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Agronomic Performance of Corn Cultivars as a Function of Phosphorus Use

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Authors' contributions

This work was carried out in collaboration with all authors. Authors LCM, WFS and JMP designed the study and performed the analysis. Authors OJFJ, ASB, RMS and LFS managed the study and helped in the interpretation of the results. Author MO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The research was carried out to evaluate the agronomic performance of corn cultivars in contrasting phosphorus environments in the state of Pará, Brazil.
Study Design: The experimental design was randomized blocks with ten treatments and three replications. The treatments were composed of ten cultivars: AG 1051, AG 8088PRO2, BR 206, BRS 3046, PR 27D28, 2B655PW, AL BANDEIRANTE, ANHEMBI, CATIVERDE 02 and ORION
Place and Duration of Study: In the 2017/18 crop, two competition trials of corn cultivars were carried out at Sítio Vitória, municipality of Santa Maria das Barreiras, state Pará, Brazil.
Methodology: Two competition trials of corn (*Zea mays* L.) cultivars were carried out under contracting conditions of phosphorus: high P (100 kg ha^{-1} of P_2O_5) and low P (50 kg ha^{-1} of P_2O_5), using simple superphosphate (18% P_2O_5) as the source. The agronomic efficiency of phosphorus

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use was obtained by the difference between grain yield in both levels, divided by the difference between doses. The variables evaluated were: ear height, plant height, ear diameter, number of rows per year, number of grains per rows and grain yield.

Results: The mean grain yield of the cultivars ranged from 5,446 kg ha^{-1} (low P) to 11,486 kg ha^{-1} (high P), and the means of all cultivars were higher in high P. The means agronomic efficiency ranged from 25.1 kg kg^{-1} (AL BANDEIRANTE) to 96.6 kg kg^{-1} (AG 1051).

Conclusion: The highest phosphorus dose (100 kg ha^{-1} of P_2O_5) resulted in higher values in the variables studied. The cultivars that stood out the most, under high and low phosphorus, were AG 8088PRO2, AG 1051 and BRS 3046, the last two being agronomically efficient.

Keywords: Abiotic stress; grain yield; phosphate fertilizer; phosphorus use efficiency; Zea mays L.

1. INTRODUCTION

Global agriculture faces the challenge of increasing food production. In this context, owing to limitations regarding the expansion of the cultivated area, it is necessary to increase crop yield [1]. Where corn (*Zea mays* L.) stands out for being the most cultivated cereal in the world and source of carbohydrate in human and animal feed [2].

Corn is a crop of food, social, economic and agronomic importance. It is used together with soy as the basis of animal feed [2]. Also, it is used in production systems for the succession or rotation of crops which leads to decreased incidence of pests and diseases and brings other benefits [3,4].

In the 2018/2019 harvest, the cultivated area in Brazil reached 17 million hectares and a total production of 100 million tons. In the state of Pará, production has been increasing year on year, but the grain yield of 3,320 kg ha^{-1} is still lower than the mean in the northern region of Brazil [5]. This low yield results from high temperatures, low technological level employed, and lack of cultivars adapted to abiotic stress conditions [6].

Corn is a nutrition-demanding plant, where nutrient extraction in the vegetative period follows the decreasing order: Potassium (K) > nitrogen (N) > phosphorus (P). On the other hand, in the reproductive period the largest extraction is of N, followed by K and P [7]. For each ton of grain produced, a mean of 14.2 kg of N, 1.5 kg of P, and 2.8 kg of K are exported [8].

About phosphorus, it is almost all translocated to the grains (87%), because it is associated with the reserve organic compounds [9]. In the plant, it performs structural functions, participates in various processes (photosynthesis, protein synthesis and energy transfer) and acts directly and indirectly on various biological phenomena. Thus, the application of P increases the content in the leaves and impacts the growth and development of plants [10].

In cerrado soils, a limitation for corn production is the low natural availability of P and the high retention potential of P applied, tending to precipitate with Fe or Al, or to be adsorbed on the surface of clay and iron and aluminum oxides [10,11,12]. In this sense, to obtain high yields, the use of phosphate fertilization is essential. However, given the high cost of these fertilizers and as the phosphate rock (raw material for manufacturing) it is a finite resource, it is necessary the proper use of phosphate fertilizers and the search for more efficient cultivars in the use of phosphorus [13].

The reduction in nutrient removal values by modern corn cultivars shows probable gains in-use efficiency [8]. However, there is still little information on the behavior of cultivars at different phosphorus levels, especially in the state of Pará.

Therefore, the objective of this research was to evaluate the agronomic performance of corn cultivars in contrasting phosphorus environments in the state of Pará, Brazil.

2. MATERIALS AND METHODS

2.1 Study Location

In the 2017/18 crop, two competition trials of corn cultivars were carried out at Sítio Vitória, municipality of Santa Maria das Barreiras, state Pará, Brazil (Fig. 1), one performed under high P (100 kg ha^{-1} of P_2O_5) and another under low P (50 kg ha^{-1} of P_2O_5), applied at sowing, using as source the fertilizer simple superphosphate (18% Of P_2O_5). The date of sowing was 23 December 2017.

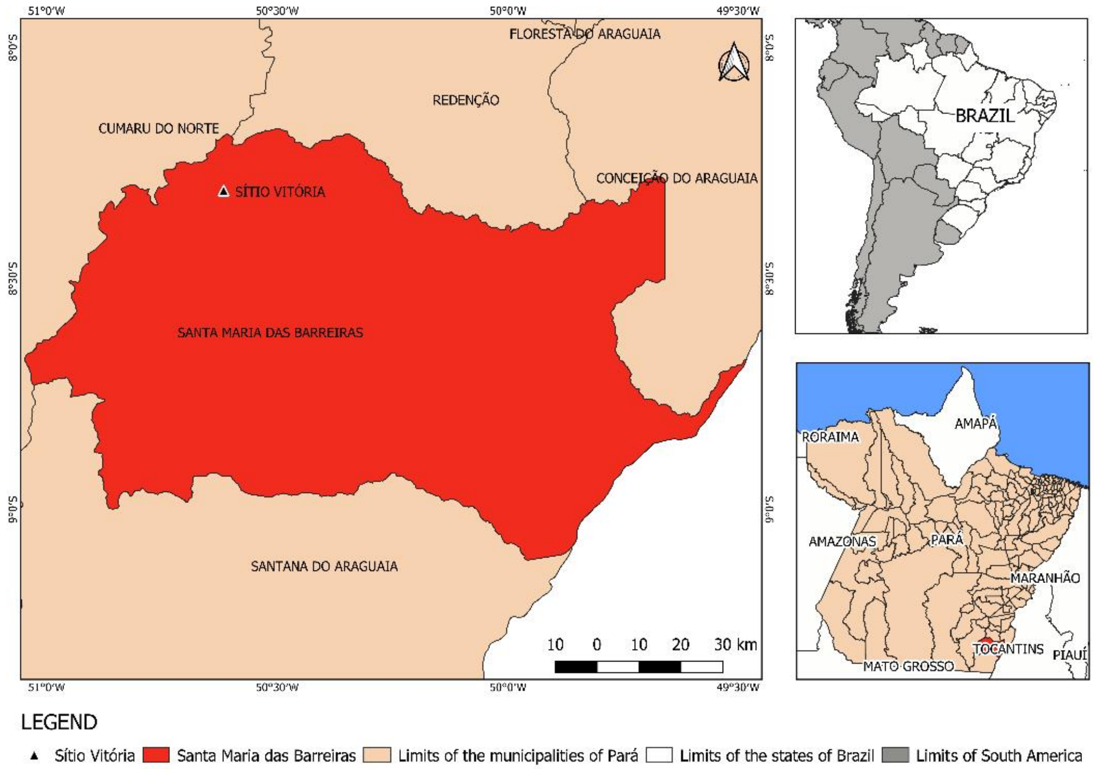

Fig. 1. Location of Sítio Vitória in Santa Maria das Barreiras, state of Pará, Brazil

The chemical and physical characteristics of the soil of the experimental area from 0 to 20 cm layer are presented in Table 1. The soil of the experimental area presents phosphorus content classified as very low [11]. The contrasting doses of phosphorus (100 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of P_2O_5) were defined according to the availability of the nutrient in the soil [14].

The climate of the region is classified as Aw according to the classification of Köppen [15]. The climatological means of precipitation, minimum and maximum temperature of the municipality of Santa Maria das Barreiras, state of Pará, are presented in Fig. 2.

2.2 Experimental Design

The experimental design used in each trial was randomized blocks with ten treatments and three replicates. The treatments were composed of ten cultivars (Table 2), seven hybrids: AG 1051, AG 8088PRO2, BR 206, BRS 3046, PR 27D28, 2B655PW and ORION and three populations of open pollination (OP): AL BANDEIRANTE, ANHEMBI and CATIVERDE 02. The experimental plot consisted of four rows of 5.00 m, with a spacing of 0.90 m.

Soil tillage using a plow, a disk harrow, and furrower. Thinning was performed after emergence, leaving the spacing of 0.20 m between plants, to obtain a population of 55,555 plants ha^{-1}.

Nitrogen and potassium fertilization, in cover, were divided into stages V4 and V8 (four and eight completely open leaves). The dose of 150 kg ha^{-1} of N and 90 kg ha^{-1} of K_2O was used, using urea (43% N) and potassium chloride (60% K_2O) as the source.

2.3 Data Collection and Analysis

The harvest was performed when the plants reached the physiological maturation stage (R6), using the two central rows of the plots, discarding 0.50 m from each end. Then, the grains weighed, moisture corrected 13% and grain yield transformed into kg ha^{-1}.

Table 1. Chemical and physical characteristics of the soil of the experimental area from 0 to 20 cm layer

Clay %	pH $CaCl_2$	OM* dag kg^{-1}	P mg dm^{-3}	K^+ mg dm^{-3}	Ca^{2+} $cmol_c$ dm^{-3}	Mg^{2+} $cmol_c$ dm^{-3}	Al^{3+} $cmol_c$ dm^{-3}	CTC $cmol_c$ dm^{-3}
15	4.8	1.7	4.9	43	1.7	0.3	0.20	5.21

**OM: Organic matter*

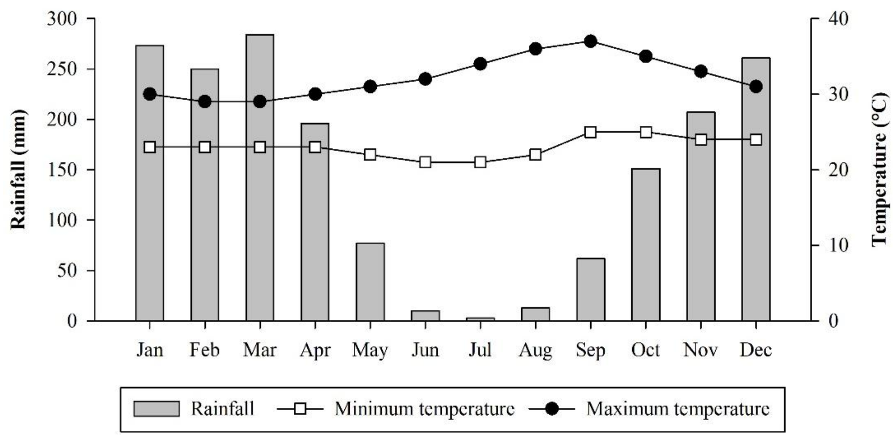

Fig. 2. Climatological means of rainfall, minimum temperature and maximum of the municipality of Santa Maria das Barreiras, State of Pará, Brazil
Adapted from Climatempo [16]

Table 2.Agronomic characteristics of the ten corn cultivars used in the experiment

Cultivar	Genetic base	Transgeny	Cycle	Use	Technological level
AG 8088PRO2	SH*	PRO2	Early	G/WPS	High
2B655PW	TH	PW	Early	G/WPS/WGS	Medium
BRS 3046	TH	C	Medium early	MV	Medium/High
AG 1051	DH	C	Medium early	G/MV/WPS	Medium/High
BR 206	DH	C	Early	G/WPS	Medium/High
ORION	DH	C	Early	G	Low/Medium
PR 27D28	DH	C	Super early	G/WPS	Low/Medium
AL BANDEIRANTE	OP	C	Medium early	G/WPS	Low/Medium
ANHEMBI	OP	C	Early	G/WPS	Low/Medium
CATIVERDE 02	OP	C	Medium early	MV/WPS	Medium

**SH: simple hybrid, DH: double hybrid, TH: triple hybrid, OP: populations of open pollination, PRO2: VT PRO 2™ technology, PW: Powercore™ technology, C: conventional, G: grain, MV: green corn, WPS: whole plant silage, WGS: wet grain silage. Adapted from Cruz et al. [17]*

The ear height (EH) and plant (PH) were measured with a metric tape, considering the distance from the soil to the insertion of the first ear and last open leaf, respectively. And the ears were determined the number of rows of grains (NR), the number of rows grains (NGR) and with the use of a caliper the diameter (ED) in its middle third.

The data were submitted to the normality test. Then, variance analysis was performed for each assay and, after, joint analysis following the criterion of homogeneity of the residual mean squares of the assays. The means were compared by the Scott and Knott [18] group test at 5% significance, using the SISVAR program [19].

The agronomic efficiency of phosphorus use, for the differentiation of cultivars, was obtained from the methodology proposed by Johnston et al. [20], which measures the difference between grain yield in both levels, divided by the difference between the P doses used.

3. RESULTS AND DISCUSSION

There was a significant effect of the interaction cultivars x assays (Table 3) for the variables: ear height, plant height and grain yield. According to Perecin and Cargnelutti Filho [21], the significance of the interaction demonstrates that the factors studied are dependent, that is, the performance of cultivars for these variables depends on the level of phosphorus.

For ear diameter and number of grains per row the effect of cultivars and asses was significant. On the other hand,for the number of rows of grains there was a significant effect only for assays.

The coefficients of variation (CV) of EH, PH, ED, NGR, and GY are classified as low and the experimental precision as high, and the NR as medium and the accuracy also mean [22].

The means of EH (Table 4) ranged from 83 to 148 cm, and the cultivars were divided into two groups of means under low P and four groups in high P. Exceptfor cultivar PR 27D28 which did not differ in the two trials, the cultivars presented higher values of AE in high P. The cultivars in low P that stood out were: PR 27D8 and CATIVERDE 02 and in high P: CATIVERDE 02, followed by ORION and AG1051. Under high P AG 8088PRO2 and BRS 3046 presented lower ears.

All cultivars had higher means of PH in high P, ranging from 182 to 240 cm. In low P six groups of means were formed, CATIVERDE 02 obtained the highest plant height and BRS 3046 at the lowest height. In high P four groups were formed, where again CATIVERDE 02 and also BR 206 obtained the highest means. On the other hand 2B655PW, AG 8088PRO2 and BRS 3046 had the lowest values in both trials.

According to Edwiges et al. [23] and Kopper et al. [24], there is a positive correlation between PH and EH, that is, generally taller plants also have higher ears.

In studies by Alves et al. [25] with fifty-eight corn genotypes and Alves et al. [26] with thirty-six genotypes, mean EH of 88 cm and 96 cm were obtained. These authors also found mean PH of 233 cm and 187 cm, respectively.

A high ear insertion height predisposes plants to lodge and also disfavors the accumulation of carbohydrates in the grains [27]. Because the leaves above the ear are more efficient in grain yield [28]. On the other hand, plant height and low ear insertion may result in losses in mechanized harvesting and a decrease in grain purity [29].

The largest ear diameter, the number of rows of grains, and the number of grains per row were obtained when a high dose of phosphorus was used.

Regarding the ED three groups of means were formed, with the highest value obtained by BRS 3046 (53.7 mm), and the lowest values coming from AL BANDEIRANTE, ANHEMBI and ORION.

For NR the cultivars did not presentsignificant differences. And P doses increased NGR from 29 to 35. The cultivars with thehighest means were BRS 3046 (36) and PR 27D28 (34) followed by BRS 206 (33) and AG 8088PRO2 (33). The lowest number of grains per row was obtained by AL BANDEIRANTE (29).

Table 3. Analysis of joint variance of ear height (EH), plant height (PH), ear diameter (ED), number of rows of grains (NR), number of grains per row (NGR) and grain yield (GY) of ten corn cultivars as a function of phosphorus doses, in the state of Pará, Brazil, crop 2017/18

Source of variation	Degree of freedom	Mean square					
		EH	PH	ED	NR	NGR	GY
Environments (E)	1	**	**	**	**	**	**
Cultivar (C)	9	**	**	**	ns	**	**
EC Interaction	9	**	**	ns	ns	ns	**
Block (Environments)	4	ns	ns	ns	ns	ns	ns
Mean		105.4	211.3	50.5	17.7	32.2	8,043.1
Coefficients of variation (%)		6.3	1.4	3.5	12.5	4.8	3.5

***: significant by the F test at 5% significance, ns: nonsignificant*

Table 4.Means ear height, plant height, ear diameter, number of rows of grains, number of grains per row, of ten corn cultivars as a function of phosphorus doses in the state of Pará, Brazil, crop 2017/18

Cultivar	Ear height (cm)		Plant height (cm)		Ear diameter (mm)	Number of grains per row	Grain yield (kg ha^{-1})		Agronomic efficiency (kg kg^{-1})
	Low P	High P	Low P	High P			Low P	High P	
PR 27D28	104 Aa*	113 Ac	195 Be	225 Ab	51.5 b	34 a	7,387 Ba	9,482 Ac	41.9
2B655PW	86 Bb	109 Ac	199 Bd	209 Ad	51.5 b	31 c	6,698 Ba	10,450 Ab	75.0
AG 1051	93 Bb	127 Ab	211 Bb	225 Ab	50.2 b	32 c	6,344 Bb	11,174 Aa	96.6
AG 8088PRO2	85 Bb	98 Ad	199 Bd	211 Ad	51.9 b	33 b	7,998 Ba	10,177 Ab	43.6
AL BANDEIRANTE	93 Bb	112 Ac	192 Be	224 Ab	48.6 c	29 d	5,824 Bb	7,077 Ae	25.1
ANHEMBI	83 Bb	117 Ac	202 Bc	216 Ac	49.0 c	31 c	5,446 Bb	8,490 Ad	60.9
BR 206	94 Bb	126 Ab	205 Bc	237 Aa	50.3 b	33 b	7,412 Ba	9,249 Ac	36.7
BRS 3046	91 Bb	105 Ad	182 Bf	205 Ad	53.7 a	36 a	7,136 Ba	11,486 Aa	87.0
CATIVERDE 02	110 Ba	148 Aa	220 Ba	240 Aa	50.6 b	32 c	5,501 Bb	7,650 Ae	43.0
ORION	94 Bb	123 Ab	203 Bc	228 Ab	47.4 c	32 c	6,169 Bb	9,710 Ac	70.8
Mean	93	118	201	222	50.5	32	6,592	9,495	58.1
Level	**Ear diameter (mm)**			**Number of rows of grains**			**Number of grains per row**		
Low P	48.2 b			16.5 b			29 b		
High P	52.8 a			18.9 a			35 a		

**Means followed by the same lowercase letter between cultivars, in the same assay. And uppercase between assays, for the same cultivar, belong to the same group, by the criteria of grouping Scott and Knott [18], at 5% significance*

Researching phosphorus doses Ribeiro et al. [30] and Oliveira et al. [31] also found means in the ED of 49 and 52 mm, in the environments with 140 and 150 kg ha^{-1} of P_2O_5, respectively. Mendoza-Mendoza et al. [32] evaluating fifty-three genotypes obtained ED of 49 mm, very close to the present study.

Jumaa and Madab [33], Mendoza-Mendoza et al. [32] and Ahmed et al. [34] found means of NR: 16.6, 15.4 and 15.2 rows, values close to those of low P.

Guimarães et al. [35] and Ullah et al. [36] found values of NGR close (36 and 35 grains per row) to the value obtained in high P.

Oliveira et al. [37] observed that in crops with high yields, above 13 Mg ha^{-1}, the mean number of rows per ear was equal to 17, and number of grains per row of 31 grains.

Corroborating these results, Bento et al. [38], Castro et al. [39], Ribeiro et al. [30] and Oliveira et al. [31] also observed an increase in EH, PH, NR and NGR with phosphorus increase.

The mean grain yield of the cultivars ranged from 5,446 kg ha^{-1} (low P) to 11,486 kg ha^{-1} (high P), and the means of all cultivars were higher in high P.

In the low P assay, the means were divided into two groups, PR 27D28, 2B655PW, AG 8088PRO2, BR 206 and BRS 3046 were the most productive. These yields were higher than the mean of 3,320 kg ha^{-1} in the state of Pará [5], demonstrating the importance of conducting regional trials to evaluate cultivars in different environments.

In high P the means were divided into five groups, where BRS 3046 (11,486 kg ha^{-1}) and AG 1051 (11,174 kg ha^{-1}) were the most productive. On the other hand, AL BANDEIRANTE (7,077 kg ha^{-1}) and CATIVERDE 02 (7,650 kg ha^{-1}) obtained the lowest yields.

The cultivars BRS 3046 and AG 1051 are indicated for environments where the technological level employed is high (Table 2), which confirms their potential use in high P.

It is noteworthy that the cultivars with the highest number of rows and the highest number of grains per row were also the most productive. According to Jumaa and Madab [33] and Ahmed et al. [34], these characters have a direct influence on yield.

The mean grain yields found by Meirelles et al. [40] for forty-two genotypes in two harvests and Colombo et al. [41] for thirty-six other genotypes were 3,941 and 6,125 kg ha^{-1} for low P, and 8,867 and 8,671 kg ha^{-1} for high P. Values lower than those found in this study.

In very low phosphorus availability, theannual cultural yield is limited by up to 40% of potential. In this environment cultivars should present mechanisms for this restriction environment. Such as: changes in the architecture and morphology of the roots, increased capacity to absorb P, rhizosphere acidification or symbiosis with microorganisms [11, 42].

The differences in yield between cultivars can be explained by the greater vigor and heterosis of hybrids, which had the highest yields at the two phosphorus levels

Regarding agronomic efficiency (AE) the means ranged from 25 kg kg^{-1} (AL BANDEIRANTE) to 97 kg kg^{-1} (AG 1051). Where cultivars AG 1051 (97 kg kg^{-1}), BRS 3046 (87 kg kg^{-1}), 2B655PW (75 kg kg^{-1}), ORION (71 kg kg^{-1}) and ANHEMBI (61 kg kg^{-1}) showed efficiency higher than the general mean (58 kg kg^{-1}). That is why they are considered efficient in the use of P [43]. Of these, BRS 3046 was highly productive in high and low P trials.

The AE values found are higher than those obtained by Fidelis et al. [44] (26.34 kg kg^{-1}) and close to those obtained by Xu et al. [45] who in three harvests and six doses of P, obtained AE of up to 60 kg kg^{-1}.

AE is a highly complex character and influenced by several factors, mainly linked to physiological processes (acquisition. translocation. assimilation and remobilization of the nutrient) and environmental conditions [46].

The improvement of this characteristic is being addressed by traditional and molecular improvement strategies, and the ZmPTF1 gene has already been identified as responsible for modifying root architecture in a P-limiting environment [47].

4. CONCLUSION

The highest phosphorus dose, 100 kg ha^{-1} of P_2O_5, resulted in higher values in the variables studied.

The cultivars that stood out the most under high and low phosphorus were: AG 8088PRO2, AG 1051 and BRS 3046, the last two being agronomically efficient.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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