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Urochloa decumbens growth and P uptake as affected by long-term phosphate fertilization, mycorrhizal inoculation and historical land use in contrasting Oxisols of the Brazilian Cerrado

Crescimento e absorção de P por *Urochloa decumbens* afetado por longos períodos de adubação fosfatada, inoculação micorrízica e histórico de uso em Latossolos contrastantes do Cerrado brasileiro

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ABSTRACT

In the fertility management of highly weathered-leached Brazilian Oxisols, P is the most limiting macronutrient. A greenhouse experiment was conducted with the objective to evaluate the influence of the interaction between P doses, mycorrhizal inoculation and historical land use on *Urochloa decumbens* growth and P uptake in four Oxisols with contrasting chemical, physical and mineralogical properties. The plants were cultivated in plastic pots containing 4 kg of soil in a completely randomized design, four replications and 2x2x2 factorial scheme: with two P doses; with and without mycorrhizal inoculation; soils cultivated for long periods and non-cultivated (under native vegetation). There were two plantings of ten weeks each. Shoot dry mater, concentration and accumulation of P in the shoot were evaluated. In the first planting, the *Urochloa* response was greater in non-cultivated soils associated with inoculation and P addition. However, in the second planting, the inoculation had a greater effect in all soils compared to the first planting associated with the lowest P dose. As the P concentration in the soil increased, P in the shoot dry matter increases. The inoculation did not affect the P concentration and accumulation in the shoot of *Urochloa*. The growth of *Urochloa decumbens* was strongly influenced by the interaction among soil class x history of land use x dose of P x inoculation.

Index terms: Long-term cultivation; Latosols; available P.

RESUMO

No manejo da fertilidade de Latossolos brasileiros altamente intemperizados e lixiviados, o P é o macronutriente mais limitante. Assim, conduziu-se um experimento em casa de vegetação, objetivando-se avaliar a influência da interação entre doses de P, inoculação micorrízica e histórico de uso do solo no crescimento de *Urochloa decumbens* e absorção de P, em quatro Latossolos com atributos químicos, físicos e mineralógicos contrastantes. As plantas foram cultivadas em vasos contendo 4 kg de solo, dispostos em um delineamento inteiramente casualizado, com quatro repetições e esquema fatorial 2x2x2: duas doses de P; com e sem inoculação micorrízica; solos cultivados por longos períodos e não cultivados (sob vegetação nativa). Realizaram-se dois cultivos com duração de 10 semanas cada. Após cada cultivo avaliaram-se a matéria seca da parte aérea, teor e acúmulo de P na parte aérea. No primeiro cultivo, maior resposta ao P aconteceu nos solos sob vegetação nativa em associação à inoculação e adição de P. No segundo cultivo, a inoculação teve maior efeito em todos os solos, associada à menor dose de P. O aumento do P no solo aumenta a concentração desse nutriente na parte aérea. A inoculação não teve efeito na concentração e no acúmulo de P na parte aérea de *Urochloa*. O crescimento de *Urochloa decumbens* foi fortemente influenciado pela interação entre classe de solo x histórico de uso da terra x dose de P x inoculação.

Termos para indexação: Cultivo por longos períodos; Latossolos; P-disponível.

INTRODUCTION

In Brazil, it is estimated that 70% of pasture areas (140 million hectares) are formed by species of the genus *Urochloa (*synonym *Brachiaria)*, 50% constituted by the species *U. decumbens*, followed by *U. brizantha*, *U. humidicola, U. ruziziensis*, *U. dictyoneura*, *U. mutica* and *U. arrecta* (Alvim; Botrel; Xavier, 2002). Although most of them are native to Africa, the species were well adapted to Brazilian soils and weather conditions, particularly in the Midwest and Southeast of Brazil - Cerrado biome. Most of the Brazilian pastures are degraded or under a degradational phase and one of the major causes for that is the lack of management of

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soil fertility. In the Brazilian Cerrado, a well-known limitation to cultivation of plants is the low availability of P (Lopes; Guilherme; Ramos, 2012) due to the high adsorption of this nutrient by iron and aluminum oxides (Bortoluzzi et al., 2015; Motta et al., 2002), mainly in Oxisols, making P less available to plants.

The symbiotic association between mycorrhizal fungi and plant roots increases P uptake capacity (Bressan et al., 2001; Rooney et al., 2011; Sharif; Classssen, 2011; Smith et al., 2011), resistance to water stress (Alizadeh; Zare; Nasr, 2011), biological nitrogen fixation (Veresoglou; Chen; Rillig, 2012), plants resistence to heavy metals (Abdelmoneim; Almaghrabi, 2013; Gucwa-Przepióra et al., 2016), soil aggregation (Tisdall; Oades, 1982) and other favorable soil conditions (Nadeem et al., 2014). Similarly to many cultivated plants, *Urochloa* also responds to mycorrhizal inoculation, which can be a good alternative in the management of pastures (Canizares et al., 2015; Costa et al., 1997; Costa et al., 2012; Santos et al., 2002; Kanno et al., 2006).

The response of a plant to inoculation with mycorrhizal fungi depends on a complex interaction of several factors, such as soil properties (Hart; Forsythe, 2012), historical land use, sources and doses of P applied to soils (Costa et al., 1997; Covacevich; Marino; Echeverría, 2006), P content in soil (Bressan et al., 2001; Covacevich; Echeverría; Aguirrezabal, 2007; Xie et al., 2014), plant nutritional status (Kiriachek et al., 2009) and the inoculum (Costa et al., 2012).

In this context, the objective of this study was to evaluate the growth of *Urochloa decumbens* and P uptake influenced by phosphorus fertilization with and without mycorrhizal inoculation in four Oxisols with contrasting chemical, physical and mineralogical properties, and different historical land use conditions (long time under cultivation and non-cultivated under native vegetation).

MATERIAL AND METHODS

Samples of four Latosols, including those with a long period of cultivations and those non-cultivated, with contrasting chemical, physical and mineralogical properties were collected. Table 1 presents historical land uses of each soil collected. For each soil, composite samples were collected at a depth of 0-20 cm under cerrado as native vegetation (non-cultivated - NC) and under cultivated areas (cultivated - C) for physical, chemical and mineralogical characterization (Donagemma et al., 2011). Physical characterization involved the determination of clay, silt and sand by the pipette method (Gee; Bauder, 1986).

The chemical characterization involved determination of the following soil attributes: pH in water, P-Mehlich 1, P-resin, Ca^{2+}, Mg^{2+}, Al^{3+}, K^{+}, $H^{+} + Al^{3+}$, organic carbon and B, Cu, Fe, Mn, Zn and S. These determinations were performed in triplicate and the original methods are compiled in Embrapa (1997). The clay fraction was evaluated regarding the following attributes: iron extracted by sodium dithionite-citrate-bicarbonate (Fed); iron extracted by ammonium acid oxalate (Feo); hematite and goethite ratio by X-ray diffraction after concentration of iron oxides; kaolinite and gibbsite contents by differential thermal analysis in samples after removal of iron oxides. Contents of SiO_2, Al_2O_3, Fe_2O_3, TiO_2 and P_2O_5 were determined in each soil after sulfuric acid digestion. The maximum phosphate adsorption capacity (MPAC) of each soil was determined according to Olsen and Watanabe (1957), with more details of the methodology described in Motta et al. (2002). The physical, chemical and mineralogical properties of the studied Latosols can be found in Motta et al. (2002).

For the planting of *Urochloa decumbens*, an experiment was conducted in pots in a greenhouse, adopting a completely randomized design with four replications and in a 2x2x2 factorial scheme, namely: i) factor H (historical land use): uncultivated (NC) and cultivated for long periods (C); P factor (P doses): P1 (lower dose) and P2 (higher dose); factor I (mycorrhizal fungi): no inoculation (NI) and inoculation (I).

For assemblage of pots, initially liming was carried out in soils in order to raise the bases saturation up to 60%, using dolomitic lime with Ca:Mg ratio of 4: 1 and total neutralizing power of 100%. The soil remained incubated for 45 days while maintaining the moisture content equivalent to 60% of the total pore volume. A basic fertilization with nutrient solutions for macro- and micronutrients was carried out in order to achieve the following nutrient content in soil (mg kg^{-1}): K (80); S (35); B (0.8); Fe (3.0); Cu (1.5); Mn (3.6); Zn (5.0); and Mo (0.15). For that, the following P.A. sources of nutrients were used: $NH_4H_2PO_4$ NH_4NO_3, K_2SO_4, H_3BO_3, $FeSO_4.7H_2O$, $CuSO_4.5H_2O$, $MnSO_4.H_2O$, $ZnSO_4.7H_2O$ and (NH_4) $6Mo_7O_{24}.4H_2O$. During the preparation of the nutrient solutions, we proceeded the balancing of the accompanying elements. Ca and Mg were supplied via liming.

The P doses applied in each soil were based on maximum phosphorus dose required for maximum dry matter production of corn, obtained in preliminary test under greenhouse conditions (data not published). The doses of P used for each case can be found in Motta et al. (2016). The highest P dose (P2) corresponds to 50% of the dose required for maximum production and the lowest P dose (P1) corresponds to 5%. These doses have been established to avoid inhibiting the development of mycorrhizae (Paula; Siqueira, 1987) regarding the highest dose, and a minimum quantity to not limit plant growth compared to the lowest dose.

Following the application of the treatments and incubation, the fumigation of soil materials with methyl bromide was performed. After the period of ventilation, the mycorrhizal fungi inoculation was performed in half of the total number of pots using 1 mL suspension containing spores of mycorrhizal fungus *Glomus etunicatum*, prepared by the method of Gerdermann and Nicolson (1963). We applied 300 spores per pot in holes where seeds were placed. Initially ten seeds were used per pot, but only two plants were allowed to grow. After planting, we performed the partial recovery of the original microbiota in all pots, via inoculation with filtered extract prepared from the same soils in conditions prior to fumigation.

The experiment included two plantings, maintaining the moisture of the soil corresponding to 60% of the total pore volume. After the first planting that lasted 10 weeks, the plants were cut close to the ground, washed and dried in an oven with forced air circulation for 72 hours at 60 °C. The roots were removed for evaluation of root colonization by mycorrhizae (Giovanette; Mosse, 1980). Also, soil samples were collected from the pots for chemical characterization.

Table 1: Information and historical land use of the studied Latosols.

Soil	Particle size distribution	Parent material	Location	Use	Management practices
LAx	Clayey	Sediments of the Barreiras Formation	Aracruz (ES)	NC: Tropical semiperennial forest	---
				C: Annual crops (corn and bean) for 11 years. Soil was maintained covered with *Panicum maximum* grass during the last 3 years prior to the sampling	Annual phosphate fertilization and occasional liming
LAd	Clayey	Product of the alteration of granitic gneiss	Lavras (MG)	NC: Tropical semicaducifolious forest	---
				C: Annual crops for more than 10 years	Annual phosphate fertilization and occasional liming
LVw	Very clayey	Sediments from the Tertiary	Uberlândia (MG)	NC: Semicaducifolious tropical cerrado	---
				C: Annual crops for more than 10 years	Strong annual phosphate fertilization and liming
LVdf	Clayey	Product of the alteration of tuffite	Patos de Minas (MG)	NC: Tropical semicaducifolious forest	---
				C: Annual crops for more than 15 years. Soil was maintained covered with *Urochloa decumbens* grass during the last 5 years prior to the sampling.	Annual phosphate fertilization and occasional liming

LAx: Dystrocohesive Yellow Latosol; LAd: Dystrophic Yellow Latosol; LVw: Acric Red Latosol; LVdf: Dystroferric Red Latosol; NC: non-cultivated; C: cultivated.

In the soil remaining from the first planting, K and S contents were increased by applying 80 mg kg^{-1} of K_2SO_4, performing a new seedling and a second planting that was also conducted for 10 weeks. The plants were then collected to be obtained the shoot dry matter and P content, in addition to evaluation of root colonization by mycorrhizae and collection of soil from the pots for chemical characterization.

Analysis of variance and test of Tukey were conducted to assess the statistical differences ($p<0.05$) of the effects of interaction between P doses, mycorrhizal inoculation and non-inoculation, and historical of land use (cultivated or non-cultivated soils) on *Urochloa* shoot dry matter, concentration of P in shoot dray matter and total accumulated phosphorus (1st + 2nd plantings).

RESULTS AND DISCUSSION

Shoot dry matter (SDM)

In the first planting, the maximum SDM occurred with the greater dose of P in non-cultivated LAx and LAd and with this very same dose in inoculated LVw and LVdf (Table 2). The minimum production of SDM occurred at the lowest dose of P in LAx and LVdf regardless the land use history. In LAd and LVw, the minimum production occurred at the lowest dose of P in non-cultivated soils. In the second planting, the maximum SDM was obtained in LAx, LAd and LVdf with the highest dose of P (cultivated or not), but in LVw, it only occurred when previously cultivated. The minimum production occurred at the lowest dose of P in non-cultivated LAx and LVw and in non-inoculated LAd and LVdf.

Table 2: *Urochloa decumbens* shoot dry matter in the 1st and 2nd plantings as affected by P doses and mycorrhizal inoculation.

	1st planting				2nd planting			
	Dose of P		Inoculation		Dose of P		Inoculation	
	P1	P2	NI	I	P1	P2	NI	I
					LAx			
NC	36.43aB	49.64aA	40.65aB	45.42aA	8.94bB	25.53aA	15.21bB	19.27bA
C	34.97aA	37.38bA	35.27bA	37.08bA	19.63aB	25.00aA	21.54aA	23.09aA
P1	---	---	34.78bA	36.62bA	---	---	12.01bB	16.56bA
P2	---	---	41.14aB	45.88aA	---	---	24.74aA	25.80aA
					LAd			
NC	23.28bB	44.00aA	34.11aA	33.17bA	10.86bB	25.93aA	15.93aB	20.86aA
C	32.32aB	40.27bA	34.62aB	37.96aA	14.51aB	26.40aA	18.52aB	22.39aA
P1	---	---	28.07bA	27.53bA	---	---	8.91bB	16.47bA
P2	---	---	40.66aA	43.61aA	---	---	25.55aA	26.78aA
					LVw			
NC	10.83bB	41.07aA	24.10bB	27.81bA	3.41bB	22.88bA	14.11bA	12.18bA
C	29.36aB	36.34bA	31.10aB	34.59aA	18.57aB	28.71aA	22.14aB	25.14aA
P1	---	---	18.91bA	21.28bA	---	---	9.16bB	12.82bA
P2	---	---	36.29aB	41.13aA	---	---	27.08aA	24.50aB
					LVdf			
NC	42.90aB	51.66aA	46.46aA	48.09aA	28.53aA	30.98aA	28.45aA	31.06aA
C	42.86aB	48.23aA	43.89aA	47.20aA	26.75aA	30.14aA	26.83aA	30.06aA
P1	---	---	42.52bA	43.23bA	---	---	25.49bB	29.79aA
P2	---	---	47.82aB	52.06aA		---	29.79aA	31.34aA

In each planting, capital letters compare mean values horizontally and lower case letters compare values vertically ($p<0.05$). NC: non-cultivated; C: cultivated; P1: lowest dose of P; P2: highest dose of P; NI: non-inoculated; I: inoculated.

The response to the addition of P had great variation among the Latosols being influenced by the history of land use as well as inoculation and planting (1st or 2nd) (Table 2). In the first planting in all soils, response to P was greater when plants were grown in soils that had not been previously cultivated due to the low natural content of P in the soil (Motta et al., 2002). Only in the cultivated LAx there was no positive response to doses with increasing P content, which can be attributed to sufficient content of this nutrient available for maximum development of the plant.

However, in the LVw, the SDM increased from 10.83 g to 41.07 g (+ 280%) as the P content in non-cultivated soil increased. In this condition, the initial P content in the soil by Mehlich-1 was 3 mg dm^{-3} (Table 3), but when this soil was pre-cultivated (initial P content equal to 54 mg dm^{-3}), SDM increased from 29.36 g to 36.34 g (+23%). Similar results were found for the clayey Yellow Latosol (available P equal to 2 mg kg^{-1}), in which phosphate fertilization, associated or not with mycorrhizal inoculation, significantly increased the SDM of *Urochloa humidicola* (Costa et al., 1997).

Regarding the effect of the inoculation, there was a greater effect on the SDM when the LAx had not been previously cultivated and when received the highest dose of P. In LAd there was only the effect of inoculation when it had been cultivated previously. In LVw (cultivated and non-cultivated), when received the highest dose of P, inoculation increased the SDM of *Urochloa*. In LVdf there was only an effect of inoculation when application of the highest dose of P occurred. Moreover, the response to the highest dose of P was greater with inoculation in LAx, LAd and LVdf, while in LVw had no difference. In a clayey Dystroferric Red Latosol treated with single superphosphate (12.5 mg kg^{-1}), a significant effect was found with inoculation in DSM of four grasses, including *U. decumbens* (Kanno et al., 2006).

In the second planting, the response to the highest dose of P in LAx, LAd, and LVw was similar to the first planting, and greater in those soils not previously cultivated. However, it is important to highlight that the LVw presented the greatest response (approximately +570%) (Table 2). Unlike the first planting, the response was greater without inoculation, except for the LVdf that did not have significant responses in the presence of inoculation. The response in LVdf was low in the absence of inoculation and not significant for all other conditions, despite the expected reduction in available P due to the large production of SDM for the first planting. Except for the LVdf, responses were higher in the second planting. In LVw, the increase of SDM in NC, which was 279% in the first planting, increased to 570% in the second planting. In LAx, it increased from 36 to 186% and, in LAd, from 89 to 139%.

The response of *Urochloa* to inoculation varied with the history of land use and the dose of P (Table 2). In the first planting, there was no effect of inoculation in LAx for the non-cultivated soil and also when applying the highest dose of P; in LAd, it occurred only for the cultivated soil; in LVw there was no effect only when applying the lowest dose of P, whereas in LVdf, the effect was only with the highest dose of P (Table 2). In the second planting, the effect of inoculation was greater in all soils, especially with the application of the lowest dose of P. For LAx, with the lowest dose of P, in which there was no effect in the first planting, inoculation increased the SDM from 12.01 g to 16.56 g (+38%) (Table 2). In this soil (non-cultivated), the P contents in the soil before the second planting were 5 and 53 mg dm^{-3} (Table 3), for P1 and P2, occurring 30% and 4% of colonization, respectively (Table 4). When under planting, the P contents were 19 and 76 mg dm^{-3}, respectively for P1 and P2, and there was no mycorrhizae colonization found.

In LAd, there was no effect of inoculation in the application of the highest dose of P, although there was a colonization of 7% in non-cultivated soil (Table 4). In LVw, there was no effect of inoculation when non-cultivated and a small effect when grown previously. In the cultivated soil, while with the highest and lowest P doses applied the contents of P in the soil reached relatively close values, 79 and 50 mg dm^{-3}, colonization was inhibited only in the former, similarly to the first planting, resulting in a colonization of 41 % in the latter. The effect of the inoculation was greatest at the lowest dose of P, therefore, there was no reduction in the SDM with the highest dose of P. In LVdf, there was an effect of inoculation only when the lowest dose of P was applied. The greater levels of P tend to reduce or inhibit the effect of inoculation, even if colonization has occurred. As found for LVw, the mycorrhizal association did not contribute to plant development in the presence of high contents of available P in the soil and it could even cause a negative effect, because it constitutes a drain of photosynthates of the plant (Sharif; Claassen, 2011).

Mycorrhizal dependency and the response of the plants appear to be most significant in adverse soil conditions (Kanno et al., 2006). This seems to meet the results obtained by Canizares et al. (2015). In their study, doses of 30, 60 and 90 kg ha^{-1} P_2O_5 were applied, with and without inoculation, and no differences were observed among the treatments, which means the inoculation with the lowest dose of P provided the same result when associated with a greater dose of P, suggesting lesser influence of phosphate fertilization. In a clayey Yellow Latosol, soil inoculation with *Acaulospora muricata* associated with natural phosphate promoted significant increase in dry matter of *Urochloa humidicola* when compared to treatments in which only an application of phosphate or inoculation was carried out, however, increasing the P content in the presence of inoculation had no effect (Costa et al., 1997). The interactions between P and mycorrhizal associations are summarized by Bethlenfalvay et al. (1982) and Sharif and Claassen (2011) as follows: the response to inoculation will depend on the P supply; if P content in soil is very low, the growth of symbionts is inhibited; if P exists in the soil (even low) it will promote growth of the host; and if the soil P content is high, the development of fungus can occur in detriment to the host.

Table 3: Soil available P (mg dm^{-3}) before 1st planting and after 1st and 2nd plantings.

H/P/I	Before 1st planting			After 1st planting			After 2nd planting		
	M-1	M-3	R	M-1	M-3	R	M-1	M-3	R
				LAx					
NC P2 I	---	---	---	53	73	50	41	57	30
NC P2 NI	81	119	80	53	74	49	49	62	32
NC P1 I	---	---	---	5	11	10	4	7	5
NC P1 NI	11	16	16	6	13	10	4	8	6
C P2 I	---	---	---	72	104	95	69	87	56
C P2 NI	111	157	97	80	107	78	66	86	54
C P1 I	---	---	---	20	26	17	16	22	15
C P1 NI	29	40	33	18	25	18	17	21	14
				LAd					
NC P2 I	---	---	---	28	47	35	19	37	26
NC P2 NI	42	64	63	25	48	33	19	39	28
NC P1 I	---	---	---	3	8	6	2	5	7
NC P1 NI	5	10	14	4	8	6	2	5	7
C P2 I	---	---	---	29	41	50	23	38	36
C P2 NI	41	58	82	30	41	55	22	39	38
C P1 I	---	---	---	11	12	19	9	12	12
C P1 NI	14	16	80	11	10	21	9	13	15
				LVw					
NC P2 I	---	---	---	13	26	40	10	27	27
NC P2 NI	32	53	84	16	29	43	11	28	29
NC P1 I	---	---	---	3	4	8	2	6	6
NC P1 NI	3	6	14	3	4	9	2	5	6
C P2 I	---	---	---	79	52	107	103	58	82
C P2 NI	109	75	114	82	54	114	74	56	77
C P1 I	---	---	---	50	19	49	47	19	37
C P1 NI	54	25	63	49	18	53	47	20	38
				LVdf					
NC P2 I	---	---	---	106	77	107	94	103	119
NC P2 NI	128	102	146	109	80	123	97	110	113
NC P1 I	---	---	---	69	58	61	60	78	75
NC P1 NI	80	62	121	68	53	58	58	81	75
C P2 I	---	---	---	97	66	89	90	98	127
C P2 NI	123	88	178	105	74	83	97	96	125
C P1 I	---	---	---	62	41	56	55	58	90
C P1 NI	71	45	109	58	41	56	59	60	77

H: Historical land use (NC – non-cultivated and C – cultivated); P: dose of P (P1 – lowest dose and P2 – highest dose); I: inoculation (NI – non-inoculated and I – inoculated); M-1: Mehlich-1; M-3: Mehlich-3; R: Resin.

Table 4: Mycorrhizal colonization of *Urochloa decumbens* roots (%) as affected by historical land use and P doses (1st and 2nd planting).

Soil	Historical land use	Dose of P	1st planting	2nd planting
LAx	NC	P2	0	4
LAx	NC	P1	22	30
LAx	C	P2	0	0
LAx	C	P1	0	0
LAd	NC	P2	0	7
LAd	NC	P1	37	41
LAd	C	P2	0	0
LAd	C	P1	19	25
LVw	NC	P2	9	9
LVw	NC	P1	38	71
LVw	C	P2	0	0
LVw	C	P1	8	41
LVdf	NC	P2	0	17
LVdf	NC	P1	17	50
LVdf	C	P2	0	0
LVdf	C	P1	11	40

NC – non-cultivated; C – cultivated; P1 – lowest dose of P; P2 – highest dose of P.

Concentration and accumulation of P in *Urochloa* shoot

In the first planting, the maximum concentration of P in the shoot took place with the highest dose of P in LAd and LVdf (Table 5), and in non-inoculated LAx and LVw (Table 6). Minimum values occurred at the lowest dose of P in LAd and LVdf (Table 5), and with the same dose in LVw and LAx both non-cultivated (Table 6).

In the second planting, the highest P concentration in the shoot were found with the greatest dose in LAd and LVdf (Table 5) as well as in LVdf when not cultivated previously. In LAx, the maximum concentration of P occurred with the highest dose of P when cultivated and in LVw, with the lowest dose when non-cultivated (Table 6). The lower contents occurred at the lowest dose in LAd and LVdf (Table 5); and with the same dose in LAx non-cultivated and in LVw cultivated (Table 6).

In the first planting, the increase of P dose increased the P content in the shoot of *Urochloa* in all soils, being influenced by the history of land use and inoculation. In LAx and LVw, the response of *Urochloa* was greater when these soils had not been previously cultivated, and not having an effect of inoculation. In LAd and LVdf, where only simple effects occurred with these factors, the response was little. In the second planting, there was a reduction of responses, mentioning, for example, LAx that had double interactions occurring in both plantings. In the first planting, increases of P, which were correspondent to 64% (cultivated) and 108% (non-cultivated), became 58% (cultivated) and 53% (non-cultivated). Increases of 80% and 87%, noted for plants inoculated and non-inoculated in the first planting, were reduced to 59% and 54% during the second planting, the same pattern occurred in LAd and LVdf. Unlike the other soils, in LVw there was a reduction in the concentration of P in the shoot when not cultivated previously, which decreased from 1.58 to 0.99 g kg^{-1} (-60%), in agreement with the great SDM increase observed in the order of 570% (a dilution effect).

In the first planting, there was no effect of inoculation for LAd, although there was colonization of 19% and 37% (Table 4) with the application of the lowest dose of P in cultivated and non-cultivated soils, respectively. In cultivated LVw, inoculation increased 11% the SDM with the lowest dose of P (Table 2), and the dilution effect caused a reduction in P content in the shoot from 1.29 to 1.09 g kg^{-1} (Table 6). In this case, the P content in the soil was 55 mg dm^{-3} (Table 3) and a colonization of 8% occurred (Table 4). With the highest dose of P, the P content in the soil reached

111 mg P dm^{-3}, and there was inhibition on mycorrhizal fungi, which, therefore, did not have an effect of inoculation. In non-cultivated soil, inoculation increased the SDM in 13% with the highest dose of P and also, by dilution effect, a reduction of P in the shoot occurred, decreasing from 1.64 to 1.43 g kg^{-1}. The P content in the soil was 30 mg dm^{-3} and there was colonization of 9%.

In the second planting, there was no effect of inoculation in LAd and LVdf (Table 5). The deleterious effect of inoculation on P in the shoot in cultivated LVw and also with the highest dose of P in the first planting disappeared in the second planting, where there was no effect of treatment (Table 6). Similar facts happened to the LVdf, whose reduction of 17% in the first planting was annulled in the second planting.

The highest accumulations of P (1st + 2nd plantings) occurred with the higher dose of P in non-cultivated LAd and LVdf (Table 7), LAx and LVw (Table 8). Lower accumulations occurred with the lowest dose of P in LAd and LVdf (Table 7), and with the lowest dose of P in non-cultivated LAx and LVw (Table 8).

Table 5: P concentration in the *Urochloa decumbens* shoot dry matter (1st and 2nd plantings) as affected by P doses and mycorrhizal inoculation in the Dystrophic Yellow Latosol (LAd) and Dystroferric Red Latosol (LVdf).

	P in the shoot (mg kg^{-1})			
	1st planting		2nd planting	
	LAd	LVdf	LAd	LVdf
NC	0.90a	1.40a	1.06a	1.22a
C	0.86a	1.00b	1.02a	1.05b
P1	0.70b	1.01b	0.95b	1.05b
P2	1.05a	1.39a	1.14a	1.22a
NI	0.91a	1.31a	1.05a	1.16a
I	0.84a	1.09b	1.04a	1.11a

NC: non-cultivated; C: cultivated; P1: lowest dose of P; P2: highest dose of P.; NI: non-inoculated; I: inoculated. Lower case letters in each soil, cultivation and non-cultivation condition compare the mean values vertically (p<0.05).

Table 6: P concentration in the *Urochloa decumbens* shoot dry matter (1st and 2nd plantings) as affected by P doses and mycorrhizal inoculation in the Dystrocohesive Yellow Latosol (LAx) and Acric Red Latosol (LVw).

	P in the shoot (mg kg^{-1})							
	1st planting				2nd planting			
	Dose of P		Inoculation		Dose of P		Inoculation	
	P1	P2	NI	I	P1	P2	NI	I
				LAx				
NC	0.75bB	1.56aA	1.18aA	1.12aA	0.80bB	1.23bA	1.04bA	0.99bA
C	0.93aB	1.52aA	1.28aA	1.18aA	1.01aB	1.60aA	1.32aA	1.29aA
P1	---	---	0.86bA	0.82bA	---	---	0.93bA	0.88bA
P2	---	---	1.60aA	1.48aA	---	---	1.43aA	1.40aA
				LVw				
NC	0.79aB	1.55aA	1.22aA	1.12aA	1.58aA	0.99aB	1.32aA	1.25aA
C	0.86aB	1.52aA	1.29aA	1.09aB	0.88bB	1.01aA	0.95bA	0.94bA
P1	---	---	0.87bA	0.78bA	---	---	1.27aA	1.19aA
P2	---	---	1.64aA	1.43aB	---	---	1.00bA	1.00bA

NC: non-cultivated; C: cultivated; P1: lowest dose of P; P2: highest dose of P; NI: non-inoculated; I: inoculated. In each cultivation, capital letters compare mean values horizontally and lower case letters, vertically (p<0.05). In each planting, capital letters compare mean values horizontally and lower case letters, vertically (p<0.05).

Table 7: Accumulated P in the *Urochloa decumbens* shoot dry matter (1st and 2nd plantings) as affected by P doses and mycorrhizal inoculation in the Dystrophic Yellow Latosol (LAd) and Dystroferric Red Latosol (LVdf).

	Accumulated P (mg)	
	LAd	LVdf
NC	51.64a	103.27a
C	53.57a	75.97b
P1	31.17b	72.24b
P2	65.81a	95.11a
NI	51.13a	92.36a
I	54.08a	86.88a

NC: non-cultivated; C: cultivated; P1: lowest dose of P; P2: highest dose of P; NI: non-inoculated; I: inoculated. Lower case letters, in each soil, cultivation and non-cultivation condition, compare mean values vertically (p<0.05).

Table 8: Accumulated P in the *Urochloa decumbens* shoot dry matter (1st and 2nd plantings) as affected by P doses and mycorrhizal inoculation in the Dystrocohesive Yellow Latosol (LAx) and Acric Red Latosol (LVw).

	Accumulated P (mg)			
	Dose of P		Inoculation	
	P1	P2	NI	I
		LAx		
NC	34.04bB	108.25aA	68.09aA	74.20aA
C	52.17aB	96.60bA	74.30aA	74.46aA
P1	---	---	41.33bA	44.88bA
P2	---	---	101.05aA	103.79aA
		LVw		
NC	13.61bB	85.80aA	49.76bA	49.65bA
C	41.26aB	83.75aA	62.55aA	62.46aA
P1	---	---	25.84bA	29.03bA
P2	---	---	86.47aA	83.08aA

NC: non-cultivated; C: cultivated; P1: lowest dose of P; P2: highest dose of P; NI: non-inoculated; I: inoculated. Capital letters compare mean values horizontally and lower case letters, vertically (p<0.05).

The elevation of P dose increased the P uptake in shoot of *Urochloa* in all soils. In LAx (Table 8), the response was influenced by the history of land use, occurring increases of 218% and 85% for non-cultivated and cultivated, respectively. The effect of inoculation was not significative. In LVw, the response varied with a history of land use and inoculation, being greater in non-cultivated (531%) than in the cultivated (103%) and in the non-inoculated (235%) than in the inoculated (186%) (Table 8). The lesser response in cultivated soils is probably due to the already existing high P content in these soils, 55 mg dm^{-3} (Table 3), before the first planting. The elevation of P dose also increased the accumulated P in 111% in LAd and only 32% in LVdf (Table 7), which is also due to the higher available P. Over all soils, we did not observe any effect of inoculation on P accumulation in the plant. According to Bago (2000), fungal hyphae can absorb P from the soil, but not necessarily increase passage of P to the interior of the roots.

Canizares et al. (2015) found no effect of inoculation associated with different doses of P in the *Urochloa decumbens* shoot. In contrast, Santos et al. (2002) found a higher accumulation of P in *Urochloa brizantha* when P levels were associated with mycorrhization. It is noteworthy, however, to highlight that the greatest effect of mycorrhization happened with the lowest doses of P used. Costa et al. (1997) concluded that inoculation and application of P promoted greater uptake of nitrogen and phosphorus by *Urochloa humidicola*.

CONCLUSIONS

The growth of *Urochloa decumbens* was strongly influenced by the interaction among soil class x history of land use x dose of P x inoculation. When planted for the first time, in general, the greater response to P occurred in soils under native vegetation and when the inoculation was associated with P addition. When planted for the second time, inoculation provided a greater effect in all soils with the application of the lowest dose of P. The application of P tends to increase the concentration of P in the shoot of *Urochloa*. In this study, inoculation did not affect the concentration and accumulation of P in the shoot of *Urochloa decumbens*.

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