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Broadcast and in line application of phosphorus in soils with different densities

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The efficiency of broadcast versus in line phosphate fertilization has been studied; however, soil density as a determining factor for soil efficiency has been less studied. Thus, the objective of this study was to evaluate the effect of broadcast and in line phosphate fertilization in soil with different densities on corn development. The experiment was conducted in pots under greenhouse condition. A completely randomized design was used in a 2x3 factorial arrangement with four replications. Treatments were two levels of soil densities (1.2 and 1.6 g cm^{-3}) and three forms of P application (broadcast, in line and without P). Corn stem diameter, plant height, root volume, root and shoot dry matter, and root and shoot phosphorus content and accumulation were evaluated. Application in line resulted in higher P accumulation by corn plant. There was higher plant dry matter accumulation at soil density 1.2 g cm^{-3} than at 1.6 g cm^{-3}. Phosphate fertilization in line at soil density 1.2 g cm^{-3} enhances dry matter accumulation in corn plants.

Key words: Compaction, macronutrient, phosphorus, soil fertility.

INTRODUCTION

Soil compaction is one of the most severe degradation processes that occurs in the soil and have been affecting about 68 million hectares around the world from the vehicular traffic (Nawaz et al., 2013). Its effect on the soil structure results in higher soil density (Souza et al., 2012) and lower soil porosity (Singh and Hadda, 2014). The availability of nutrients for plants is reduced in compacted soils (Barzegar et al., 2016), such as phosphorus (Novais et al., 2007). Besides that, soil compaction leads to lower crop yield due to increased resistance to root growth and reduced efficiency of water and nutrient use (Twum and Nii-Annang, 2015).

The nutrient P participates on plant metabolism as the main component of adenosine triphosphate (Taiz et al., 2017), this nutrient has an essential role in physiological and biochemical processes, acting as an energy transfer agent within the plant; thus enabling photosynthesis and respiration (Hawkesford et al., 2012), having essential

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role on plant development (Amanullah and Almas, 2012).

The soils with a high degree of weathering help to maintain low levels of available phosphate resulting from high P adsorption capacity of iron and aluminum oxides and hydroxides in soils (DeLong et al., 2013; Fink et al., 2014). Slow diffusion contributes to low level of available P in soil which limits plant uptake (Shen et al., 2011). Moreover, in line fertilization (close to root system) should be chosen over other methods to favor plant uptake of P (Prado, 2008).

The most common method of P application in grain production is soil surface with or without incorporation, in row placement and in band placement (Galetto et al., 2014). Among the determining factors for the best P application method are soil physical and chemical proprieties, fertilizer type and crop type (Ceretta et al., 2007). The phosphate fertilizer applied on the surface will keep contact with soil, causing the P fixation and affecting the absorption by the plants (Barbosa et al., 2018).

Reports have shown that application of phosphate fertilizers using broadcast method without incorporation in a no till system leads to different distribution of P within the soil profile compared to in line application, this will enhance P concentration in superficial layer from 0 to 5 cm (Souza et al., 2016). However, soil compaction might affect the broadcast phosphate fertilization management in no till areas (Santos et al., 2005), as root development and crop production especially in areas under water deficiency might be reduced (Valadão et al., 2015).

Therefore, it is possible that in line phosphate fertilization has higher efficiency than broadcast application, especially in compacted soils. The objective of this study is to evaluate the effect of broadcast and in line phosphate fertilization in soil with different densities on corn development.

MATERIALS AND METHODS

The experiment was conducted in the greenhouse and in the Laboratory of Soil, Fertilizer and Foliar Analysis (LASAF) of University of Mato Grosso State – UNEMAT (09° 51' 42'' S and 56º 04' 07'' W), campus Alta Floresta – MT, in 2016. According to Köppen classification, the weather is classified as Aw with two well defined seasons: raining summer and dry winter, with temperatures around 26 °C and average rainfall between 2000 and 3000 mm (Alvares et al., 2014).

A red-yellow dystrophic oxisol (Embrapa, 2013) was collected from 0-20 cm. The chemical and physical characteristics of the soil are: pH ($CaCl_2$) = 5.0; organic matter (OM) = 26.9 g dm^{-3} ; $H^{+}+Al^{3+}$ $_{(calcium\ acetate)}$ = 28.5 $mmol_{(c)}$ dm^{-3}; P $_{Mehlich\ 1}$= 1.3 mg dm^{-3} ; K $_{Mehlich\ 1}$= 1.66 $mmol_{(c)}$ dm^{-3}; Ca = 11.2 $mmol_{(c)}$ dm^{-3}; Mg = 4.5 $mmol_{(c)}$ dm^{-3} ; base saturation = 38%; Cation Exchange Capacity (CEC) of 46.0 $cmol_{(c)}$ dm^{-3}; sand fraction = 578 g kg^{-1}; silt fraction = 57 g kg^{-1}; and clay fraction of 365 g kg^{-1}.

The experiment was conducted in a completely randomized design in a factorial 2x3 with 4 replications. The treatments were two soil densities D1 1.2 g cm^{-3} (normal) and D2 1.6 g cm^{-3} (compacted), without P application (T1), with superficial broadcast P (T2), and with in line P (T3). Each experimental unit was composed using a pot of 4 dm^{-3} capacity.

Soil density was determined using Beutler and Centurion (2004) methodology. The soil was pressed 15 times with a 3.5 kg wood of 50 cm high and a diameter lower than the 4 dm^{-3} plot of PVC (17.5 cm of height and 17.3 cm of diameter). The soil was compacted on each 1.7 cm soil layer until the soil densities was 1.2 and 1.6 g cm^{-3}.

The soil was dried and sieved before dolomite lime application (with 85 relative efficiency of reactivity – RER) so as to enhance soil base saturation to 60%, as suggested by Sousa and Lobato (2004). The soil was incubated in pots with periodic irrigation for the duration of 90 days. After this period, 200 mg dm^{-3} of P (Mono-Ammonium-Phosphate – 50% of P_2O_5) was applied to broadcast and in line pots, according to the methodology of Malavolta (1981). In line application was placed under and next to the seed in order to simulate field situation. Corn sowing was done with six seeds per pot. All pots were applied with 60 kg ha^{-1} of K_2O (Potassium chloride – 60% of K_2O), 20 kg ha-1 of N at sowing and 40 kg ha^{-1} of N later (urea - 45% of N) (Sousa and Lobato, 2004). Boron was applied during sowing at 2 kg ha^{-1} (boric acid 17% of B) and zinc at 6 kg ha^{-1} (zinc sulfate - 20% of Zn) (Sousa and Lobato, 2004).

Irrigation with tap water was done every day, in order to maintain soil water capacity of about 60%. After 35 days of emergency, the stem diameter, shoot height, root volume, root and shoot dry matter, and root and shoot P content and accumulation were evaluated.

The roots were separated from shoots, washed with tap water followed by distillated water, and left submerged inside a graduated cylinder containing low level of water. The difference between initial and final volume was used to determine root volume. Roots and shoots were placed into Kraft papers and dried in a forced-ventilated oven at 65°C for 72 h to determine its dry matter content. Shoots and roots samples were ground in a Wiley grinder and chemically analyzed for P content using Embrapa (2009) methodology.

The results, for normality (Shapiro-Wilk) and homoscedasticity, were analyzed. The analysis of variance (ANOVA) was done with F test ($p<0.05$), and the means compared through Tukey test at 5% of significance, using ASSISTAT software version 7.7.

RESULTS AND DISCUSSION

There was a significant interaction effect between P application and soil density on corn root and shoot P content (Table 1). Root P content at density 1 did not show significant difference among P application, whereas at density 2 higher root P content was observed on plants treated with in line P compared to broadcast and without P (Table 2). There was no effect of soil density on root P content when in line P application was used; however, higher root P content was observed at the lowest density in plants under broadcast P application and without P treatment (Table 2). These results support the hypotheses that soil compaction decrease P diffusion flow, thus reduces ion-root contact and plant uptake. According to Barbosa et al. (2018) the lower levels of P provided by broadcast fertilization P are justified by the low initial level of this nutrient in the soil, causing a reduction in the availability of P within the reach of the root. Amanullah and Almas (2012) affirmed the application of localized P enhances root system and provides upper

Table 1. Effect of P application method and soil density on root P content (RPC), shoot P content (SPC), root P accumulation (RPA) and shoot P accumulation (SPA) of corn plants cultivated under greenhouse condition.

Treatment	RPC	SPC	RPA	SPA
	g kg^{-1}		g pot^{-1}	
Without P	0.57	0.69	0.64	0.65
Broadcast	0.71	0.64	5.30	4.18
In line	0.86	0.55	7.26	5.58
LSM	0.143	0.128	1.061	1.087
Densities		g cm^{-3}		
D1 – 1.2 g cm^{-3}	0.81	0.65	4.87	3.91
D2 – 1.6 g cm^{-3}	0.62	0.61	3.93	3.02
LSM	0.096	0.086	0.710	0.731
		F values		
Density (D)	17.20**	1.25	7.82*	6.41*
P application(PA)	13.63**	3.55*	134.84**	71.34**
Interaction DxPA	3.929*	6.62**	1.450	2.459
CV%	15.69	16.02	18.81	24.55

* and ** of F test significant at $p<0.01$ and $p<0.05$, respectively.

Table 2. Effect of interaction between P application method and soil density on root P content and shoot P content of corn plants cultivated under greenhouse condition.

Density	Treatment		
	Without P	Broadcast	In line
Root P (g kg^{-1})			
D1 – 1.20 g cm^{-3}	0.689^a	0.863^a	0.868^a
D2 – 1.60 g cm^{-3}	0.449^b	0.548^b	0.854^a
Shoot P (g kg^{-1})			
D1 – 1.20 g cm^{-3}	0.712^a	0.772^a	0.590^b
D2 – 1.60 g cm^{-3}	0.662^a	0.515^b	0.512^b

^{ab} means in both column and row of the same superscript are not significantly different ($p<0.05$).

contact with nutrients.

At density 1, in line application of P resulted in higher shoot P content compared to broadcast and without P application (Table 2). In contrast, at density 2 higher shoot P content was observed in plants under in line and broadcast application compared to plants without P fertilization (Table 2). Regardless of soil density effect within P application, no significant effect was observed in plants without P fertilization. However, density 1 resulted in higher shoot P content when P was broadcast and in line applied compared to those without P application. This might be explained by the dilution effect (Martuscello et al., 2009), which is elucidated by the higher dry matter content of corn plants showed on Table 3.

Accumulation of P in shoots and roots was higher with in line P application than with broadcast and without P (Table 1). It was observed that in line P increased 37 and 24% of P accumulation in roots and shoots, respectively, compared to broadcast application. Souza et al. (2016) verified in line application of phosphate fertilizers may increase concentration of P in the zone of initial radicular growth compared to broadcast application. Da Ros et al. (2017) verified that for in plants of corn and sunflower, the location of the phosphate fertilizer is very important in

Table 3. Effect of P application method and soil density on stem diameter (SD), plant height (PH), root volume (RV), root dry matter (RDM) and shoot dry matter (SDM) of corn plants cultivated in greenhouse condition.

Treatment	SD	PH	RV	RDM	SDM
	cm		$g\ L^{-1}$	$g\ pot^{-1}$	
Without P	4.03	9.48 b	9.86	1.12	0.94
Broadcast	9.06	17.51 a	51.12	7.74	6.41
In line	9.93	18.47 a	84.13	8.46	10.11
CV%	7.39	9.59	17.72	12.43	7.39
LSM	0.72	1.87	10.96	0.92	0.55
Densities					
D1 – 1.2 g cm^{-3}	7.43	15.07	58.33	5.73	6.31
D2 – 1.6 g cm^{-3}	7.79	15.55	38.42	5.82	5.32
LSM	0.48	1.26	7.35	0.62	0.37
F values					
Density (D)	1.11	0.62	32.4**	0.10	31.8 **
P application(PA)	252**	96.8**	151.6**	254.2**	920.1**
DxPA	7.4**	0.18	10.51**	16.71**	13.6 **
CV%	7.39	9.59	17.72	12.43	7.39

** of F test significant at p<0.01, respectively.

the accumulation of P in the plants.

Moreover, in no till areas, broadcast application of P enhances P content in the superficial soil layer compared to sub superficial layers (Santos et al., 2005) which increases contact between phosphate fertilizer and soil. Therefore, higher rate is required in broadcast application to achieve similar fertilizer efficiency than in line application (Prado et al., 2001).

There was higher accumulation of P in shoot and root of plants cultivated in soil with density 1 than in soil with density 2 (Table 1). Therefore, it was noticed that soil density of 1.6 g cm^{-3} was harmful to root and shoot growth and P uptake. Also, soil compaction results in higher resistance to mechanical penetration that limits radicular development and reduces root capacity of water uptake, hence it affects plant growth (Ortigara et al., 2014).

Plants with P applied in line and broadcast were 94.83% and 84.70%, respectively, which are higher than plants without P fertilization (Table 3). This is explained by P essentiality on plant metabolism, the component of nucleotides used in energy metabolism of plants (such as ATP) and in DNA and RNA (Taiz et al., 2017); resulting in smaller plants in soils with lower P availability.

A significant interaction effect between density and P application was observed for the other measured variables (Table 3). At density 1, stem diameter was higher with application of P in line than broadcast fertilization and without P (Table 4). In contrast, similar diameter was observed with in line and broadcast application at density 2, which were higher than those without P application. There was no effect of soil density on plant diameter when P was not applied and applied in line; however, higher stem diameter was observed at density 2 when broadcast was applied.

Regardless of soil density, root volume was higher when P was applied in line compared to broadcast application and without P application (Table 4). Moreover, higher root volume was observed at density 1 when P was in line applied. Since P has low mobility in soil, lower root volume affects uptake of P by corn plants (Santos et al., 2005) and also affects root distribution and biomass within soil profile ((Twum and Nii-Annang, 2015); resulting in reduction in crop yield. This fact elucidates the importance of knowing crop threshold for soil compaction, as well as of monitoring soil compaction, especially in tropical regions in which there is low levels of available P.

Regardless of soil density, root and shoot dry matter accumulation were higher in plants under in line P application, expect for root dry matter in plants broadcast applied with P, in which similar results to in line application were observed (Table 4).

Moreover, plants treated with in line P presented lower accumulation of root and shoot dry matter at soil density 2. The effect of soil density in plants applied with broadcast P was only observed for root dry matter, in which lower values was observed at density 2. No effect of soil density on root and shoot dry matter was observed in plants without P application.

Grzesiak et al. (2014) observed the negative effect of soil compaction in maize and triticale, with a decrease of aerial parts and roots dry matter and changes in roots distribution in the soil profile. Sarto et al. (2018)

Table 4. Interaction effect between P application method and soil density on stem diameter (SD), root volume (RV), root dry matter (RDM) and shoot dry matter (SDM) of corn plants cultivated in greenhouse condition.

Density	Treatment		
	Without P	Broadcast	In line
SD (cm)			
D1 – 1.20 g cm^{-3}	4.02[a]	8.34[b]	10.28[a]
D2 – 1.60 g cm^{-3}	4.04[a]	9.77[a]	9.57[a]
RV (g L^{-1})			
D1 – 1.20 g cm^{-3}	12.50[c]	57.25[b]	105.25[a]
D2 – 1.60 g cm^{-3}	7.25[c]	45.01[b]	63.00[b]
RDM (g pot^{-1})			
D1 – 1.20 g cm^{-3}	1.20[b]	8.88[a]	9.35[a]
D2 – 1.60 g cm^{-3}	1.04[b]	6.60[a]	7.54[a]
SDM (g pot^{-1})			
D1 – 1.20 g cm^{-3}	1.05[c]	6.65[b]	11.26[a]
D2 – 1.60 g cm^{-3}	0.83[c]	6.18[b]	8.98[a]

[abc] means in both column and row of the same superscript are not significantly different ($p<0.05$).

elucidated that in compacted soil, the roots under hypoxia produce high quantity of ethylene. This hormone inhibits root elongation and induces root swelling in plants (Geisler-Lee et al. 2010). This might explain higher root values (60%) in plants applied with in line P at soil density 1.2 g cm^{-3} (D1) compared to soil density 1.6 g cm^{-3} (D2). Grzesiak et al. (2013) indicate that soil compaction reduces plant system roots; consequently, affecting the development and productivity of several crops (Gubiani et al., 2014; Valadão et al., 2015)

Shoot dry matter of plants that received in line P application was 60% higher than broadcast application, and 11 times higher than plants without P fertilization (Table 4). According to Santos et al. (2005), maximum accumulation of shoot dry matter in corn plants cultivated in pots with nutritive solution occurred with application of 400 mg dm^{-3} of P ($NH_4H_2PO_4$). These authors observed a maximum of 6.02 g pot^{-1}, which was lower than shoot dry matter observed in the present study (11 g pot^{-1}). Souza et al. (2008) also observed that application of 400 mg dm^{-3} of P in corn plants cultivated at densities of 1.34 a 1.67 g cm^{-3} resulted in 4.5 a 3.5 g of shoot dry matter, respectively; these were also lower than shoot dry matter accumulation observed for plants treated with in line P in the present study. This might be due to the application method used, in which corn dry matter increases with increasing availability of P through localized application of fertilizers, as observed in the present study with in line treatment.

Therefore, higher root and shoot dry matter (Table 4) might be explained through higher accumulation of P in corn root and shoot (Table 1). These results elucidate the importance of accurate management of phosphate fertilization in order to increase plant nutrition.

Conclusions

Phosphorus application in line resulted in higher P accumulation in plant. There was higher plant dry matter accumulation at soil density 1.2 g cm^{-3} compared to 1.6 g cm^{-3}. In line phosphate fertilization at soil density 1.2 g cm^{-3} enhances dry matter accumulation in corn plants.

CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

REFERENCES

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G (2014). Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22(1):711-728.

Amanullah AM, Almas LK (2012). Agronomic efficiency and profitability of fertilizers applied at different planting densities of maize in Northwest Pakistan. Journal Plant Nutrient 35(2):331-341.

Barbosa NC, Pereira HC, Arruda EM, Brod E, Almeida RF (2018). Spatial distribution of phosphorus in the soil and soybean yield as function of fertilization methods. Bioscience Journal 34(1):88-94.

Barzegar A, Yousefi A, Zargoosh N (2016). Water stress and soil compaction impacts on clover growth and nutrient concentration. Eurasian Journal of Soil Science 5(2):139-145.

Beutler AN, Centurion JF (2004). Soil compaction and fertilization in soybean productivity. Scientia Agricola 61(2):626-631.

Ceretta CA, Silva LS, Pavinato A (2007). Manejo da adubação In: Novais, R.F., Alvarez, V.H., Barros, N.F., Fontes, R.L.F., Cantarutti, R.B., and Neves, J.C. L. (ed.): Fertilidade do solo. Viçosa: SBCS.

Da Ros CO, Matsuoka M, Silva RF, Silva VR (2017) . Interference from the vertical variation of soil phosphorus and from water stress on growth in maize, the soybean and sunflower. Revista Ciência Agronômica 48(3):419-427

DeLong M, Vandecar KL, D'Odorico P, Lawrence D (2013). The impact of changing moisture conditions on short-term P availability in weathered soils. Plant Soil 365(3):201-209.

Embrapa (2013). Sistema Brasileiro de Classificação de Solos. Rio de Janeiro: Centro Nacional de Pesquisa em Solos 342 p.

Embrapa (2009). Manual de análises químicas de solos, plantas e fertilizantes. Brasília-DF: Embrapa Informação Tecnológica; Brasília, DF: Embrapa Solos 627 p.

Fink JR, Inda AV, Bayer C, Torrent J, Barrón V (2014). Mineralogy and phosphorus adsorption in soils of south and central-west Brazil under conventional and no-tillage systems. Acta Sci Agron 36 (2):379-387.

Galetto SL,Fonseca AF, Harkatin S, Auler AC, Carvalho IQ (2014). Availability of phosphorus for maize in crop-livestock integration system. Revista Ciência Agronômica 45(5):956-967.

Geisler-Lee J, Calwell CE, Gallie DR (2010). Expression of the ethylene biosynthetic machinery in maize roots is regulated in response to hypoxia. Journal of Experimental Botany 61(2):857-871.

Grzesiak S, Grzesiak MT, Hura T, Marcińska I, Rzepka A (2013). Changes in root system structure, leaf water potential and gas exchange of maize and triticale seedlings affected by soil compaction. Environmental and Experimental Botany 88(2):2-10.

Grzesiak MT, Ostrowska A, Hura K, Rut G, Janowiak F, Rzepka A, Hura T, Grzesiak S (2014) Interspecific differences in root architecture among maize and triticale genotypes grown under drought, waterlogging and soil compaction. Acta Physiologiae Plantarum 36(2):3249-3261.

Gubiani PI, Reichert JM, Reinerter DJ (2014). Interação entre disponibilidade de água e compactação do solo no crescimento e na produção de feijoeiro. Revista Brasileira de Ciência do Solo 38(3):765-773.

Hawkesford M, Horst, W, Kichey T, Lambers H, Schjoerring J, Moller IS, White P (2012). Functions of macronutrients. In: Marschner, P. (ed.). Mineral nutrition of higher plants. 3.ed. New York: Elsevier pp. 171-178.

Malavolta E (1981). Manual de química agrícola: adubos e adubação. São Paulo: Agronômica Ceres.

Martuscello JA, Fonseca DM, Moreira LM, Ruppin RF, Cunha, DNFV (2009). Níveis críticos de fósforo no solo e na parte aérea no estabelecimento de capim- elefante. Revista Brasileira de Zootecnia 38(2):1878-1885.

Nawaz M, Bourrié G, Trolard F (2013). Soil compaction impact and modelling. A review. Agronomy for Sustainable Development 33(2):291-309.

Novais RF, Smyth TJ, Nunes FN (2007). Fósforo. In: Novais, R.F. Alvarez, V.V. H., Barros, N.F.; Fontes, R.L.F., Cantarutti, R.B., and Neves, J.C.L.(ed.). Fertilidade do solo. Viçosa: SBCS.

Ortigara C, Koppe E, Luz FB, Bertollo AM, Kaiser DR, Silva VR (2014). Uso do solo e propriedades físico-mecânicas de Latossolo Vermelho. Revista Brasileira de Ciência do Solo 38(3):619-626.

Prado RM (2008). Nutrição de plantas. Jaboticabal, São Paulo: Editora UNESP.

Prado RM, Fernandes FM, Roque CG (2001). Resposta da cultura do milho a modos de aplicação e doses de fósforo, em adubação de manutenção. Revista Brasileira de Ciência do Solo 25(2):83-90.

Santos GA, Dias Junior MS, Guimares PTG, Furtini Neto AE (2005). Diferentes graus de compactação e fornecimento de fósforo influenciando no crescimento de plantas de milho (*Zea mays* L.) cultivadas em solos distintos. Ciência e Agrotecnologia 29(1):740-752.

Sarto MVM, Bassegio D, Rosolem CA, Sarto JRW (2018). Safflower root and shoot growth affected by soil compaction. Bragantia, Campinas 77(2):348-355.

Shen J, Yuan L, Zhang J, Li H, Bai Z, Chen X, Zhang W, Zhang F (2011). Phosphorus Dynamics: From Soil to Plant. Plant Physiology 15(6):997-1005.

Singh J, Hadda MS (2014). Soil and plant response to subsoil compaction and slope steepness under semi-arid irrigated condition. International Journal of Food, Agriculture and Veterinary Sciences 4(3):95-104.

Sousa DMG, Lobato E (2004). Cerrado: Correção do Solo e Adubação. Brasília:Embrapa Informação Tecnológica 360 p.

Souza MAS, Faquin V, Guelfi DR, Oliveira GC, Bastos CEA (2012). Acúmulo de macronutrientes na soja influenciado pelo cultivo prévio do capim-marandu, correção e compactação do solo. Revista de Ciências Agronômica 43(2):611-622.

Souza DMG, Nunes RS, Rein TA, Santos Junior JDG (2016). Manejo do Fósforo na Região de Cerrado, in: Flores, R.A., and Cunha, P.P. (ed.). Práticas de manejo do solo para adequada nutrição de plantas no cerrado. Goiânia: UFG.

Taiz L, Zeiger E, Moller I, Murphy A (2017). Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: Artmed 888 p.

Twum EKA, Nii-Annang S (2015). Impact of Soil Compaction on Bulk Density and Root Biomass of *Quercus petraea* L. at Reclaimed Post-Lignite Mining Site in Lusatia, Germany. Applied and Environmental Soil Science 5(2):1-5

Valadão FCA, Weber OLS, Valadão Junior DD, Scapinelli A, Deina FR, Bianchini A (2015). Adubação fosfatada e compactação do solo: sistema radicular da soja e do milho e atributos físicos do solo. Revista Brasileira Ciência do Solo 39(2):243-255.