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Phosphorus use efficiency by maize cultivars for the production of green ears

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ABSTRACT: The objective of this study was to evaluate the efficiency of the use of phosphorus by maize cultivars for the production of green ears. Two experiments were carried out, one in the rainy season (March to June) and the other in the dry period (August to December), both at the Rafael Fernandes Experimental Farm, in the community of Alagoinha, belonging to the Universidade Federal Rural do Semiárido, in the municipality of Mossoró, RN, Brazil. The treatments consisted of a combination of three levels of phosphorus (low, medium and high) and eight corn cultivars (Dona Josélia, Carrapateira, Pontinha, Cruzeta, Potiguar, BRS 2022, Status and AG 1051). A randomized block design was used in a 3 × 8 factorial scheme, with four repetitions. The evaluated characteristics were: number and total mass of green ears, number and mass of tradable, stuffed and depleted green ears, agronomic and physiological efficiency of production of recovery and use of phosphorus. The cultivars showed better productive performance when fertilized with phosphorus. The cultivars Cruzeta, Potiguar, BRS 2022, Status, AG 1051 and Carrapateira were the most efficient in the use of phosphorus to produce green maize.

Key words: *Zea mays*, productivity, mineral nutrition

Eficiência do uso de fósforo por cultivares de milho visando a produção de espigas verdes

RESUMO: Objetivou-se avaliar a eficiência da utilização de fósforo por cultivares de milho para produção de espigas verdes. Foram conduzidos dois experimentos, um no período chuvoso (março a junho) e outro no período seco (agosto a dezembro), ambos na Fazenda Experimental Rafael Fernandes, na comunidade de Alagoinha, pertencente à Universidade Federal Rural do Semiárido, no município de Mossoró, RN. Os tratamentos foram constituídos pela combinação de três níveis de fósforo (baixo, médio e alto) e oito cultivares de milho (Dona Josélia, Carrapateira, Pontinha, Cruzeta, Potiguar, BRS 2022, Status e AG 1051). Foi utilizado o delineamento experimental em blocos ao acaso, em esquema fatorial 3 × 8, com quatro repetições. As características avaliadas foram: número e massa total de espigas verde, número e massa de espigas verdes comercializáveis (empalhadas e despalhadas), eficiências agronômica, fisiológica, de produção de espigas, de recuperação e de utilização do fósforo. As cultivares apresentaram melhor desempenho produtivo quando adubadas com fósforo. As cultivares Cruzeta, Potiguar, BRS 2022, Status, AG 1051 e Carrapateira foram as mais eficientes na utilização do fósforo para a produção de milho verde.

Palavras-chave: *Zea mays*, produtividade, nutrição mineral

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Introduction

Maize (*Zea mays* L.) is the main cereal cultivated in the world, and Brazil is the third largest producer, where it is grown in all regions. It is mainly marketed in the form of grains, but in recent years the demand for green ears for fresh consumption has increased (Paiva et al., 2012; Corrêa Junior et al., 2014; Couto et al., 2017).

Factors related to soil fertility are among those that most contribute to the low yield of green ears in the Northeast region of Brazil, especially phosphorus (P), the third nutrient most required by the crop, considered one of the main nutrients that limit maize yield (Machado & Souza, 2012; Oliveira et al., 2015).

The low rate of P utilization by maize suggests the use of large amounts in phosphate fertilization, which substantially increases the costs with this management practice (Gazola et al., 2013). In addition, global P stocks can be depleted within 300 years (USGS, 2019) and its excess in soil can cause environmental pollution, such as eutrophication of rivers and lakes (Klein & Agne, 2012).

Several researchers have developed methodologies to evaluate the adaptation of maize to soils with low P availability (Sousa et al., 2012; Mendes et al., 2014; Meirelles et al., 2016; Colombo et al., 2018), highlighting that there are differences between maize genotypes regarding the ability to absorb and use the P available in soil.

The objective of this study was to evaluate the efficiency of P utilization by maize cultivars for the production of green ears.

Material and Methods

The experiments were carried out from March to July (season 1) and from August to December 2017 (season 2), at the Rafael Fernandes Experimental Farm, in the community of Alagoinha, belonging to the Universidade Federal Rural do Semiárido (UFERSA), in the municipality of Mossoró, RN, Brazil (5º 11" S and 37º 20" W , with 18 m of altitude).

The climate of the region is semi-arid according to Thornthwaite, and BSwh', hot and dry, according to Köppen's classification, with average annual rainfall of 673.9 mm, average temperature of 27 °C and air relative humidity of 68.9%, with two climatic seasons: a dry one, which usually occurs from June to January, and a rainy one, from February to May (Carmo Filho & Oliveira, 1995).

The experiments were conducted in areas that were under spontaneous vegetation, not yet fertilized. The soil of the experimental areas was classified as Oxisol, of sandy loam texture and flat relief.

Before installing the experiments, composite soil samples were collected in the experimental areas at depths of 0-20 cm and 20-40 cm, for chemical characterization and determination of clay content (Table 1).

Some climatic data were recorded along the experiments, as presented in Table 2.

The treatments consisted of the combination of three levels of P (low, medium and high) and eight maize cultivars (Dona Josélia, Carrapateira, Pontinha, Cruzeta, Potiguar, BRS 2022, Status, AG 1051). The experimental design was randomized blocks in a 3 x 8 factorial scheme, with four repetitions.

Each experimental plot consisted of three rows with length of 3 m, spaced apart by 0.8 m, containing 10 plants in each row, considering as the usable area the central row, disregarding one plant on each end.

The three P levels were used to evaluate the efficiency of P use by maize cultivars. The low level corresponds to the original P content of the soil, while the medium and high levels correspond to the P_2O_5 doses of 40 and 80 kg ha^{-1}, that is, 50 and 100% of the dose recommended for maize, according to Cavalcanti (2008).

Table 1. Chemical attributes and soil clay content before the experiment, evaluated in the 0-20 and 20-40 cm layers, in two seasons

Depth (cm)	pH	P	K	Na	Ca	Mg	Al	(H+Al)	Clay
		(mg dm^{-3})			($cmol_c$ dm^{-3})				(g kg^{-1})
Season 1 (March to July, 2017)									
0-20	5.00	0.1	35.5	8.8	0.40	0.60	0.05	1.16	153
20-40	4.40	0.1	34.5	4.8	0.20	0.50	0.15	1.32	244
Season 2 (August to December, 2017)									
0-20	5.80	2.0	36.9	8.0	0.80	0.30	0.15	0.99	140
20-40	5.40	1.0	40.9	5.0	0.30	0.30	0.25	1.49	229

Table 2. Climatological data of Mossoró, RN, Brazil, from March to December 2017[1]

Month	Temperature (ºC)			Total global radiation	Accumulated precipitation	Air relative humidity (%)	
	Max	Mean	Min	(W m^{-2})	(mm)	Max.	Min.
March	36.04	27.24	22.49	225.83	137.00	98.10	44.50
April	36.47	27.33	20.77	234.00	62.60	99.00	45.60
May	38.64	27.97	19.39	226.38	15.40	98.00	31.90
June	36.31	27.72	20.65	211.31	14.20	97.30	31.50
July	35.64	26.99	19.10	198.87	58.60	98.20	29.30
August	37.92	27.45	19.37	254.67	0.20	93.50	29.00
September	38.45	27.96	19.56	263.64	2.40	90.80	24.50
October	38.64	28.32	21.03	267.05	0.80	91.40	29.30
November	37.15	28.04	20.96	277.66	0.60	91.50	32.90
December	37.29	28.40	21.84	250.93	1.40	93.50	36.70

[1]Data obtained in a semi-automatic weather station installed at Rafael Fernandes Experimental Farm, UFERSA; Max - Maximum; Min - Minimum

Soil tillage was carried out with one plowing and one harrowing, followed by the opening of the furrows with approximately 0.20 m depth for basal fertilization, according to soil analysis and to the recommendation of Cavalcanti (2008) for maize: 30 kg ha^{-1} of N; 60 kg ha^{-1} of K_2O; 1.0 kg ha^{-1} of B; 3.0 kg ha^{-1} of Zn and 0.5 kg ha^{-1} of Cu, whereas P was applied according to the treatments.

The sources used were: urea, potassium chloride, boric acid, zinc sulfate, copper sulfate and triple superphosphate. Topdressing fertilization was performed by applying 30 kg ha^{-1} of N at 15 days after emergence (DAE) and 30 kg ha^{-1} of N when the plant had eight true leaves.

Sowing was performed on 03/16/2017 in Season 1 and on 08/24/2017 in Season 2, with three seeds per pit, at 0.8 x 0.3 m spacing, and thinning was carried out when the plants had four true leaves (nine days after sowing), leaving one plant per pit, in a total of 41,667 plants ha^{-1}.

Irrigation was applied by a drip system, with emitters spaced by 0.3 m and flow rate of 1.4 L h^{-1}. In Experiment 1, irrigations were performed when necessary; a supplementary water depth of 388 mm was applied, as it rained 288 mm along this period. In Experiment 2, as there was virtually no rain (5.4 mm), a 664 mm water depth was applied.

Weed control, when necessary, was performed by manual weeding in the rows and using a hoe in the interrows. Four sprays were performed using the insecticides Decis® (200 mL ha^{-1}) and Premio® (100 mL ha^{-1}) to control fall armyworm (*Spodoptera frugiperda* J. E. Smith).

Harvest was performed manually at the phenological stage R3 (milky grains) at 70 days after sowing (DAS), in both seasons, except for the cultivar Carrapateira, harvested at 85 DAS, in both seasons.

The numbers and yields of marketable unhusked green ears (ears with no evidence of pest or disease attack, ≥ 22 cm long) and marketable husked green ears (ears full of grains and ≥ 18 cm long) were determined.

Two plants per plot were divided into leaves, stem, roots and ears, separately placed in paper bags and dried in a forced air circulation oven at 65 ºC until reaching constant weight.

P analysis was performed in extract obtained by sulfuric digestion of dry material samples. The P concentration in each extract was read using the molybdenum blue method (Malavolta et al., 1997).

P accumulation in each plant part was obtained through the product between the P concentration and the dry matter of the respective parts.

With the data of dry matter, P accumulation and yield of green ears, the following indices were calculated (Fageria, 2008): Agronomic efficiency (AE); Physiological efficiency (PE); Ear production efficiency (EPE); Recovery efficiency (RE) and Use efficiency (UE), using the following equations:

$$AE\left(kg\ kg^{-1}\right) = \frac{\left(PEwP - PEw/oP\right)}{QPa} \quad (1)$$

$$PE\left(kg\ kg^{-1}\right) = \frac{\left(TDMwP - TDMw/oP\right)}{\left(PAwP - PAw/oP\right)} \quad (2)$$

$$EPE\left(kg\ kg^{-1}\right) = \frac{\left(PEwP - PEw/oP\right)}{\left(PAwP - PAw/oP\right)} \quad (3)$$

$$RE\left(kg\ kg^{-1}\right) = \frac{\left(PAwP - PAw/oP\right)}{QPa} \quad (4)$$

$$UE\left(kg\ kg^{-1}\right) = PE\ RE \quad (5)$$

where:

PEwP - production of greens ears with phosphate fertilization, kg;

PEw/oP - production of greens ears without phosphate fertilization, kg;

QPa - quantity of P_2O_5 applied, kg;

TDMwP - total dry matter production with phosphate fertilization, kg;

TDMw/oP - total dry matter production without phosphate fertilization, kg;

PAwP - total P accumulation with phosphate fertilization, kg; and,

PAw/oP - total P accumulation without phosphate fertilization, kg.

The data were subjected to analysis of variance, and the means of P levels were compared by Tukey test, $p \leq 0.05$, while the means of the cultivars were compared by Scott-Knot test, at $p \leq 0.05$, using the statistical program SISVAR (Ferreira, 2011).

Results and Discussion

In both seasons, there was a significant effect ($p \leq 0.05$) of the interaction between P levels and cultivars for all variables. Plants in treatments that did not receive phosphate fertilization (low level of P) were stunted, with purplish color up to V3 stage (first three weeks) and high attractiveness to fall armyworm (*Spodoptera frugiperda*).

The total number of ears (TNE), number of marketable unhusked ears (NMUE), number of marketable husked ears (NMHE), total yield of ears (TYE), yield of marketable unhusked ears (YMUE) and yield of marketable husked ears (YMHE) increased with the increase in P levels (Tables 3, 4 and 5).

The cultivar BRS 2022 had higher TNE at all doses, followed by the cultivars Status, AG 1051 and Potiguar in Season 1. In Season 2, the cultivar Status was statistically superior to the others, followed by AG 1051 (Table 3).

By comparing the TNE of the environment without P application (low level of P) with that of the environment with fertilization (medium and high levels of P), it is possible to observe significant increments when phosphate fertilization was used; according to the overall mean, the highest level of P promoted increments of 41 and 38% compared to the lowest level of P, in Seasons 1 and 2, respectively.

Likewise, NMUE and NMHE also increase with the application of P (Tables 3 and 4), i.e., maize crop responds very well to phosphate fertilization, mainly in terms of the production

Table 3. Mean values for the total number of ears (TNE) and number of marketable unhusked ears (NMUE) in the maize crop as a function of cultivars and P levels in the soil

Cultivar	TNE ha^{-1}			NMUE ha^{-1}		
	Soil P levels			Soil P levels		
	Low	Medium	High	Low	Medium	High
			Season 1 (March to July, 2017)			
Dona Josélia	28646 cC	42969 cB	48177 bA	24740 bB	41667 aA	44271 cA
Carrapateira	16927 eB	32552 dA	35156 dA	16927 cB	29948 bA	35156 dA
Pontinha	19531 eB	42969 cA	41667 cA	19531 cB	40365 aA	40365 cA
Cruzeta	27344 cB	50781 bA	46875 bA	23438 bB	44271 aA	42969 cA
Potiguar	33854 bC	42969 cB	55990 aA	18229 cC	39063 aB	52083 bA
BRS 2022	40365 aB	55990 aA	53385 aA	39063 aB	41667 aB	48177 bA
Status	41667 aC	52083 bB	58594 aA	18229 cC	45573 aB	58594 aA
AG 1051	23438 dB	53385 aA	54688 aA	16927 cC	42969 aB	49479 bA
CV (%)		9.12			9.95	
			Season 2 (August to December, 2017)			
Dona Josélia	22135 cB	44177 bA	42969 eA	22135 cB	41667 bA	39063 cA
Carrapateira	15625 dB	31250 cA	35156 fA	15625 dB	31250 cA	35156 dA
Pontinha	29948 bB	44271 bA	41667 eA	29948 bB	37760 bA	41667 cA
Cruzeta	28646 bB	50781 aA	46875 dA	28646 bB	50781 aA	46875 bA
Potiguar	32552 bC	41667 bB	54688 bA	32552 bC	41667 bB	52083 aA
BRS 2022	39063 aB	41667 bB	49479 cA	39063 aB	42969 bB	48177 bA
Status	41667 aC	52083 aB	59896 aA	29948 bC	50781 aB	57292 aA
AG 1051	28646 bB	53385 aA	54688 bA	28646 bB	52083 aA	54688 aA
CV (%)		8.04			8.56	

Means followed by the same letters, uppercase in the row and lowercase in the column, do not differ by Tukey test at $p \leq 0.05$ and by Scott-Knot test at $p \leq 0.05$, respectively

Table 4. Mean values for the number of marketable husked ears (NMHE) and total yield of ears (TYE) in the maize crop as a function of cultivars and P levels in the soil

Cultivar	NMHE ha^{-1}			TYE (kg ha^{-1})		
	Soil P levels			Soil P levels		
	Low	Medium	High	Low	Medium	High
			Season 1 (March to July, 2017)			
Dona Josélia	0 aC	22135 cB	39063 aA	2752 aC	9232 bB	10121 cA
Carrapateira	0 aB	14323 dA	18229 dA	2719 aB	7757 cA	8418 dA
Pontinha	0 aB	18229 cA	18229 dA	2490 aB	9139 bA	9165 dA
Cruzeta	0 aB	26042 bA	23438 cA	2876 aC	12185 aB	13962 aA
Potiguar	0 aB	28646 bA	28646 bA	2549 aC	9725 bB	14230 aA
BRS 2022	0 aC	19531 cB	29948 bA	3177 aC	11624 aB	13021 bA
Status	0 aC	32552 aB	37760 aA	2876 aB	12749 aA	11818 cA
AG 1051	0 aB	32552 aA	35156 aA	1426 bC	10341 bB	11784 cA
CV (%)		17.05			12.10	
			Season 2 (August to December, 2017)			
Dona Josélia	5208 bB	36458 bA	39063 aA	3074 bB	10184 cA	10424 bA
Carrapateira	6510 bB	15625 cA	18229 cA	3314 bB	8788 cA	9060 cA
Pontinha	15625 aB	33854 bA	29948 bA	5884 aB	10151 cA	11591 bA
Cruzeta	7813 bC	32552 bB	39063 aA	4995 aB	13673 aA	13618 aA
Potiguar	13021 aB	39063 aA	40365 aA	6216 aB	12901 aA	14540 aA
BRS 2022	14323 aC	33854 bB	39063 aA	5962 aB	11527 bA	12969 aA
Status	5208 bB	40365 aA	39063 aA	4792 aB	12875 aA	12990 aA
AG 1051	10417 aC	33854 bB	39063 aA	3215 bB	12117 bA	12941 aA
CV (%)		10.39			11.13	

Means followed by the same letters, uppercase in the row and lowercase in the column, do not differ by Tukey test at $p \leq 0.05$ and by Scott-Knot test at $p \leq 0.05$, respectively

of unhusked ears, husked ears and total. Ribeiro et al. (2016) and Rodrigues et al. (2018) agree that there is an increase in the production of green ears with the increase in P levels.

For the number of marketable unhusked ears (NMUE), the cultivar Status was statistically superior in both seasons, not differing from Potiguar and AG 1051 in Season 2 (Table 3). The cultivar BRS 2022 stood out with respect to NMUE at the low level of P, that is, almost all plants of BRS 2022 produced marketable ears at the minimum level of P, although the result is quite different when the ears are husked.

The cultivars Dona Josélia, Status and AG 1051 had the highest number of marketable husked ears (NMHE) in Season 1. In Season 2, the cultivar Potiguar proved to be better at all P levels, without differing from Dona Josélia, Cruzeta, BRS 2022, Status and AG 1051 (Table 4). There was no difference between the medium and high levels of P for most cultivars, with respect to TNE, NMUE and NMHE.

In Season 1, none of the cultivars produced marketable husked ears at the low level of P. Soil P contents in both experimental areas were below the sufficiency level for maize proposed by Malavolta et al. (1997), who suggest 6 mg dm^{-3} of P in the superficial layer of 0-10 cm.

However, the available P content in the soil in Season 1, in the 0-20 cm layer, was 20 times lower than that of Season 2, which contributed to the non-occurrence of marketable husked ears at the low level of P in this season.

Table 5. Mean values for the yield of marketable unhusked ears (YMUE) and yield of marketable husked ears (YMHE) in the maize crop as a function of cultivars and P levels in the soil

Cultivar	YMUE (kg ha^{-1})			YMHE (kg ha^{-1})		
	Soil P levels			Soil P levels		
	Low	Medium	High	Low	Medium	High
			Season 1 (March to July, 2017)			
Dona Josélia	2372 aB	10121 bA	10266 cA	0 aC	4919 aB	6508 aA
Carrapateira	2613 aC	7757 dB	9067 dA	0 aC	1422 cB	3012 cA
Pontinha	2046 bB	9139 cA	9165 dA	0 aB	2068 cB	4208 bA
Cruzeta	2766 aC	11402 aB	13962 aA	0 aB	4928 aA	5031 bA
Potiguar	1622 bC	9725 bB	13762 aA	0 aB	5323 aA	6227 aA
BRS 2022	3177 aC	9706 bB	12195 bA	0 aC	3461 bB	5397 aA
Status	1798 bB	12176 aA	11704 bA	0 aB	5970 aA	6530 aA
AG 1051	910 bC	9276 cB	11353 bA	0 aB	4532 aB	6256 aA
CV (%)		13.51			25.92	
			Season 2 (August to December, 2017)			
Dona Josélia	3074 bB	10184 bA	10424 bA	378 bC	5271 bB	6892 bA
Carrapateira	3314 bB	8788 bA	9460 bA	689 bB	2960 cA	3169 cA
Pontinha	5796 aB	10151 bA	11591 aA	2605 aB	5991 bA	6102 bA
Cruzeta	4878 aB	13673 aA	13618 aA	1017 bB	6172 bA	7335 aA
Potiguar	5992 aB	12901 aA	12302 aA	1754 aB	7690 aA	8393 aA
BRS 2022	5895 aC	9840 bB	12473 aA	1884 aB	5625 bA	6595 bA
Status	3901 bC	10549 bB	12875 aA	749 bB	7967 aA	7367 aA
AG 1051	3215 bB	12117 aA	12941 aA	813 bB	6900 aA	8005 aA
CV (%)		12.82			17.89	

Means followed by the same letters, uppercase in the row and lowercase in the column, do not differ by Tukey test at $p \leq 0.05$ and by Scott-Knot test at $p \leq 0.05$, respectively

In the rainy period, there was a higher incidence of pests in the area of Season 1, especially in the environment without P application. In addition, the month of March, planting period in Season 1, concentrated the largest amount of rains of the year (Table 2), which may have washed some nutrients from the profile, mainly the nitrogen applied as basal fertilization.

The conditions described above also contributed to the absence of marketable husked ears, as well as to the lower production of ears at the low level of P in Season 1.

The cultivars Cruzeta and Potiguar differed statistically from the others, with the highest values of total yield of ears (TYE) in Season 1. For Season 2, Cruzeta, Potiguar and Status were the best at all doses, followed by BRS 2022 and AG 1051. The cultivars did not differ statistically between the medium and high levels of P in Season 2 (Table 4).

In relation to the yield of marketable unhusked ears (YMUE), the cultivars Cruzeta and Potiguar showed higher values at the high level of P in Season 1. In Season 2, Cruzeta stood out at all levels of P, followed by AG 1051, Status, BRS 2022, Potiguar and Pontinha. There was difference between the medium and high levels of P in Season 2 only for the cultivars BRS 2022 and Status (Table 5).

For the yield of marketable husked ears (YMHE), Dona Josélia, Status, AG 1051, Potiguar and BRS 2022 were better in Season 1, under the high level of P. Among these, only BRS 2022 differed statistically at the medium level of P.

In Season 2, the cultivars Potiguar, AG 1051, Status and Cruzeta had higher values. Except for Dona Josélia, the cultivars did not differ between the medium and high levels of P in Season 2 (Table 5).

In general, the variables TYE, YMUE and YMHE were higher in Season 2 than in Season 1, especially at the low level of P (Tables 4 and 5). Besides the higher P content in the area of Season 2, another relevant factor is the global solar radiation along this season, which was much higher (Table 2), especially in October, the period of ear filling.

The maximum use of radiation occurs in pre-flowering and grain filling, which represent the most critical period (Rosa et al., 2017). The effect of radiation is also responsible for the similarity of values between the medium and high levels of P for TYE, YMUE and YMHE in Season 2. Thus, a lower level of P can be used and, despite that, a large amount of green ears can be obtained.

The good performance of Cruzeta and Potiguar in terms of TYE, YMUE and YMHE is due to the fact that these cultivars are adapted to the region where the experiments were conducted, with excellent characteristics of adaptability to the northeastern climate and good production stability, being able to express all their production potential.

AG 1051 also stood out with respect to these variables, which was expected given the purpose of use of this cultivar, which is production of green ears, besides being recommended for the climatic conditions of the area where the experiments were installed. Status was another relevant cultivar in the present study, due to its good production stability and wide adaptation to the management adopted.

It is worth pointing out that the above-mentioned cultivars were highly responsive to the use of P, with significant increases in the production of green ears and, whatever the purpose, production of either unhusked or husked ears, the experiment conducted in the dry period (Season 2) showed better results than that conducted in the rainy period (Season 1), especially in relation to the production of marketable husked ears.

In both seasons, regarding the indices of nutritional efficiency, there was a significant difference between cultivars for all efficiency indices evaluated, whose means can be observed in Table 6.

The cultivars Cruzeta, Potiguar, BRS 2022 and AG 1051 showed higher agronomic efficiency (AE) in Season 1. Thus, for each kg of P_2O_5 applied to the soil, these cultivars produced 138.57, 146.01, 123.05 and 129.47 kg of green ears, respectively. In Season 2, AG 1051, Cruzeta, Potiguar and Status were the most efficient cultivars (Table 6).

Table 6. Mean values for agronomic efficiency (AE), physiological efficiency (PE), ear production efficiency (EPE), recovery efficiency (RE) and utilization efficiency (UE) in maize crop

Cultivar	AE	PE	EPE	RE	UE
	(kg kg^{-1})				
Season 1 (March to July, 2017)					
Dona Josélia	92.11 b	478.46 d	440.94 c	0.21 e	100.26 f
Carrapateira	71.24 c	431.14 e	187.62 e	0.38 a	163.59 a
Pontinha	83.44 c	425.23 e	333.09 d	0.25 c	106.47 e
Cruzeta	138.57 a	609.75 b	659.61 a	0.22 e	128.39 c
Potiguar	146.01 a	491.20 d	672.49 a	0.22 e	106.58 e
BRS 2022	123.05 a	685.66 a	741.94 a	0.17 f	113.51 d
Status	111.77 b	499.22 d	424.98 c	0.26 b	131.15 c
AG 1051	129.47 a	588.13 c	566.68 b	0.23 d	134.37 b
CV (%)	22.51	12.44	23.47	14.59	15.42
Season 2 (August to December, 2017)					
Dona Josélia	91.88 b	444.47 b	573.95 a	0.16 c	71.29 b
Carrapateira	71.83 b	415.60 c	212.18 c	0.34 a	140.18 a
Pontinha	71.34 b	443.70 b	401.05 b	0.18 b	78.59 b
Cruzeta	107.80 a	402.64 c	595.11 a	0.18 b	73.38 b
Potiguar	104.05 a	456.54 b	621.63 a	0.17 c	76.31 b
BRS 2022	87.58 b	473.14 b	520.26 a	0.17 c	79.53 b
Status	101.04 a	556.34 a	677.78 a	0.15 c	82.89 b
AG 1051	121.58 a	413.89 c	671.71 a	0.18 b	75.29 b
CV (%)	19.11	14.24	21.63	15.31	16.59

Means followed by the same letter do not differ by Scott-Knot test at $p \leq 0.05$

It is worth remembering that, in order to obtain high yields, the recommended quantity does not always correspond to the same quantity that promotes gains in agronomic efficiency, so agronomic efficiency may decrease as a function of P levels, because the supply of P exceeds the needs of the crop (law of diminishing returns).

For physiological efficiency (PE), the cultivar BRS 2022 showed higher value in Season 1, when for each kg of accumulated P, the plant produced 685.66 kg of dry matter (Table 6). In Season 2, Status stood out from the others, producing 556.34 kg of dry matter per kg of accumulated P. It can be said that these cultivars were the most efficient in the absorption and conversion of P to dry matter production.

In relation to ear production efficiency (EPE), which indicates the efficiency of the cultivar in converting P for the production of ears, Cruzeta, Potiguar and BRS 2022 reached the highest values in Season 1.

In Season 2, Status showed the highest value, without differing statistically from AG 1051, Potiguar, Cruzeta, Dona Josélia and BRS 2022 (Table 6). It can be inferred that these cultivars were the most efficient in the processes associated with the absorption, assimilation and redistribution of P in the plant.

For recovery efficiency (RE), amount of nutrient accumulated per unit of nutrient applied, the cultivar Carrapateira had the highest value in both seasons (Table 6). This result was already expected, because Carrapateira was the cultivar that had the highest P accumulation in both seasons.

However, this cultivar did not show the best values of agronomic efficiency or ear production efficiency, that is, there was greater contribution of leaves and stems in P partition to the detriment of the ears.

The greater amplitude in P accumulation between the low and high levels of P, i.e., very low accumulations at the minimum level and high accumulation at the maximum level of P, contributed to the higher recovery efficiency of the cultivars in Season 1.

Regarding the use efficiency (UE), Carrapateira was the best in both seasons, because of the higher RE of this cultivar, since UE corresponds to the product of physiological efficiency and recovery efficiency (Table 6). Here also, the values of Season 1 were higher than those of Season 2, being directly influenced by the greater difference between P accumulations at low and high levels of P.

The good performance of the cultivar Carrapateira in terms of UE is due to its higher mass and volume of roots, which contributes to the greater absorption and accumulation of P. DoVale et al. (2013) agree that the large volume of roots in maize plants favors P use efficiency.

Other authors (Bayuelo-Jiménez & Ochoa-Cadavid, 2014; Pelá et al., 2017; Spolaor et al., 2018) argue that there are variations among maize cultivars regarding P use efficiency, which was observed in the present study. In this context, the cultivar Carrapateira has great potential to be explored in breeding programs aiming at P use efficiency.

Conclusions

1. The cultivars showed better production performance when fertilized with phosphorus.

2. The cultivars Cruzeta, Potiguar, BRS 2022, Status, AG 1051 and Carrapateira were the most efficient ones in the use of phosphorus for the production of green maize.

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