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Agronomic Efficiency and Productivity of Sorghum in Response to Fertilizers With Different Phosphorus Solubilities in Greenhouse Conditions

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Abstract

The experiment was conducted under controlled conditions in the municipality of Sobral, Ceará, Brazil, to evaluate the agronomic efficiency of phosphate fertilizers with different solubilities on the cultivation of sorghum in a Luvisol. The experimental design comprised randomized blocks in a 2 × 6 factorial scheme (two genotypes and five phosphorus treatments plus the control, without phosphorus). The treatments were: monoammonium phosphate, triple superphosphate, sheep manure, organic compost based on livestock residues, and organomineral fertilizer. Three blocks were used, and each plot comprised composed of a pot containing two plants. Sixty-five days after germination, the plants were harvested for evaluation of biometric data, biomass, accumulation of nutrients in the aerial part, soil fertility, agronomic efficiency index of the phosphate fertilizers and triple superphosphate equivalent. The organomineral and triple superphosphate fertilizers had the highest agronomic efficiency for production of sorghum biomass. The more soluble sources (organomineral, triple superphosphate and monoammonium phosphate) enabled a better phosphorus recovery rate and physiological efficiency than the sources with low solubility.

Keywords: hybrid, semiarid, *Sorghum bicolor*, variety

1. Introduction

Evaluation of the agronomic efficiency of fertilizers on annual crops provides valuable information, especially when considering the possible use of alternative nutrient sources. Some studies have demonstrated the advantages of knowing the efficiency of organic fertilizers and minerals in comparison to reference sources (Lourenço, Corrêa, Ernani, Lopes, & Nicoloso, 2013). Interest is growing in the reuse of wastes from different sources for application in agriculture, with organic residues and animal manure being the most common (Nunes, Menezes, Benites, Lima Júnior, & Oliveira, 2015; Mahomood, Khan, Ashraf, Shahzad, Hussain, Abid, & Ullah, 2017).

The need for use fertilizers is particularly strong in semiarid regions, owing to the characteristics of low rainfall (±800 mm $year^{-1}$) and soils with low concentrations of organic matter (OM), nitrogen and phosphorus (Menezes et al., 2012). Family farmers in these regions typically have low crop productivity because of small nutrient replacement (Souza et al., 2014). This, together with periods of below-average rainfall, compromises food security (Marengo et al., 2018).

Studies to investigate the effects of organic fertilizers have shown positive effects on the yields of many crops and improved soil fertility (Souza et al., 2016; Mahomood et al., 2017). In addition, the semiarid region of Brazil has the largest herds of goats and sheep in the country, about 8 and 10 million head, respectively (Anualpec, 2014).

Some studies mention that the use of organic compounds or even residues from agricultural activities can supply part of the phosphorus demanded by the crops; furthermore, their combination with mineral fertilizers can potentiate or increase the efficiency of phosphorus use (Borges et al., 2019; Sá et al., 2017).

Therefore, the use of the manure manure could be a better alternative for nutrient supply than the use of conventional mineral fertilizers. Furthermore, the use of organic inputs associated with mineral fertilizers is fundamental for sustainable production systems (Nunes et al., 2015; Lourenço et al., 2013; Fernandes, Grohskopf, Ferreira, & Bull, 2015).

In semiarid regions, sorghum culture is an important alternative to feed the animals, because it is a plant with a good potential for mass production and it is adapted to the tropical conditions of these regions (Gomes, Pitombeira, Neiva, & Candido, 2006).

Therefore, the objective of this work was to evaluate the agronomic efficiency of phosphorus sources with different solubilities on the growth of sorghum plants with different demands, and their effects on the fertility of a Luvisol.

2. Methods

The experiment was carried out in a greenhouse located in the municipality of Sobral, state of Ceará, in northeastern Brazil, in the first half of 2016. The physical structure allowed for the control of humidity and temperature, with averages during the study of 85% and 28 °C, respectively. Besides this, the structure had a spray irrigation system to maintain the soil moisture.

The soil used in the experiment was a Haplic Luvisol; the chemical and granulometric characteristics of this soil are described in Table 1. Luvisol was used because it is a representative soil class of Brazilian semiarid areas where rainfed agriculture is practiced.

Table 1. Chemical and physical properties of the soil

pH(water)	O.M.	P (Mehlich-1)	K	Ca	Mg	H+Al	SB	CEC	V
	g dm^{-3}	-------- mg dm^{-3} --------		----------------------- mmol$_c$ dm^{-3} -----------------------					%
6.2	18	32	183	40	15	25	59.9	84.9	70
S-SO$_4^{2-}$	Na	Cu	Fe	Zn	Mn	B	Clay	Silt	Sand
-- mg dm^{-3} --							-------------- g kg^{-1} ---------------		
4	6	0.5	8	0.85	0.21	0.21	189	181	630

Note. pH in water, v/v; OM: organic matter, Walkley-Black method; P, K, Na, Cu, Fe, Zn, Mn: Mehlich-1 method; Ca, Mg Al: 1 mol L^{-1} KCl method; H+Al: potential acidity, calcium acetate 0.5 mol L^{-1} pH7 method; SB: sum of bases; CEC: cation exchange capacity; V: base saturation; S-SO$_4^{2-}$: method BaCl2; B: hot water; Coarse sandy, fine sandy, silt, clay: pipette method.

The experimental design was completely randomized blocks (CRB) in a 2 × 6 factorial scheme, with three repetitions. The CRB design was chosen because the greenhouse used has shade on one of its lateral faces, with the presence of expanded clay, which is used to control the relative humidity. Therefore, the repetitions were grouped to assure homogeneous insolation within the blocks. One of the experimental factors was sorghum genotype (BRS Ponta Negra variety and an experimental hybrid developed by the Embrapa Corn and Sorghum research unit called CNPMS); the over was different phosphorus fertilizers. Two of these were organic fertilizers (sheep manure- SM and organic compost from livestock residues-OCLR), one was organomineral fertilizer (OMF), and two were mineral fertilizers (monoammonium phosphate-MAP and triple superphosphate-TSP), in addition to the control without fertilization. The organic compost was produced from wastes from the breeding and slaughter of goats and sheep, as described by Souza et al. (2019). After the composting procedure, the material was passed through a sieve with a 2 mm mesh. SM was obtained from the livestock breeding area of the Embrapa Goat and Sheep research unit (*Embrapa Caprinos e Ovinos*) and was cured in a manure storage tank.

The organomineral fertilizer was produced in the laboratory of the Embrapa Soil research unit using OCLR as the organic matrix and MAP as the mineral matrix, in proportions of 67% OCLR and 33% MAP. The OMF was granulated in a disc granulator, dried at 65 °C to constant moisture and classified by passing through sieves with mesh sizes between 1 and 4 mm.

Based on the analysis of the soil employed and the sorghum fertilization parameters recommended for the state of Ceará, according to Fernandes (1993), we applied per pot 0.08 g of N, 0.15 g of P_2O_5 and 0.11 g of K_2O per pot, and in the top dressing 0.15 g of N per pot; the corresponding in kg per hectare of 20, 40 and 30 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, in addition to 40 kg ha^{-1} of N as top dressing. There was no need for acid neutralization. Table 1 reports the concentrations of N, P_2O_5 and K_2O in the fertilizers used in this study. In light of the nutrient values, we calculated for each source the respective quantity necessary to achieve the recommended phosphorus dose (total) for each source and then corrected the other elements; urea (45% N) and potassium chloride (60% K_2O) were used when necessary. The SM had a positive balance of nitrogen and potassium, so there was no need for complementation. The other fertilizers presented a negative balance of these nutrients, thus they were replaced by the mineral fertilizers (Table 2). The control treatment involved application only of nitrogen and potassium, to comply with the soil analysis and the recommendations for sorghum growth.

Table 2. Chemical composition and quantities applied of fertilizers

Treatments	N	P_2O_5[1]	K_2O	Physical form	Fertilizers	N	P_2O_5	K_2O
					Quantity applied			
	%				g/pot			
Recommendation						0.23[2]	0.15	0.11
Sheep Manure (SM)	2.0	0.6	2.2	Powder	25.00	0.25	0.15	0.55
				Remainder				
						+0.02	0	+0.44
Organic Compost Based on Livestock Residues (OCLR)	2.1	2.1	1.9	Powder	7.20	0.14	0.15	0.13
				Remainder				
						-0.09	0	+0.02
Organomineral Fertilizer (OMF)	4.0	16.0	1.0	Granulated	0.94	0.04	0.15	0.09
				Remainder				
						-0.19	0	-0.10
Monoammonium Phosphate (MAP)	10.0	50.0	0.0	Granulated	0.30	0.03	0.15	0
				Remainder				
						-0.20	0	-0.11
Triple Superphosphate (TSP)	0.0	43.0	0.0	Granulated	0.35	0	0.15	0
				Remainder				
						-0.23	0	-0.11

Note. [1]P_2O_5 total. [2]Quantity considering the planting dose and nitrogen top dressing. (+) Positive balance between what was applied with the fertilizer tested and no need for supplementation with another source. (-) Negative balance between what was applied with the fertilizer tested and the need for complementation with another source (mineral).

The fertilizers MAP, TSP and OMF were applied in the furrow, at a depth of 5 cm in each pot. The organic fertilizers OCLR and SM were applied on the surface, with slight incorporation (approximately 2-3 cm deep). Differences in application are is in relation to the quantities recommended; of organic fertilizers, the quantities were larger in relation to mineral fertilizers. Thus, we aimed to accelerate and aiming to accelerate the mineralization of organic sources by incorporating manure and organic compost.

The plants were grown in pots containing 10 kg of soil; ten sorghum seeds were sown for of each genotype, according to the treatment. Seven days after emergence, the plantlets were culled, leaving only the two most vigorous plantlets in each pot. The experiment lasted 65 days after germination.

The biometric variables evaluated were: height; stem diameter; number of leaves; leaf area (in cm^2; with a LI-COR® LI3100 leaf area meter) (Payne, Wendt, Hossner, & Gates, 1991), and relative chlorophyll content (determined in the middle of the leaf blade +3, using a Minolta SPAD 502® chlorophyll meter) (Yamamoto, Nakamura, Adu-Gyamfi & Saigusa, 2002). After these variables were measured, the plants were cut and divided into stems and leaves for quantification of dry weight after drying the material in forced-air ovens (60 °C) to constant weight. The values of dry weight of stems and leaves were used to calculate the total dry biomass, and then the material was ground for analysis of macro and micronutrients (Miyazawaet al., 2009). The nutrient values were multiplied by the total weight of plants (per pot) to calculate the accumulation of nutrients. After harvesting of the plants, the soil was collected from each pot for chemical analysis of the following parameters: pH, OM, P, K, Ca, Mg, Na, H+Al, $S\text{-}SO_4^{2-}$, B, Cu, Fe, Mn and Zn, as described by Donagemma et al. (2011); finally, the following attributes were calculated: sum of bases (SB), cation exchange capacity (CEC), and base saturation (V).

The response variables of the treated sorghum plants were used to calculate the agronomic efficiency index: AEI (%) = $[(TDW_1 - TDW_2)/(TDW_3 - TDW_2)] \times 100$ (Goedertet al., 1986); the triple superphosphate equivalent: Eq.TSP (%) = $100 \times (TDW_3/TDW_1)$ (Goedert et al., 1986); physiological efficiency of phosphorus: Phys.Ef. (mg mg^{-1}) = $(TDW_1 - TDW_2)/(AcP_1 - AcP_2)$ (Fageria, 2000); and phosphorus recovery rate, PRR (%) = $(AcP_1 - AcP_2)/(QPa) \times 100$ (Fageria, 2000); where TDW_1 is the total dry weight of sorghum per pot according to the sources studied (SM, OCLR, OMF, and MAP); TDW_2 is the total dry weight of sorghum in the control pot (absence of phosphorus); TDW_3 is the total dry weight of sorghum per pot according to the triple superphosphate source; AcP_1 is the accumulation of phosphorus per pot from the source studied; AcP_2 is the accumulation of phosphorus per pot in the control (absence of phosphorus); and QPa is the quantity of phosphorus applied per pot.

The data were submitted to analysis of variance (ANOVA), and according to the significance, were submitted to the Scott-Knotttest (at 5%) regarding the effects of the different phosphorus solubilities of the treatments (low and high solubility). Finally, the a *t*-test was used to compare the genotypes. All the analyses were performed with the help of the SISVAR software (Ferreira, 2011).

3. Results

Analysis of soil fertility revealed no differences between the two genotypes. However, for the fertilizer type factor, the variables pH and potential acidity presented significant differences. The soil pH was highest when using SM (6.1); low values for potencial acidity were observed for the control (25 $mmol_c$ dm^{-3}), SM (25 $mmol_c$ dm^{-3}) and organomineral fertilizer (24 $mmol_c$ dm^{-3}). With respect to phosphorus, an effect of interaction between genotypes and sources was observed (Table 3).

The interaction between genotypes and phosphorus sources was significant for phosphorus in the soil. For BRS Ponta Negra, there were no differences between the fertilizers studied, whereas for the sorghum hybrid, the highest values were obtained for the fertilizers that contained mineral sources. Regarding the effect of the sorghum genotypes within each fertilizer treatment in relation to the concentration of phosphorus in the soil, there was a difference the control and SM treatments, in which the P value was higher for BRS Ponta Negra than for the hybrid (Table 3).

Table 3. Concentration of phosphorus in the soil, biomass of plant, accumulation of nitrogen, phosphorus and potassium in the plants, agronomic efficiency index of phosphate fertilizers in function of sorghum genotypes and source of phosphate

	P_{soil} (mg dm^{-3})		MST (g/plot^{-1})		N_{plant} (mg/plot)	
	BRS Ponta Negra	Hybrid exp. CNPMS	BRS Ponta Negra	Hybrid exp. CNPMS	BRS Ponta Negra	Hybrid exp. CNPMS
Control	$20^{aA\,£}$	12^{bB}	8.7^{cA}	5.7^{eB}	106^{bA}	52^{dA}
SM	23^{aA}	15^{bB}	10.9^{bA}	10.5^{dA}	115^{bA}	109^{cA}
OCLR	18^{aA}	16^{bA}	11.3^{bA}	12.9^{cA}	179^{aA}	117^{cB}
OMS	20^{aA}	20^{aA}	17.3^{aA}	19.9^{aA}	162^{aA}	193^{aA}
MAP	17^{aB}	24^{aA}	11.8^{bA}	13.3^{cA}	153^{aA}	135^{bA}
TSP	16^{aA}	21^{aA}	19.6^{aA}	16.4^{bB}	178^{aA}	149^{bA}
	P_{plant} (mg/plot)		K_{plant} (mg/plot)		AEI (%)	
	BRS Ponta Negra	Hybrid exp. CNPMS	BRS Ponta Negra	Hybrid exp. CNPMS	BRS Ponta Negra	Hybrid exp. CNPMS
Control	6.0^{cA}	3.7^{cA}	150^{cA}	127^{cA}	-	-
SM	9.5^{bA}	8.8^{bA}	202^{cA}	239^{bA}	16.6^{bB}	46.0^{cA}
OCLR	7.8^{cA}	9.1^{bA}	221^{cB}	310^{aA}	25.6^{bB}	69.3^{cA}
OMS	10.9^{bA}	14.3^{aA}	262^{bB}	417^{aA}	79.6^{aB}	130.7^{aA}
MAP	12.8^{aA}	10.5^{bA}	254^{bB}	343^{aA}	25.3^{bB}	71.6^{cA}
TSP	15.5^{aA}	10.6^{bB}	338^{aA}	368^{aA}	100.0^{aA}	100.0^{bA}

Note. [£]Mean values followed by the same lowercase letters in the column and uppercase in the row do not differ by the Scott-Knott test (5%).

Regarding the interaction between genotypes and fertilizers for dry weight production, the hybrid presented greater productivity if combined with the organomineral fertilizer (compared to other fertilizers), whereas for BRS Ponta Negra, the highest values were obtained with the organomineral and triple superphosphate fertilizers (Table 3).

For the input MAP, with readily available phosphorus (P in the soil), the superiority of the hybrid over BRS Ponta Negra was more pronounced, a result opposite from that observed in the control and SM treatments. With respect to the biometric and biomass variables, the hybrid was superior in terms of plant height but was inferior in terms of number of leaves in relation to the BRS Ponta Negra variety. No effects were observed for phosphorus sources for relative to chlorophyll content, whereas for plant height, the SM, organomineral fertilizer and triple superphosphate treatments were superior to the others; regarindg the number of leaves, leaf area and total dry weight the result was similar, where the organomineral and triple superphosphate fertilization promoted higher values than the other sources. Finally, all the phosphorus sources used promoted higher dry weight values than the control treatment (Table 4).

Table 4. Mean values, significance and coefficient of variation for biometric variables, indirect chlorophyll measurements and biomass in function of sorghum genotypes and sources of phosphorus

Genotypes (G)	Height	No. Leaves	Leaf Area	RCC	Total DW
	cm		cm^2		g/plot
BRS Ponta Negra	108b	9.7a	4197	35.2	13.2
Hybrid exp. CNPMS	122a	9.0b	4571	32.3	13.0
Significance	*	*	Ns	ns	Ns
Sources(S)					
Control	99b[1]	8.5b	3759b	34.7	7.2c
SM	120a	8.9b	4166b	31.8	10.7b
OCLR	100b	9.3b	4087b	36.2	12.1b
OMF	142a	10.4a	5327[a]	32.1	18.3[a]
MAP	102b	9.3b	4170b	35.6	12.6b
TSP	130a	9.8a	4805[a]	31.9	18.0a
Significance	**	*	*	ns	**
G × S	ns	ns	Ns	ns	**
CV (%)	16.6	9.5	17.4	12.7	10.6

Note. RCC: relative chlorophyll content; Total DW: total dry weight. [ns], * and **: Not significant, significant at 5 and 1% probability. [1]Mean values followed by the same letters in the column do not differ by the Scott-Knott test (5%).

Regarding the increases in dry weight in the plants grown with fertilizer in comparison with the control, the following decreasing order was noted: OMF (154%) > TSP (150%) > MAP (75%) > OCLR (68%) > SM (49%). These results indicate the superiority in using phosphorus sources with high solubility over those with low solubility, and that the organomineral fertilizer, which contains MAP, promoted better results, but similar to those of the reference source (triple superphosphate).

Irrespective of genotype, the application of phosphate from all sources increased the production of dry matter in relation to the control treatment. Regarding the effect of each input between the two genotypes, higher values were observed for BRS Ponta Negra in the control and triple superphosphate treatments, with no differences between genetic materials for the other treatments.

The sorghum genotypes presented distinct responses in accumulation of the nutrients nitrogen (N), potassium (K), calcium (Ca), sulfur (S), boron (B), iron (Fe) and manganese (Mn): BRS Ponta Negra performed best for accumulation of N, Ca, S, Fe and Mn and the hybrid was best for K and B (Table 5).

Table 5. Mean values, significance and coefficient of variation for the accumulation of macro and micronutrients in function of sorghum genotypes and sources of phosphorus

Genotypes (G)	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	mg/pot						μg/pot				
BRS Ponta Negra	149^{a}	10.4	238^{b}	43^{a}	23	15^{a}	199^{b}	50	1821^{a}	988^{a}	342
Hybrid exp. CNPMS	126^{b}	9.4	301^{a}	33^{b}	21	11^{b}	248^{a}	55	1260^{b}	710^{b}	321
Significance	**	ns	**	**	ns	**	*	ns	**	**	ns
Sources(S)											
Control	79^{d1}	4.8^{c}	138^{d}	19^{c}	11^{c}	8^{b}	116^{c}	29^{b}	804^{c}	462^{b}	185^{b}
SM	112^{c}	9.1^{b}	220^{c}	29^{b}	18^{b}	10^{b}	212^{b}	44^{b}	1060^{c}	651^{b}	295^{a}
OCLR	148^{b}	8.5^{b}	266^{b}	35^{b}	21^{b}	14^{a}	196^{b}	45^{b}	1882^{b}	889^{a}	336^{a}
OMF	177^{a}	12.5^{a}	340^{a}	50^{a}	30^{a}	17^{a}	243^{b}	66^{a}	2513^{a}	1156^{a}	361^{a}
MAP	144^{b}	11.6^{a}	298^{b}	37^{b}	24^{a}	14^{a}	201^{b}	62^{a}	1333^{c}	877^{a}	427^{a}
TSP	163^{a}	13.1^{a}	353^{a}	58^{a}	30^{a}	18^{a}	373^{a}	72^{a}	1708^{b}	1061^{a}	385^{a}
Significance	**	**	**	**	**	**	**	**	**	**	**
G × S	**	*	*	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	13.1	20.3	16.6	24.7	26.3	23.4	29.6	26.5	28.3	33.3	29.9

Note. ns, * and **: Not significant, significant at 5% and 1% probability. [1]Means followed by the same letter in the column do not differ by the Scott-Knott test (5%).

In relation to the sources studied, some groupings of results can be formed. For N, K, and Ca, the highest accumulations were produced when organomineral and triple superphosphate fertilizers were applied; for P, Mg, S, Mn and Zn, the highest levels were achieved when applying fertilizers with soluble sources (OMF, MAP and TSP); for B, the highest accumulation occurred when the source was triple superphosphate; and for Zn, all the sources applied promoted higher values in comparison with the control. In general, there was a significant difference between the application of phosphate and the control, leading to higher accumulation of all the nutrients (N, P, K, Ca, Mg, B and Zn) when employing any of the fertilizers (Table 5).

The interaction (genotypes × sources) was significant for the accumulation of NPK (Table 6). Analyzing the effect of the inputs on the hybrid, OMF was superior in supplying nitrogen and phosphorus, whereas there was greater accumulation of potassium by applying OMF, TSP, MAP, and OCLR. In turn, for the BRS Ponta Negra variety, accumulation of N was the greatest with the use of OMF, TSP, MAP and OCLR, whereas TSP and MAP promoted the highest accumulation of P, and TSP did the same for K (Table 3). OMF also promoted the greatest accumulation of macronutrients in the sorghum plants (Table 5).

Analysis of the effect of each input regarding the accumulation of N between the genotypes revealed the superiority of OCLR for BRS Ponta Negra, whereas the highest accumulation of P by this genotype occurred with use of TSP; for the accumulation of K, the content in the hybrid was highest when using OMF, MAP, and OCLR (Table 3).

The variables associated with nutritional efficiency were different between the genotypes in relation to the agronomic efficiency index (AEI), triple superphosphate equivalent (Eq.TSP) and physiological efficiency (Phys.Ef.). The results indicated higher AEI and Phys. Ef. for the hybrid and greater Eq.TSP for the BRS Ponta Negra variety (Table 6).

Table 6. Mean values, significance and coefficient of variation for agronomic efficiency index (AEI), triple superphosphate equivalent (EqTSP), phosphorus recovery rate (PRR) and physiological efficiency (Phys.Eff.) in function of sorghum genotypes and sources of phosphorus

Genotypes	AEI	EqTSP	PRR	Phys.Eff.
	-------------------- % --------------------		---------------- mg mg^{-1} ----------------	
BRS Ponta Negra	49.9^b	149^a	3.7	980^b
Hybrid exp. CNPMS	83.5^a	118^b	4.6	1359^a
Significance	**	**	ns	*
Sources(S)				
Control	-	-	-	-
Sheep Manure	31.3^{b1}	169^a	2.9^b	792^b
Org. Compost	47.5^b	154^a	2.8^b	1212^b
Organomineral	105.1^a	99^b	4.5^a	1545^a
MAP	48.5^b	144^a	5.1^a	794b
Super T.	100.0^a	100^b	5.5^a	1506^a
Significance	**	**	*	**
C × S	*	ns	ns	Ns
CV (%)	21.7	17.2	42.3	35.1

Note. ^{ns}, *, and **: Not significant, significant at 5% and 1% probability. [1]Mean values followed by the same letters in the column do not differ by the Scott-Knott test (5%).

These results are coherent because another study showed that hybrids presented better nutritional efficiency and were more responsive to fertilization in relation to varieties, including higher recovery of the phosphorus applied (Carvalho, Von Pinho, & Davide, 2012). Among the fertilizers tested, the highest values fir the AEI and Phys. Eff. were obtained with the triple superphosphate and organomineral fertilizer; the greatest PRR rate was associated with the soluble sources (TSP, OMF, MAP), and for the Eq.TSP, the highest values were produced by the organomineral, with values similar to that of TSP.

Regarding the breakdown of the interactions between the inputs and genotypes for the AEI the organomineral source was superior for the hybrid, whereas for the BRS Ponta Negra genotype, the inputs TSP and OMF were associated with the highest AEI values (Table 3). Comparing the genotypes in function of each fertilizer, the hybrid was superior to BRS Ponta Negra in all cases except for TSP (Table 3).

4. Discussion

The potential acidity, in turn, was higher than the other treatments (including the control) when the fertilizer applied involved a mineral matrix, *i.e.*, TSP, MAP and OMF. There are reports in the literature that some organic fertilizers can increase the soil pH (Jin et al., 2016). For sources that reduce the pH, there are studies mentioning that this process is more pronounced when growing plants in pots, where the interactions and reaction are limited by the volume of the pots used (Fernandes et al., 2015).

For differences between fertilizers, this result can be explained by the fact that these fertilizers provide prompt release of phosphorus, making it more available to the plants. Another explanation is the form of application, because the organic fertilizers (SM and OCLR) were applied on the soil surface with slight incorporation, in contrast to the mineral fertilizers, which were applied in the furrow at the time of sowing. In the furrow, the fixation is less than when applied on the total area because the fixation points become saturated quickly, leaving the rest of the phosphorus for uptake by the plants (Caione, Fernandes, & Lange, 2015).

In situations or regions with high concentrations of phosphorus, as in the soil used in this study, the phosphorus moves around the granules of phosphate fertilizers much more easily than in the remainder of the soil solution, where the movement is restricted to a few millimeters (Oliveira, Ernani, Gatiboni, & Pegoraro, 2014). Soil with high initial phosphorus concentrations can be improved by the effects of the mineral fertilizers applied in this study.

Considering that the control treatment did not receive phosphate fertilization (the plants obtained this element exclusively from the phosphorus originally in the soil, which was in high concentrations), we believe that the hybrid was more efficient in absorbing phosphorus than the BRS Ponta Negra. Analogous reasoning can be applied regarding manure.

The greater availability of phosphorus in the soil cultivated with the hybrid can be related to the more efficient use of the nutrient by this genotype. The results of a study involving phosphorus uptake kinetics with different corn varieties revealed different uptake capacities in function of the availability of the nutrient (Inran, Hussan, Zafar-Ul-Hye, & Rehman, 2016). Some inferences can be drawn from the superiority of the organomineral fertilizer. The presence of an organic matrix, in this case the compost made from livestock waste, indicates a synergistic effect of using the two matrices.

Despite the balance of mineral sources of nitrogen and potassium on the inputs OCLR, MAP, OMF, and TSP, as well as the control, distinct behavior was observed regarding the accumulation of these nutrients; this was also observed for the others. In the case of the control treatment, this can be explained by the smaller growth of the plants in the absence of a phosphate fertilizer (law of the minimum), wich causing a the lower accumulation of the elements (macro and micronutrients). Regarding the accumulation of phosphorus, the result can be attributed to the fact that the three inputs (OMF, MAP, and TSP) contain soluble phosphorus.

The organic compost produced similar results to the mineral fertilizers, with regard to accumulation of nitrogen in BRS Ponta Negra, and of potassium in the hybrid. This can be explained by its low C/N ratio, contributing to faster mineralization. A field study indicated that this input increased the levels of N and K in the soil and in corn plants (Souza et al., 2016). Another work compared the effect of mineral and organic fertilizers and reported superiority in those that quickly release the nutrients in comparison to those that need time for the nutrients to mineralize, even when employing organic inputs with low C/N ratio, such as poultry bedding (Lourenço et al., 2013). Some inferences from this study can be drawn regarding morphology of the roots, which can present distinct behaviors. There were differences in the response depending on the initial concentration of phosphorus in the soil, as well as the increase in concentrations of this element in the soil.

The organomineral fertilizer used in this study contains MAP and OCLR, which were also studied individually and presented results below those of OMF. Hence, it can be inferred that the interaction of the two sources had a synergistic effect, with efficiency near that of TSP. Other possible benefits of employing organomineral fertilizers are the positive residual effect of this input on successor crops and a possible increase in the macro fauna in the soil (Sá et al., 2017).

Regarding the organic fertilizers studied, the decomposition of SM is strongly related to the moisture level. Because this study was developed with irrigation, we expected a greater release of nutrients, with beneficial effects on the growth of sorghum. Some authors have reported positive effects on soil fertility and accumulation of nutrients from organic compost produced from residues from the breeding and slaughter of small ruminants (Souza et al., 2016), and that in irrigated conditions this material mineralizes rapidly (Meneses, Sampaio Giongo & Marin, 2017).

The rainfed agriculture practiced in Brazil's semiarid zone relies on a short, wet season, mainly in the first half of the year. In these conditions, organic sources of nutrients associated with mineral fertilizers can adequately supply the nutritional needs of plants, increasing the yield of annual crops. Besides this, application of the material resulting from livestock breeding is beneficial for improving soil fertility, recycling wastes, and increasing crop productivity.

5. Conclusions

The organomineral and triple superphosphate fertilizers presented the highest agronomic efficiency for production of sorghum biomass in comparison with the other phosphorus sources tested. The soluble sources (organomineral, triple superphosphate and monoammonium phosphate) produced a higher phosphorus recovery rate and better physiological efficiency than the sources with low solubility.

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