Scientific Note

Effects of bone meal and hydrogel on the leaf contents of dwarf cashew[1]

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ABSTRACT

In semi-arid regions, where seasonal drought or irregular rainfall distribution are common occurrences, agricultural management techniques or strategies, such as the use of bone meal and/or hydrogel, can mitigate adverse conditions and ensure crop production. This study aimed to evaluate the effects of bone meal doses (0, 250, 500, 750 and 1,000 g pit^{-1}), in association or not with hydrogel (0 and 5 g pit^{-1}, respectively), on the leaf nutrient content of the dwarf cashew cultivar BRS 226. The leaf nutrient contents were evaluated during two growing seasons. For being a good source of macronutrients, the bone meal increased the levels of N, P, Ca, K and Mg in the dwarf cashew leaves. The leaf contents of the micronutrients Zn, Fe and Mn decreased with increasing bone meal doses. The nutrient accumulation in the leaves of the dwarf cashew planted in pits with bone meal and hydrogel has the following order: N > K > Ca > Mg > P > Mn > Fe > Zn > Cu. The application of bone meal at levels close to 600 g pit^{-1}, mainly with the use of hydrogel, is a viable fertilizer alternative for dwarf cashew.

KEYWORDS: *Anacardium occidentale*, plant nutrition, soil conditioner.

RESUMO

Efeitos de farinha de osso e hidrogel nos teores foliares de cajueiro anão

Em regiões semiáridas, onde a seca sazonal ou a distribuição irregular de chuvas são ocorrências comuns, técnicas ou estratégias de manejo agrícola, como o uso de farinha de osso e/ou hidrogel, podem mitigar condições adversas e garantir a produção agrícola. Objetivou-se avaliar os efeitos de doses de farinha de osso (0, 250, 500, 750 e 1,000 g cova^{-1}), em associação ou não com hidrogel (0 e 5 g cova^{-1}, respectivamente), sobre o teor de nutrientes foliares da cultivar de cajueiro-anão BRS 226. Os teores de nutrientes nas folhas foram avaliados durante duas safras. Por ser boa fonte de macronutrientes, a farinha de osso aumentou os níveis de N, P, Ca, K e Mg nas folhas do cajueiro anão. Os teores foliares dos micronutrientes Zn, Fe e Mn diminuíram com o aumento das doses de farinha de osso. O acúmulo de nutrientes nas folhas do cajueiro anão plantado em covas com farinha de osso e hidrogel tem a seguinte ordem: N > K > Ca > Mg > P > Mn > Fe > Zn > Cu. A aplicação de farinha de osso em níveis próximos a 600 g cova^{-1}, principalmente com o uso de hidrogel, é uma alternativa viável de fertilizante para cajueiro-anão.

PALAVRAS-CHAVE: *Anacardium occidentale*, nutrição de plantas, condicionador de solo.

The cashew tree (*Anacardium occidentale* L.) is a fruit species native to South America cultivated in tropical regions of Asia, Africa, South and Central America. Its production in Brazil is concentrated in the Northeast region, particularly in the states of Ceará, Rio Grande do Norte and Piauí, which account for around 90 % of the national cultivated area and production. However, in the last decade, there has been a decrease in the harvested area due to aging orchards, a drought period between 2012 and 2017, inadequate agricultural practices and phytosanitary problems (Serrano et al. 2013, Araújo et al. 2020).

In this scenario, new technologies are being used to increase the sustainability of cashew farming, and the need to expand the scientific knowledge on the interactions between cashew trees and the main soil parameters has intensified in semi-arid regions (Araújo et al. 2014, Lima et al. 2020), as it contributes to developing production systems that can

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meet the concepts advocated by agriculture with low environmental impact.

Cashew trees are often grown under rainfed conditions, in soils with low nutrient levels, and associated with inadequate nutritional management during early growth, what has further hampered the expression of their productive potential (Cavalcante Júnior et al. 2019). However, the use of nutritionally more efficient plants is an important adaptation strategy to low-fertility soils.

In that regard, organic fertilization is recognized as an efficient intervention to change soil organics through increased microbial activity, nutrient supply and cycling, and physicochemical protection (Gmach et al. 2020). One example of organic fertilizer is bone meal, an easily accessible by-product of the animal recycling-processing industry (as it is made up of cattle carcasses, leftover fat and meat residues) (Piash et al. 2023) that is abundant in Brazil, as the country is one of the largest cattle producers (Casagranda et al. 2023). Bone meal contains nutritive elements such as P, K and Ca, and shows a gradual solubilization, which can increase its residual effect on the soil (Cascarosa et al. 2012, Jatana et al. 2020). Silva et al. (2019) evaluated the application of bone meal in sugarcane and concluded that it performed better than single superphosphate, in terms of plant height, number of nodes, fresh and dry mass, soluble solids and phosphorus content in the leaves, therefore being recommended as an organic fertilizer, and, furthermore, a low-cost polyacrylamide. Polymers, also known as hydrogel, have been widely studied as soil conditioners in contrasting environments (Silva et al. 2018) and identified as potential reducers of nutrient loss through leaching (Farrell et al. 2013, Paradelo et al. 2019). However, the efficiency of hydrogel is influenced by complex conditions involving physical and chemical properties inherent to polymers and soils (Crous 2017).

In semi-arid regions, where seasonal drought or irregular rainfall distribution are common, agricultural management techniques, or strategies such as the use of bone meal and/or hydrogel, can mitigate adverse conditions and ensure crop production (Navroski et al. 2016, Tomášková et al. 2020). In that regard, Felippe et al. (2021) evaluated the effect of hydrogel on *Eucalyptus* plants under water restriction and observed that its use promotes a significant increase in soil water retention, thus delaying water deficit symptoms in plants. Shankarappa et al. (2020) observed that the application of 2.5-5.0 kg ha^{-1} of hydrogel before lentil sowing and subsequent nutrition with NPK was considered effective to increase seed production and yield, constituting a viable alternative for cultivation in semi-arid environments, as it improves the moisture retention capacity, what helps to increase nutrient availability.

From this perspective, this study aimed to evaluate the effects of the application of bone meal to planting pits of the dwarf cashew cultivar BRS 226, associated or not with hydrogel.

The experiment was carried out in Boa Saúde, Rio Grande do Norte state, Brazil (6º07'06.4"S, 35º33'30.0"W and altitude of 110 m), from April 2017 to May 2019.

According to the Köppen classification (Alvares et al. 2013), the regional climate is classified as *As*' and *Bsh*', characterized as a semi-arid tropical climate with rainy summers, mean annual rainfall of 700 mm concentrated from March to June, mean annual temperature of 28 ºC and air humidity of 75 %.

The soil in the experimental area has a sandy texture in the 0-20 cm layer, with 810, 126 and 64 g kg^{-1} of sand, clay and silt, respectively, being classified as Argissol (Embrapa 2018) or Utissol (USDA 2014). The soil chemical attributes are shown in Table 1.

The orchard was set up in a randomized block design, in a 5 × 2 factorial arrangement, for a total of 10 treatments, with four replications and three plants per plot, each in its own planting pit. The treatments consisted of five doses of bone meal (0, 250, 500, 750 and 1,000 g pt^{-1}), with or without the application of the moisture-retaining hydrogel (0 and

Table 1. Soil chemical attributes of the experimental area prior to the application of the treatments with bone meal and hydrogel.

pH	P	K	Na	Fe	Zn	Cu	Mn	Ca	Mg	H + Al	Al	SB	CEC	V	m	SOM
	mg dm^{-3}							cmol dm^{-3}						%		g kg^{-1}
5.2	3.01	56.15	0.01	10.86	0.99	0.16	3.26	0.23	0.15	1.62	0.10	0.5252	2.15	24.79	15.77	5.64

SB: sum of bases; CEC: cation exchange capacity; V: base saturation; m: aluminum saturation; SOM: soil organic matter.

5 g pit^{-1}, respectively). The Bone meal doses were based on the soil P content and the P recommendation for the crop (Serrano 2016), by establishing values above and below the recommended ones. The hydrogel concentration followed the manufacturer's recommendation for fruit trees.

The bone meal used in the experiment came from an animal waste processing industry and was obtained after cooking cattle carcasses (eliminating the fat), drying and crushing. The results of its chemical analysis are provided in Table 2.

The hydrogel used in the study (Forth®) was characterized by the manufacturer as a potassium polyacrylate/polyacrylamide copolymer, in white grains, with particle size of 100-800 µm and pH of 5.5-6.0.

The orchard was implemented by completely cleaning the experimental area and preparing the soil with heavy harrowing, followed by light harrowing for leveling.

Planting pits measuring 0.4 × 0.4 × 0.4 m (width x length x depth) were manually dug with hoes by observing a spacing of 10 m between plants and 10 m (Serrano & Cavalcanti Junior 2016) between rows, totaling 1.2 ha of experimental area.

The fertilization at planting consisted of the application of 90 g pit^{-1} of single superphosphate (18 % of P_2O_5, 10 % of S and 18 % of Ca), 90 g pit^{-1} of potassium chloride (60 % of K_2O) and 100 g pit^{-1} of FTE BR 12® (source of oxysilicate micronutrients) composed of 1.08 % of B, 0.8 % of Cu, 2 % of Mn, 9 % of Zn and 1.0 % of S. The fertilization was based on the soil analysis and followed the recommendations of Serrano (2016).

The seedlings were produced in polyethylene bags (11 × 23 cm) filled with a substrate consisting of hydromorphic soil and dried and shredded carnauba bagasse (leaf fibers after wax extraction) in a 2:1 ratio (Serrano & Cavalcanti Junior 2016). At the time of transplanting, the seedlings had a mean height of 19.0 ± 1.5 cm, mean stem diameter of 10.0 ± 3.0 mm and four to six fully expanded leaves (Serrano & Cavalcanti Junior 2016).

The transplanting was carried out on May 10 (2017), in pre-prepared planting pits. The hydrated polymer was used at the time of planting according to the treatments and following the manufacturer's guidelines.

Topdressing fertilization was carried out after planting by applying 60 g plant^{-1} of ammonium sulfate (21 % of N; 23 % of S) and 90 g plant^{-1} of potassium chloride (60 % of K_2O), split into two applications, one at 60 days and one at 90 days post-planting, with distribution in circular furrows, based on the soil analysis and following the recommendations of Serrano (2016). Four annual sprayings were carried out to prevent pest attacks, using a Deltamethrin-based insecticide and an adhesive spreader, at the recommended dose for the crop (0.1 mg L^{-1}). Weed control was performed by periodic harrowing between rows and manual weeding within a 0.5-m radius in the first year and 1.0 m in the second year.

Subsequently, twelve newly mature and fully expanded leaves free from mechanical damage or insect attack were collected from the four quadrants of each plot (Miyazawa et al. 2009). The leaves were then placed in previously identified plastic bags, stored in a cooler at a low temperature and sent for laboratory analysis.

At the laboratory, the leaf samples were washed in running distilled water, dried on paper towels, placed in paper bags and oven-dried to constant weight at ± 65 ºC. The leaves were subsequently ground in a Wiley mill and then subjected to sulfuric digestion to determine the N content, and to nitric-perchloric digestion to determine the levels of P, K, Ca, Mg, Cu, Fe, Mn and Zn (Miyazawa et al. 2009).

The data were initially tested for normality using the Shapiro-Wilk test ($p \leq 0.05$) and homogeneity of variances using the Bartlett test ($p \leq 0.05$), followed by analysis of variance using the F-test ($p \leq 0.05$). The effects of the hydrogel application were compared using the Tukey test ($p \leq 0.05$), whereas the bone meal doses were adjusted by polynomial regression analysis up to the second degree, by adopting as selection criteria the significance of the equation parameters

Table 2. Chemical attributes of the bone meal used in the experiment.

OC	OM	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
%		g kg^{-1}						mg kg^{-1}				
27.02	46.58	41.13	28.10	0.14	294.35	17.81	4.15	2.0	2.0	259.0	7.5	68.0

OC: organic carbon; OM: organic matter.

($p \leq 0.05$). All analyses were conducted with the R software, version 4.0.0 (R Core Team 2020).

The leaf contents of the macronutrients N, P, K, Ca and Mg and the micronutrients Fe, Zn, Mn and Cu were significantly affected ($p \leq 0.01$) by the interaction between bone meal and hydrogel application for the dwarf cashew BRS 226 plants in the two years of cultivation.

The leaf N content increased linearly in the first year by 63.79 %, with increasing bone meal doses and hydrogel application, whereas the absence of hydrogel resulted in a quadratic behavior and achieved a maximum of 27.52 g kg^{-1} of N with the estimated bone meal dose of 607.5 g pit^{-1} (Figure 1A). Since bone meal mineralizes faster than other organic fertilizers, it promotes high levels of N in the assimilable form (NH_4^+ and NO_3^-), corresponding to about 50 % of the added N, with a high concentration of phosphates and elevated soil microbial activity (Mondini et al. 2008). However, excessive doses of bone meal cause toxicity (Silva et al. 2019).

On the other hand, the leaf N content increased linearly in the second year with increasing bone meal doses, both with and without hydrogel, with increases of 94.18 and 59.29 %, respectively, when comparing the doses of 0 and 1,000 g pit^{-1}, amounting to 15.50 and 14.84 g kg^{-1} (0 g pit^{-1}) and 30.10 and 23.64 g kg^{-1} (1,000 g pit^{-1}), respectively with and without hydrogel. A greater increase in N accumulation was observed when using hydrogel, due to the bone meal being rich in nutrients and the hydrogel promoting a slower release of nutrients from organic fertilizer, favoring an indirect increase in macronutrient absorption (Tomášková et al. 2020).

The leaf P content increased linearly by 68.09 % with the bone meal doses (0-1,000 g pit^{-1}) and hydrogel application in the first year, amounting to 1.02 g kg^{-1} (0 g pit^{-1}) and 1.73 g kg^{-1} (1,000 g pit^{-1}). On the other hand, without hydrogel, this parameter reached a maximum of 1.62 g kg^{-1} with the estimated dose of 500 g pit^{-1} of bone meal (Figure 1B). In the second year, the leaf P content with bone meal doses without hydrogel increased from 0.47 to 1.07 g kg^{-1} at the respective doses of 0 and 1,000 g pit^{-1}, an increase equivalent to 125.52 %, whereas a quadratic behavior was observed with hydrogel, reaching a maximum value of 1.35 g kg^{-1} at the estimated dose of 600 g pit^{-1} and decreasing thereafter.

The leaf K content had a quadratic behavior for all the treatments in the two years of cultivation (Figure 1C). In the first year, with and without hydrogel, this parameter reached a maximum of 12.37 and 15.08 g kg^{-1} of K, respectively, at the estimated bone meal doses of 560 and 750 g pit^{-1}. In the second year, the maximum values were 13.80 and 10.07 g kg^{-1}, respectively, at the estimated bone meal doses of 760 and 625 g pit^{-1}.

The leaf Ca content behaved similarly to the leaf K content, except for the treatment without hydrogel in the second year (Figure 1D). In the first year, the treatments with and without hydrogel provided similar results, with maximum values of 3.73 and 4.16 g kg^{-1} of Ca, respectively, at the estimated bone meal doses of 488 and 425 g pit^{-1}. In the second year, the hydrogel application resulted in the highest Ca content, reaching a maximum of 3.85 g kg^{-1} at the estimated bone meal dose of 833 g pit^{-1}, with a subsequent decrease, whereas the absence of hydrogel resulted in a linear increase with the addition of bone meal doses (0-1,000 g pit^{-1}), amounting to 70.42 %.

The leaf Mg content (Figure 1E) increased linearly by 57.80 % in the first year with bone meal doses (0-1,000 g pit^{-1}) and with hydrogel application, whereas the absence of hydrogel increased this parameter until reaching a maximum of 2.11 g kg^{-1} of Mg at the estimated bone meal dose of 450 g pit^{-1}. A quadratic behavior was observed both with and without hydrogel in the second year. The treatment with hydrogel reached a maximum of 2.15 g kg^{-1} of Mg at the estimated bone meal dose of 550 g pit^{-1}, whereas the treatment without hydrogel reached a maximum of 2.79 g kg^{-1} with the bone meal dose of 1,000 g pit^{-1}, with both decreasing thereafter.

The increase in the bone meal doses resulted in the accumulation of higher leaf nutrient contents (N, P, K, Ca and Mg) up to certain doses, probably because of the phytotoxicity caused by the high bone meal concentrations, as bone meal is rich in macro (P, N, Ca and Mg) and micronutrients (Fe and Zn) (Table 2). Studies involving bone meal confirm this management technique as favoring plants by increasing the supply of nutrients in the soil and in the plant (Nogalska et al. 2013, Stepién & Wojtkowiak 2015, Nogalska 2016, Silva et al. 2019). Excessive concentrations, however, can cause phytotoxicity (Nogalska 2016).

The leaf contents of N, P and Ca, as a function of bone meal application, were lower in the second year of cultivation. Nogalska et al. (2013) studied the application of bone meal to corn plants and concluded that the absorption of P, Ca and Mg by plants was lower in the second year of cultivation, recommending that new fertilizers be added at every two years of cultivation. Jeng et al. (2004) reported that, even if bone meal has high N levels, which are present in organic compounds, 80 % remain in the assimilable form in the soil in the first year of cultivation, resulting in reduced leaf N contents in the second year.

The leaf contents of N, P, K, Ca and Mg with the use of hydrogel stood out from treatments without

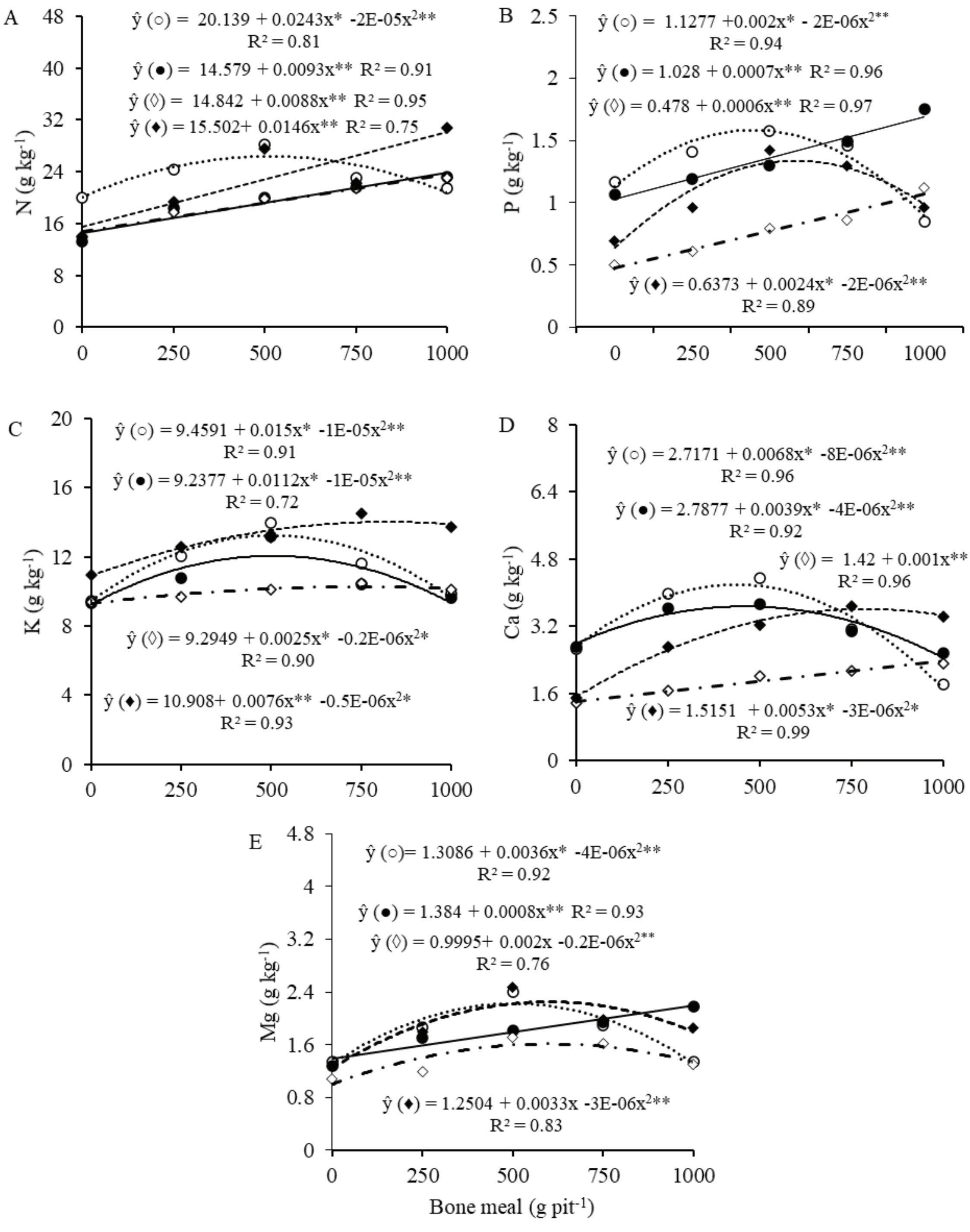

Figure 1. Leaf contents of nitrogen (A), phosphorus (B), potassium (C), calcium (D) and magnesium (E) in dwarf cashew, as a function of bone meal doses with (●) and without hydrogel (○) in the first year of cultivation and with (♦) and without hydrogel (◊) in the second year of cultivation.

hydrogel only in the second year of cultivation. This was possibly due to the low solubility of macronutrients soon after their application to the soil (Mondini et al. 2008). It could also be because cashew is a perennial plant, and its root system develops gradually (Dendena & Corsi 2014), with the root formation being one of the main characteristics improved by hydrogel (Navroski et al. 2015), what contributes to nutrient uptake over time. The hydrogel application also contributed to the increase in the leaf contents of N, P, K, Ca and Mg in *Eucalyptus dunnii* (Navroski et al. 2015). Thus, it can be suggested that the use of hydrogel is very beneficial to plants, as it increases the soil water storage capacity without causing nutrient leaching (Tomášková et al. 2020, Felippe et al. 2021).

There was no variation in the leaf Zn content in the first year with the application of hydrogel and bone meal, with an average of 22.8 mg kg^{-1} (Figure 2A). In the treatment without hydrogel, the leaf Zn content decreased linearly with the bone meal doses by 43.15 % (0-1,000 g pit^{-1}). In the second year, the hydrogel decreased the Zn content with bone meal doses up to the estimated dose of 642 g pit^{-1}, at which it reached a minimum of 21.74 mg kg^{-1} and then increased. However, this parameter did not change with the hydrogel, with a mean value of 20.39 mg kg^{-1}. The application of 100 g pit^{-1} of FTE BR 12® (micronutrient source) may have saturated the plants with high levels of micronutrients, resulting in declines at increased bone meal doses, since it contains a large amount of Fe and Zn (Table 2).

The leaf Cu content did not vary among the bone meal doses in the absence of hydrogel in the first year, reaching a mean value of 6.62 mg kg^{-1}. In contrast, in the presence of hydrogel, this parameter increased to a maximum of 9.04 mg kg^{-1} at the estimated dose of 635 g pit^{-1}, after which it decreased

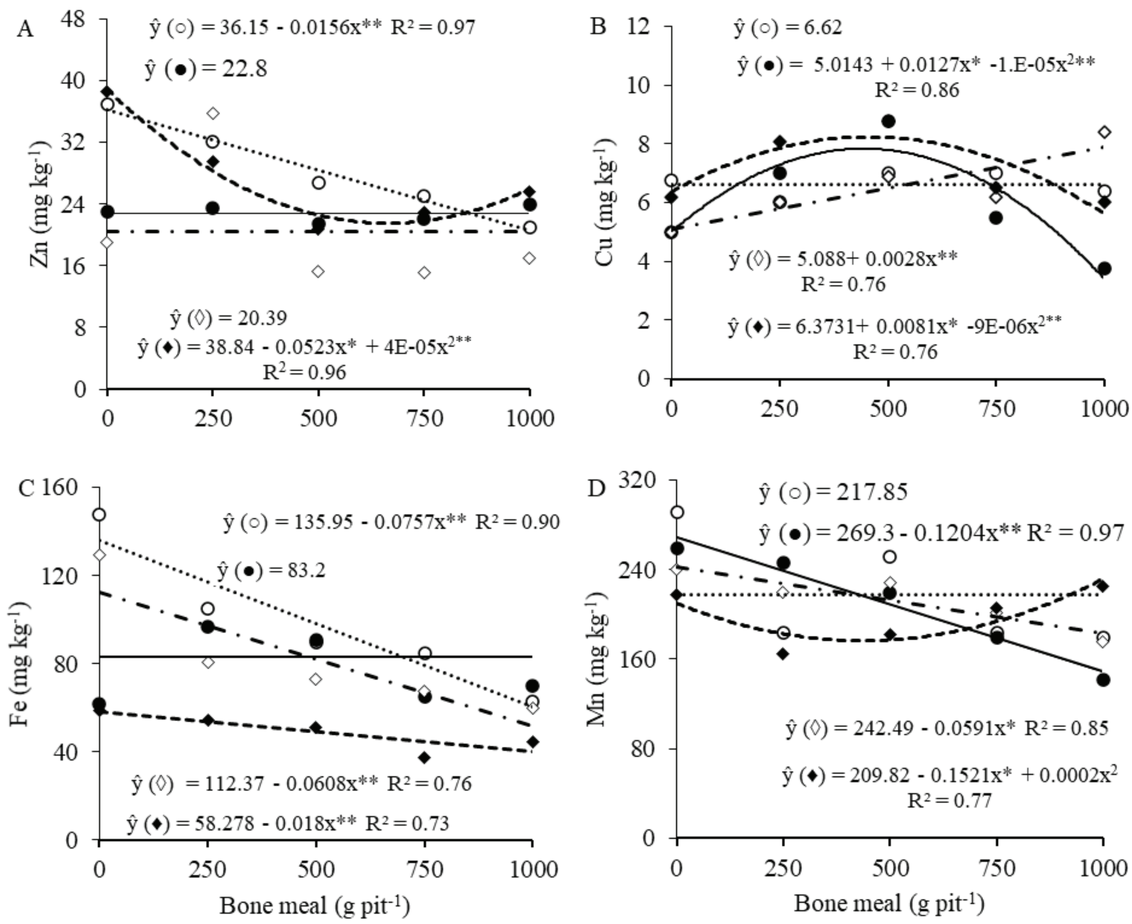

Figure 2. Leaf contents of zinc (A), copper (B), iron (C) and manganese (D) in dwarf cashew, as a function of bone meal doses with (●) and without hydrogel (○) in the first year of cultivation and with (♦) and without hydrogel (◊) in the second year of cultivation.

(Figure 2B). Likewise, in the second year, with hydrogel application, the Cu content increased to a maximum of 8.19 mg kg^{-1} at the estimated dose of 450 g pit^{-1}. In the absence of hydrogel, the Cu content increased from 5.08 mg kg^{-1} (0 g pit^{-1}) to 7.96 mg kg^{-1} (1,000 g pit^{-1}), being equivalent to 13.75 % with the addition of bone meal doses.

The hydrogel did not contribute to the leaf Cu accumulation when the bone meal doses were higher than 450 g pit^{-1}. However, the Cu content increased up to 1,000 g pit^{-1} without hydrogel in the second year. These results corroborate those by Navroski et al. (2015), who observed reductions in the Cu content of *Eucalyptus* leaves with 4.5 g L^{-1} of hydrogel. These authors explained that this is because Cu is strongly linked to organomineral colloids in the soil, and the higher the organic matter content and pH, which increased with the use of hydrogel, the lower the availability of Cu to plants, since this parameter is strongly related to pH.

The leaf Fe content did not vary with the application of hydrogel and bone meal doses (83.2 mg kg^{-1}) in the first year. In contrast, without hydrogel, the leaf Fe content decreased by 55.68 % (0-1,000 g pit^{-1}) (Figure 2C). In the second year, the Fe content decreased linearly with increasing bone meal doses (0-1,000 g pit^{-1}), both with and without hydrogel, with reductions of 30.88 and 54.10 %, respectively.

The highlight for the Fe content was its reduction with increased bone meal doses in the absence of hydrogel in the two years of cultivation. Generally, as the amount present in the soil is abundant, the adequate Fe supply seems to depend more on other factors (e.g., pH), with greater Fe availability at acidic pH levels (Navroski et al. 2015), as observed in the present study, when the soil pH increased and the Fe content decreased.

The leaf Mn content did not vary with the addition of bone meal doses in the first year without the use of hydrogel, with an average of 217.85 mg kg^{-1}. However, the use of hydrogel decreased the Mn content from 269.3 mg kg^{-1} (0 g pit^{-1}) to 148.9 mg kg^{-1} (1,000 g pit^{-1}), reducing this parameter by 11.02 % per each unit increase in the bone meal doses (Figure 2D). In the second year, without the use of hydrogel, the Mn content decreased from 242.49 mg kg^{-1} (0 g pit^{-1}) to 183.39 mg kg^{-1} (1,000 g pit^{-1}), a reduction equivalent to 24.37 % with bone meal doses (0-1,000 g pit^{-1}). With hydrogel, the Mn content decreased to the estimated dose of 380 g pit^{-1}, at which it reached a minimum of 180.90 mg kg^{-1}, increasing thereafter.

With regard to micronutrients, the addition of bone meal increased the leaf Cu content and reduced the contents of Fe, Mn and Zn. This finding can be explained by the competition in the uptake of Fe and Zn with Cu and P, with high contents of Cu and P reducing the uptake of Fe and Zn (Malavolta et al. 2002).

It was possible to conclude that bone meal is a good source of macronutrients, increasing the levels of N, P, Ca, K and Mg in dwarf cashew leaves; the leaf contents of the micronutrients Zn, Fe and Mn reduced with increasing bone meal doses; the nutrient accumulation in the leaves of the dwarf cashew cultivar BRS 226 planted in pits with bone meal and hydrogel showed the following order: N > K > Ca > Mg > P > Mn > Fe > Zn > Cu; and that the application of bone meal at levels close to 600 g pit^{-1}, mainly with the use of hydrogel, is a viable fertilizer alternative for dwarf cashew.

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REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, v. 22, n. 6, p. 721-728, 2013.

ARAÚJO, E. A.; ARTUR, A. G.; TANIGUCHI, C. A. K.; NATALE, W.; SERRANO, L. A. L. Rootstock/scion in dwarf cashew improves aluminum tolerance. *Journal of Plant Nutrition*, v. 44, n. 10, p. 1458-1467, 2020.

ARAÚJO, L. F.; LIMA, R. E. M.; COSTA, L. O.; SILVEIRA, E. M. C.; BEZERRA, M. A. Alocação de íons e crescimento de plantas de cajueiro-anão-precoce irrigadas com água salina no campo. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 18, n. 1, p. S34-S38, 2014.

CASAGRANDA, Y. G.; WIŚNIEWSKA-PALUSZAK, J.; PALUSZAK, G.; MORES, G. D. V.; MORO, L. D.; MALAFAIA, G. C.; AZEVEDO, D. B. D.; ZHANG, D. Emergent research themes on sustainability in the beef cattle industry in Brazil: an integrative literature review. *Sustainability*, v. 15, n. 5, e4670, 2023.

CASCAROSA, E.; GEA, G.; ARAUZO, J. Thermochemical processing of meat and bone meal: a review. *Renewable and Sustainable Energy Reviews*, v. 16, n. 1, p. 942-957, 2012.

CAVALCANTE JÚNIOR, L. F.; SOARES, I.; TANIGUCHI, C. A. K.; SERRANO, L. A. L.; MELO, D. S. Nutrient accumulation and nutritional efficiencies of cashew genotypes. *Journal of Plant Nutrition*, v. 42, n. 4, p. 344-350, 2019.

CROUS, J. W. Use of hydrogels in the planting of industrial wood plantations. *Southern Forests*, v. 79, n. 3, p. 197-213, 2017.

DENDENA, B.; CORSI, S. Cashew, from seed to market: a review. *Agronomy for Sustainable Development*, v. 34, n. 4, p. 753-772, 2014.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUARIA (Embrapa). *Sistema brasileiro de classificação de solos*. Brasília, DF: Embrapa Solos, 2018.

FARRELL, C.; ANG, X. Q.; RAYNER, J. P. Water-retention additives increase plant available water in green roof substrates. *Ecological Engineering*, v. 52, n. 1, p. 112-118, 2013.

FELIPPE, D.; NAVROSKI, M. C.; PEREIRA, M. O.; BAPTISTA, K. R. S. P. Hydrogel in the seedling growth of *Eucalyptus dunnii* Maiden under different irrigation management. *Revista Ambiente e Água*, v. 16, n. 1, e2582, 2021.

GMACH, M. R.; CHERUBIN, M. R.; KAISER, K.; CERRI, C. E. P. Processes that influence dissolved organic matter in the soil: a review. *Scientia Agricola*, v. 77, n. 3, e20180164, 2020.

JATANA, B. S.; KITCHENS, C.; RAY, C.; THARAYIL, N. Regulating the nutrient release rates from proteinaceous agricultural byproducts using organic amendments and its effect on soil chemical and microbiological properties. *Biology and Fertility of Soils*, v. 56, n. 1, p. 747-758, 2020.

JENG, A. S.; HARALDSEN, T. K.; VAGSTAD, N.; GRONLUND, N. Meat and bone meal as nitrogen fertilizer to cereals in Norway. *Agricultural and Food Science*, v. 13, n. 3, p. 268-275, 2004.

LIMA, G. S.; SILVA, J. B.; SOUZA, L. P.; NOBRE, R. G.; SOARES, L. A. A.; GHEYI, H. R. Tolerance of precocious dwarf cashew clones to salt stress during rootstock formation stage. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 24, n. 7, p. 474-481, 2020.

MALAVOLTA, E.; GOMES, F. P.; ALCARDE, J. C. *Adubos e adubações*. Nobel: São Paulo, 2002.

MIYAZAWA, M.; PAVAN, M. A.; MURAOKA, T.; CARMO, C. A. F. S.; MELO, W. J. Análise química de tecido vegetal. *In*: SILVA, F. C. (ed.). *Manual de análises químicas de solos, plantas e fertilizantes*. 2. ed. Brasília, DF: Embrapa Informação Tecnológica, 2009. p. 191-233.

MONDINI, C.; CAYUELA, M. L.; SINICCO, T.; SÁNCHEZ-MONEDERO, M. A.; BERTOLONE, E.; BARDI, L. Soil application of meat and bone meal: short-term effects on mineralization dynamics and soil biochemical and microbiological properties. *Soil Biology and Biochemistry*, v. 40, n. 2, p. 462-474, 2008.

NAVROSKI, M. C.; ARAÚJO, M. M.; CUNHA, F. S.; BERGHETTI, Á. L. P.; PEREIRA, M. O. Redução da adubação e melhoria das características do substrato na produção de mudas de *Eucalyptus dunnii*. *Ciência Florestal*, v. 26, n. 4, p. 1155-1165, 2016.

NAVROSKI, M. C.; ARAÚJO, M. M.; REININGER, L. R. S.; MUNIZ, M. F. B.; PEREIRA, M. O.; ARAÚJO, M. M. Influência do hidrogel no crescimento e no teor de nutrientes das mudas de *Eucalyptus dunnii*. *Floresta*, v. 45, n. 2, p. 315-328, 2015.

NOGALSKA, A. Meat and bone meal as fertilizer for spring barley. *Plant Soil Environment*, v. 62, n. 8, p. 373-378, 2016.

NOGALSKA, A.; SKWIERAWSKA, M.; NOGALSKI, Z.; KASZUBA, M. The effect of increasing doses of meat and bone meal (BM) applied every second year on maize grown for grain. *Chilean Journal of Agricultural Research*, v. 73, n. 4, p. 430-434, 2013.

PARADELO, R.; BASANTA, R.; BARRAL, M. T. Water-holding capacity and plant growth in compost-based substrates modified with polyacrylamide, guar gum or bentonite. *Scientia Horticulturae*, v. 243, n. 3, p. 344-349, 2019.

PIASH, M. I.; UEMURA, K.; ITOH, T.; WABUCHI, K. Meat and bone meal biochar can effectively reduce chemical fertilizer requirements for crop production and impart competitive advantages to soil. *Journal of Environmental Management*, v. 336, n. 1, e117612, 2023.

R CORE TEAM. *R*: a language and environment for statistical computing. Viena: R Foundation for Statistical Computing, 2020.

SERRANO, L. A. L. Implantação e tratos culturais do pomar de cajueiro. *In*: SERRANO, L. A. L. (org.). *Sistema de produção do caju*. 2. ed. Brasília, DF: Embrapa Informação Tecnológica, 2016. p. 43-54.

SERRANO, L. A. L.; CAVALCANTI JUNIOR, A. T. Produção de mudas de cajueiro. *In*: SERRANO, L. A. L. (org.). *Sistema de produção do caju*. 2. ed. Brasília, DF: Embrapa Informação Tecnológica, 2016. p. 43-54.

SERRANO, L. A. L.; MELO, D. S.; TANIGUCHI, C. A. K.; VIDAL NETO, F. C.; CAVALCANTE JÚNIOR, L. F. Porta-enxertos para a produção de mudas de cajueiro. *Pesquisa Agropecuária Brasileira*, v. 48, n. 1, p. 1237-1245, 2013.

SHANKARAPPA, S. K.; MUNIYANDI, S. J.; CHANDRASHEKAR, A. B.; SINGH, A. K.; NAGABHUSHANARADHYA, P.; SHIVASHANKAR, B.; EL-ANSARY, D. O.; WANI, S. H.; ELANSARY, H. O. Standardizing the hydrogel application rates and foliar nutrition for enhancing yield of lentil (*Lens culinaris*). *Processes*, v. 8, n. 4, e420, 2020.

SILVA, A. R.; BEZERRA, F. T. C.; CAVALCANTE, L. F.; PEREIRA, W. E.; ARAÚJO, L. M.; BEZERRA, M. A. F. Frequency of irrigation with saline water in sugar-apple seedlings produced on substrate with polymer. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 22, n. 12, p. 825-830, 2018.

SILVA, W. M.; CARVALHO, M. A. C.; YAMASHITA, O. M.; TAVANTI, T. R.; TAVANTI, R. F. R. Bone meal as a source of phosphorus for forage sugarcane. *Pesquisa Agropecuária Tropical*, v. 49, e55629, 2019.

STEPIÉN, A.; WOJTKOWIAK, K. Variability of mineral nitrogen contents in soil as affected by meat and bone meal used as fertilizer. *Chilean Journal of Agricultural Research*, v. 75, n. 1, p. 105-110, 2015.

TOMÁŠKOVÁ, M.; SVATOŠ, J.; MACKŮ, H.; VANICKÁ, K.; RESNEROVÁ, J.; ČEPL, J.; HOLUŠA, S. M.; HOSSEINI, A.; DOHRENBUSCH, A. Effect of different soil treatments with hydrogel on the performance of drought-sensitive and tolerant tree species in a semi-arid region. *Forests*, v. 11, n. 2, e211, 2020.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). Soil Survey Staff. *Keys to soil taxonomy*. 12. ed. Washington, DC: USDA, 2014.