



## Efficiency and Response to Phosphorus Use of Corn Cultivars in the Tropical Climate

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### Authors' contributions

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

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### ABSTRACT

**Aims:** The present study evaluated the efficiency and response to phosphorus (P) use of corn cultivars in the tropical climate in southern Para State, Brazil.

**Study Design:** Two experiments were carried out, in low P (50 kg ha<sup>-1</sup>) and high P (200 kg ha<sup>-1</sup>) applications in Randomized block design (RBD), three replicates, and fourteen cultivars were used for the experiment.

**Place and Duration of Study:** The experiment was carried out in the 2019-20 harvest at Sitio Vitoria (8°18'32" S, 50°36'58" W), located in the municipality of Santa Maria das Barreiras, a southern region of Para state, Brazil.

**Methodology:** Phosphate fertilization was used in the sowing groove. In low P, 50 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> were applied, and in high P were 200 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>. The source was simple superphosphate (18% P<sub>2</sub>O<sub>5</sub>). The dose in high P was defined to achieve high yields and considering the nutrient

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content in the soil, in low P the dose was well below. Nitrogen and potassium fertilization in cover were divided: 50% in V4 and 50% in V8. Doses of 150 kg ha<sup>-1</sup> of N and 90 kg ha<sup>-1</sup> of K<sub>2</sub>O were used, and fertilizers were used: urea (43% N) and potassium chloride (60% K<sub>2</sub>O).

**Results:** The highest means were: 8,710 kg ha<sup>-1</sup> efficiency and 29.78 kg kg<sup>-1</sup> response. The efficient cultivars were: ORION, BR 2022, CR 120, AL BANDEIRANTE, M 274, BRS 3046, and AG 8088. And those considered responsive were: BM 3061, BR206, CATIVERDE 02, BR 205, ANHEMBI, BR 2022, and BRS 3046.

**Conclusion:** The cultivar BR 2022 and BRS3046 showed high efficiency and also a response to phosphorus use.

*Keywords: Technological; grain yield; phosphate fertilization.*

## 1. INTRODUCTION

On the world stage, there is a need for increased food production. Considering that the expansion capacity in agricultural areas is limited, the challenge becomes even greater [1]. To solve this problem, corn (*Zea mays* L.) is of fundamental importance, because it is the most cultivated grain, and a source of fundamental carbohydrates for human and animal food [2].

In Brazil, corn production has increased, mostly due to increased productivity. In the 2019-20 harvest, production was 102 million tons of grain in about 18 million hectares. As significant as this value is, it is still far from the country's real production capacity [3].

The State of Para has low productivity, with a mean of 3,155 kg ha<sup>-1</sup>, lower than the national state of 5,520 kg ha<sup>-1</sup> [3]. These low yields of corn in the tropical climate are associated with the low technological level of production, little knowledge of cultivars adapted to the region, and edaphoclimatic conditions.

Low-level technology is linked to low fertilizer utilization. In this scenario, phosphorus (P) limits productivity, since it is one of the nutrients most extracted by corn plants [4]. And most soils in the region have low natural availability of this nutrient [5].

P is also linked to physiological processes of photosynthesis and respiration, but it is also a constituent of proteins and coenzymes, nucleic acids and has a fundamental role in the storage of energy in the plant. P deficiency also occurs initially in older leaves, which have a darker than normal green initial color. Subsequently, they acquire a reddish-purplish color (anthocyanin accumulation) at the tips and margins of the leaf blade, which may extend to the culm. The plant also shows reduced growth [5-11].

Therefore, phosphate fertilization is essential for high yields. And as the raw material for the manufacture of these fertilizers is finite, it is necessary to search for cultivars with efficient use and responsive application of phosphorus. Within this context, several researchers have sought to obtain these cultivars with greater efficiency and use of P for the cultivation of corn [4-12].

Therefore, the present study evaluated the efficiency and response to phosphorus use of corn cultivars in the tropical climate in southern Pará State, Brazil.

## 2. MATERIALS AND METHODS

### 2.1 Site Description

Two experiments were carried out in the experimental area of Sitio Vitoria, located in the municipality of Santa Maria das Barreiras, the State of Para, Brazil (8°18'32.0"S, 50°36'58.0"W, 278 MASL). The climate of the region was classified as Aw, with rainfall in summer and dry in winter [13].

The soil of the experiments presented sandy texture, with 150 g kg<sup>-1</sup> of clay, and the following chemical attributes (0 - 20 cm): 4.8 pH CaCl<sub>2</sub>, 17 g kg<sup>-1</sup> organic matter, 4.9 mg dm<sup>-3</sup> phosphorus, 43 mg dm<sup>-3</sup> potassium, 1.7 cmol<sub>c</sub> dm<sup>-3</sup> calcium, 0.3 cmol<sub>c</sub> dm<sup>-3</sup> magnesium, 0.2 cmol<sub>c</sub> dm<sup>-3</sup> aluminum, 5.21 cmol<sub>c</sub> dm<sup>-3</sup> cation exchange capacity, and 40% base saturation.

### 2.2 Experimental Design

The experiments were carried out in two phosphorus levels: low P and high P. An experimental design was used in randomized blocks, with three replications. The treatments were fourteen maize cultivars Table 1.

**Table 1. Agronomic characteristics of the fourteen corn cultivars used in the experiment**

Cultivar	GB <sup>a</sup>	Cycle	Use	Technological level
AG 1051	DH	Medium early	G/MV/WPS	Medium/High
AG 8088	SH	Early	G/WPS	High
AL Bandeirante	OP	Medium early	G/WPS	Low/Medium
ANHEMBI	OP	Early	G/WPS	Low/Medium
BM 3061	TH	Early	MV/WPS	Medium/High
BR 2022	DH	Early	G/WPS	Medium/High
BR 205	DH	Early	G/WPS	Medium/High
BR 206	DH	Early	G/WPS	Medium/High
BRS 3046	TH	Medium early	MV	Medium/High
CATIVERDE 02	OP	Medium early	MV/WPS	Medium
CR 120	DH	Early	G/WPS	Medium/High
M 274	OP	Early	G/WPS	Low/Medium
ORION	DH	Early	G	Low/Medium
PR 27D28	DH	Super early	G/WPS	Low/Medium

<sup>a</sup>GB: Genetic base, SH: simple hybrid, DH: double hybrid, TH: triple hybrid, OP: populations of open pollination, G: grain, MV: green corn, WPS: whole plant silage, WGS: wet grain silage. Adapted from [14-16]

The experimental plot consisted of four rows of 5.0 meters, with a spacing of 0.9 meters. Sowing was carried out on January 7, 2020. Thinning was performed and a final population of 55,555 plants ha<sup>-1</sup> was obtained.

### 2.3 Phosphate Fertilization

Phosphate fertilization was used in the sowing groove. In low P, 50 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> were applied, and in high P were 200 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>. The source was simple superphosphate (18% P<sub>2</sub>O<sub>5</sub>). The dose in high P was defined to achieve high yields and considering the nutrient content in the soil, in low P the dose was well below the recommended [6].

Nitrogen and potassium fertilization in cover were divided: 50% in V4 (plant with four fully unfolded leaves) and 50% in V8 (plant with eight fully unfolded leaves). Doses of 150 kg ha<sup>-1</sup> of N and 90 kg ha<sup>-1</sup> of K<sub>2</sub>O were used, and fertilizers were used: urea (43% N) and potassium chloride (60% K<sub>2</sub>O). Doses of P applications were recommended [6].

### 2.4 Data Collection

The two central rows of the plots were harvested at the physiological maturation stage, discarding 0.50 m from each extremity. Grain mass corrected moisture to 13%.

The characteristics of ear diameter (ED) and ear length (EL) without straw were measured with a caliper and metric rule, respectively. The number of grains per row (NG) and the number of rows

per year (NR) was determined. And with a scale, the ear weight with straw (EW) and the grain yield (GY).

The methodology of [17] was used to classify the cultivars as to the efficiency and response to phosphorus use. The efficiency corresponded to the grain yield in low P. And the response was calculated by the equation:

$$RP_i = \frac{GYH_i - GYL_i}{PH - PL}$$

Where: RP<sub>i</sub> was the response to the use P of the i- th cultivar, GYH<sub>i</sub> was the grain yield of the i- th cultivar in high P, GYL<sub>i</sub> was the grain yield of the i-th cultivar in low P, PH was the phosphorus dose in high, and PL the phosphorus dose in low.

### 2.5 Statistical Analysis

The data were submitted to the normality test. Variance analysis was performed for each experiment, and joint analysis was followed by the criterion of homogeneity of the residual mean squares of the experiments. The means were compared by the [18] cluster criterion, at 5% significance. For the analyses, the SISVAR program was used [19].

## 3. RESULTS AND DISCUSSION

There was a significant effect of the PxC interaction for all variables (Table 2). The significance of the interaction demonstrates that the performance of cultivars is dependent on the level of phosphorus. The coefficients of variation of ED, EL, NG, EW, and GY were low (<10%), and high experimental accuracy [20].

**Table 2. Analysis of joint variance of fourteen maize cultivars to the use of phosphorous in the tropical climate**

Source of variation	Degree of freedom	Middle square					
		ED	EL	NG	NR	EW	GY
Phosphorus (P)	1	157.44*	24.42*	360.42*	25.19*	60.160.76*	133257090.04*
Cultivar (C)	13	41.07*	9.28*	42.67*	14.50*	4758.73*	5544975.33*
PxC	13	7.41*	6.68*	39.60*	1.49*	2328.63*	1202412.79*
Block	4	9.83	1.07	9.59	3.04	898.47	318126.95
Residue	52	5.06	1.57	8.77	2.58	441.66	353324.80
Mean		50.41	16.28	33.11	15.30	212.23	8131.72
Coefficient of variation %		4.46	7.63	8.94	10.50	9.90	7.31

\* Significant by the F test to 5% significance

For characteristic ED (Table 3) only cultivars BR 206, CATIVERDE 02, CR 120, and ORION increased using P. For both levels cultivars AG 8088, BR 205, BRS 3046, CR 120, and M 274, had the largest diameters, along with AL BANDEIRANTE and ANHEMBI down P and high P, respectively.

The cultivars presented a different performance for the variable EL. The cultivar M 274 had a decrease in length. Cultivars BM 3061, BR 206, BRS 3046, CATIVERDE 02, and ORION increased. The others had no statistical difference between P levels were in the group with the highest means at the two levels: AG8088 and ANHEMBI.

For the characteristic NG, the cultivars also performed differently. The only one that decreased the number of rows per ear was AG 1051. P did not influence the NG of cultivars: AG 8088, CR 120, ORION, and PR 27D28. With high P the lowest NR were AG 1051, BR 205, and CR 120.

Only the cultivar ORION had an increase in NR using P. Cultivars with higher ED were also the ones with the highest NR. This was due to these two characteristics having a high correlation [21].

An increase in-ear weight was observed using P in almost all cultivars, except AG 8088, AL BANDEIRANTE, and BR 2022, the latter had higher EW in low P. Cultivars AG 8088, AL BANDEIRANTE, ANHEMBI, CR 120, M 274, and PR 27D28 had the highest EW in the two levels of P. Cultivars that were in the group with the highest mean in high and low P also had the highest NG. These two characteristics have a high correlation [22].

The cultivar AG 8088 had the highest means for all variables in low P and high P. And the M 274 was not only in the group of the highest means of EL (high P) and NG (low P). On the other hand, cultivars AG 1051, BR 2022, and BR 206 had only the lowest means in most.

Corroborating these data, [23,22] found means of ED, EL, NG, and NR close to this research. And [14,15] also found an increase in ED, EL, NG, and EW with the use of P. The grain yield variation (Figure 1) was 4,759 kg ha<sup>-1</sup> (low P) to 10,656 kg ha<sup>-1</sup> (high P). All cultivars showed higher yields in high P. The means in low P were separated into three groups. The group with the lowest low means was composed of: BM 3061 (5,724 kg ha<sup>-1</sup>), BR 205 (4,759 kg ha<sup>-1</sup>), BR 206 (5,749 kg ha<sup>-1</sup>) and CATIVERDE 02 (5,106 kg ha<sup>-1</sup>). In the group with the highest means were the cultivars: AG 8088 (8,710 kg ha<sup>-1</sup>) and BRS 3046 (8,120 kg ha<sup>-1</sup>).

These means are higher than the mean of the State of Pará [3]. This highlights the importance of regional tests of cultivars in different environments. Furthermore, it demonstrates that the correct choice of cultivars can increase the mean productivity of the state.

In high P, the mean productivity was also divided into three groups. The group with the lowest means had the cultivars: BR 205 (7,402 kg ha<sup>-1</sup>) and CATIVERDE 02 (7,954 kg ha<sup>-1</sup>). And the group with the highest means, was formed by: AG 8088 (10,556 kg ha<sup>-1</sup>), ANHEMBI (9,691 kg ha<sup>-1</sup>), BM 3061 (10,192 kg ha<sup>-1</sup>), BR 2022 (10,031 kg ha<sup>-1</sup>), BR 206 (9,691 kg ha<sup>-1</sup>), BRS 3046 (10,656 kg ha<sup>-1</sup>), CR 120 (9,931 kg ha<sup>-1</sup>) and M 274 (9,819 kg ha<sup>-1</sup>).

Although the compositions of the low P and high P groups were different, the cultivars AG 8088 and BRS 3046 were among the most productive in the two levels of P.

The mean yields found by [9] for forty-two genotypes, and [10] for thirty-six other genotypes, were 3,941 and 6,125 kg ha<sup>-1</sup> in low P, and 8,867 and 8,671 kg ha<sup>-1</sup> in high P. These values are lower than the means of cultivars in this study. This may be due to the lower doses used by these authors.

The efficiency values in the use of P (Figure 2) range from 4,749 kg ha<sup>-1</sup> (BR 205) to 8,710 kg ha<sup>-1</sup> (AG 8088), with a mean of 6,872 kg ha<sup>-1</sup>. The highest values were reached by the cultivars: ORION, BR 2022, PR 27D28, CR 120, AL BANDEIRANTE, M 274, BRS 3046, and AG

8088. These cultivars are in quadrants I and IV and were classified as efficient because they have higher efficiency than the general mean of cultivars.

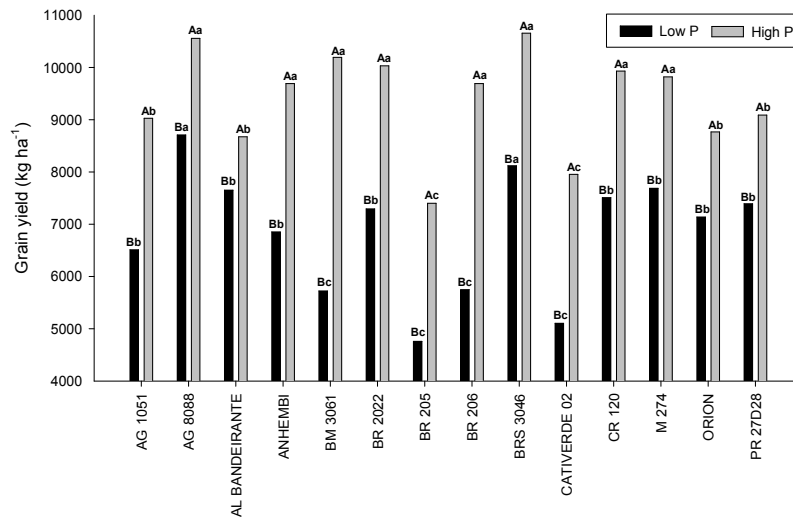
The development of efficient cultivars has been occurring by traditional and molecular strategies [12]. The cultivars of this work with high efficiency, have potential use in the improvement for this characteristic, and must have genes that favor them in a limiting environment of P.

The responses ranged from 6.82 kg kg<sup>-1</sup> (AL BANDEIRANTE) to 29.78 kg kg<sup>-1</sup> (BM 3061), and the mean was 16.79 kg kg<sup>-1</sup>. The most responsive to the use of phosphorus was cultivar BM 3061, from 5,724 kg ha<sup>-1</sup> at low P to 10,192 kg ha<sup>-1</sup> in high P, with a response equal to 29.78 kg of grains per kg of phosphorus applied.

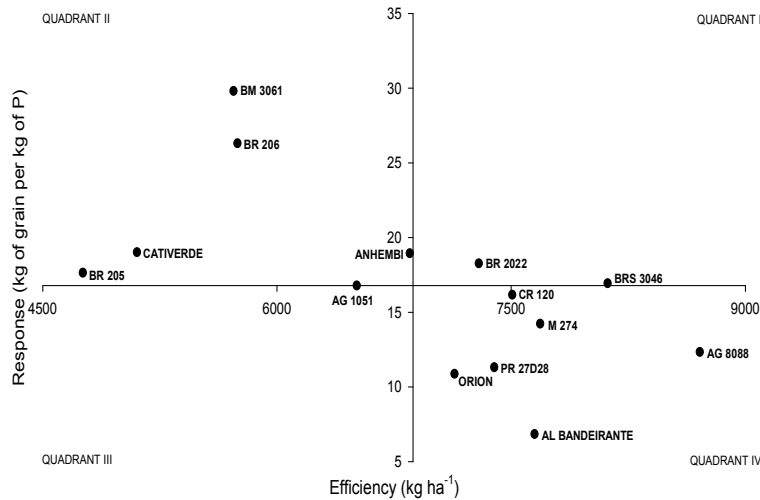
**Table 3. Means ear diameter, ear length, number of grains per row, number of rows per ear, and ear weight with the straw of fourteen maize cultivars to the use of phosphorous in the tropical climate**

Cultivar	Ear diameter (mm)		Ear length (cm)		Number of grains		Number of rows		Ear weight (g)	
	Low P	High P	Low P	High P	Low P	High P	Low P	High P	Low P	High P
AG 1051	47.6	50.3	16.4	16.6	37.6	27.6	14.0	16.0	178.3	222.0
	Ab <sup>a</sup>	Ab	Ab	Aa	Aa	Bb	Ab	Ab	Bb	Ab
AG 8088	51.3	54.0	18.0	17.8	33.3	36.6	17.3	19.3	235.0	257.0
	Aa	Aa	Aa	Aa	Aa	Aa	Aa	Aa	Aa	Aa
AL BAND.	51.6	50.3	14.7	16.1	27.6	33.6	15.3	15.3	210.6	234.0
	Aa	Ab	Ac	Ab	Bb	Aa	Aa	Ab	Aa	Aa
ANHEMBI	48.6	52.6	17.6	18.3	30.0	38.6	14.0	15.3	187.3	260.6
	Ab	Aa	Aa	Aa	Bb	Aa	Ab	Ab	Ba	Aa
BM 3061	48.3	50.6	14.8	17.0	30.6	35.3	14.0	14.0	154.3	302.0
	Ab	Ab	Bc	Aa	Bb	Aa	Ab	Ab	Bb	Aa
BR 2022	48.3	46.6	13.9	14.6	29.6	36.0	14.6	15.3	204.0	169.0
	Ab	Ab	Ac	Ab	Bb	Aa	Ab	Ab	Aa	Bc
BR 205	50.6	53.6	14.4	13.8	24.3	29.3	16.0	16.6	122.3	193.6
	Aa	Aa	Ac	Ab	Bb	Ab	Aa	Aa	Bc	Ac
BR 206	44.6	50.6	15.6	18.1	27.6	37.0	14.0	14.0	170.6	220.3
	Bb	Ab	Bc	Aa	Bb	Aa	Ab	Ab	Bb	Ab
BRS 3046	50.6	54.0	14.3	17.6	34.0	42.0	15.3	16.0	202.0	264.0
	Aa	Aa	Bc	Aa	Ba	Aa	Aa	Ab	Ba	Aa
CATIVERDE	46.3	51.3	13.5	17.6	29.0	38.6	15.3	15.3	136.0	193.6
	Bb	Ab	Bc	Aa	Bb	Aa	Aa	Ab	Bc	Ac
CR 120	51.6	56.6	16.3	14.6	30.6	31.3	16.6	18.6	226.3	269.3
	Ba	Aa	Ab	Ab	Ab	Ab	Aa	Aa	Ba	Aa
M 274	55.0	55.6	19.2	16.1	30.0	35.0	16.0	17.3	207.3	267.3
	Aa	Aa	Aa	Bb	Bb	Aa	Aa	Aa	Ba	Aa
ORION	46.3	50.3	15.1	19.2	36.6	36.0	12.0	15.3	170.3	246.6
	Bb	Ab	Bc	Aa	Aa	Aa	Bb	Ab	Bb	Aa
PR 27D28	45.3	48.3	16.2	17.8	33.3	35.3	12.0	13.3	192.0	246.0
	Ab	Ab	Ab	Aa	Aa	Aa	Ab	Ab	Ba	Aa

<sup>a</sup>Means followed by the same letter belong to the same group, lowercase for the cultivar and uppercase for the level of P, by the criteria of the grouping of [18], at 5% significance



**Fig. 1. Grain yield of fourteen maize cultivars to the use of phosphorous in the tropical climate**  
*Means followed by the same letter belong to the same group, lowercase for the cultivar and uppercase for the P level, by the grouping criterion of [18], at 5% significance*



**Fig. 2. Efficiency and response to phosphorus use of fourteen maize cultivars to the use of phosphorous in the tropical climate**

The cultivars with the highest responses were: CATIVERDE 02, BR 205, ANHEMBI, BM 3061, BR 206, BR 2022, and BRS 3046. These cultivars were considered responsive because they had a higher response rate than the general mean of the cultivars. And they were represented in quadrants I and II.

These values are higher than the mean of the cultivars studied.

The cultivars BR 2022 and BRS 3046 classified as efficient and responsive had a response of 18.24 kg kg<sup>-1</sup> and 16.91 kg kg<sup>-1</sup>, and efficiency of 7,295 and 8,120 kg ha<sup>-1</sup>. Because they have high productivity in low P availability and large increment with the use of high doses of phosphate fertilizers, these cultivars are

Corroborating these data, [11] found a mean response of 26.34 kg kg<sup>-1</sup>, and [24] of 60 kg<sup>-1</sup>.

recommended for low and high technological production.

On the other hand, cultivar AG 1051 was considered inefficient and non-responsive, its response was 16.76 kg kg<sup>-1</sup> and the efficiency was 6,513 kg ha<sup>-1</sup>. So, it is not recommended for low or high technological level.

#### 4. CONCLUSION

The cultivars BM 3061, BR 206, CATIVERDE 02, ANHEMBI, and BR 205 were responsive to the use of phosphorus and recommended for production with a high technological level.

The cultivars AG 8088, BRS 3046, ORION, PR 27D28, M 274, CR 120, and AL BANDEIRANTE were efficient in the use of phosphorus and therefore recommended for production with low technological level.

The cultivars BR 2022 and BRS 3046 were classified as efficient and responsive to the use of phosphorus. Therefore, may be useful for production with a high and low technological level.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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