Research Article

Manganese fertilization for sweet cassava production under organic management system[1]

Giuliano Marchi[2], Josefino de Freitas Fialho[2], Thomaz Adolpho Rein[2], João de Deus Gomes dos Santos Junior[2], Eduardo Alano Vieira[2], José Carlos Sousa-Silva[2], Juaci Vitória Malaquias[2], Douglas Ramos Guelfi Silva[3]

ABSTRACT

Organic management farms in the Federal District, Brazil, usually present overlimed and overfertilized soils, with high content of organic matter and high pH. These conditions lead to a low availability of manganese to crops. Many sweet cassava (*Manihot esculenta* Crantz.) crops were diagnosed with Mn deficiency in the region, presenting low yields. In order to overcome such condition, an experiment was established comprising the following treatments: application of $MnSO_4$ banded in rows; treatment of cassava cuttings with a $MnSO_4$ solution before planting; application of $MnSO_4$ and elemental sulfur (S^0) banded in the rows, to acidify the soil, increasing the Mn solubility; and leaf spraying of a Mn solution. The best results were revealed when the Mn was applied by foliar spraying and using a combination of methods (treatment of cassava cuttings with Mn, and Mn and S^0 applied to the soil before planting). This treatments provided a fresh root yield of 19.5 Mg ha^{-1}, contrasting with the control treatment (3.6 Mg ha^{-1}).

KEYWORDS: *Manihot esculenta* Crantz, root production, micronutrients.

RESUMO

Fertilização com manganês na produção de mandioca de mesa sob sistema de manejo orgânico

Solos de propriedades agrícolas do Distrito Federal sob manejo orgânico normalmente apresentam calagem e fertilizantes em excesso, contendo alto conteúdo de matéria orgânica e elevado pH. Essas condições levam a uma baixa disponibilidade de manganês às culturas. Muitas culturas de mandioca de mesa (*Manihot esculenta* Crantz.) foram diagnosticadas com deficiência de Mn na região, apresentando baixa produtividade. Para superar essa condição, um experimento foi instalado com os seguintes tratamentos: aplicação de $MnSO_4$ nas linhas de plantio; tratamento das manivas com solução de $MnSO_4$ antes do plantio; aplicação de $MnSO_4$ e enxofre elementar (S^0) nas linhas de plantio, para acidificar o solo, aumentando a solubilidade de Mn; e aplicação foliar de uma solução de Mn. Os melhores resultados foram obtidos quando o Mn foi fornecido via foliar e pela combinação de métodos (tratamento de manivas com Mn, e Mn e S^0 aplicados ao solo antes do plantio). Esses tratamentos promoveram uma produção de raízes frescas de 19,5 Mg ha^{-1}, contrastando com o tratamento controle (3,6 Mg ha^{-1}).

PALAVRAS-CHAVE: *Manihot esculenta* Crantz, produção de raízes, micronutrientes.

INTRODUCTION

Manganese (Mn) deficiency in sweet cassava crops has been noticed in many farms in the Federal District, Brazil, particularly those that use organic management systems (Fialho et al. 2020). It was also observed that the use of lime, poultry manure and thermal phosphate applied in excess in these farms have caused an increase in the soil pH. However, as the soil pH increases, the amounts of exchangeable Mn^{2+} and readily reducible Mn in the soil decrease, as well as the uptake of Mn^{2+} by plants (Reuter et al. 1988). Manganese deficiency is more common in soils with pH above 6.5 (Galrão 1999). This pH condition is common in soils under organic management in the region.

Manganese deficiency causes cassava to present low yields and interveinal chlorosis of upper and middle leaves (Howeler 2002), due to the fact that the Mn functions as an enzyme activator for steps in photosynthesis (Broadley et al. 2012). Therefore, cassava crops present yellowish tips when Mn is poorly translocated in the plant, and deficiency symptoms appear first on young leaves (Galrão 1999).

[1] Received: Oct. 13, 2020. Accepted: Nov. 27, 2020. Published: Dec. 21, 2020. DOI: 10.1590/1983-40632020v5066133.

[2] Empresa Brasileira de Pesquisa Agropecuária (Embrapa Cerrados), Planaltina, DF, Brasil.
E-mail/ORCID: giuliano.marchi@embrapa.br/0000-0002-2887-790X, josefino.fialho@embrapa.br/0000-0003-2146-0981, thomaz.rein@embrapa.br/0000-0002-0146-0012, joão.jr@embrapa.br/0000-0003-1113-3178, eduardo.alano@embrapa.br/0000-0003-4931-3895, jose.sousa-silva@embrapa.br/0000-0001-5648-6773, juaci.malaquias@embrapa.br/0000-0001-6720-9624.
[3] Universidade Federal de Lavras, Departamento de Ciência do Solo, Lavras, MG, Brasil.
E-mail/ORCID: douglasguelfi@dcs.ufla.br/0000-0002-4674-4780.

Manganese availability to plants is influenced by soil type, organic matter content, moisture, soil aeration and pH (Reuter et al. 1988, Husson 2013). When the organic matter increases in organic management systems, the amount of exchangeable Mn reduces, due to the increased formation of organic matter and Mn complexes (Alejandro et al. 2020).

The high porosity and drainage of the Ferralsols in the Federal District may strongly contribute to the Mn deficiency, mainly when the organic matter contents and pH values are high. On the other hand, Mn deficiency seems to be related more to soil particle size than to organic matter content (Reuter et al. 1988). When the soil pH and organic matter content are high, the methods used to estimate the Mn availability to plants, such as DTPA-TEA pH 7.3, HCl 0.1 mol L^{-1}, Mehlich-1 and 3, may not work properly. Although these methods indicate adequate concentrations of available Mn in the soil, the Mn is unavailable to plant uptake. Such tests seem to be unable to consistently account for the nature of the inorganic and organic reactions to which Mn is subject in soils (Hannam & Ohki 1988).

Although Mn fertilization is not recommended in soils where its content is higher than 5 mg kg^{-1} (Galrão 1999, Souza et al. 2009), in soils presenting high pH, organic matter, drainage and porosity, Mn is less available. The Mn application banded in rows is recommended in such situations, in order to provide a short-term Mn supply (Reuter et al. 1988, Camberato 2004), as it oxidizes rapidly in soils under these conditions (Reuter et al. 1988). Yet, the high pH of a soil could be locally attenuated by adding acidifying fertilizers, such as elemental sulfur (S^0) (Reuter et al. 1988). After the plants present leaves, it is possible to provide Mn by foliar spraying (Howeler 2002, Schmidt et al. 2016). Another efficient form of overcoming the Mn deficiency is by treating the cassava stem cuttings with Mn solutions before planting (Howeler 2002).

The study of forms of fertilizaton with Mn is important, because they may contribute to decrease the Mn deficiency in cassava grown in soils where the Mn deficiency impacts negatively the crop production, allowing farmers to obtain healthy and profitable crops.

Accordingly, this study aimed to evaluate traits of sweet cassava grown under organic management system, in soil with high pH and Mn deficient, after different forms of Mn fertilization.

MATERIAL AND METHODS

The study was conducted in a farm under organic management system since 2007, in the Federal District, Brazil (15º40'25.54"S and 48º09'48.40"W; altitude: 1,237 m a.s.l.). The climate is characterized as tropical - Savanna (AW), according to the Köppen classification, comprising an annual average rainfall of 1.552 mm, with monthly average rainfall ranging from 9 mm (June) to 249 mm (December) (Ghisi et al. 2009).

The soil was classified as Acrustox (USDA 2015), and the soil analysis (0-20 cm) presented the following characteristics (Embrapa 2017): pH (H_2O) was 6.75; P and K were 255.7 and 156.0 mg dm^{-3}, respectively (Mehlich-1; 0.05 mol L^{-1} of HCl + 0.0125 mol L^{-1} of H_2SO_4; 1:10 soil:solution ratio); Ca, Mg and Al were 6.5, 2.5 and < 0.1 $cmol_c$ dm^{-3} (1 mol L^{-1} of KCl); Cu, Zn and Mn (Mehlich-1) were 0.7, 52.0 and 29.0 mg dm^{-3}, respectively; B: 2.4 mg dm^{-3} (hot water); sand: 254 g kg^{-1}; silt: 346 g kg^{-1}; clay: 399 g kg^{-1}; organic matter: 39.2 mg g^{-1}.

The area had been previously fertilized and cultivated with green vegetables, following the current farm practices (organic agriculture). A composite sample from a nearby area under native Brazilian Savanna vegetation was collected as a reference. The reference soil, analyzed using the same methods previously described, presented the following characteristics: pH (H_2O): 5.2; P: 0.5 mg dm^{-3}; K: 19.0 mg dm^{-3}; Ca: 1.1 $cmol_c$ dm^{-3}; Mg: 0.6 $cmol_c$ dm^{-3}; Al: 0.3 $cmol_c$ dm^{-3}; Cu: 0.7 mg dm^{-3}; Zn: 0.4 mg dm^{-3}; Mn: 4.2 mg dm^{-3}; B: 0.5 mg dm^{-3}; sand: 330 g kg^{-1}; silt: 276 g kg^{-1}; clay: 388 g kg^{-1}; organic matter: 41.8 mg g^{-1}.

The experiment was designed in randomized blocks, with six treatments and four replications. The treatments were: T_1: control; T_2: 4.28 kg ha^{-1} of Mn ($MnSO_4.H_2O$) banded in rows before planting; T_3: Mn stem cuttings treatment [cuttings were immersed in a 5 % Mn - $MnSO_4.H_2O$ solution for 15 min (Howeler 2002)]; T_4: combined Mn stem cuttings treatment and Mn banded in rows; T_5: combined Mn stem cuttings treatment, Mn banded in rows and 150 kg ha^{-1} of elementary sulfur (banded in rows before planting); T_6: 0.5 % Mn - $MnSO_4.H_2O$ (2 L). This last formula was sprayed over the leaves weekly in each plot (Howeler 2002), from the 30th to the 51st day after planting. The plots consisted of five 4 m-rows with five plants each, spaced 1.2 x 0.8 m (24 m^2). No supplementary fertilizers were added to the experimental area.

The sweet cassava (*Manihot esculenta* Cranz) IAC 576-70 cultivar, widely known as "Japonesinha", was chosen due to its high-quality culinary properties (Fialho et al. 2009), as well as due to the presence of a severe interveinal chlorosis in leaves and low yield while under Mn deficiency stress.

Cassava stem cuttings (20 cm long) were planted on December, 04 (2014) and harvested on December, 11 (2015). The nutrient concentrations in the plant tissues were analyzed in the fourth month after the emergence of plants and at the harvest time. In the fourth month after the emergence of the plants, the fourth expanded leaf of all plants from the nine central plants in each plot was collected (Ribeiro et al. 1999). The leaves from each plot were dried in an oven at 60 ºC, for 72 h, and 0.2 g digested by HNO_3:$HClO_4$, in a digestion block (Bataglia et al. 1983), for analysis of nutrients. Macro (P, K, Ca, Mg and S) and micronutrients (Fe, Cu Mn and Zn) were determined by inductively coupled plasma, using an optical emission spectrometry (ICP-OES). For determining the N content in the roots, stems and leaves, 0.1 g samples of dried and ground plant tissue were submitted to sulfuric acid digestion. Thereafter, the N content was determined by vapor drag, in a semi-micro Kjeldahl apparatus (Malavolta et al. 1997).

At the harvest time, the following growth variables were recorded: plant height, first branch height, fresh shoot and root yield, number of roots, starch percentage in roots by the hydrostatic weight scale (Grosmann & Freitas 1950) and cooking time (Alves et al. 2005). The leaf and root samples were collected from the nine central portion plants of each plot. A sample of each collected material was dried and a composed sample, homogenized by the quartering reduction method (Campos-M & Campos-C 2017), was chemically analyzed.

Tests of normality (Shapiro & Wilk 1965) and equal variance (O'Neill & Mathews 2000) were used prior to the analysis of variance. The data were submitted to the analysis of variance using the F test ($p < 0.05$) and, when the means were statistically significant, the Tukey test was applied. A Pearson's correlation analysis to relate the data from the soil and plant chemical analysis was performed using the Sigma Plot (version 12.0) software.

RESULTS AND DISCUSSION

Some plant traits, such as first branch height, cooking time and starch percentage, were not affected by any treatment applied, and the means observed for these traits were (mean ± standard deviation) 0.96 ± 0.10 m, 21'05" ± 3'14" and 21.92 ± 2.35 %, respectively.

The lack of response for the Mn applied to the soil in leaves collected in the fourth month (Table 1) agrees with Souza et al. (2009) and Galrão (1999). According to them, Mn applied in soils with high pH values will not be available to plant absorption. Thus, the Mn applied to the soil oxidizes rapidly by microorganisms, with pH values ranging from 6 to 8, and is favored by aerobic conditions (Reuter et al. 1988).

The sweet cassava plant height, fresh shoot and root yield and number of roots showed positive responses to the Mn treatments, except the single application of 4.28 kg ha^{-1} banded in rows (Table 2), which was not different from the control (no Mn) treatment. The nutritional status for Mn assessed by its concentration in the leaves collected in the fourth month is classified as "low" (5-10 mg kg^{-1}), according to Howeler (2002).

The fresh root yield was higher when the cassava received Mn by leaf spraying (T_6), through the integration of treatments (T_5), which included treating the stem cuttings with Mn and the application of Mn and S^0 banded in rows before planting, stem cuttings treated with Mn solutions (T_3) and the combination of the T_2 and T_3 treatments (T_4). These four treatments produced approximately five times more roots than the control. The fresh root yield, however, was lower than the yields reported in other publications, using the same cultivar under conventional (not organic) management (Fialho et al. 2009, Vieira et al. 2015), following the nitrogen fertilization and other recommendations (Fialho & Vieira 2013). The fresh root yield means obtained by Fialho et al. (2009) were 55.93, 28.67, 33.08 and 31.92 Mg ha^{-1}, respectively in Brazlândia, Gama, Jardim and Planaltina (all cities located in the Federal District), in experiments carried out from 1999 to 2004; and by Vieira et al. (2015), which reached 35.62 and 35.67 Mg ha^{-1}, during the 2010/2011 and 2011/2012 crop seasons, respectively, in Unaí (Minas Gerais state).

Therefore, there is still room to work, in order to overcome the Mn deficiency in sweet cassava

Table 1. Mean plant nutrients concentration in leaves collected in the fourth month, and adequate concentration of nutrients according to some authors.

Treatments	Mn	Fe	Cu	Zn	Ca	Mg	P	N	K	S
	mg kg^{-1}				g kg^{-1}					
T_1: control (no Mn)	ns	ns	5.8 a	ns	9.3 b	ns	4.6 ab	55.8 ab	ns	ns
T_2: 4.28 kg ha^{-1} of Mn (banded)	ns	ns	4.9 ab	ns	8.9 b	ns	5.0 a	64.4 a	ns	ns
T_3: Mn stem cutting	ns	ns	4.9 ab	ns	13.1 ab	ns	4.3 ab	51.8 b	ns	ns
T_4: T_3 + T_2	ns	ns	4.0 b	ns	12.4 ab	ns	4.0 b	54.8 b	ns	ns
T_5: T_3 + T_2 + banded S^0	ns	ns	3.8 b	ns	14.8 a	ns	4.5 ab	52.5 ab	ns	ns
T_6: leaf Mn spraying	ns	ns	3.7 b*	ns	12.8 ab	ns	2.9 c	46.4 b	ns	ns
Means	7.6	88.2	4.5	64.2	11.9	3.0	4.2	54.3	26.2	3.2
*s***	1.7	15.3	0.9	5.5	3.0	0.5	0.8	6.9	6.5	0.4
References	Adequate concentration									
Oliveira (2004); Raij et al. (1997)	25-100	60-200	5-25	35-100	5.0-15	2.0-5.0	2.5-5	45-60	10.0-20.0	3.0-4.0
Howeler (2002)	50-150	120-140	6-10	35-57	5.0-7.2	2.4-2.9	3.8-5	51-58	14.2-18.8	3.0-3.6
Ribeiro et al. (1999)	50-120	120-140	6-10	30-60	7.5-8.5	2.9-3.1	3.0-5	51-58	13.0-20.0	2.6-3.0

* Means followed by different letters in the columns are statistically different ($p < 0.05$) by the Tukey test. ** Standard deviation: n = 24.

Table 2. Means of plant height, fresh shoot and root yield and number of roots of sweet cassava evaluated after applying six manganese fertilization treatments within an organic management system.

Treatments	Plant height	Fresh shoot yield	Fresh root yield	Number of roots
	m	Mg ha^{-1}		unities per plant
T_1: control (no Mn)	2.14 ab*	10.9 b	3.6 b	3.16 b
T_2: 4.28 kg ha^{-1} of Mn (banded)	1.95 b	9.5 b	3.9 b	2.87 b
T_3: Mn stem cutting	2.36 a	23.3 a	16.6 a	9.62 a
T_4: T_3 + T_2	2.40 a	24.6 a	18.1 a	9.41 a
T_5: T_3 + T_2 + banded S^0	2.34 a	25.5 a	19.5 a	10.21 a
T_6: leaf Mn spraying	2.46 a	26.0 a	19.4 a	11.16 a
Means	2.28	20.8	14.4	8.15
*s***	0.23	7.35	7.40	3.58

* Means followed by different letters in the columns are statistically different ($p < 0.05$) by the Tukey test. ** Standard deviation: n = 24.

crops under Mn deficiency, for the reasons previously described. The plant height means obtained by Vieira et al. (2015) were 2.13 m, for both the 2010/2011 and 2011/2012 crop seasons, and the fresh shoot yield means reached by these authors were 24.26 and 23.92 Mg ha^{-1}, respectively. Both the plant height and fresh shoot yield were similar to those shown in the present experiment.

Most the treatments of the present experiment, although effective to increase the cassava production traits, were insufficient to reach a maximum yield when taking into account the data of fresh root yield obtained by Vieira et al. (2015) and Fialho et al. (2009). As a matter of fact, in the present experiment, to all the treatments concerned, cassava plants showed Mn deficiency symptoms such as interveinal or uniform chlorosis of upper and middle leaves (Howeler 2002). In the treatment in which Mn was sprayed over leaves, they recovered the green color; however, as soon as the spraying cycle was finished, the new, younger leaves, came up yellowish, revealing that the plant growth became severely depressed by the Mn deficiency (Schmidt et al. 2016).

The mean Mn concentration in the leaves at the harvest time (Table 3) was 28 % higher than in the fourth month (Table 1); however, it was still bellow the critical concentration (Raij et al. 1997, Ribeiro et al. 1999, Howeler 2002, Oliveira 2004), indicating a severe Mn defficiency. On the other hand, the concentrations of Mn, Ca, P and N in the leaves collected in the fourth month were correlated (Table 4). At the same time, the Mn in the leaves collected in the fourth month showed important

Table 3. Mean plant nutrients concentration in leaves and roots collected at the harvest time.

Treatments	Mn	Fe	Cu	Zn	Ca	Mg	P	N	K	S
	mg kg^{-1}				g kg^{-1}					
					Leaves					
T_1: control (no Mn)	9.2 ab	ns	1.8 ab	ns	ns	ns	4.2 a	ns	ns	ns
T_2: 4.28 kg ha^{-1} of Mn (banded)	9.8 ab	ns	1.2 b	ns	ns	ns	3.0 b	ns	ns	ns
T_3: Mn stem cutting	8.4 ab	ns	0.7 b	ns	ns	ns	2.6 b	ns	ns	ns
T_4: $T_3 + T_2$	11.4 a	ns	1.2 b	ns	ns	ns	2.5 b	ns	ns	ns
T_5: $T_3 + T_2$ + banded S^0	12.0 a	ns	1.6 ab	ns	ns	ns	2.6 b	ns	ns	ns
T_6: leaf Mn spraying	7.2 b	ns	2.5 a	ns	ns	ns	2.4 b	ns	ns	ns
Means*	9.7	215.5	1.5	58.9	17.9	4.2	2.9	37.7	19.3	2.6
*s***	2.3	69.8	0.6	17.9	1.9	0.3	0.7	6.6	1.7	0.4
					Roots					
T_1: control (no Mn)	ns	ns	1.3 a	ns	ns	ns	ns	ns	ns	0.2 b
T_2: 4.28 kg ha^{-1} of Mn (banded)	ns	ns	1.3 a	ns	ns	ns	ns	ns	ns	0.4 b
T_3: Mn stem cutting	ns	ns	1.2 a	ns	ns	ns	ns	ns	ns	0.1 b
T_4: $T_3 + T_2$	ns	ns	1.7 a	ns	ns	ns	ns	ns	ns	0.3 b
T_5: $T_3 + T_2$ + banded S^0	ns	ns	0.7 b	ns	ns	ns	ns	ns	ns	0.1 b
T_6: leaf Mn spraying	ns	ns	1.7 a	ns	ns	ns	ns	ns	ns	1.8 a
Means	1.1	85.5	1.3	10.8	1.2	0.9	1.9	8.8	18.8	0.5
*s***	0.3	21.1	0.5	2.1	0.4	0.2	0.5	2.1	3.5	0.7

* Means followed by different letters in the columns are statistically different ($p < 0.05$) by the Tukey test. ** Standard deviation: n = 24.

Table 4. Main Pearson's correlation analysis of the plant growth attributes and nutrient concentration in leaves collected in the fourth month[1].

	Ca	P	N	Cu	Mn
Fresh root yield	0.70	-0.61	-0.71	-0.59	0.78
Fresh shoot yield	0.71	-0.64	-0.81	-0.64	0.70
Plant height	-	-0.65	-0.74	-	-
Number of roots	0.74	-0.61	-0.78	-0.61	0.66

[1] Probability of all correlations < 0.01; n = 24.

hints, concerning plant nutrition, revealing the status of Mn in the plant, as well as the status of other nutrients, such as Ca, P, N and Cu, which revealed to have been impacted by the attempts to increase the Mn availability for the crop. Phosphorus, nitrogen and copper were probably partially "diluted" with the cassava growth, due to the increase of the Mn availability, while Ca was gradually absorbed into the plants according to the plant growth, rendering negative correlations (Table 4).

These results showed that the conditions existing for a high sweet cassava yield under Mn deficiency should be further studied. Another important aspect to be considered is that soil management practices under organic systems in the Federal District must be adequate to prevent Mn to become unavailable to plants. Avoiding overliming is also paramount.

In soils presenting a high pH and high organic matter content, in which prior Mn deficiency in plants was observed, a preventive treatment of cassava cuttings with a $MnSO_4$ solution is recommended. Other methods, such as the use of acidic fertilizers, and even soil compaction, have been previously suggested (Reuter et al. 1988). As a last resource for cassava crops presenting Mn deficiency, the best alternative found is foliar spraying, as it is the most economic way to overcome the Mn deficiency (Potafos 1996). However, cassava leaves are covered by wax and present a low number of stomatal pores (Zinsou et al. 2006), hindering the nutrient absorption. Further studies on foliar spraying, concerning the Mn nutrition of cassava, consequently, should include the application frequency, doses, pH of solutions, and even the use of dispersing agents and of chelates, aiming to increase the Mn absorption by leaves.

Finally, in accordance with Reuter et al. (1988), before the plants present sufficient foliage to intercept foliar sprays, sufficient Mn fertilizer needs to be applied, banded in rows, at sowing, to ensure that the crop continues to grow without Mn stress. However, following the results of the present study, $MnSO_4$ should preferably be accompanied by an S^0 application before planting.

CONCLUSIONS

1. In soils of the Federal District, Brazil, under organic management systems, where manganese (Mn) presents a low availability to sweet cassava plants (IAC 576-70 cultivar), treatments such as Mn foliar spraying, treating cassava cuttings with Mn solutions and adding S^0 banded in rows before planting are important to partially overcome the Mn deficiency, increasing both the root and shoot yield;
2. Except for the exclusive band application of Mn, which was non-effective in alleviating the Mn deficiency, the other application methods and their combinations are similarly effective, increasing the mean of fresh shoot and root yield and number of roots per plant of cassava in 227, 516 and 319 %, respectively, as related to the control (no Mn) treatment.

REFERENCES

ALEJANDRO, S.; HOLLER, S.; MEIER, B.; PEITER, E. Manganese in plants: from acquisition to subcellular allocation. *Frontiers in Plant Science*, v. 11, e300, 2020.

ALVES, A.; CANSIAN, R. L.; STUART, G.; VALDUGA, E. Alterações na qualidade de raízes de mandioca (*Manihot esculenta* Crantz) minimamente processadas. *Ciência e Agrotecnologia*, v. 29, n. 2, p. 330-337, 2005.

BATAGLIA, O.; FURLANI, A.; TEIXEIRA, J.; FURLANI, P.; GALLO, J. *Métodos de análise química de plantas*. Campinas: Instituto Agronômico, 1983.

BROADLEY, M.; BROWN, P.; CAKMAK, I.; RENGEL, Z.; ZHAO, F. Function of nutrients: micronutrients. *In*: MARSCHNER, H. (ed.). *Marschner's mineral nutrition of higher plants*. London: Elsevier, 2012. p. 191-248.

CAMBERATO, J. *Manganese deficiency and fertilization of cotton*. Clemson: Clemson University, 2004. (Soil fertility series, 1).

CAMPOS-M, M.; CAMPOS-C, R. Applications of quartering method in soils and foods. *International Journal of Engineering Research and Application*, v. 7, n. 1, p. 35-39, 2017.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (Embrapa). *Manual de métodos de análise de solo*. 3. ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos, 2017.

FIALHO, J. D. F.; VIEIRA, E. *Mandioca no Cerrado*: orientações técnicas. 2. ed. Planaltina, DF: Embrapa Cerrados, 2013.

FIALHO, J. F.; VIEIRA, E. A.; MARCHI, G.; SANTOS JUNIOR, J. D.; REIN, T. A.; SOUSA-SILVA, J. C.; MALAQUIAS, J. V.; GUELFI-SILVA, D. R. *Desempenho de genótipos de mandioca de mesa em sistema orgânico de produção no Distrito Federal*. Planaltina, DF: Embrapa Cerrados, 2020. (Boletim de pesquisa e desenvolvimento, 366).

FIALHO, J. F.; VIEIRA, E. A.; SILVA, M. S.; PAULA-MORAES, S. V. de; FUKUDA, W. M. G.; SANTOS FILHO, M. O. S. dos; SILVA, K. N. Desempenho de variedades de mandioca de mesa no Distrito Federal. *Revista Brasileira de Agrociência*, v. 15, n. 1, p. 31-35, 2009.

GALRÃO, E. Z. *Correção da deficiência de micronutrientes em solos de Cerrado para culturas anuais*. Planaltina, DF: Embrapa Cerrados, 1999.

GHISI, E.; TAVARES, D. D. F.; ROCHA, V. L. Rainwater harvesting in petrol stations in Brasília: potential for potable water savings and investment feasibility analysis. *Resources, Conservation and Recycling*, v. 54, n. 1, p. 79-85, 2009.

GROSMANN, J.; FREITAS, A. D. Determinação do teor de matéria seca pelo método de peso específico em raízes de mandioca. *Revista Agronômica*, v. 14, n. 1, p. 75-80, 1950.

HANNAM, R. J.; OHKI, K. Detection of manganese deficiency and toxicity in plants. *In*: GRAHAM, R. D.; HANNAM, R. J.; UREN, N. C. (ed.). *Manganese in soils and plants*. Dordrecht: Springer, 1988. p. 243-259.

HOWELER, R. H. Cassava mineral nutrition and fertilization. *In*: HILLOCKS, R. J.; THRESH, J. M.; BELLOTTI, A. (ed.). *Cassava*: biology, production and utilization. Wallingford: Cabi Publishing, 2002. p. 115-147.

HUSSON, O. Redox potential (Eh) and pH as drivers of soil/plant/microorganism systems: a transdisciplinary overview pointing to integrative opportunities for agronomy. *Plant and Soil*, v. 362, n. 1-2, p. 389-417, 2013.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. *Avaliação do estado nutricional das plantas*: princípios e aplicações. 2. ed. Piracicaba: Potafos, 1997.

OLIVEIRA, S. Análise foliar. *In*: SOUZA, D.; LOBATO, E. (ed.). *Cerrado*: correção do solo e adubação. 2. ed. Brasília, DF: Embrapa Cerrados, 2004. p. 245-256.

O'NEILL, M. E.; MATHEWS, K. A weighted least squares approach to Levene's test of homogeneity of variance. *Australian & New Zealand Journal of Statistics*, v. 42, n. 1, p. 81-100, 2000.

POTAFOS - ASSOCIAÇÃO BRASILEIRA PARA PESQUISA DA POTASSA E DO FOSFATO. Informação agronômica sobre nutrientes para as culturas. *Arquivo do Agrônomo*, n. 10, p. 1-24, 1996.

RAIJ, B. V.; CANTARELLA, H.; QUAGGIO, J.; FURLANI, A. *Recomendações de adubação e calagem para o Estado de São Paulo*. 2. ed. Campinas: Instituto Agronômico, 1997.

REUTER, D.; ALSTON, A.; MCFARLANE, J. Occurrence and correction of manganese deficiency in plants. *In*: GRAHAN, R. D.; HANNAM, R. J.; UREN, N. C. (ed.). *Manganese in soils and plants*. Dordrecht: Kluwer Academic Publishers, 1988. p. 205-224.

RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ, V. H. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais*: 5ª aproximação. Viçosa: CFSEMG, 1999.

SCHMIDT, S. B.; JENSEN, P. E.; HUSTED, S. Manganese deficiency in plants: the impact on photosystem II. *Trends in Plant Science*, v. 21, n. 7, p. 622-632, 2016.

SHAPIRO, S. S.; WILK, M. B. An analysis of variance test for normality (complete samples). *Biometrika*, v. 52, n. 3/4, p. 591-611, 1965.

SOUZA, L. S.; SILVA, J.; SOUZA, L. D. *Recomendação de calagem e adubação para o cultivo da mandioca*. Cruz das Almas: Embrapa Mandioca e Fruticultura Tropical, 2009. (Comunicado técnico, v. 133).

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). *Ilustrated guide to soil taxonomy*. Lincoln: National Soil Survey Center, 2015.

VIEIRA, E. A.; FIALHO, J. de F.; CARVALHO, L. J. C. B.; MALAQUIAS, J. V.; FERNANDES, F. D. Desempenho agronômico de acessos de mandioca de mesa em área de Cerrado no município de Unaí, região noroeste de Minas Gerais. *Científica*, v. 43, n. 4, p. 371-377, 2015.

ZINSOU, V.; WYDRA, K.; AHOHUENDO, B.; SCHREIBER, L. Leaf waxes of cassava (*Manihot Esculenta* Crantz) in relation to ecozone and resistance to *Xanthomonas* Blight. *Euphytica*, v. 149, n. 1-2, p. 189-198, 2006.