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Short-term effects of lime management in soybean no-tillage system implementation in Brazilian savannah

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Abstract

The aim of this research was to assess the effect of lime management under no-till system implementation to evaluate the millet cover crop and soybean performance. This experiment was carried out during the years 2012 and 2013 in the municipality of Ponta Porã, state of Mato Grosso do Sul, Brazil. The experimental design in blocks with four replicates and three treatments (Treat-1; Lime surface application without incorporation; Treat-2; Lime surface application and incorporated with intermediate disk harrow followed by leveling disk harrow; Treat-3; Lime surface application and incorporated with chisel plow, followed by intermediate disk harrow and leveling disk harrow), the amount of lime was 2.7 tonnes ha^{-1}. The crops evaluated were millet (*Pennisetum glaucum* cv. BRS-1501) and soybean (*Glycine max* cv. BMX-Potência RR) in crop rotation. The millet was planted as cover crop to produce above-ground dry mass. The soybean was sowed under millet dry mass in no-till system. After 12 months from planting, the lime management promoted chemical and physical changes in soil properties through the profile. The Treat-2 and 3 resulted in better lime incorporation in the layer 10-20 cm and 20-30 cm. The highest dry mass of millet was obtained in Treat-2 (6,460 kg ha^{-1}) and Treat-3 (6,690 kg ha^{-1}). The highest soybean productivity (3,330 kg ha^{-1}) was reached in Treat-3. The absence of lime incorporation into the soil caused decrease in millet and soybean production. Even if the soil chemical is adequate for a good performance for crops, the SPR may limit the root development. The Treat-2 and 3 reduced the SPR and increased the vegetable production of soybean and millet.

Keywords: Liming; cover crop; crop rotation; soil penetration resistance; millet; soil fertility.
Abbreviations: SPR_Soil Penetration Resistance; CEC_Cation Exchange Capacity; SOM_Soil Organic Matter; Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow, followed by leveling disk harrow; Treat-3_ Lime surface application and incorporated with chisel plow in the 0-30 cm soil profile, followed by intermediate disk harrow and leveling disk harrow.

Introduction

The most amount of tropical soil in South American is considered poor in nutrients contents, as well as the savannah region of Brazil (Leal et al., 2013). These soils are well-known by the extreme weathering and leaching of nutrients, which increase the soil acidity limiting the agricultural performance (Novais and Smith, 1999). The correction of soil acidity is commonly through the application of lime, which contributes to increase crop production, because of the best chemical, physical and biological properties in the soil. However, the lime has low solubility, this way its efficiency is related to an unbiased application in soil surface and incorporation in soil profile, which must be done to assure that the lime will reach higher contact with the soil particles (Raij et al., 1997; Kaminski et al., 2005; Miranda et al., 2005). Besides the correction of soil acidity (pH), the lime increased the content of exchangeable Ca^{2+} and Mg^{2+} (Caires et al., 2001), and decreased the exchangeable Al^{3+} level (Pavan et al., 1982; Caires et al., 2005). The exchangeable Al^{3+} is up taken by roots which cause disarrangement into the cell membrane of plants and effect their metabolism, as the interruption of DNA synthesis and mitosis (Peixoto et al., 2007). The Brazilian savannah soils are located in regions where the weather condition increases the process of soil organic matter mineralization (Souza and Lobato, 2002). To be feasible the no-till system, first of all it is necessary to have above-ground organic matter remained from the cover crops, this way the farmer may choose the forage grass species with high potential of dry mass production and great adaptability in tropical soils. The millet (*Pennisetum glaucum* L.) is a good option to be introduced as cover crop (Leal et al., 2013). This species is annual in tropical conditions and one of its most important features is to be resistant to drought season. The millet root system can reach 2 m deep, which is recognized for recycling nutrients in deep layer (Alvarenga et al., 2001; Rosolem et al., 2002). Besides, the mineralization of its root system improves the quantity of soil organic matter in deep layers, what is quite important in sandy and with low natural fertility soil, as the Oxisol (Foy, 1997). When liming and cover crop resistant to dry are associated in no-till system, there is potential to increase soil quality because of the maintenance of soil organic matter above- and below-ground, besides the decrease of temperature range and increase of soil moisture conservation (Duley, 1939). The soil organic matter remained from millet may improve the physical qualities, because of the formation of the stable aggregate in soil in long-term (Brancalião et al., 2008). In no-till system in Brazil, the soybean [*Glycine max* (L.) Merrill] is the most used crop in cropping rotation with cotton, rice, corn, etc. The soybean is the most important grain crop cultivated in the world. In Brazil, the area planted with soybean is 29 millions hectare and the average productivity is 3,000 kg ha^{-1}, this area corresponds to 45% of the whole area cultivated with commercial crops in Brazil (Conab, 2014). The aim of this work was to assess the effect of lime management in no-till system implementation to evaluate the millet as cover crop and soybean performance.

Result and Discussion

Consequence in soil chemical, millet height and above-ground millet dry mass

Although the experimental time was just one cropping season, it was observed that many soil chemical and physical properties were influenced by the lime management, in the depths evaluated in this work (Table 1). There was no significant difference ($p>0.05$) among the treatments in relation to the pH in all depths evaluated, however it was noticed that the liming increased the soil pH when comparing to the initial soil chemical analysis, which was made before the implementation of the experiment (Table 2). In the Fig. 1A, it is observed that the average value of the pHin 20-30 cm depth showed smaller values than the other depths, it is because of the highest pH in deeper layers. In this experimental results, even the highest pH value in the Treat-3 for these, it was not statistically different ($p>0.05$) (Fig. 1A). According to Miranda et al. (2005), the suggestion to improve the problem of low solubility lime would be the deepest incorporation in soil. In previous research, Weirich Neto et al. (2000) worked with methods of lime incorporation and observed that deeper incorporation raises the pH value to acceptable levels for better crops development. The P content was affected by the treatments, there was difference ($p\leq0.05$) among the treatments in 0-10 cm depth and 10-20 cm. The highest P content was observed in 0-10 cm depth in the Treat-1 (Fig. 1B). This result can be explained because of the no-till in the Treat-1, this way the P 0-10 cm depth was more concentrated than the other layers. But, in the Treat-2 and 3, the tillage promoted homogeny of the P content in the soil profile (Fig. 1B). Before the implementation of the experiment, this experimental area was used with forage grass in livestock system for 10 years. In this specific area there was no-till during these years, but the forage grass fertilizer was applied in soil surface. This way, the P content on the soil surface was increasing throughout these years, what is feasible to observe in the Treat-1 (Fig. 1B). The P in the soil shows low mobility, along this line, the application in surface does not promote the increase in deeper layers. These results are in accordance to the results obtained by Fasinmirin and Reichert (2011). The exchangeable K^+ differs ($p\leq0.05$) only in 0-10 cm depth (Fig. 1C). The smallest content of exchangeable K^+ showed in the Treat-1 which is probably related to the cover crop. The millet has high capability to uptake K^+ and the mineralization of the above-ground dry mass raises the K^+ content in the surface layers. However, in the Treat-1 the development of millet root may be compromised due to the no-tillage to incorporate the lime in the soil and high soil resistance penetration (SPR). In the Treat-1 the SRP was 3.5 times over the Treat-2 and 3. The above-ground millet dry mass production showed significant difference ($p\leq0.05$) between the Treat-1 and 3 (Fig. 1D). The Treat-1 showed the smallest value of above-ground millet dry mass and the highest value was observed in Treat-3. Based on the results obtained in this work, the no incorporation of the lime deeper in soil may damage the maintenance of the no-till system because of the smallest above-ground dry mass. This feature is considered the first step to exist a no-till sustainable system. To implement the no-till system it is quite important the maintenance of above-ground dry mass. As recorded by Bressan et al. (2013), to have the sustainability of the no-till system it is necessary at least 5,000 kg ha^{-1} of above-ground dry mass. It is possible to observe that all the treatments in this work were over than the limit of 5,000 kg ha^{-1} (Fig. 1D). Nevertheless, it is important to mention that in tropical savannah condition as Brazilian country, the mineralization of organic matter is faster due to the weather condition being favorable for quick decomposition of the organic matter, as high temperature and humidity. Due to the fast organic matter mineralization, it is important to achieve above-ground dry mass over than 5,000 kg ha^{-1}. The mineralization is quite important to supply nutrient back to the soil, on the other hand, this process reduces the amount of above-ground dry mass, so it is suggested in tropical climate the use of cover crops with high potential of biomass production. In results of Moraes (2011), it was consisted that millet above-ground mineralization was higher in 63 days after the desiccation. The height of millet was different ($p\leq0.05$) among the treatments, the smallest height was obtained in the Treat-1 (Fig. 1E), which is correlated ($r = 0.998$) to the above-ground millet dry mass (Table 1). It was observed that the above-ground millet dry mass is proportional to the height of millet, because of the positive correlation, even with the capability of the millet in growing tillers, the height is a measurement that expresses high influences on above-ground millet dry mass. The other factor observed in this work which influences the above-ground millet dry mass production is the SPR. It was measured the correlation between SPR versus above-ground millet dry mass, and the results showed the negative correlation among these variables (Table 1). The high values of SPR decrease the above-ground millet dry mass.

Base saturation, calcium, magnesium, potassium and aluminium saturation.

The calcium saturation was higher in the surface layer (0-20 cm) in comparison to the other depths, but no significant difference was obtained among the treatments ($p>0.05$). In in 20-30 cm depth the Treat-3 showed higher calcium saturation, followed by Treat-2 and 1 ($p\leq0.01$) (Fig. 2A). The use of chisel plow increased the incorporation of lime deeper in soil (20-30 cm), what is considered quite important to the roots development. The problem in incorporating the lime in layer under 20 cm occurs frequently in the moment of no-till system implementation, because usually the implements used for the procedure cannot incorporate the lime under this layer. In Brazilian savannah, generally the incorporation of the lime is made just with the use of disk harrow, what may be occurring in limitation of lime incorporation deeper in

Table 1. Correlation matrix of dependent variable.

	AMDM	HM	SPR 0-10	SPR 10-20	SPR 20-30	RLS 0-10	RLS 10-20	RLS 20-30	HS	HFPI	SP	†K^+	†Ca^{2+}	†Mg^{2+}
					------------------------------	cm	----------------------------							
AMDM	1	0.998	-0.972	-0.763	-0.931	0.998	0.994	0.536	-0.619	-0.956	0.697	0.964	-0.927	-0.824
HM		1	-0.983	-0.430	-0.700	0.934	0.9515	0.1420	-0.887	-0.992	0.930	0.988	-0.951	-0,861
SPR (0-10 cm)			1	0.590	0.820	-0.984	-0.992	-0.323	0.786	0.998	-0.846	-0.999	0.989	0.934
SPR (10-20 cm)				1	0.946	-0.725	-0.687	-0.955	-0.036	0.539	-0.068	-0.563	0.466	0.263
SPR (20-30 cm)					1	-0.909	-0.886	-0.807	0.290	0.783	-0.388	-0.800	0.728	0.561
RLS (0-10 cm)						1	0.999	0.487	-0.663	-0.971	0.737	0.977	-0.947	-0.855
RLS (10-20 cm)							1	0.440	-0.702	-0.982	0.772	0.987	-0.963	-0.882
RLS (0.20-0.30)								1	0.331	-0.264	-0.232	0.291	-0.181	0.036
HS									1	0.823	-0.995	-0.806	0.868	0.955
HFPI										1	-0.877	-1.000	0.996	0.954
SP											1	0.863	-0.914	-0.980
†K^+												1	-0.994	-0.946
†Ca^{2+}													1	0.976
†Mg^{2+}														1

AMDM=Above-ground millet dry mass; HM=Height of millet; SPR=Soil Penetration Resistance; RLS=Root Length of Soybean; HS=Height of Soybean; HFPI= Height of First Pod Insertion; OSDM=Above-ground soybean dry mass; SP= soybean production; †Exchangeable.

Table 2. Some initial soil physical and chemical soil properties from the experimental site.

	Depth (cm)		
	0-10	10-20	20-30
pH ($CaCl_2$)	4.43	4.10	3.60
SOM (g kg^{-1})	32.10	28.40	24.50
CEC	116.30	108.80	78.00
P (mg dm^{-3})	19.50	9.70	2.00
Al^{3+} ($mmol_c$ dm^{-3})	0.23	0.86	4.00
K^+ ($mmol_c$ dm^{-3})	1.80	0.70	0.40
Ca^{2+} ($mmol_c$ dm^{-3})	44.10	39.20	18.30
Mg^{2+} ($mmol_c$ dm^{-3})	26.10	19.40	5.80
H+Al ($mmol_c$ dm_{-3})	44.30	49.50	53.50
BS (%)	61.90	54.50	31.41
SPR (kg cm^{-2})	17.90	43.00	47.10

SOM: Soil Organic Matter; CEC: Cation Exchange Capacity; SPR: Soil Penetration Resistance; total acidity pH 7.0 (H^+ +Al^{3+}); Exchangeable (KCl 1 mol L^{-1}) Ca, Mg and Al; BS: Base Saturation=(∑cations/CEC)x100.

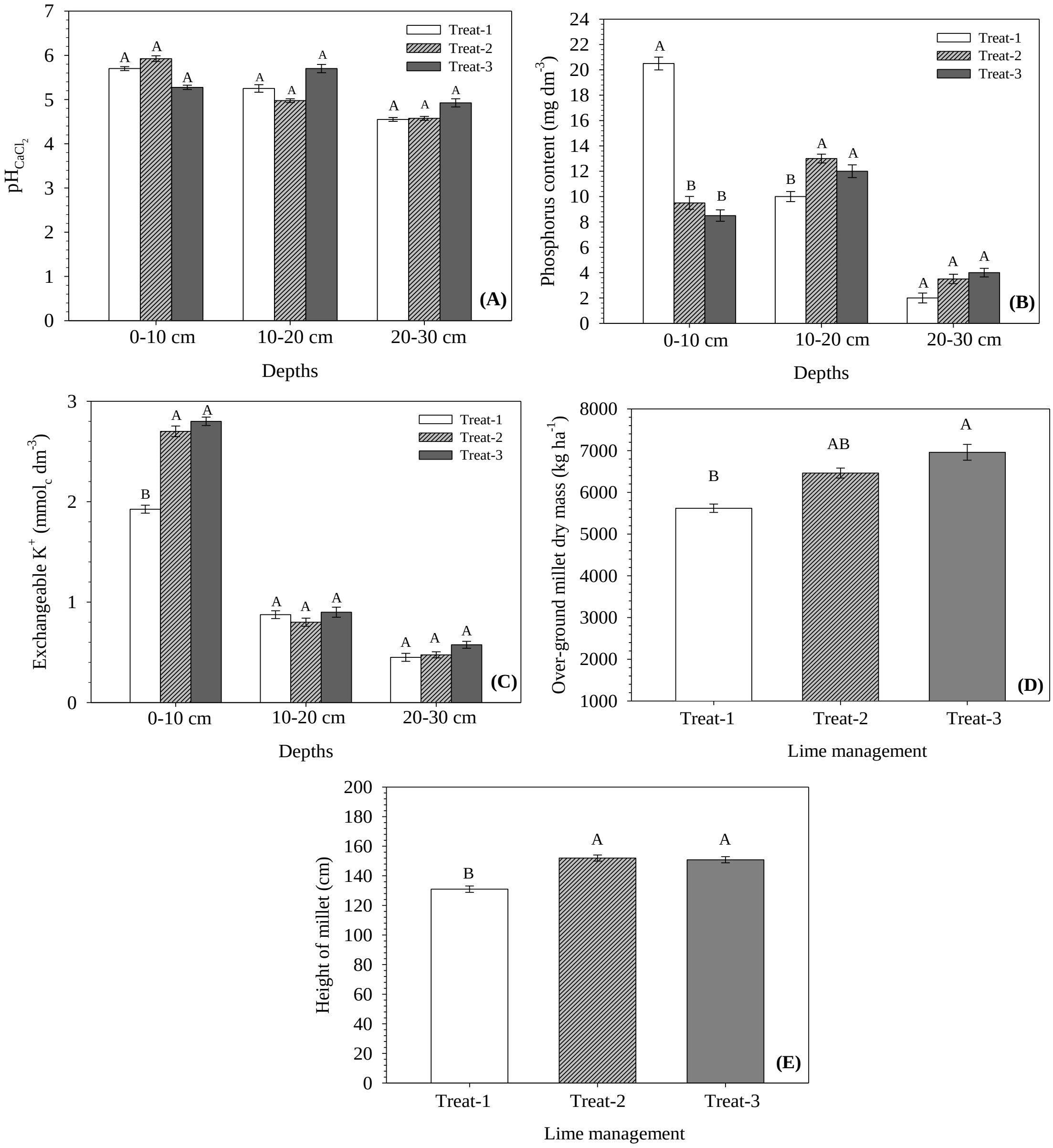

Fig 1. Soil chemical and plant features. Mean in each bar followed by the same capital letter are not significantly different at $p \leq 0.05$ according to the Tukey's test of mean. Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow, followed by leveling disk harrow; Treat-3_ Lime surface application and incorporated with chisel plow in 0-30 cm soil profile, followed by intermediate disk harrow and leveling disk harrow.

soil. As it was feasible to observe in this research, the Ca^{+2} saturation did not achieve value over than 43% (Fig. 2A). As reported by Fageria (2009), the maximum grain yield soybean was obtained at 51% calcium saturation in a Brazilian Oxisol. The magnesium saturation did not differ ($p>0.05$) among the treatments in the layer of 0-10 cm (Fig. 2B). However, in the depths of 10-20 cm and 20-30 cm, the treatments were different ($p \leq 0.05$). The Treat-3 showed higher value ($p \leq 0.05$) of magnesium saturation in the depth of 10-20 cm. Nevertheless, no difference was observed ($p>0.05$) between the Treat-2 and 3 in the depth of 20-30 cm, but both of them showed higher value than the Treat-1. The higher magnesium saturation in the depth 20-30 cm in the Treat-2 and 3 must be related to the incorporation of the lime deeper in the soil by these treatments, because in the Treat-1, the lime was applied on the soil surface without incorporation into the soil, in this Treat-1 and in the depth 20-30 cm, the value of magnesium saturation showed 8.5% of magnesium saturation (Fig. 2B). As reported by Eckert (1987) this value is under the recommended (10% to 15%) for magnesium saturation. This result indicated that the practice of implementing the no-till system without incorporation of the lime must be rethought. The magnesium saturation must be at least 10% for a good plant development (Camberato, 1999). The potassium saturation showed significant difference ($p \leq 0.05$) among the treatments only in the depth 0-10 cm (Fig. 2C). The Treat-3 showed the highest value of potassium saturation (1.9%), followed by Treat-2 (1.7%) and Treat-1 (1.2%) (Fig. 2C). In the other depths the potassium saturation was under than 0.7%. These values are under the recommendation, because many scientific results indicated that the values must be over than 2% of potassium saturation.

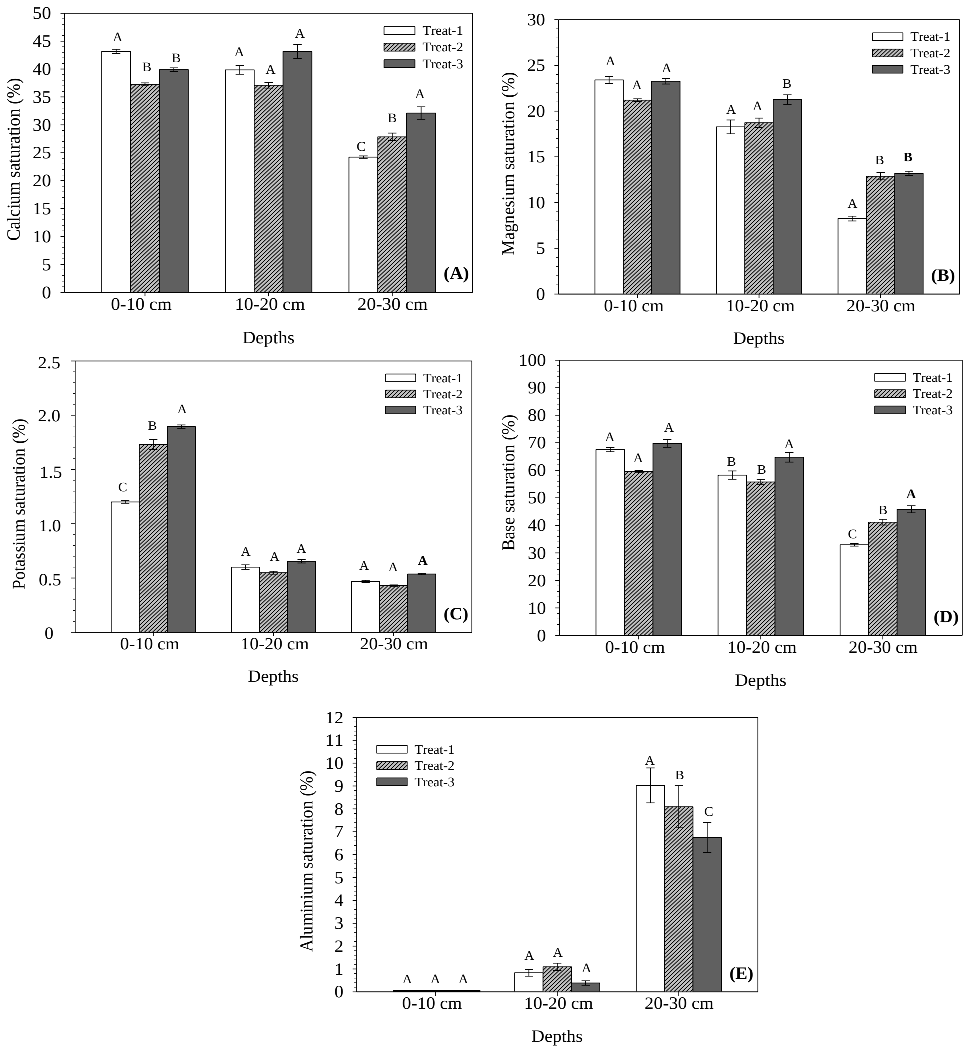

Fig 2. Base saturation, calcium, magnesium, potassium and aluminium saturation. Mean in each bar followed by the same capital letter are not significantly different at $p \leq 0.05$ according to the Tukey's test of mean. Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow, followed by leveling disk harrow; Treat-3_ Lime surface application and incorporated with chisel plow in the 0-30 cm soil profile, followed by intermediate disk harrow and leveling disk harrow.

As reported by Eckert (1987), the potassium saturation must be into the range of 2 to 5%. The base saturation differed ($p \leq 0.05$) in the depths 10-20 cm and 20-30 cm (Fig. 2D). The Treat-3 incorporated the lime deeper in the soil, by this reason the base saturation in the depth 20-30 cm was higher (45.8%) than the others treatments (Fig. 2D). In Brazilian savannah the recommendation for base saturation is 50% in the depth 0-20 cm, according to Souza and Lobato (2002). However, further research has shown that this percentage varies considerably affecting soybean productivity. In this research, the base saturation until the depth 20 cm showed value over than 58.3% which is considered adequate for soybean in Brazilian savannah. But, the basis saturation must be balanced with the cations saturation. It was observed that potassium saturation was under the adequate value. The aluminium saturation does not differ ($p > 0.05$) among the treatments in the depths 0-10 cm and 10-20 cm. However, the aluminium saturation showed significant difference ($p \leq 0.05$) in the depth 20-30 cm (Fig. 2E). According to Fageria (2009), the aluminium saturation in Oxisol for soybean must be under 19%. The aluminium saturation did not achieve value over than 9% in this research. But, it is important to observe that the Treat-3 obtained the smallest value (6.7%) due to the best incorporation of the lime deeper in the soil (Fig. 2E).

Effect of lime management in exchangeable Ca^{2+} and Mg^{2+}, soil penetration resistance and soybean root length

The exchangeable Ca^{2+} in the soil was statistically different ($p \leq 0.05$) among the treatments analyzed in the depths 0-10 cm and 20-30 cm (Fig. 3A). Although the exchangeable Mg^{2+} in the depth 0-10 cm in the Treat-1 showed higher value than the Treat-2 and 3, this difference was not statistically proved ($p > 0.05$) (Fig. 3B). The highest content of exchangeable Ca^{2+} was showed in the depth 0-10 cm in the Treat-1 (Fig. 1A). These results are due to the soil surface application of the lime in the Treat-1, this way the exchangeable Ca^{2+} amount in surface layer increased, on the other hand, no significant difference ($p > 0.05$) was observed for the treatments in the layer 10-20 cm, probably because of the low lime mobility in the soil, even more when the lime is applied on the soil surface. In accordance to Freiria et al. (2008), the lime application on soil surface caused mobility until the depth 0-5 cm in 326 days after application, in soil properties similar in

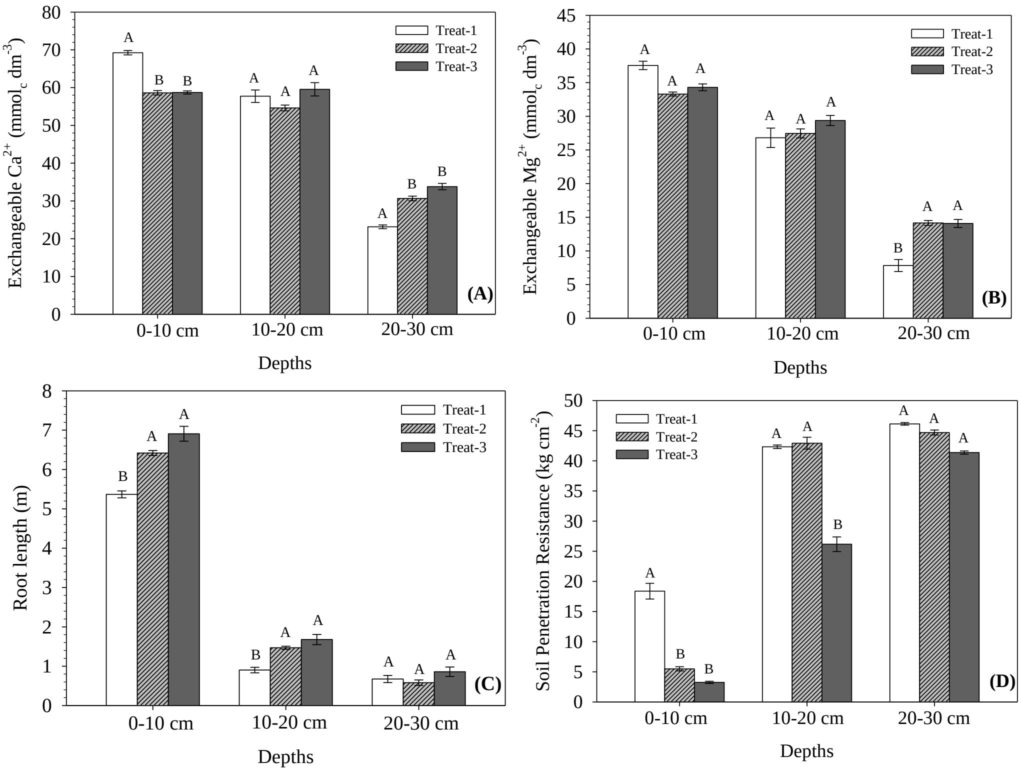

Fig 3. Exchangeable Ca2+ and Mg2+ resistance and soybean root length. Mean in each bar followed by the same capital letter are not significantly different at p≤ 0.05 according to the Tukey`s test of mean. Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow, followed by leveling disk harrow; Treat-3_ Lime surface application and incorporated with chisel plow soil profile, followed by intermediate disk harrow and leveling disk harrow.

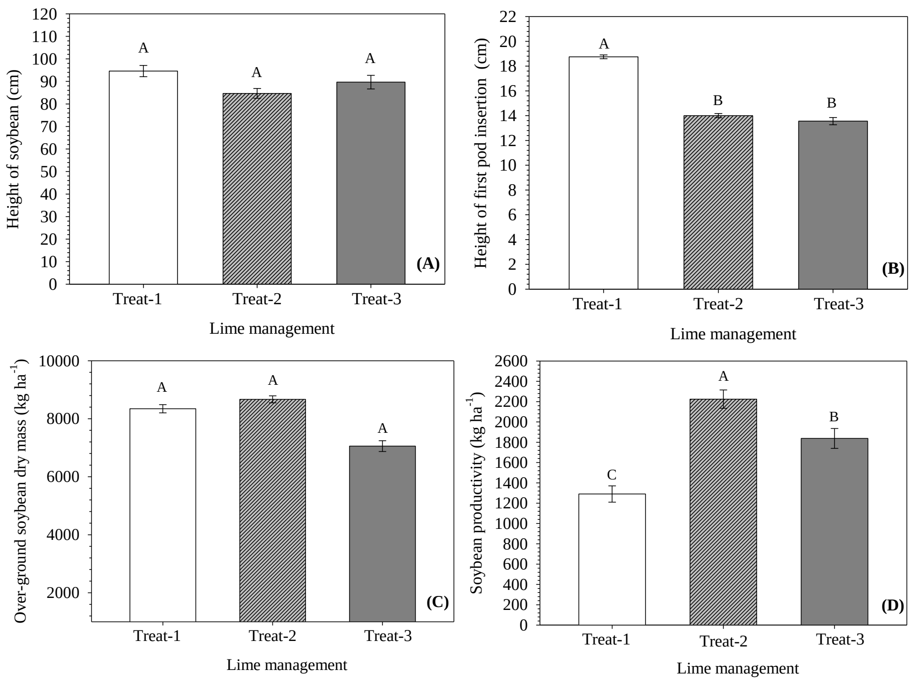

Fig 4. Features of soybean in function of the lime management. Mean in each bar followed by the same capital letter are not significantly different at p≤0.05 according to the Tukey's test of mean. Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow, followed by leveling disk harrow; Treat-3_ Lime surface application and incorporated with chisel plow in the 0-30 cm soil profile, followed by intermediate disk harrow and leveling disk harrow.

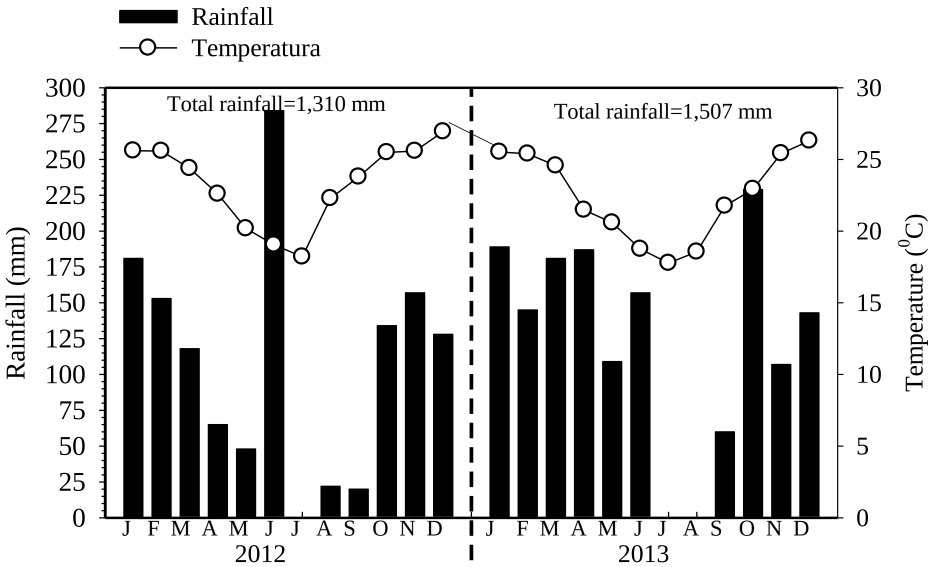

Fig 5. Monthly rainfall and temperature from January 2012 to December 2013.

this experiment. In the depths 20-30 cm, the Treat-1 showed the smallest content of exchangeable Ca^{2+} and Mg^{2+}. In the Treat-2 and 3 the average results were higher, but not different ($p>0.05$). This result indicated that the lime incorporation method in the soil was efficient to allocate the lime and increase the content of exchangeable Ca^{2+} and Mg^{2+} deeper in the soil. In results obtained by Freiria et al. (2008), it was observed that the surface liming increases the exchangeable Ca^{2+} and Mg^{2+} until 0-5 cm of depth and the lime incorporated in depth 0-20 cm the exchangeable Ca^{2+} and Mg^{2+} were increased until 30 cm depth. These results are in according to the results obtained in this experiment (Fig. 3A and B). Another explanation to assure these results of the exchangeable Ca^{2+} and Mg^{2+} increase in depth is the formation and migration of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ to the deepest layers of the soil, as well as the possibility of translocation in deepest layers of lime through the galleries left by soil insects and root system decomposed in the soil (Caires et al., 2000). The length of the soybean root was significantly different ($p\leq0.05$) among the types of lime management (Fig. 3C). The soybean root showed smaller length in the Treat-1 in the soil profile 0-20 cm. In the Treat-1, depth 0-10 cm, the soybean length was smaller than the Treat-2 and 3, this result was repeated in the depth 10-20 cm, as well. Between the Treat-2 and 3 there was no difference ($p>0.05$) in the soybean root length in the depths 0-10 cm and 10-20 cm. Among all the treatments there was no difference ($p>0.05$) in the soybean root length in the depth 20-30 cm. The smallest growth of the soybean root system in the Treat-1 is correlated to the SPR. It was possible to observe that the SPR was higher in the Treat-1 in depths, 0-10 cm and 10-20 cm (Fig. 3D). The high negative correlation (Table 1) between the SPR versus root length in the depth 0-10 cm demonstrated that the soybean root length is damaged for the high values of SPR. It was observed in this work that values above 5.5 kg cm^{-2} damage the soybean rooting growth.

Features of soybean in function of the lime management

The soybean height does not differ signifficantly ($p>0.05$) among the treatments (Fig. 4A). It was observed that in all treatments the average height was 90 cm, this height is in accordance to what it is expected from the soybean cultivar BMX-Potência RR that was cropped in the south region of Mato Grosso do Sul, Brazil. For the height of first pod inserction, there were different results among the treatments ($p\leq0.05$). The Treat-1 differed from the others, which reached the highest height of first pod inserction. The results showed that in all treatments the height of the first pod inserction was over than 13 cm (Fig. 4B). The correlation between the soybean productivity and height of first pod was negative (Table 1). The increase of soybean productivity depends on the decrease of soybean height of the first pod insertion. When the plant is stretched the inter nodes are longer than in regular plants, which probably compromises the plant productivity, because of the small amount of pod in the whole plant. The matrix of correlation showed that SPR is highly correlated to the height of the first pod insertion (Table 1), which is showed in plants with higher height of the first pod insertion, the soil showed higher values of SPR. This soybean feature is quite important because of the harvest, at the moment of the harvest if the height of the first pod is under than 10 cm it may cause the reduction of the grain yield, because of the grain loss. The harvester needs to be adjusted for the height of the first pod inserction. According to Sediayama et al. (1999), to reduce the grain loss in the moment of the harvest it is important that the soybean height of the first pod inserction must be between 10 to 12 cm in land with flat topography, on the other hand in sloping land the height of the first pod inserction may not be under 15 cm. The above-ground soybean dry mass does not differ from the other treatments ($p>0.05$), this is probably due to the no difference among soybean height ($p>0.05$). Nevertheless, the soybean productivity was different among the treatments ($p\leq0.05$). The smallest soybean productivity was obtained in the Treat-1, followed by the Treat-3 and Treat-2 (Fig. 4D). The SPR and soybean productivity were positively correlated, being possibly to be observed that the increase of SPR reduces the soybean productivity (Table 1). In the Treat-1, there was no-till to incorporate the lime into the soil profile, this way the results of SPR reach average value of 18.38 kg cm^3 (depth of 0-10 cm). This value of SPR decreases the soybean productivity, factor that is correlated to the decrease of soybean root length (Table 1).

Materials and Methods

Site description and soil

This research was carried out in the crop season of 2012-2013 in a dystroferric Red Latosol, classified according to Santos et al. (2006), located in the municipality of Ponta Porã, state of Mato Grosso do Sul, (approximately 22˚34'08''S, 55˚30'30'W, average altitude 589 m asl). Before the establishment of the experiment, in January 2012, some chemical and physical properties of the soil were analyzed from the 0–20 cm depth. The analysis showed the following results: 420, 130, and 450 g kg^{-1} of clay, silt, and sand respectively, according to Claessen (1997). The rainfall and temperature in the region of the experimental site is showed in Fig. 5.

Historic of the experimental site

Before the implementation of the experiment, the field site was being used for pasture for 10 years (2002-2011). At the first three years the area was cultivated with *Cynodon lemfuensis* Vanderyst (2002-2004), after this period of time it was liming with dolomitic lime 2.5 tonnes ha^{-1} (33% calcium oxide and 15% magnesium oxide). The lime was incorporated with disk harrow of 28 inches, followed by the leveling disk harrow of 22 inches, and 30 days after the lime incorporation, the pasture *Brachiaria decumbens* Stapf. cv. Basilisk was sowed and cultivated for 7 years (2005-2011).

Implementation of the experiment

In February 2012 the experiment was implemented. The *Brachiaria decumbens* Stapf. cv. Basilisk was desiccated with glyphosate herbicide (1.08 kg e.a. ha^{-1}) in the whole area of the experiment. The analyses of the soil chemical and physical properties were accomplished with 10 simple samples in each depth (0-10 cm; 10-20 cm; 20-30 cm), that formed one composite sample by each layer. These samples were used to determine the soil chemical and physical properties, according to Claessen (1997). The results of these analyses are shown in Table 2. Based on the average of the soil chemical analyses in the soil profile (0-30 cm), it was determined the quantity of lime to rise the base saturation in 70%, to accomplish this procedure it was applied 2.7 tonnes ha^{-1} of dolomitic lime (80 percent of calcium carbonate equivalence).

Experimental design and treatments

The experimental design was set up in completely randomized blocks with four replicates and three treatments (Treat) of lime management; [Treat-1_ Lime surface application without incorporation into the soil; Treat-2_ Lime surface application and incorporated with intermediate disk harrow (24 disks with 32 inches) followed by leveling disk harrow (52 disks with 22 inches); Treat-3_ Lime surface application and incorporated with chisel plow (15 legs) in the 0-30 cm soil profile, followed by intermediate disk harrow (24 disks with 32 inches) and leveling disk harrow (52 disks with 22 inches)]. The experimental units had dimension of 50 m length by 25 m width. All operations were executed with a tractor wheel of 112 HP (Horsepower). For the seeding procedure it was used grain drill with the rows spaced 45 cm apart for planting soybean and millet. These operations of lime management were executed during the period from March to May 2012.

Plant material and measurement

The millet (*Pennisetum glaucum* cv. BRS-1501) and soybean (*Glycine max* cv. BMX-Potência RR) crops were established in crop rotation to be feasible the implementation of a no-till system for soybean. The millet crop was planted to produce above-ground dry mass. The millet was sowed right after the operations of lime management. Before planting, the millet seeds were analyzed and showed 93% of germination and 98% of purity. The seed density was 20 seeds by meters and the dose of fertilizer was N=32, P_2O_5=32, K_2O=32 kg ha^{-1}. The fertilizer was applied in line of seeding, with 8 cm depth, which was allocated under and beside the seed to avoid contact with the seed. In the reproductive stage of millet, it was evaluated the following features: height and above-ground dry mass, this evaluation was accomplished in 5 meters of length by 0.9 m of width in the center of each experimental unit. After four months from the millet sowed, the millet was desiccated with glyphosate herbicide (1.44 kg e.a. ha^{-1}). The soybean (BMX-Potência RR) was sowed after 14 days from the millet desiccation. The soybean germination and purity of the seed were 95 and 99%, respectively. The seed density was 15 seeds per meter and resulted in plant stand of 333,333 plants per hectare. In the R2 reproductive stage (Full bloom), it was determined the height, dry matter of aerial part and the root length in three different depths (0-10 cm; 10-20 cm; 20-30 cm). At the harvest moment, the height of the first pod insertion and productivity were evaluated. The above-ground soybean biomass was evaluated harvesting all the plants in a dimension of 5 m by 0.9 m in the center of the experimental unit as well as millet. This biomass was dried in stove with air pressure at 65^0 C, this biomass remained in this stove until the constant weight. The soybean and millet height were measured starting on soil surface until the uppermost main-stem nodes. After the soybean harvest, the above-ground soybean dry mass was evaluated as well as the soil depths to determine the soil physical and chemical properties. To determine the percentage of above-ground soybean and millet dry mass it was used a rope of 10 meters, containing 100 nodes equal to 10 cm, according to Sloneker and Moldenhauer (1977). The soybean productivity was measured by the manual harvest in the experimental unit in a dimension of 5 m by 0.9 m in the center. The grains were weighed and the productivity was showed in kg ha^{-1}.

Soil measurement

The soil was sampled between the crop rows. It was used Dutch auger type to sample the soil. In each depth of evaluation (0-10 cm; 10-20 cm; 20-30 cm) it was accomplished four soil samples per depth plot, but all of them were mixed to form just one sample to be analyzed. The following parameters were evaluated in the soil sample; total acidity pH 7.0 (H^++Al^{3+}), phosphorus content, potassium exchangeable, aluminum exchangeable, calcium exchangeable, magnesium exchangeable, Cation Exchange Capacity (CEC), base saturation (BS%), calcium (%Ca), magnesium (%Mg), potassium saturation (%K), Soil Organic Matter (SOM), soil density, soil bulk density and total pores, according to Claessen (1997). The apparatus "Soil Control SC60" was used to determine the SPR. The average water content in the soil was 28% of moisture in the following depths: 0-5; 5-10; 10-15; 15-20; 20-25; 25-30 cm. The methodology to determine the soil moisture was accordance to Claessen (1997).

Measurement of root length

It was dug trenches in each plot to evaluate the root length. This evaluation was accomplished in reproductive stage R2 (Full bloom). The trenches had the dimension of 22.5 cm x 6.5 cm x 5.0 cm, to be possible the measurement and it was built a pathway of iron to make sure that all samples would have the same dimension, following the method of Marsh (1971) and Tennant (1975). The samples were extracted from all layers (0-10 cm; 10-20 cm; 20-30 cm). To determine the length of roots, the soil collected was washed with tap water on sieve of 0.25 mm mesh opening. All the root system was collected and put in a stove with forced air circulation at the temperature of 65-70^{0}C, during 72 hours. After this period of time, the root length was measured.

Statistical analysis

The variables evaluated in this experiment were submitted to the analysis of variance (ANOVA) by the F-test. The mean was compared by the Tukey test of mean ($P \leq 0.05$). These tests were carried out with the use of SISVAR software (Ferreira, 2010).

Conclusions

The Treat-2 and 3 performed better incorporation of deeper lime in soil, what resulted in higher soybean productivity. The effect of deeper lime in soil changed the soil chemical, increasing base saturation and decreasing the aluminium saturation which promoted the increase of root length. Based on the results of this work, it is not recommended the absence of lime incorporation into the soil, because it decreases the cover crop and soybean production in Brazilian savannah in no-till system implementation. Besides, incorporating the lime in soil profile is quite important to achieve better results in the implementation of no-till system. Because, even if the soil chemical is adequate for a good performed of crop production, the soil resistance penetration may limit the root development. It was showed in the results that the Treat-2 and 3 reduced the soil penetration resistance and increased the vegetable production of soybean and millet. The values of SPR above 5.5 kg cm^{-2} damage the soybean rooting growth. The amount of lime recommended was not enough to achieve the Ca^{2+} and Mg^{2+} saturation adequate as it is suggested in literature, it is important to infer that the recommendation in this work followed the usual in Brazilian savannah. The results of this work suggest that, it is feasible to accomplish more works related to the Ca^{2+}, Mg^{2+} and K^+ saturation in Brazilian savannah to be sure that these values of base saturation are adequate for higher soybean production.

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