 cm with a dose of 190 kg of N $ha^{-1}$, whereas the AG8025 showed a linear response to N doses applied in bands (Figure 2 b). The correlation between SL and yield was high (r= 0.70**). The SL was also associated with a high Pearson correlation coefficient for DPGS (r= 0.88**), ODPAP (r= 0.85** and 1000GW (r= 0.71**). Mean SL obtained herein, irrespective of the hybrid and N doses applied was 17.99 cm, being higher than that obtained by Subedi and Ma (2005) for three corn hybrids (15.9; 16.0 and 16.2 cm), pointing out a likely influence of genetic differences.

The response of the crop for the diameter of stalk (DS) as a function of N doses in bands was increasing linearly (Figure 2c). The correlation analysis revealed a strict relationship between DS and yield (r= 0.71**), DPGS (r= 0.82**) and ODPAP (r= 0.79**). Nevertheless, the mean value of DS obtained in the current work was 51.2 mm, evidencing those thresholds reported by Subedi and Ma (2005) when subjected to statistical analyses for three hybrids (42.0; 43.0 and 45.0 mm).

One thousand grain weight (1000GW) variable responded significantly to N doses applied in bands regardless of the hybrid in consideration (Figure 2d). The fit was quadratic, being 265 kg of N $ha^{-1}$, an estimated dose in bands that lead to the maximum 1000GW, which was 389.10 g. The correlation between 1000GW and yield was positive (r= 0.66**), as well as between the first and DPGS (r= 0.82**) and ODPAP (r= 0.81**).

The responsiveness reached herein differs from that obtained by Silva et al. (2005), since such authors observed a linear effect for 1000GW in relation to N doses applied in bands. However, it was estimated for the dose of 180 kg of N $ha^{-1,}$ a value of 1000GW equivalent to 317.86 g. This was below the one reported by Sangoi et al. (2007), where they applied 100 kg of N $ha^{-1}$ at the phenological stage $V_5$, whose values were

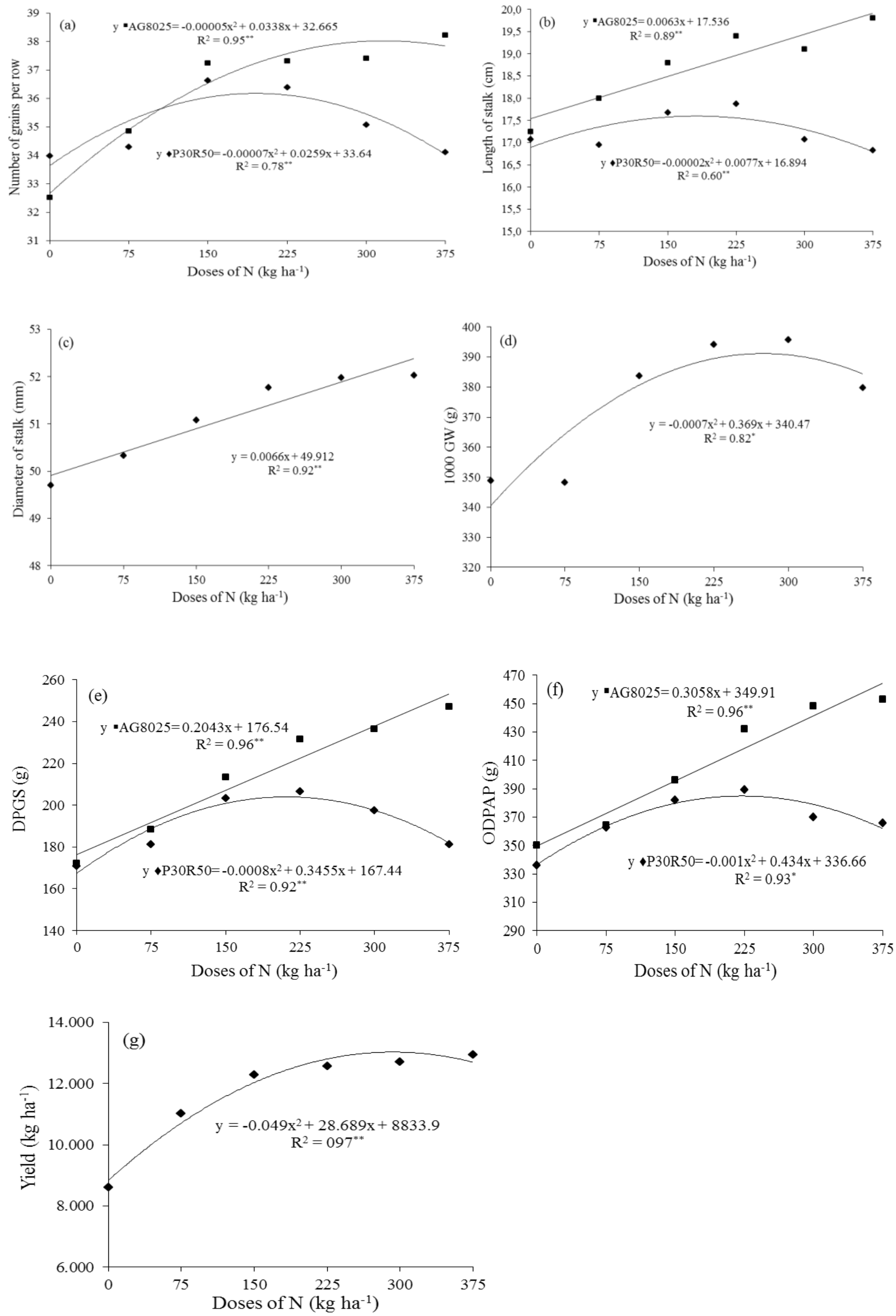


**Figure 2.** Number of grains per row (NGR) (a), length of stalk (LS) (b), diameter of stalk (DS) (c), 1000 grain weight (1000GW) (d), dry phytomass of grains per stalk (DPGS) (e), overall dry phytomass of the aerial part per plant (ODPAP) (f) and yield (g) as a function of corn hybrids and N doses applied in bands. $^{*}$ p<0.05 and $^{**}$ p<0.01. Ponta Grossa, PR, Brazil. 2012.

339; 332 and 305 g for the simple hybrid DKB909 during a three-year assessment. For Gomes et al. (2007), N doses did not influence 1000GW, whose mean value was 320.40 g. 1000GW correlated positively with NGR, LS and DS (0.59; 0.71 and 0.71**, respectively).

The variable dry phytomass of the straw of the aerial part per plant (DPSAPP) was influenced only by the corn hybrids. Variables, such as dry phytomass of grains per stalk (DPGS) and overall dry phytomass of the aerial part per plant (ODPAP), were significantly affected by both factors and interaction between corn hybrids and N doses applied in bands. The ODPAP correlated positively with NGR, LS, DS, 1000GW, ODPAP, DPGS and yield (0.76; 0.85; 0.79; 0.81; 0.86; 0.93 and 0.73**, respectively). Pearson correlation coefficients between DPGS and NGR, LS, DS, 1000GW, ODPAP and yield were 0.84; 0.88; 0.82; 0.82; 0.61 and 0.77**, respectively. Taking into account the regression analysis between ODPAP and NGR, LS, DS, 1000GW and yield r coefficients were 0.47; 0.60; 0.56; 0.60 and 0.50**, respectively.

The ODPAP was the highest (8.33% in average) for the AG8025 hybrid (192.39 g) compared to P30R50 (177.59 g). Coherency in AG8025 hybrid showed the highest plant heights (PH) at all the phenological stages evaluated, even having presented 0.75 leaves less at $R_1$ for P30R50 hybrid. The highest ODPAP caused the AG8025 hybrid to have a photosynthetically efficiency above P30R50 along with a high 1000GW and DPGS, making it become more productive. This corroborates the findings of Cui et al. (2009), who stated that more productive genotypes are those that produce the largest amounts of dry phytomass at a given site. Thus the highest yield obtained by the AG8025 hybrid might be ascribed to the largest accumulation of ODPAP, DPGS and ODPAP for the P30R50 hybrid.

There was an increasing linear relationship of the DPGS for the AG8025 hybrid (96%) and a 92% fit of the data to the second degree equation for the P30R50 hybrid. The maximum value estimated by means of the fitted equation for the P30R50 hybrid was of 204.74 g with the dose of 215 kg of N $ha^{-1}$ applied in bands (Figure 2e).

Sangoi et al. (2007) obtained DPGS of 157, 153 and 115 g during a three-year evaluation for the simple corn hybrid DKB909 with an application of 100 kg of N $ha^{-1}$ in bands at stage $V_5$. Whereas Gomes et al. (2007) found a DPGS of 183 g with a dose of 150 kg of N $ha^{-1}$ in bands, whose values were below that obtained herein (202.47 g) irrespective of the hybrid and N dose applied in bands.

The fact that DPGS has responded in a quadratic and linear way to the N doses for P30R50 and AG8025 hybrids resulted in increments of ODPAP, once the variable ODPAP did not respond to N doses applied in bands. The unfolding of N doses within each corn hybrid for ODPAP revealed for the P30R50 hybrid a fit to the quadratic equation. Its estimated dose of 215 kg of N $ha^{-1}$ led to a yield of 383.75 g of ODPAP, whilst AG8025 hybrid showed a linear response (Figure 2f).

The mean value obtained for the variable HI was 0.52, being similar to that of two corn hybrids (Pioneer 3905 and Pioneer 30F06 Bt) and superior to Maizex LF850 RR hybrid studied by Subedi and Ma (2005), whose values were of 0.54; 0.51 and 0.46, respectively. The HI obtained herein for the P30R50 and AG8025 hybrids are in accordance with those obtained by Echarte and Andrade (2003), who reported that corn simple hybrids had shown a more stable HI irrespective of the amount of ODPAP or yield of grains per plant. HI correlated positively with NGR, LS, DS, 1000GW, DPGS and yield (0.56; 0.45; 0.44; 0.41; 0.61 and 0.45**, respectively).

The AG8025 hybrid, besides showing a higher yield as opposed to P30R50 hybrid, also showed a high ODPAP and ODPAP, reinforcing such a relevance and necessity of accumulation of dry phytomass to express productivity potential of the crop at a given site (Cui et al., 2009). Moreover, such a mean HI obtained herein (0.52) falls into the most frequent ranges for a high productive potential of corn hybrids (0.50 to 0.55), being 0.60 the threshold reported for most of the crops in the literature (Sharma-Natu and Ghildiyal, 2005). HI showed a significant correlation with yield (0.45**).

The AG8025 hybrid yield (12,438.81 kg $ha^{-1}$) was superior in relation to the P30R50 hybrid (10,929.21 kg $ha^{-1}$), resulting in a difference of 13.81%. Argenta et al. (2003) obtained a difference of 2,900 kg $ha^{-1}$ between the P32R21 and Premium hybrids, whose yields were 12,400 and 9,500 kg $ha^{-1}$, respectively. Discrepancies in yield for corn hybrids were also found by Ferreira et al. (2009), with a maximum yield of 10,553 kg $ha^{-1}$.

Variables such as NGR, LS, DPGS and ODPAP were simultaneously affected by the factors, corn hybrids and N doses applied in bands; however, interaction between such factors was not observed for yield. These results prove that yield of corn hybrids comes from the expression of each one of such components, as well as from the accumulation of dry phytomass as influenced by N availability.

A fitted second degree equation (Figure 2g) allowed the identification of the dose 295 kg of N $ha^{-1}$ in bands, with which the maximum yield is to be achieved (13,032.93 kg $ha^{-1}$). Hurtado et al. (2009) obtained an estimated maximum yield of 9,210 kg $ha^{-1}$, corresponding to the dose of 242 kg of N $ha^{-1}$ applied in bands. Nevertheless, Holland and Schepers (2010) over the course of three years of evaluation reached the conclusion that the dose of 200 kg of N $ha^{-1}$ caused the crop to attain yields of 11,530, 12,110 and 13,660 kg $ha^{-1}$.

Sangoi et al. (2009) reported that the application of two doses of 100 kg of N $ha^{-1}$ in bands at phenological stages of $V_4$ and $V_{10}$ of the Ritchie scale (Ritchie et al., 2003) resulted in yields of 12,634 kg $ha^{-1}$ for the simple P30F53 hybrid. Such an outcome is quite similar to yields obtained in the current work for the AG8025 hybrid under the dose of 295 kg of N $ha^{-1}$ in bands with only one application at $V_5$. This is important because the P30F53 simple hybrid is largely grown in production fields of the region of Campos Gerais, Paraná, Brazil.

The assessment of amounts of N on corn plants for most of the variables evaluated in the current study revealed a significant effect. However, for variables such as NTEL and NGRS no effect of N applied in bands was observed in production fields of corn. Nevertheless a connection between N responsiveness, as well as differentiation timing and definition of plant variables, indicates the possibility of managing N at different stages under sustainable approaches in agricultural systems.

The scrutiny of corn plants by means of variables related to crop growth and development, yield components, as well as accumulation of dry phytomass in compliance with N availability allows for the characterization of corn yield – a fact that might be confirmed by the positive correlation between corn yields with most of the studied variables herein. There is high correlation between yield and NGR (0.70**); LS (0.70**); DS (0.71**) and 1000GW (0.66**), as well as dry phytomass of grains per stalk (r = 0.77**) and overall dry phytomass of the aerial part per plant (0.73**). Moreover, from the characterization of corn yield the importance of the plant as a parameter to manage N in bands might be taken into account in order to maximize productivity and minimize the costs of production in a given corn farming system.

## Conclusions

The N application at the phenological stage $V_5$ allowed for the identification of differentiated responses of the studied variables, including lack of response for some of them. This permitted characterization of the effect of N on corn hybrids and also the identification of phenological stages for N management, where $V_7$-$V_8$ was considered to be the limits for N application in bands under the environmental conditions in this study.

Knowledge of the influence of N doses either on the variables related to crop growth and development, yield components or accumulated overall dry phytomass and its dependence relationship with yield at each production field might lead to the formation of yield, and to manage nitrogen fertilization in bands under sustainable approaches in agricultural systems.

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## Conflict of Interests

The authors have not declared any conflict of interests.

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