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Cientific Paper

Effect of green manure and sources of phosphorus on the morphology and yield of maize plants

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Abstract

The aim of this study was to evaluate the behavior of the maize crop in succession to different species of green manures, with different sources of phosphorus and their interaction. A completely randomized block in a split plot design was used, with three main treatments and seven secondary treatments, with three replications. The treatments consisted of three sources of phosphorus (plots) and six species of green manures (subplots). It was used maize plants of cultivar Premium Flex®. It were evaluated plant height, leaf number, stem diameter, leaf area index, leaf and stem dry weight, specific leaf area, ear number, mass of one hundred grains, stand and yield. There was no interaction effect on all traits. However, the dry weight of stem and seed yield showed significant difference between the sources of phosphorus, with positive results for both sources of phosphorus in relation to the control. This suggests that the shoot dry weight is responsive to the presence of phosphorus. It was observed that the phosphate rock has potential to achieve crop yield similar to that obtained with superphosphate.

Key words: *Zea mays* L.; phosphorus fertilization; leaf area index.

Efeito de adubação verde e fontes de fósforo na morfologia e produção de plantas de milho

Resumo

O objetivo deste trabalho foi avaliar o comportamento de plantas de milho em sucessão a diferentes espécies de adubos verdes, com diferentes fontes de fósforo e sua interação. Foi utilizado delineamento experimental de blocos ao acaso com parcelas subdivididas, sendo três tratamentos principais e sete tratamentos secundários, com três repetições. Os tratamentos constaram de três fontes de fósforo (parcelas) e seis espécies de adubos verdes (subparcelas). Foram utilizadas plantas de milho da cultivar Premium Flex®. Foram avaliados a altura de plantas, número de folhas, diâmetro de colmo, índice de área foliar, massa seca de folhas e colmo, área foliar específica, número de espigas, peso de cem grãos, estande e produtividade. Não houve efeito de interação em nenhuma das características avaliadas. No entanto, a massa seca de colmo e a produtividade de grãos apresentaram diferença significativa entre as fontes de fósforo, apresentando resultados positivos para ambas as fontes de fósforo em relação à testemunha. Isso sugere que a produção de massa seca da parte aérea seja responsiva a presença de fósforo. Verificou-se que o fosfato natural apresenta potencial de alcançar rendimento agrícola semelhante ao obtido com superfosfato simples.

Palavras chave: *Zea mays* L.; adubação fosfatada; índice de área foliar.

Efecto de abonos verdes y fuentes de fósforo en la morfología y rendimiento de las plantas de maíz

Resumen

El objetivo de este estudio fue evaluar el comportamiento de las plantas de maíz en sucesión a diferentes especies de abonos verdes, con diferentes fuentes de fósforo y su interacción. El diseño experimental utilizado fue bloques al azar con parcelas divididas, con tres tratamientos principales y siete tratamientos secundarios con tres repeticiones. Los tratamientos consistieron en tres fuentes de fósforo (parcelas) y seis especies de abonos verdes (subparcelas o parcelas secundarias). Se utilizaron plantas de maíz de la variedad Premium Flex®. Fueron evaluadas la altura de planta, número de hojas, diámetro

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del tallo, índice de área foliar, masa seca de hojas y tallo, área foliar específica, número de mazorcas, peso de cien granos, stand y productividad. No se observó efecto de interacción en ninguna de las características evaluadas. Sin embargo, el peso seco del tallo y el rendimiento de grano mostró diferencias significativas entre las fuentes de fósforo, presentando resultado positivo para ambas fuentes de fósforo en relación con los resultados del control. Esto sugiere que la producción de masa seca de la parte aérea de la planta es sensible a la presencia de fósforo. Se encontró que el fosfato natural presenta potencial de lograr rendimiento similar a lo obtenido con superfosfato simple.

Palabras clave: *Zea mays* L.; abono con fosfato; índice de área foliar

Introduction

The maize (*Zea mays*) is a crop of great socio economic importance, besides being one of the main sources of carbohydrates in the human consumption and energetic component in the animals feed (FANCELLI and DOURADO NETO, 2000).

Brazil is an important worldwide producer of maize, being that in the 2009/10 season produced 55 millions of tons of this cereal, corresponding to 6.6% of the global production (FAO, 2012). This production demands great quantity of nutrients, being that among the primary macronutrients, the phosphorus is the element with better tax of exporting, coming up to 80% (COELHO and ALVES, 2004).

Due to the naturally poor soils in phosphorus and to high adsorption of nutrients of soils with elevated content of clay, common in several areas of the Brazilian territory, the correct management of this nutrient is essential to make it available to plants (CAMARGO et al., 1974). Studies observing positive response of the maize grains yield to the phosphorus fertilization are common (RAUN and BARRETO, 1995; PRADO, 2001).

Among the most used sources of phosphorus, stand out the soluble phosphates. These present good results, while the natural phosphates present low solubility and lesser agronomic efficiency, however generally have lower costs. According to HOROWITZ and MEURER (2004), soluble phosphates gave better efficiency in short term, while in the natural phosphates, the efficiency increases with the time passed after its application on the soil.

The technique known as green manure is based in the use of cover crops, which can improve the physical and chemical conditions of the soil, benefiting future crops. The green manure can improve the availability of phosphorus, favoring the development and yield of the crops (BASAMBA et al., 2006; FISCHLER et al., 1998), once the green manure promotes increase in the biological activity (HERNANI et al., 1995; HU et al., 2009) and improve the physical quality (ASTIER et al., 2006) of the soil. RAMOS et al. (2001) verified that some leguminous species used as green manure are capable of allocating 39 to 40% of the nitrogen accumulated in the underground part. This technique acts on the soil fertility, improving the potential of recycling and mobilizing leaching or little soluble nutrients (TEJADA et al., 2008; CHEN and WEIL, 2011). Furthermore, the technique can be used to suppress weed plants growth, depending of the species used (DHIMA et al., 2009).

PYPERS et al. (2007) strongly suggests that green manure with leguminous in crop rotation system increase the yield and growth of the maize plants, possibly for microbiological reasons.

LIU et al. (2004), studying maize genotypes with contrasting efficiency for the adsorption of phosphorus, concluded that, the greater root system, allied to a better ability of acidify the rhizosphere and excrete phosphatase in the root zone, are the main characteristics of the efficient genotype in the adsorption of this element. STRÖM et al. (2002) observed that the addiction of organic oxalate acid in the root zone increased approximately two times the accumulation of phosphorus in the maize shoots.

In this way, it is important to study the growth of the subsequent crops to green manure, to search evidences of the potential of use of these as solubilizers of natural phosphate, what could serve as subside to more advanced studies.

The objective of this study was to assess the behavior of maize plants in succession to different species of green manure and different sources of phosphorus.

Material and Methods

This experiment was part of a long-term project which was installed in 2004, in an experimental area in the municipality of Guarapuava – PR. The altitude of the area of the experiment is 1.033 m, being found at the geographical coordinates 25º 23'

14" S and 51º 29' 26" W. The classification of the weather of the region is humid mesothermal and the average annual rainfall is 1.961 mm (THOMAZ and VESTENA, 2003). The soil of the experiment is a Latossolo Bruno[1] of clayey texture, which presented the following chemical composition at the depth of 0 to 20 cm: pH ($CaCl_2$), 5.5; organic carbon, 26.2 g dm^{-3}; P (*Mehlich*), 1.1 mg dm^{-3}; Al^{3+}, 0.0 $cmol_c$ dm^{-3}; $H^+ + Al^{3+}$, 5.2 $cmol_c$ dm^{-3}; Ca^{2+}, 5.0 $cmol_c$ dm^{-3}; Mg^{2+}, 5.5 $cmol_c$ dm^{-3}; K^+, 0.2 $cmol_c$ dm^{-3} and saturation of bases of 67.3%.

The experimental design used was of completely randomized blocks in a split plot design and three sources of phosphorus (plots) and six species of green manure cultivated in the winter and a control without cultivation (subplots), with three repetitions. The treatments allocated in the plots were: a) without phosphorus fertilization (ØP), b) phosphorus fertilization with simple superphosphate in the dose of 100 kg ha^{-1} of P_2O_5 (SFS), c) phosphorus fertilization with natural phosphorus in the dose of 100 kg ha^{-1} of P_2O_5 (FN). In the subplot were allocated in June of 2009 the species of green manure of winter: common vetch (Vicia sativa), white lupine (Lupinus albus), wild radish (Raphanus sativus), ryegrass (Lolium multiflorum), black oat (Avena strigosa), rye (Secale sereale) and the control (winter fallow), being that the subplots measured 4 x 5 m and were cultivated in the winter with these species since 2004. The management of the used species with green manure was done in the season of full flowering, antecedent to maize sowing. The maize, cultivar Premium Flex® (Syngenta Seeds) was sowed in November 10th of 2009 (during the season 2009/2010), with population of 55000 plants ha^{-1}, with spacing of 0.8m between the rows.

In the implantation of green manure, was done potassium fertilization at the dose of 60 kg ha^{-1} of K_2O (KCl) in all treatments and nitrogen fertilization with Urea ($CO(NH_2)_2$) at the dose of 40 kg ha^{-1} of N, besides doing or not the fertilization with phosphorus with different sources. It was done a light harrowing for the incorporation of phosphorus and potassium fertilization. The base fertilization for the maize crop was of 16 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5 and 40 kg ha^{-1} of K_2O. In the cover were done two applications, one with 30 kg ha^{-1} of N at the 25 days after sowing (DAS) and the second with 30 kg ha^{-1} of N and 30 kg ha^{-1} of K_2O at the 43 DAS. The sequence and quantity of fertilization are summarized in the Chart 1.

It were collected four plants from the useful area of each plot at the 73 DAS, when the maize plants were in full flowering, collecting two plants from the two central rows of each plot, leaving a surrounding line in each side and leaving around 1 m of the of the edge of the plot surrounding line.

In this collection, it was taken the data of the plants height, leaf number, diameter of the stem and also was obtained the dry weight and leaves of the stem, the leaf area index (LAI) and the specific leaf area. The plants height was measured until the height of insertion of the floral tassel in the plant apex. For the leaf number were considered all the leaves present in the plant, excluding the senescent. The stem diameter was observed with the assistance of a caliper rule, at a height of 10 cm of the stem base. To

1 Brazilian soil classification.

Chart 1. Data of the fertilization realized in the experiment evaluating the effect of green manure and sources of phosphorus on the morphology and yield of maize plants, Guarapuava-PR, 2009.

Fertilization			Nutrient	Dose (kg ha^{-1})	Source	Treatment
Winter – Green manure			P_2O_5	100	FN[1]	NP
			P_2O_5	100	SSP[2]	SFS
			K_2O	60	KCl[3]	All
			N	40	Urea	All
Summer - Maize	Base		N	16	Urea	All
			P_2O_5	60	SFS	All
			K_2O	40	KCl	All
	Cover (DAS[4])	25	N	30	Urea	All
		43	N	30	Urea	All
		43	K_2O	30	KCl	All

1): NP: Natural Phosphate; 2) SSP: Simple Superphosphate; 3) KCl: Potassium chloride; 4) DAS: days after sowing.

calculate the LAI, it was pierced 15 disks of 2.84 cm^2 each, of the leaf margin of the collected plants per plot. These samples of the leaves of each plot along with the other leaves were placed in a greenhouse for drying (70 °C, forced aeration until a constant weight) for afterwards do the weighing and the estimative of dry weight and of the LAI. The specific leaf area was calculated based in the relation between the leaf surface area of the plant by its dry weight.

Afterwards, at the 150 DAS, it was assessed the following data of the two central rows plants of the remaining useful area of the plot: number of ears, weight of a thousand grains, stand and yield. For the yield data of productivity and grains weight the moisture was corrected to 130 g kg^{-1}.

The data was submitted to variance analysis and, when significant, the averages were compared through the Tukey test ($p<0.05$) using the Sisvar statistical program version 5.3 (FERREIRA, 1999).

Results and Discussion

It was not verified effect of interaction between the green manure and sources of phosphorus for any assessed parameter in this experiment.

The results of the plants height, leaf number and steam diameter can be verified in Table 1.

It was not observed difference in any of these factors in response to different green manures or quantity of phosphorus used in this experiment, despite of verifying a weak evidence ($p = 0.07$) of having a difference between plants height in response to phosphorus fertilization.

HE et al. (2012), testing green manures intercropping with maize in acid soils, deficient in phosphorus, verified that the interspecific stimulation of phosphorus adsorption can be a general phenomenon, more controlled by the phosphorus available in the soil than in the species cultivated, or type of soil. The authors also verified that the effect of the green manure is related to alteration of the microbial community in the rhizosphere, however this effect is less expressive in acid soils, as the observed in the present study.

The observed plants height in this experiment was similar to the observed by FONTOURA (2005) in the average of 10 years in several maize hybrids fertilized with 200 kg ha^{-1} of N, suggesting that the quantity of N provided in the present experiment was sufficient for the crop development, even with the use of green manure with high relation C:N, as the black oat, ryegrass and rye.

In Table 2 are presented the data of LAI, dry weight of leaves, of the steam and specific leaf area. The parameter leaf dry weight did not present difference. The same was verified as the LAI and specific leaf area. However, the stem dry weight presented difference between the sources of phosphorus, where the treatments with the sources of NP and SSP presented higher values. This demonstrates that the production of the shots dry weight is sensible to phosphorus presence.

These data agree with the affirmations of USUDA and SHIMOGAWARA (1991), MACHADO

Table 1. Height, number of leaves and stem diameter of the corn plants grown on different sources of phosphorus and mulching of green manures in Guarapuava-PR, 2010

Green manure	Height (m)				Number of leaves (plant)				Diameter of the stem (mm)			
	ØP[1]	FN	SSSP	MAverage	ØP	FN	SNP	MAverage	ØP	FN	SNP	Average
Black oat	2.24	2.40	2.35	2.33	15.6	15.3	15.0	15.30	24.4	28.6	26.3	26.4
White lupine	2.32	2.43	2.36	2.37	15.1	15.2	15.1	15.13	27.3	28.0	28.8	28.0
Ryegrass	2.23	2.34	2.37	2.31	15.2	15.1	15.2	15.17	26.1	29.3	28.8	28.1
Fallow	2.29	2.46	2.37	2.37	15.3	15.2	14.9	15.13	27.9	28.9	26.1	27.6
Wild Radish	2.29	2.35	2.38	2.34	15.0	14.9	15.7	15.20	27.9	28.9	27.3	28.0
rye	2.31	2.33	2.39	2.34	14.8	15.5	15.0	15.10	26.8	28.5	29.3	28.2
Hairy vetch	2.39	2.47	2.42	2.43	15.2	15.1	15.1	15.13	26.7	26.8	26.9	26.8
Average	2.29	2.39	2.37	2.35	15.2	15.2	15.1	15.17	26.8	28.4	27.7	27.63
Anova												
Phosphorus fertilization			ns[2]				ns				ns	
Green manure			ns				ns				ns	
Interaction			ns				ns				ns	

Averages followed by the same letter do not differ, by the Tukey test at 5% of probability. 1) ØP: Without phosphorus; NP: Natural Phosphate; SFS: Simple Superphosphate. 2) ns = not significant.

Table 2. Leaf area index, dry mass (MS) of leaves, MS of stem and specific leaf area of the corn plants grown on different sources of phosphorus and mulching of green manures in Guarapuava-PR, 2010

Green manure	Leaf DW (g m^{-2})				Stem DW (g m^{-2})				LAI (m^2 m^{-2})				Specific Leaf Area (cm^2 g^{-1})			
	ØP[1)]	FN	SSSP	MAve	ØP	FN	SSSP	MAve	ØP	FN	SSSP	MAve	ØP	FN	SSSP	MAve
Black oat	308	397	377	360	737	998	880	872	8.5	9.9	7.5	8.6	278	250	258	262
White lupine	365	384	387	379	823	964	834	874	10.5	10.0	9.8	10.1	288	260	251	266
Ryegrass	315	421	426	387	710	1070	962	914	8.0	10.9	10.5	9.8	255	263	280	266
Fallow	372	420	275	355	874	993	836	901	11.1	10.6	7.9	9.9	298	254	292	281
Wild Radish	369	332	363	354	1030	825	1209	1021	9.6	8.3	10.0	9.3	260	251	275	262
Rye	313	392	311	338	748	1037	968	918	8.4	9.5	7.7	8.5	271	243	247	254
Hairy vetch	345	329	358	344	797	1024	964	928	9.2	8.6	9.8	9.2	266	256	279	267
Average	341	382	357		816 b	987 a	950 a		9.3	9.7	9.0		274	254	269	
Anova																
Phosphorus fertilization	ns[2]				**				ns				ns			
Green manure	ns				ns				ns				ns			
Interaction	ns				ns				ns				ns			

*Averages followed by the same letter do not differ by the Tukey test at 5% of probability. [1)] ØP: Without phosphorus; NP: Natural phosphorus; SSP: Simple Superphosphate. [2)] ns = not significant; ** = significant at 1%. Ave: average.*

et al. (1999), and YAO et al. (2007), who evaluating grass species verified that doses of adequate phosphorus fertilization increased the weight and density of the plants stem. However, this effect can be conditioned by the genotype of the used maize plant, as stated by FRITSCHE NETO et al. (2010).

Studying sorghum plants, BLUM (1997) verified that bigger stems provided better accumulation of energy, which reflected in a better filling of grains when the plants were found in stress conditions. Possibly a more pronounced effect of the NP could have occurred, if there was restriction of rains in the period of filling of grains in this experiment.

In Table 3 are presented the stand data, weight of a thousand grains, number of ears and yield. It

Table 3. Stand, weight of thousand grains, number of ears and yield of the corn plants grown on different sources of phosphorus and mulching of green manures in Guarapuava-PR, 2010.

Green manure	Stand (plants m^{-2})				Weight thousand grains (g)				Number of ears (m^2)				Yield (g m^{-2})			
	ØP[1)]	FN	SSSP	MAve	ØP	FN	SFS	MAve	ØP	FN	SFS	MAve	ØP	FN	SFS	MAve
Black oat	7.50	8.33	7.67	7.83	283	217	369	290	7.50	8.33	8.00	7.94	676	798	769	748
White lupine	8.00	8.00	7.83	7.94	244	283	369	298	8.00	8.00	7.67	7.89	755	855	787	799
Ryegrass	7.50	8.67	8.17	8.11	263	211	237	237	7.50	9.17	8.33	8.33	671	864	735	757
Fallow	9.00	8.50	7.50	8.33	263	204	217	228	8.67	8.50	7.50	8.22	771	801	667	746
Wild Radish	8.00	7.50	8.33	7.94	217	204	188	203	8.00	7.33	8.17	7.83	767	780	908	818
Rye	7.83	9.00	7.17	8.00	178	277	191	215	7.50	9.00	7.50	8.00	677	863	685	742
Hairy vetch	7.50	7.83	7.67	7.67	290	224	263	259	7.50	8.67	8.17	8.11	762	875	705	781
Average	7.90	8.26	7.76		248	231	262		7.81	8.43	7.90		725 b	833 a	750 ab	
Anova																
Phosphorus Fertilization	ns[2]				ns				ns				*[3)]			
Green manure	ns				ns				ns				ns			
Interaction	ns				ns				ns				ns			

*Averages followed by the same letter do not differ by the Tukey test at 5% of probability. [1)] ØP: Without phosphorus; NP: Natural phosphorus; SSP: Simple Superphosphate. [2)] ns = not significant; ** = significant at 1%. Ave: average.*

was not observed difference in the stand parameters, weight of the grains and number of ears for any studied factor. Even so, the yield data presented difference between the sources of phosphorus, being that the treatments which received NP were superior to the treatments ØP, while the treatments with SSP did not differ from NP as the ØP.

GARG and BAHL (2008) verified that incubated organic fertilizers with inorganic phosphorus incremented the available content of this element, using the Olsen extractor. Similar effect can have occurred in the present experiment, where the used green manure may have assisted in the liberation of labile phosphorus from the source NP. PYPERS et al. (2007) found increase in the maize crop yield using NP, applying this fertilizer in the preceding crop, a leguminous (*Mucuna pruriens*). Similar fact can have occurred in this experiment, where the NP is being applied for five years along with the cultivation of green manure.

ALMEIDA et al. (2003) found out a positive correlation between the maize grains yield and the parameters DW and LAI. In the present study, possibly the sum of small non significant increments in these same parameters, must have influenced in the difference in grains yield, thus as a greater DW of the stem, observed at the 73 DAS (Table 2).

As expected, the ØP treatment presented the smallest yield average, since the phosphorus is very demanded nutrient by the maize crop. The treatment with SSP, although being a high solubility in water source and of high agronomic application, did not statistically differ so much from the NP as for the ØP. KORNDÖRFER et al. (1999), comparing the maize yield in response to natural phosphorus and super triple, obtained similar results to the present study.

Conclusions

It was not verified effect of the green manures and of the interaction between them and the sources of phosphorus in any analyzed parameter. The sources of phosphorus caused difference in the stem dry weight and in the maize grains yield, being the natural phosphate the best choice.

References

ALMEIDA, M.L.; SANGOI, L.; NAVA, I.C.; GALIO, J.; TRENTIN, P.S.; RAMPAZZO, C. Crescimento inicial de milho e sua relação com o rendimento de grãos. **Ciência Rural**, v.33, n.2, p.189-194, 2003.

ASTIER, M.; MAASS, J.M.; ETCHEVERS-BARRA, J.D.; PEÑA, J.J.; GONZÁLEZ, F.L. Short-term green manure and tillage management effect on maize yield and soil quality in an Andisol. **Soil & Tillage Research**, v.88, p.153-159, 2006.

GARG, S.; BAHL, G.S. Phosphorus availability to maize as influenced by organic manures and fertilizer P associated phosphatase activity in soils. **Bioresource Technology**, v.99, p.5773–5777, 2008.

BASAMBA, T. A.; BARRIOS, E.; AMÉZQUITA, E.; RAO, I.M.; SINGH, B. R. Tillage effects on maize yield in a Colombian savana oxisol: soil organic matter and P fractions. **Soil & Tillage Research**, v.91, p.131-142, 2006.

BLUM, A.; GOLAN, G.; MAYER, J.; SINMENA, B. The effect of dwarfing genes on sorghum grain filling from remobilized stem reserves, under stress. **Field Crops Research**, v.52, p.43-54, 1997.

CAMARGO, O.A.; RAIJ, B.; GROHMANN, F. Fixação de fósforo em solos avaliados pelo índice de Bache e Williams e sua correlação com outras propriedades. **Ciência e Cultura**, v.26, p.681-685, 1974.

CHEN, G.; WEIL, R.R. Root growth and yield of maize as affected by soil compaction and cover crops. **Soil & Tillage Research**, v.117, p.17-27, 2011.

COELHO, A.M.; ALVES, V.M.C. Adubação fosfatada na cultura do milho. In: Yamada, T.; Abadalla, S. R. S. (Eds.). **Fósforo na agricultura brasileira**. Piracicaba: Potafós, 2004. p.242-283.

DHIMA, K.V.; VASILAKOGLOU, I.B.; GATSIS, T.D.; PANOU-PHILOTHEOU, E.; ELEFHEROHORINOS, I.G. Effect of aromatic plants incorporated as green manure on weed and maize development. **Field Crops Research**, v.110, p.235-241, 2009.

FANCELLI, A. L.; DOURADO NETO, D. **Ecofisiologia e fenologia**. In: Fancelli, A. L.; Dourado Neto, D. Produção de milho. Guaíba: Agropecuária, 2000. p.21-54.

FAO. **Production - Crops**. <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor >. 10 out. 2012.

FERREIRA, D.F. **SISVAR 5.3** - Sistema de análises estatísticas. Lavras: UFLA, 1999.

FISCHLER, M.; WORTMANN, C.S.; FEIL, B. Crotalaria (*C. ochroleuca G. Don*.) as a green manure in maize-bean cropping systems in Uganda. **Field Crops Research**, v.61, p.97-107, 1998.

FONTOURA, S.M.V. **Adubação nitrogenada na Cultura do Milho em Entre Rios, Guarapuava, Paraná**. Guarapuava: Fundação Agrária de Pesquisa Agropecuária, 2005. 94p.

FRITSCHE NETO, R.; MIRANDA, G. V.; DELIMA, R.O.; SOUZA, L.V.; SILVA, J. Herança de caracteres associados à eficiência de utilização do fósforo em milho. **Pesquisa Agropecuária Brasileira**, v.45, p.465-471, 2010.

HE, Y.; DING, N.; SHI, J.; WU, M.; LIAO, H.; XU, J. Profiling of microbial PLFAs: Implications for interspecific interactions due to intercropping which increase phosphorus uptake in phosphorus limited acidic soils. **Soil Biology & Biochemistry**, 2012.

HERNANI, L. C.; ENDRES, V.C.; PITOL, C.; SANTON, J.C. **Adubos verdes de outono/inverno no Mato Grosso do Sul**. Dourados- MS: Embrapa-CPAO, 1995. 93p.

HOROWITZ, N.; MEURER, E. J. **Eficiência agronômica dos fosfatos naturais**. In: Yamada, T; Abdalla S.R.S. (Org.) Fósforo na agricultura Brasileira. Piracicaba: Potafos, 2004. p.665–687.

HU, J.; LIN, X.; WANG, J.; DAI, J.; CUI, X; CHEN, R.; ZHANG, J. Arbuscular mycorrhizal fungus enhances crop yield and P-uptake of maize (*Zea mays* L.): a field study on a sandy loam soil as affected by long-term P-deficiency fertilization. **Soil Biology & Biochemistry**, v.41, p.2460-2465, 2009.

KORNDÖRFER, G.H.; CABEZAS, W.A.L.; HOROWITZ, N. Eficiência agronômica de fosfatos naturais reativos na cultura do milho. **Scientia Agricola**, v.56, p.391-396, 1999.

LIU, Y.; MI, G.; CHEN, F.; ZHANG, J.; ZHANG, F. Rhizosphere effect and root growth of two maize (*Zea mays* L.) genotypes with contrasting P efficiency at low P availability. **Plant Science**, v.167, p.217-223, 2004.

MACHADO, C.T.T.; GUERRA, J.G.M.; ALMEIDA, D.L.; MACHADO, A.T. Variabilidade entre genótipos de milho para eficiência no uso de fósforo. **Bragantia**, v.58, p.109-124, 1999.

PRADO, R.M.; FERNANDES, F.M.; ROQUE C.G. Resposta da cultura do milho a modos de aplicação e doses de fósforo, em adubação de manutenção. **Revista Brasileira de Ciência do Solo**, v.25, p.83-90, 2001.

PYPERS, P.; HUYBRIGHS, M.; DIELS, J.; ABAIDOO, R.; SMOLDERS, E.; MERCKX, R. Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability? **Soil Biology & Biochemistry**, v.39, p.2555-2566, 2007.

RAMOS, M.G.; VILLATORO, M.A.A.; URQUIAGA, S.; ALVES, B.J.R.; BODDEY, R.M. Quantification of the contribution of biological nitrogen fixation to tropical green manure crops and the residual benefit to a subsequent maize crop using ^{15}N-isotope techniques. **Journal of Biotechnology**, v.91, p.105-115, 2001.

RAUN, W.R.; BARRETO, H.J. Regional maize grain yield response to applied phosphorus in Central America. **Agronomy Journal**, v.87, p.208-213, 1995.

STRÖM, L.; OWEN, A.; GODBOLD, D.L.; JONES, D.L. Organic acid mediated P mobilization in the rhizosphere and uptake by maize roots. **Soil Biology & Biochemistry**, v.34, p.703-710, 2002.

TEJADA, M.; GONZALEZ, J.L.; GARCÍA-MARTÍNEZ, A.M.; PARRADO, J. Effect of different green manures on soil biological properties and maize yield. **Bioresource Technology**, v.99, p.1758-1767, 2008.

THOMAZ, E.L.; VESTENA, L.R. **Aspectos climáticos de Guarapuava – PR**. Guarapuava: Unicentro, 2003. 106p.

USUDA, H.; SHIMOGAWARA, K. Phosphate Deficiency in Maize. I. Leaf phosphate status, growth, photosynthesis and carbon partitioning. **Plant & Cell Physiology**, v.32, p.497-504, 1991.

YAO, Q.L.; YANG, K.C.; PAN, G.T.; RONG, T.Z. The effects of low phosphorus stress on morphological and physiological characteristics of maize (*Zea mays* L.) Landraces. **Agricultural Science in China**, v.6, p.559-566, 2007.