Australian Journal of Crop Science AJCS

AJCS 11(1):63-70 (2017) ISSN:1835-2707
doi: 10.21475/ajcs.2017.11.01.pne234

Manganese accumulation and dry matter production of Guinea Grass (*Panicum maximum*) after application of increasing doses of Mn fertilizer

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Abstract

The manganese (Mn) is an important nutrient to forage development; however, there is a lack of information regarding to adequate Mn-fertilizer rates for Guinea Grass **(***Panicum maximum)* species growing in Brazilian soils. The objective of this research was to evaluate the effect of Mn on growth, nutrition and yield of Guinea Grass. The study was carried out under greenhouse conditions in a randomized block design, with five Mn rates (0, 15, 30, 60 and 120 mg dm^{-3}) and four replicates, using manganese sulfate (35.5% Mn) as Mn source. Plant's growth parameters, dry mass production, Mn^{2+} levels and accumulation in plant's tissues were measured and Mn efficiencies of absorption, transport and utilization were calculated. Enhancing Mn doses, there was a proportional increase of Mn^{2+} levels in the leaves and the roots. Regarding to the growth parameters, the number of leaves and both root and aboveground dry mass were slightly affected by Mn application. The highest Mn efficiency of absorption and transport by Guinea Grass was ob using 30 mg dm^{-3} of Mn; however, the Mn utilization efficiency was higher when Mn was not applied. In this way, the Mn fertilization in Guinea Grass is economically viable using doses up to 30 mg dm^{-3}.

Keywords: Micronutrients; pastures; phytotoxicity; fertilization; plant nutrition.
Abbreviations: AB_{ef}_Absorption efficiency; DM_Dry matter; LA_Leaf area; Mn_Manganese; RCI_Relative chlorophyll index; TR_{ef}_Transport efficiency; UT_{ef}_Utilization efficiency; Mn_manganese; NL_number of leaves; H_plant height; SD_stem diameter; RDM_Root dry matter; SDM_Shoot dry matter; NP_power neutralization; RPTN_Relative Neutralization Total Power; DAS_days after sowing.

Introduction

The cultivation of *Panicum* gender has increased in recent years, due to its high dry matter yield potential (Braz et al., 2010), high adaptability, forage quality and ease establishment (Mingotte et al., 2011). However, several factors may limit the achievement of high yields, especially the occurrence of nutritional imbalances. Micronutrients are essential elements for plant growth and development, although they are required in small amounts, their imbalance can impair production (Malavolta, 2006). Manganese (Mn), for example, is found in concentrations ranging from 20 up to 3000 mg kg^{-1}, with average values around 350 mg kg^{-1} (Malavolta, 1980). Mn exerts many functions in plants, integrating processes related to protein synthesis, membrane permeability, ion absorption, respiration, starch synthesis and hormonal control (Teixeira et al., 2005). This micronutrient is a cofactor in enzymatic reactions, and an enzyme constituent involved in the water photolysis in photosystem II (Malavolta, 2006; Peiter et al., 2007). Plant species with nutrient deficiency have reduced root growth (Prado, 2008) and, consequently, lower crop yields. On the other hand, in high concentrations it may be toxic (Doyle et al., 2003), conditioning morphological (Arruda et al., 2016.) and biochemical disorders in vegetables (Lidon et al., 2004; Millaleo et al., 2010; Marschner, 2012; Millaleo et al., 2013), and in forages, can trigger animal poisoning after ingestion (Prado, 2008). The main factors driving the Mn availability in soils are pH, redox potential, organic matter content and balance with other soil cations (Prado, 2008). Decreasing soil pH bellow 5.0, there are an increase in the Mn soluble compounds, which may is toxic to the living organisms, including plants. However, the nutrient toxicity may occur at higher pH soils as we, if there are reducing conditions caused by water saturation, soil compaction or accumulation of organic matter (Foy et al., 1978). The Mn availability is determined by the element reactions in soil; Mn^{2+} to be oxidized reaches M^{4+} form, and then precipitates as oxides and hydroxides, becoming unavailable to plants (Borkert, 1991; Herndon et al., 2015). Despite the importance of this nutrient in plant nutrition, adequate Mn levels have not yet been established for the development of Guinea Grass, a specie widely used in animal feed. Adequate Mn rates can increase both production and forage quality, and consequently, enhance livestock production. Thus, the aim of this study was to evaluate the effect of manganese rates applied into the soil on growth, nutrition and dry matter production of Guinea Grass.

Results and Discussion

Height, leaf area and stem diameter

The application of increasing Mn rates into the soil affected the number of leaves (NL) of Guinea Grass, either at the first or at the second cut of the forage (Table 1). In both cases, there was quadratic adjustment, and the maximum number of leaves obtained at the first cut was 6.51 per plant, using 49.67 mg dm^{-3} of Mn, and 4.32 per plant with 75.83 mg dm^{-3} of Mn, at the second cut. At the second cut increasing Mn rates reduced NL by 28.5% (Fig 1). Mn rates, which showed average values of 13.15 and 14.78 cm for plant height (H), and 1.17 and 2.28 cm for stem diameter (SD), at the first and second cuts, respectively, did not affect the others growth parameters evaluated.

High Mn accumulation can reduce leaf biomass (Saidi et al., 2014) and plant growth (Shenker et al., 2004) due to degradative process (Shenker et al., 2004; Papadakis et al., 2007, Marschner, 2012), chlorophylls synthesis reduction (Lidon et al., 2004; Wang et al., 2009) and low carboxylation (Millaleo et al., 2010; Millaleo et al., 2013). Thus, Mn interferes with the photosynthetic performance (Kitao et al., 1997; Nable et al., 1988; Vitti et al., 2006; Schmidt et al., 2013), and its excess can potentiate reactions with oxygen, causing damage cells (Papadakis et al., 2007), directly affecting the operation of photosystem II, responsible for water photolysis (Dechen and Nachtigall, 2007).

Mn^{2+} content in roots and shoot

There was an increase in the Mn^{2+} content in leaves and roots with increasing rates applied (Table 2). The nutrient content was 233.51 and 175.31 mg kg^{-1} in the shoot (first cut) and roots (second cut), respectively, fallowing the highest rate (120 mg dm^{-3}) application (Fig 2). The Mn^{2+} content in the shoot at the second cut showed quadratic adjustment due to the application of Mn^{2+} increasing rates, with the maximum content of 568.74 mg kg^{-1} obtained with 81.64 mg dm^{-3} (Fig 2). Cavalcante et al. (2013) found plants of *Urochloa brizantha* cv. MG5 not showing significant effects at the second cut, when subjected to Mn similar rates used in this study.

The increases in the Mn^{2+} content were approximately 19, 74 and 39% in the shoot, at the first and at the second cut, and in the root at the second cut compared with the initial contents of 196; 327 and 126 mg kg^{-1}, respectively.

These results are similar to those observed by Arruda et al., (2016), who showed higher concentrations of Mn^{2+} in *Urochloa humidicula* at the second cut. They attributed this increase in Mn^{2+} concentration to the greater root development compared with the first cut, which favored the nutrient absorption (Arruda et al., 2016). Guirra et al. (2011) and Sylvestre et al. (2012) observed the same pattern when assessing the effect of Mn in Tanzania grass (*Panicum maximum*) and *Urochloa brizantha* cv. Marandu, attributing the highest nutrient levels to the development of the root system.

Some authors suggest that high Mn concentrations at the middle of the plant growth period imply in higher accumulation of nutrients in the shoot. In fact, Lidon (2001) observed increases in the Mn^{2+} content in plant tissue, when evaluating *Oryza sativa* L. cv. Safari at the beginning of the growth period. However, plants may have regulatory mechanisms when subjected to high Mn concentrations (Lidon and Teixeira, 2000), which gives some grass species tolerance to high Mn concentrations (Paschke et al., 2005).

Although Mn^{2+} is absorbed by root interception (Prado, 2008), its absorption can also be passive when high concentrations of this nutrient are present in the soil solution (Dechen and Nachtigall, 2007; Yasuor et al., 2015). Some authors suggest that nitrogenous ammonia-based fertilizations may condition soil pH reductions (Ducic and Polle, 2005), as a result of the ammonium transformation process in nitrate (Cantarella et al., 2007), and consequently, increasing the availability of Mn^{2+} in the solution (Smith and Paterson, 1990; Freitas et al., 2007). This process may explain the Mn^{2+} increase in the shoot from the first to the second cut (Sylvestre et al., 2012; Arruda et al., 2016), whereas spaced fertilizations of urea were conducted using rates of 100 mg dm^{-3} of N at sowing and 50 mg dm^{-3} 30 days after.

Dry matter production

The application of increasing Mn rates raised shoot dry matter production (SDM) up to the 60 mg dm^{-3} rate (Table 3), followed by a decrease at the 120 mg dm^{-3} rate at the first cut. At the second cut, the highest dry mass production (8.38 g per plant) was achieved without Mn. Root dry matter (RDM) showed similar results to those of SDM at the first cut, with higher production at the rate of 60 mg dm^{-3}, around 0.62 g per plant, followed by a decrease of 54.84% in production. While shoot dry mass production was high without the application of Mn, being 23.84% higher when compared with the production of the corresponding rate of 15 mg dm^{-3}.

Quadratic adjustments were verified in SDM and RDM parameters at the second cut, with values of 5.86 g per plant for SDM and 0.47 g per plant for RDM at the rates 68.25 and 57.50 mg dm^{-3} (Fig 3). In contrast to the results obtained at the second cut, Mn rates applied did not affect the production of SDM at the first cut.

The increases observed in shoot, root and whole plant dry matter production are attributed to increased photosynthetic rate, due to the necessary Mn absorption for the metabolic functions of plant (Schmidt et al., 2013; Arruda et al., 2016). However, the excess of exchangeable Mn in the soil promotes biochemical disturbances that can reduce the plant biomass production (Papadakis et al., 2007; Millaleo et al., 2010; Millaleo et al., 2013), as observed at the highest rates applied.

To evaluate the effect of Mn fertilizer rates in the production of *Urochloa Brizantha*, Puga et al. (2011) observed that the rate of 120 mg dm^{-3} favored Mn accumulation in the leaves of the grass, without harming dry matter production. Some authors observed reduction in dry matter production and root development (Saidi et al., 2014) and associated this effect to the reduction of chlorophylls, linked to Mn excess (Lindon et al., 2004) and to photosynthetic rate decrease (Wang et al., 2009; Marschner, 2012), as well as reduction of carbohydrate synthesis (Mingotte et al., 2011).

Mn^{2+} accumulation in roots and shoot

The increased supply of this nutrient to the soil raised Mn^{2+} levels in shoots and roots of Guinea Grass at both cuts (Table 4), except for the effect of the highest Mn rate on the roots dry mass (RDM). The nutrient contents were 233.51 and 175.31 mg kg^{-1} in shoots at the first cut and in the roots at the second cut, with the application of the highest rate (120 mg dm^{-3}), with quadratic adjustment regarding the content of Mn^{2+} at the first and second cuts, followed by a maximum content of 0.17 and 2.45 mg kg^{-1} with 70 and 107.5 mg dm^{-3} (Fig 4). While at the second cut an increment of accumulated Mn^{2+} in the roots was observed, followed by a quadratic

Table 1. Height (H), stalk diameter (SD) and number of leaves (NL) of Guinea Grass, according to the application of manganese in the soil.

Rates of Manganese	First CUT			Second cut		
	Height	SD	NL	Height	SD	NL
mg dm^{-3}	cm	cm	$planta^{-1}$	cm	cm	$planta^{-1}$
0	12.85	1.19	5.55	15.65	2.17	6.60
15	13.07	1.10	6.55	13.85	2.34	4.60
30	13.30	1.20	6.35	15.82	2.41	4.95
60	13.70	1.08	6.55	15.35	2.04	4.80
120	12.82	1.26	5.75	15.25	2.42	4.95
F test	1.14^{ns}	0.22^{ns}	18.59**	1.02^{ns}	1.46^{ns}	4.29*
C.V. (%)	5.16	26.58	3.54	10.19	11.94	15.04
[1]LR	0.07^{ns}	0.14^{ns}	1.35^{ns}	0.05^{ns}	0.45^{ns}	3.19^{ns}
[2]QR	4.34^{ns}	0.34^{ns}	54.50**	0.01^{ns}	0.68^{ns}	6.41*

[1]Linear regression; [2]Quadratic regression; [n.s.], *, ** – not significant at the 5%; significant at the 5% and significant at the 1% level probability by the F test, respectively.

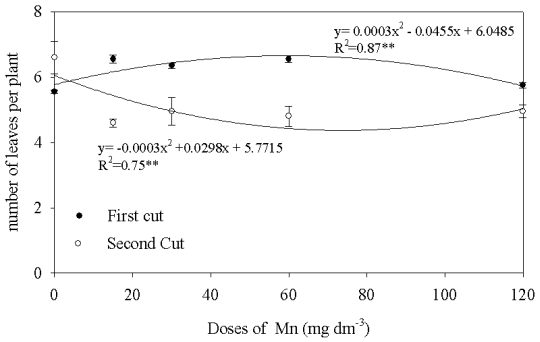

Fig 1. Number of leaves per plant of Guinea Grass in the first and second cut forage, according to the application of manganese in the soil. ** and * - significant at the 1 and 5% level probability by the F test, respectively.

Table 2. Manganese content in plants of Guinea Grass in the aerial part at the first and second cuts and the second cut roots, according to the application of manganese in the soil.

Rates of Manganese	First cut	Second cut	
	Aerial Part	Aerial Part	Roots
mg dm^{-3}	---------- mg kg^{-1} ----------		
0	188.25	283.25	105.75
15	203.25	472.50	136.75
30	211.00	477.25	153.75
60	221.75	519.75	159.25
120	228.75	522.00	166.50
F test	7.99**	88.36*	26.98**
C.V. (%)	5.33	4.62	6.46
[1]LR	26.64**	166.78**	61.35**
[2]QR	4.96*	121.28**	1.70^{ns}

[1]Linear regression; [2]Quadratic regression; [n.s.], *, ** – not significant, significant at the 5% and significant at the 1% level probability by the F test.

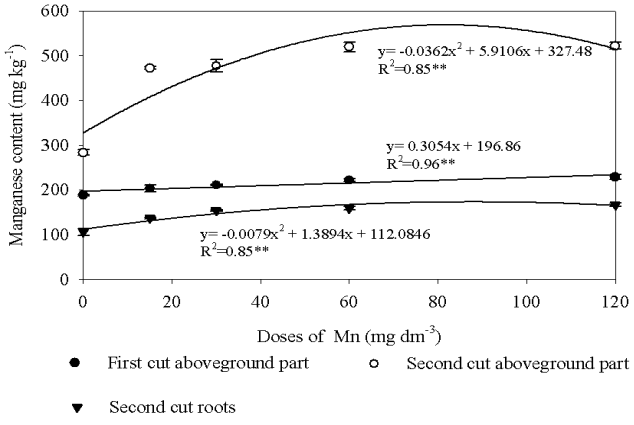

Fig 2. Manganese content in plants of Guinea Grass in the aerial part at the first and second cuts, and second cut roots, according to the application of manganese in the soil. ** - significant at the 1% level probability by the F test.

Table 3. Dry matter production in plants of Guinea Grass in the aerial part at the first and second cuts, in the roots of the second cut and total aerial parts forage, according to the application of manganese in the soil.

Rates of Manganese	First cut	Second CUT		Total
	Dry matter Aerial Part	Dry matter Aerial Part	Dry matter roots	Dry matter Aerial Part
mg dm^{-3}	---------- g $plant^{-1}$ ----------			
0	0.89	8.38	0.34	9.27
15	1.02	6.04	0.37	7.06
30	1.14	6.33	0.26	7.47
60	1.28	6.27	0.62	7.55
120	1.23	6.43	0.28	7.66
F test	2.4^{ns}	4.22*	11.57**	3.08*
C.V. (%)	18.48	13.88	22.47	12.38
[1]LR	6.03*	3.08^{ns}	0.96^{ns}	1.36^{ns}
[2]QR	3.60^{ns}	6.51*	17.80**	4.20^{ns}

[1]Linear regression; [2]Quadratic Regression; [n.s.], *, ** – not significant; significant at the 5% and significant at the 1% level probability by the F test.

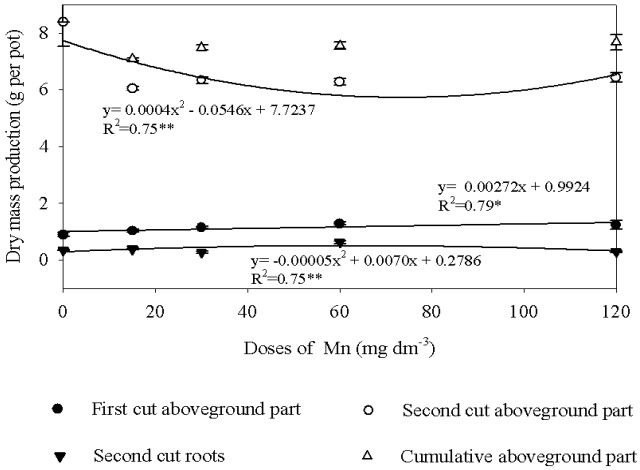

Fig 3. Dry matter production in plants of Guinea Grass in the aerial part at the first and second cuts, in the roots of the second cut and total aerial part forage, according to the application of manganese in the soil.
* and ** - significant at the 5 and 1% level probability by the F test.

Table 4. Manganese accumulation in plants of Guinea Grass in the aerial part at the first and second cuts, in the roots of the second cut and total aerial part forage, according to the application of manganese in the soil.

Rates of Manganese	First cut	Second CUT		Total
	Aerial Part	Aerial Part	Roots	Aerial Part
mg dm^{-3}	---------- mg $plant^{-1}$ ----------			
0	0.17	2.37	0.04	2.54
15	0.21	2.86	0.05	3.07
30	0.24	3.02	0.04	3.26
60	0.28	3.25	0.10	3.53
120	0.28	3.35	0.05	3.63
F Test	5.15**	8.18**	12.80**	9.28**
C.V. (%)	18.58	9.16	26.22	4.30
[1]LR	14.83**	23.59**	3.61^{ns}	26.88**
[2]QR	5.76*	7.84*	28.06**	9.09**

[1]Linear regression; [2]Quadratic Regression; [n.s.], *, ** – not significant; significant at the 5% and significant at the 1% level probability by the F test.

Table 5. Absorption efficiency, transport efficiency and utilization efficiency of manganese in plants of Guinea Grass, according to the application of manganese in the soil.

Rates of Manganese	Absorption efficiency	Transport Efficiency	Utilization Efficiency
mg dm^{-3}	mg g^{-1}	%	mg g^{-1}
0	7.67	98.58	35.99
15	8.59	98.36	17.79
30	15.30	98.75	18.20
60	6.02	97.25	18.39
120	13.39	98.71	17.16
F test	2.92^{ns}	8.14**	18.39**
C.V. (%)	45.46	0.44	17.59
[1]LR	1.42^{ns}	0.08^{ns}	23.14**
[2]QR	0.14^{ns}	15.24**	23.44**

[1]Linear regression; [2]Quadratic regression; [n.s.], *, ** – not significant; significant at the 5% and significant at the 1% level probability by the F test.

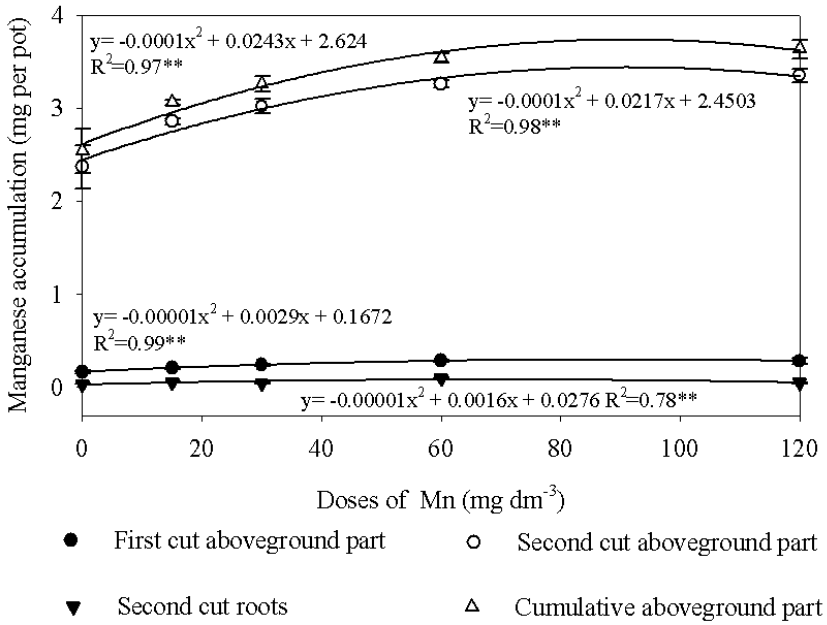

Fig 4. Manganese accumulation in plants of Guinea Grass in the aerial part at the first and second cuts, in the roots of the second cut and total aerial part forage, according to the application of manganese in the soil.
* and ** - significant at the 5 and 1% level probability by the F test.

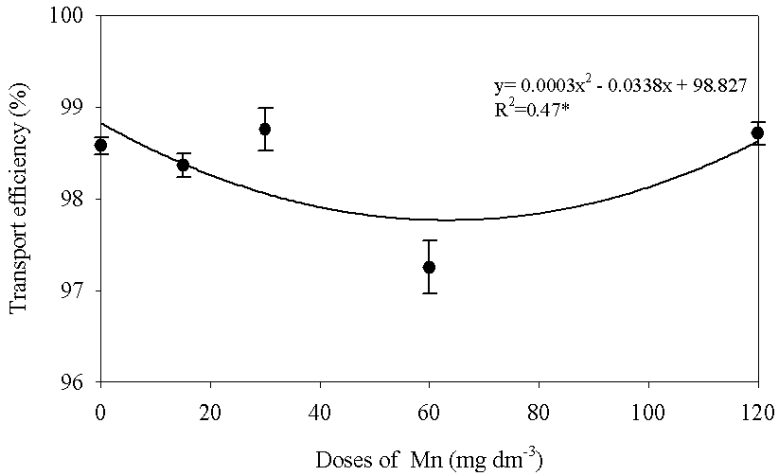

Fig 5. Transport efficiency of manganese in plants of Guinea Grass, according to the application of manganese in the soil.
** - significant at the 1% level probability by the F test.

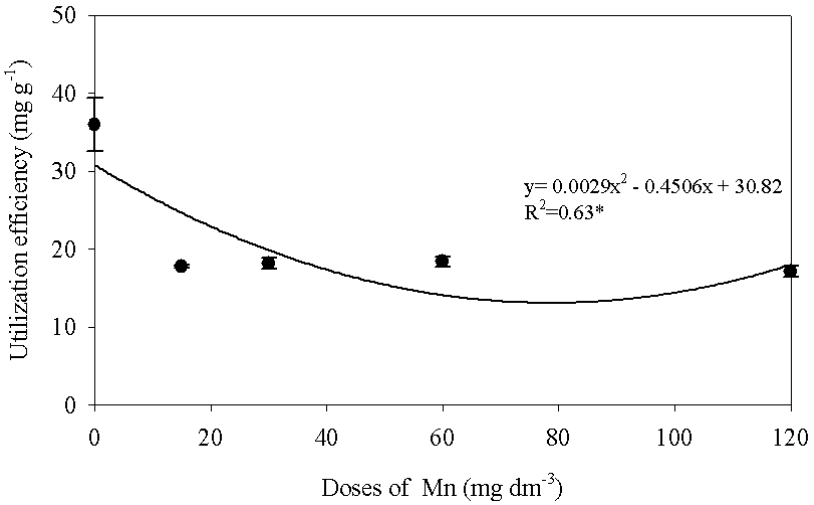

Fig 6. Utilization efficiency of manganese in plants of Guinea Grass, according to the application of manganese in the soil.
** - significant at the 1% level probability by the F test.

adjustment ($p<0.05$) of 0.087 mg kg^{-1} at the rate of 75 mg kg^{-1} of Mn. Mn^{2+} accumulation in plants was approximately 80; 26 and 61% in the shoots at the first and second cuts, and in the roots at the second cut, compared with the initial content of 196; 327 and 126 mg kg^{-1}, respectively. The distribution of Mn^{2+} may occur through active transport in epidermal root cells and then it is absorbed in divalent form (Mn^{2+}) and redistributed in the plant (Gherardi and Rengel, 2004; Pittman, 2005). The Mn^{2+} absorption by roots is characterized as a two-phase process, involving the primary transport to the xylem, and transference from the xylem to the phloem (Humphries et al., 2007).

However, low Mn^{2+} phloem mobility, as well as the redistribution depends on the plant species and stage of development (Herren and Feller, 1994); therefore, the accumulation of nutrients in the tissue is related to the amount of exchangeable Mn^{2+} in the soil solution; thus controlling absorption and accumulation. In view of some aspects related to the use of forage in animal production, Mn^{2+} accumulation should be monitored, as high rates can be harmful to animals, affecting the integrity of sperm and acrosome plasma membranes (Reis et al., 2014), which can reduce the reproductive capability of the bull. On the other hand, Carvalho et al. (2010) reported that Mn deficiency affects embryogenesis, causing poor reproductive formation and birth of calves with congenital defects in skeletal and articulate tissues. Thus, Mn^{2+} content cumulus in plants is important, both in biomass production in forage, as in livestock production, whereas imbalances can cause deleterious effects.

Efficiency indices: Absorption, transport and utilization

Guinea Grass plants showed better absorption and transport efficiency when 30 mg kg^{-1} of Mn was applied, with absorption efficiency values of 15.30 mg g^{-1} and 98.75% transport efficiency, contrasting with the rate of 60 mg kg^{-1} of Mn, with values of 6.02 mg g^{-1} and 97.25% of those parameters, respectively, which were the lowest values among the Mn rates evaluated. However, the control rate showed satisfactory results on the order of 35.99 mg g^{-1}, corresponding to 52.32% higher than the lowest rate, regarding efficiency use. The absorption efficiency of Mn (AB_{ef}) did not differ among the evaluated Mn rates. In *Urochloa humidicola* Arruda et al., (2016) observed an enhanced AB_{ef} with the increase of Mn doses. Since this nutrient is toxic when its level is high in soil, these results suggested that Guinea Grass may is less susceptible to the toxic stress by Mn than *Urochloa humidicola*. Both Mn transport (TR_{ef}) and utilization efficiency (UT_{ef}) were affected by Mn rates ($P<0.05$) and showed a quadratic adjustment, wherein the models (Fig 5 and Fig 6) predict values greater than 30 mg kg^{-1} of Mn (Table 5). Despite the fact that TR_{ef} differed among Mn doses, only slightly differences were observed and it may is not important agronomically. In fact, for *Urochloa humidicola,* Arruda et al., (2016) observed no effect of increasing Mn rates on $TR_{ef.}$. Regarding the $UT_{ef,}$ it was decreased with the increase of Mn doses. Similar results were observed by Arruda et al. (2016). Since 30 mg kg^{-1} of Mn is a low fertilization rate and this fertilizer has low cost; the Mn utilization in Guinea Grass at this rate is economically viable.

Materials and Methods

Growing conditions

This research was conducted in a greenhouse at Federal University of Goias, State of Goias, Brazil, coordinates: 16° 35" latitude south and 49° 21' longitude west, at approximately 730 m of altitude and 1,600 mm average annual rainfall. The climate regional is Aw (mega thermal) or tropical savannah, with dry winters and rainy summers (Köppen, 1948). The soil analysis showed the following properties: pH = 5.0; Organic matter = 2.0 g dm^{-3}; P = 5.5 mg dm^{-3}; K = 60 mg dm^{-3}; Ca = 2.7 $mmol_c$ dm^{-3}; Mg = 0.5 $mmol_c$ dm^{-3}; B = 0.21 mg dm^{-3}; Cu = 2.8 mg dm^{-3}; Fe = 82 mg dm^{-3}; Mn = 44 mg dm^{-3}; Zn = 4.6 mg dm^{-3}; H+Al = 1.8 $mmol_c$ dm^{-3}; CEC = 5.2 $mmol_c$ dm^{-3}; Base saturation (%) = 65.1%, with 432 g kg^{-1} of clay.

Treatments and experimental design

The treatments were as 0 (control), 15, 30, 60 and 120 mg dm^{-3} of Mn as manganese sulfate (35.5% Mn), arranged in an entirely randomized bloc design, with four replicates. Each experimental unit consisted of one 4 dm^3 pot, filled with 3.5 dm^3 of a clayey dystrophic red Oxisol (Santos et al., 2013), drawn from the topsoil layer (0-0.2m deep).

Treatments application and analysis

Liming was performed on August 2, 2014, using calcined lime (CaO = 58.5%; MgO = 9%; NP = 127%; RPTN = 99.4%), to reach base saturation (V%) equal to 80%, while maintaining the moist soil mass at 60% retention capacity, and incubated for 30 days.

After the incubation period, a fertilizer solution was applied to the soil with the following rates of micronutrients: 1.5 mg dm^{-3} of Cu ($CuSO_4.5H_2O$ p.a.); 0.8 mg dm^{-3} of B (H_3BO_3 p.a.); 0.15 mg dm^{-3} of Mo ($NaMoO_4.2H_2O$ p.a.); 4.0 mg dm^{-3} of Fe [$Fe_2 (SO_4)_3.4H_2O$ p.a.] and 5.0 mg dm^{-3} of Zn ($ZnSO_4$ p.a.) (Mesquita et al., 2004). The following rates of macronutrients were also applied: 305 mg dm^{-3} of P as single superphosphate; 150 mg dm^{-3} of N as urea applied at sowing (100 mg dm^{-3} of N) and the remaining (50 mg dm^{-3} of N) at 30 days after, according to Mesquita et al. (2004); and 200 mg dm^{-3} of K (KCl p.a.) (Bonfim et al., 2004). Treatments (Mn rates) were applied to the soil surface and incorporated 10 cm deep at seedling emergence.

Traits measured and nutritional indices

Sowing has held on September 4, 2014, and thinning performed 10 days after emergence, leaving five plants per pot and irrigation done with deionized water by the weighing method, keeping soil moisture content at 60% retention capacity.

Plants were evaluated daily for symptoms of nutritional disorder. Two cuts were performed: the first at 60 days after sowing (DAS) and the second at 94 DAS. At 60 DAS and 94 DAS the plant´s height was recorded by measuring the largest tiller from the base to the last leaf insertion, and stalk diameter was measured aid of a digital caliper, and the total number of sheets in a whole plant.

Plant tissue samples were washed with a 0.1% detergent solution, a 0.3% acid solution and distilled water, and dried in oven at 65 °C for 48 hours for aerial part and root dry mass determinations (second cut, only). The Mn^{2+} contents from aerial part and root plant tissues were determined following methodology described by Bataglia et al. (1983).

From the dry matter and content of nutrients in plants data were performed the calculation of the nutritional indices comprising absorption efficiency (AB_{ef}), translocation efficiency/transport (TR_{ef}) and utilization efficiency of nutrients for conversion to dry matter (UT_{ef}) (Prado, 2008). The calculation of these indices is below:

Equation Swiader et al. (1994):

$$AB_{ef} = \frac{\text{total nutrient conten in plant}}{\text{root dry matter}}$$

Equation Li et al. (1991):

$$TR_{ef} = \frac{\text{nutrient conten in aerial part}}{\text{total nutrient conten in the plant}}$$

Equation Siddiqi and Glass (1981):

$$UT_{ef} = \frac{(\text{total dry matter produced})^2}{\text{total nutrient content in the plant}}$$

Statistical analysis

Results were subjected to the analysis of variance using software Sisvar®, Brazil (Ferreira, 2014) and to polynomial regression analysis. Linear and quadratic mathematical models were tested to select the one that provided the best data adjustment, based on the magnitude of the regression coefficients significance at 5% probability by the t test. The maximum points were calculated by deriving the significant equations.

Conclusions

Enhancing Mn doses, there was a proportional increase of Mn^{2+} levels in the leaves and the roots.

Regarding to the growth parameters, the number of leaves and both root and aboveground dry mass was slightly affected by Mn application. The highest Mn efficiency of absorption and transport by was obtained using 30 mg dm^{-3} of Mn, however, the Mn utilization efficiency was higher when Mn was not applied. In this way, the Mn fertilization in Guinea Grass is recommended using doses up to 30 mg dm^{-3}.

Acknowledgements

We appreciate to the course postgraduate in Agronomy, soil concentration area and water, from the Federal University of Goias (UFG), and the following Brazilian institutions for financial support: FAPEG, CAPES and CNPq.

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