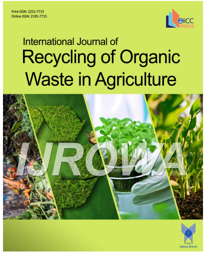

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Organomineral fertilizer based on wood ash in bean cultivation in acidic tropical soil

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Original Research

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Abstract:

Purpose: Organomineral fertilizer using wood ash, an agro-industrial waste, as an organic material has potential in agriculture as an alternative fertilizer. The objective was to evaluate the effects of the use of organomineral fertilizers from wood ash in comparison with conventional mineral fertilization in the cultivation of cowpea in acid tropical soil.
Method: The experimental design used was randomized blocks, in a 4×3 factorial scheme, corresponding to three levels of base saturation (no liming $-$ 0%, V = 30% and V = 60%), and four fertilization treatments: mineral, wood ash, organomineral and granulated organomineral, with four replications. The soil used was Oxisol. To produce organomineral fertilizer–wood ash and mineral fertilizers were used as organic raw material. The fertilizer granulated organomineral used the same composition as the organomineral. The test crop used was cowpea.
Results: The highest soil pH values of 6.8 and 6.2 were observed at 30 days after emergence in wood ash and organomineral fertilizers, respectively. The organomineral fertilizer provided the highest shoot dry mass (23.0 g/pot) when no lime was applied, when compared to the other fertilizers. The highest grain yield of cowpea was observed in wood ash and organomineral, in the absence of liming. The nodulation capacity of cowpea plants was reduced when lime was applied (V = 30% and 60%) and fertilized with wood ash and organomineral.
Conclusion: The transformation of wood ash into organomineral fertilizer proved to be a promising step in converting a solid waste into a commercially viable agricultural fertilizer.

Keywords: Alternative fertilizer; Nodulation; Solid residue; *Vigna unguiculata*

1. Introduction

To meet the world population's demand for food, which is growing every year, food production in developing countries must increase (Dias et al., 2022). As a result, the demand for fertilizers will also increase, especially for sustainable fertilizers that do not have an environmental impact.
With growing global environmental awareness, it is becoming necessary to develop alternative products for use in agriculture that allow for the reuse and recycling of materials, such as agro-industrial waste, to produce composts as fertilizer alternatives (Barán et al., 2024). A sustainable alternative is organomineral fertilizers, which are products obtained by physically mixing different sources of organic material with mineral fertilizer (Bonfim-Silva et al., 2020; Magela et al., 2019). Several authors point out that organomineral fertilizers have many advantages: the gradual release of nutrients during the crop cycles, providing a greater residual effect of the fertilizer used and promoting sustainable production (Dias et al., 2022; Vieira et al., 2020).

Among the sources of organic matter, wood ash, which has high concentrations of P, K, Ca, Mg, B and Zn, has been applied in the cultivation of several plants and has increased production (Dourado et al., 2021).

The possibility of combining sources of organic materials and sources of mineral fertilizers in a single formulation constitutes a relevant technology in fertilizers, as it increases the efficiency of nutrient sources, since the organic matter present in the fertilizer allows greater protection from the elements and favors the maintenance of physical, chemical and microbiological characteristics of the soil (Magela et al., 2019).

According to Bonfim-Silva et al. (2020) it appears that organomineral fertilizers derived from wood ash and modified by the addition of mineral fertilizers are suitable for soil application and have a yield response comparable to conventional fertilizers.

The production of organomineral fertilizers can be carried out in any region, as long as there is abundant availability of organic waste and the source of waste production is close to the factory (Magela et al., 2019). Therefore, organomineral fertilizers stand out as an important strategy in this context, since industrial wastes when used to produce fertilizers can reduce the costs of their disposal and the dependence on fertilizer minerals, in addition to the damage caused by their accumulation in the environment (Magela et al., 2019).

In this context, the study was developed with the hypotheses that the use of wood ash as a raw material for an organomineral fertilizer can increase the productivity of cowpea compared to conventional mineral fertilization. In addition, the short-term effects on soil properties will be stronger for non-granulated organomineral fertilizer than for granulated organomineral fertilizer, and finally. The third hypothesis is that organomineral with wood ash partially or totally replaces liming in acidic soils. Thus, the objective was to evaluate the effects of the use of organomineral fertilizers from wood ash in comparison with conventional mineral fertilization in the cultivation of cowpea in acid tropical soil.

2. Materials and methods

Soil

The soil for the experiment was collected in an area of native Cerrado vegetation, located at latitude 16°27′49.39″S, longitude 54°34′46.59″W and altitude of 289 m, on Campus da Federal University of Rondonópolis, Mato Grosso, Brazil. The soil used was Oxisol (Santos et al., 2018), collected in the $0-20$ cm layer, and chemical and granulometric characterization was performed (Table 1).

Experimental design and conduction

The experimental design used was randomized blocks, in a 4×3 factorial scheme, corresponding to three levels of base saturation (without liming (0%), V = 30% and V = 60%), and four fertilization treatments (mineral fertilization, wood ash, simple organomineral and granulated organomineral), with four replications. The experimental units were composed of pot with a volume of 6 dm^3 of soil.

To evaluate the effects of soil acidity in the fertilizers used, soil liming was carried out to raise the base saturation in 3 levels: Base saturation of 60%, which is the recommended value for the bean crop (Sousa and Lobato, 2004); Base saturation of 30%, half of the recommendation for the culture; Control treatment (without lime application). The treatments that received liming were incubated for 30 days.

Fertilizers

Mineral fertilization (MF) was performed according to the Cerrado bulletin recommendation (120 kg/ha of P_2O_5; 100 kg/ha of K_2O and 100 kg/ha of FTE micronutrients) (Sousa and Lobato, 2004). The dose applied in the experimental units with mineral fertilization (50 mg/dm^3) of FTE micronutrients was composed of 1.95 mg of sulphur, 0.9 mg of boron, 0.425 mg of copper, 1 mg of manganese and 4.5 mg of zinc.

The wood ash used came from the burning of *Eucalyptus sp.*, for energy generation in the industry. Wood ash was analyzed as a corrective fertilizer (Table 2). Fertilization with wood ash (WA) was performed at a dose of 20 g/dm^3, according to previous experiments (Bonfim-Silva et al., 2022; Dourado et al., 2021).

To produce organomineral fertilizer (ORM), wood ash (WA) was used as organic raw material and commercial mineral fertilizers (simple superphosphate, potassium chloride, and FTE micronutrients). Materials were not ground for mixing.

For the preparation of the granulated organomineral fertilizer (ORM-G) the same composition of the simple organomineral fertilizer was used. The method used in the

Table 1. Chemical and particle-size characterization of the Oxisol collected in the $0-20$ cm layer.

pH	OM	P	K	S	Ca	Mg	Al	H + Al	SB	CEC
$CaCl_2$	g/kg	——mg/dm^3——			——cmolc/dm^3——					
3.7	27.1	1.6	42.4	6.1	0.6	0.25	0.95	6.0	1.0	7.0
V	M	Zn	Mn	Cu	Fe	B	Sand*	Silt*	Clay*	
——%——		——mg/dm^3——					——g/kg——			
14.4	48.4	1.3	9.8	0.3	41	0.25	395	175	430	

pH = potential of hydrogen (soil pH in $CaCl_2$ (0.01 mol/L) were measured with a 1:2.5 soil-to-solution ratio); Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Cu = copper, Mn = manganese, B = boron, Fe = iron, P = phosphorus, K = potassium, Al = aluminum, H = hydrogen, CEC = cation exchange capacity at pH 7.0, OM = organic matter, V = base saturation, M = aluminum saturation. *Particle size determined by the Bouyucos method – NaOH + sodium hexametaphosphate dispersant.

Table 2. Chemical and granulometric analyses of wood ash (WA).

Characteristic	Unity	Value	Characteristic	Unity	Value
pH ($CaCl_2$)	-	10.67	Mg	g/kg	42
NP	%	30	S	..	6
PRNT	..	24.76	Fe	..	7.2
N	g/kg	4.9	M.M.	..	546.4
P_2O_5	..	7.9	CaO	..	91
K_2O	..	32.5	MgO	..	65
Zn	..	0.2	Granulometry: 4.8 mm	%	0.48
Cu	..	1	Granulometry: 2.0 mm	..	3.07
Mn	..	0.4	Granulometry: 1.0 mm	..	10.53
B	..	0.4	Density	g/cm^3	0.4
Ca	..	49.6			

pH = potential of hydrogen (soil pH in $CaCl_2$ (0.01 mol/L) were measured with a 1:2.5 soil-to-solution ratio); NP = Neutralizing power; PRNT = Relative power of total neutralization; N = Nitrogen; P_2O_5 = Phosphorus; K_2 O = Potassium; Ca = Calcium; Mg = Magnesium; S = Sulphur; Zn = Zinc; Cu = Copper; Mn = Manganese; B = Boron; Fe = Iron; MM = Mineral matter; CaO = calcium oxide; MgO = Magnesium oxide. *Granulometry determined by Bouyoucos method – dispersant NaOH + sodium hexametaphosphate.

production of ORM-G was wet granulation, using cassava starch as a binding agent. After granulation, the material produced went through the curing process, where it had to be air-dried to eliminate excess moisture and increase the mechanical strength of the granules. The chemical composition of each fertilizer used in the study is described in Table 3.

Conducting the experiment

Fertilizers: wood ash; mineral, simple organomineral and granulated organomineral, were applied at the time of sowing, during the installation of the experiment. All these fertilizers were incorporated into the soil of each corresponding experimental unit for a homogeneous distribution. Sowing was performed immediately after setting up the experiment. Ten seeds of *Vigna unguiculata (L.)* Walp were sown per pot. On the third day after emergence, thinning was performed, leaving only three plants per pot.

Irrigation management was performed using a subsurface self-irrigating system, with continuous water replacement, the method described by Bonfim-Silva et al. (2007). This system consists of a porous ceramic capsule, with a diameter of 50 mm and a height of 70 mm, placed in the vertical position, in the upper fraction of the pot. A flexible microtube, with an internal diameter of 5 mm, connects the capsule to a Mariotte flask, arranged below the pot. The Mariotte flask has a level scale on the outside for the quantification of water consumption, the water potential was determined by the height of the water column (30 cm) (Fig. 1).

Variables analyzed

The soil pH variable was determined on three occasions during the experiment. The first evaluation was performed 15 days after emergence (DAE), the second was performed at 30 DAE, and the third was performed at harvest at 60 DAE. The pH determination methodology was performed according to Embrapa: (2017), using $CaCl_2$ (0.01 mol/L) measured with a 1:2.5 soil-to-solution ratio.

The variables analyzed when the plants were cut were shot dry mass (stem + leaves) -the plants were cut close to the ground, packed in paper bags, identified and taken to a forced ventilation oven at 65 °C, for 72 hours. After that, the samples were weighed to determine the dry mass; Dry mass and number of nodules: after cutting the plants, the contents of the pot were washed over a sieve to remove soil from the root system. Subsequently, the separation

Table 3. Final chemical composition of each fertilizer.

Fertilizers	N	P_2O_5	K_2O	S	Ca	Mg	Zn	Mn	B	Fe	Cu
	mg/dm^3										
Mineral (MF)	0	60.0	50.0	40.4	54.0	0	0.9	0.2	0.2	0	0.1
Wood ash (WA)	19.6	31.6	130.0	24.0	198.4	168.0	0.8	1.6	1.6	28.8	0
Organomineral (ORM)	9.8	45.8	90.0	32.2	126.2	84.0	0.9	0.9	0.9	14.4	0
Granulated organomineral (ORM-G)	9.8	45.8	90.0	12.2	99.2	84.0	0.9	0.9	0.9	14.4	0

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Figure 1. General view of the experiment and its irrigation system (A, B); and top view of the soil wetting front generated by the flow of water from the reservoir to the pot at the time of sowing (C) and when the beans were already developing (D).

and manual counting of the nodules were performed. After counting, the samples were packed in paper bags, properly identified and taken to a forced ventilation oven at 65 °C for 72 hours, then the samples were weighed and the nodules dry mass was determined; Dry mass of grains and number of grains-the pods were harvested when the plants were cut, at 60 DAE. After harvesting, the pods were threshed, and the grains counted. Subsequently, the grains were placed in paper bags, identified and taken to a forced air circulation oven at 65 °C for 72 hours, after which the dry mass of the grains was determined; Root dry mass-the roots were washed on a sieve, placed in plastic bags, identified and taken to a forced air circulation oven at 65 °C for 72 hours and then weighed.

Statistical analysis

To verify if the data follow a normal distribution, they were submitted to the Shapiro-Wilk test ($p > 0.05$). Having followed a normal distribution, the data were submitted to the Tukey test of 5% significance. The software used for all analyzes was R Studio 3.6.1 (R Core Team, 2019).

3. Result and discussion

Soil acidity: pH

The soil pH variable was modified by base saturation levels and fertilizer sources at 15, 30 and 60 DAE (Fig. 2). For the treatment, base saturation levels were expected to influence soil pH, since calcium and magnesium carbonates present in limestone neutralize soil acidity (Mahmud and Chong, 2022). At 15 DAE, the treatment that provided the highest soil pH value were the WA, ORM and ORM-G fertilizers (Fig. 2). At 15 days after emergence, WA already presents significantly higher pH values than the other fertilizers, both for treatments without liming and for treatments with 30% of base saturation. This is probably due to the granulometric properties of WA, with most of its particles < 1.00 mm (Table 2), even if it has not been incubated in the soil, the reactions occur very quickly, causing, in 15 days, the acidity is already corrected (Bonfim-Silva et al., 2019).

At 30 DAE, when comparing the applied fertilizers, the increasing order of pH values were as follows: MF < ORM-G < ORM < WA (Fig. 2). In MF, the base saturation that provided the highest soil pH value was 60%. In WA, wood ash raise soil pH from 0% saturation to the same value as 30% and 60% base saturation. These results suggest that there is no need to apply lime to correct soil acidity when WA is applied.

At 60 DAE, the trend remained, with WA showing the highest soil pH values, and with no influence on liming in this treatment. This effect can be observed because in WA, ORM and ORM-G, when comparing 0, 30 and 60% of base saturation in each of these fertilizers, there was no significant difference, that is, these fertilizers increased the values of base saturation (0% - no liming) for the same level of treatments that received liming (30 and 60% base saturation). This is probably due to the composition of WA (Table 2) which is an alkaline material (pH = 10.6), and this property is conferred due to the presence of alkaline bases (Ca, Mg, K, Na), related to carbonates, oxides, hydroxides, chlorides, sulfates, phosphates, nitrates, silicates and amorphous materials, such compounds react with free hydrogens (H^+) reducing soil acidity (Nnadi et al., 2019) and aluminum toxicity (Al^{3+}) (Bonfim-Silva et al., 2019). Several studies prove the efficiency of WA as an acidity corrector (Nnadi et al., 2019).

However, the response of WA in the correction of soil acidity was reduced when the ORM was granulated, since the

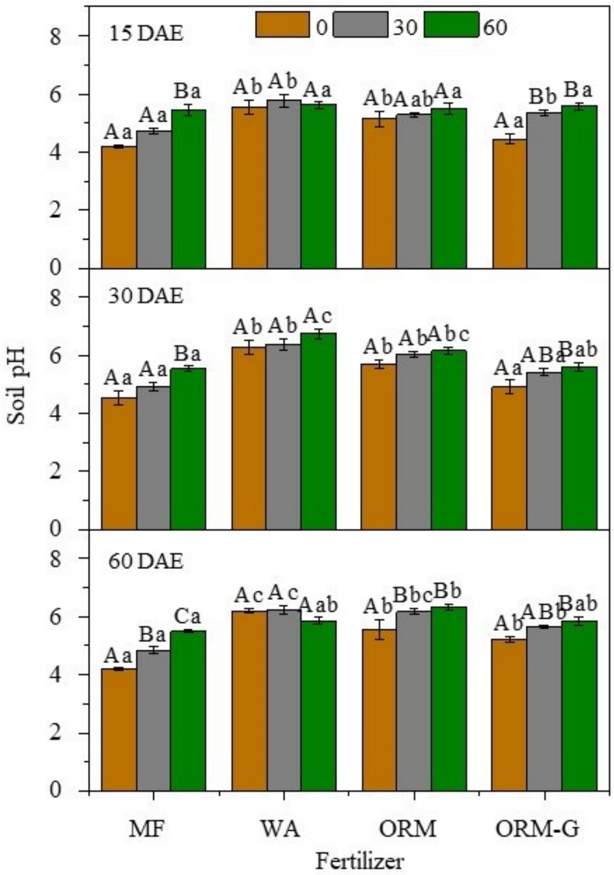

Figure 2. Soil pH cultivated with cowpea fertilized with four types of fertilizers: mineral (MF), wood ash (WA), organomineral (ORM) and granulated organomineral (ORM-G); and three levels of base saturation: 60% (60) and 30% (30) of base saturation and control treatment without liming (0); at 15, 30 and 60 days after emergence (DAE). Lowercase letters compare fertilizer sources within each base saturation level, uppercase letters compare base saturation levels within each fertilizer source, according to Tukey test ($p < 0.05$).

ORM-G fertilizer showed less ability to change soil pH (Fig. 2), when compared to WA and ORM. Probably, ORM-G has a delayed release of its components, due to the granulation process (Pesonen et al., 2017). Thus, even though the ORM-G contains WA in its organic fraction, the effects on soil acidity were gradual and slower when compared to the residue in its original state (WA).

Among the fertilizers used, MF was the one that provided the lowest pH values at all evaluated times. It is observed that mineral fertilizers do not have the ability to change the pH of the soil, requiring the use of limestone to correct the acidity of the soil before the application of mineral fertilizers. This was evident when a significant effect of base saturation levels was observed, with the 60% level providing the highest pH value of 5.53 at 30 DAE (Fig. 2).

Soil pH is considered one of the most important parameters in soil fertility, as it can influence the availability and absorption of nutrients, as well as the composition and activity of microbial communities in the soil. For most crops, the ideal pH for the availability of essential nutrients (P, K, Ca and Mg) is 5.5 to 6.5 (Sousa and Lobato, 2004), which is in agreement with the pH values of our soil modified by WA and ORM fertilizers (Fig. 2).

Shoot dry mass

The production of shoot dry mass of cowpea was influenced by the applied fertilizers (Fig. 3). For this variable, the levels of base saturation showed no significant influence, since the highest shoot dry mass (23 g/pot) was observed in the treatment without liming (0), in the ORM fertilizer. The WA fertilizer provided the second highest average of the shoot dry mass production (13 g/pot) and the absence of the liming effect was also observed in this treatment.

The results related to the effect of organic (WA) and organomineral (ORM) fertilizers on bean yield presented here are in agreement with those obtained by Smith et al. (2001) and Adeleke and Akinrinde (2011) who claim that an application of organic fertilizer and organic fertilizer with inorganics increases the production of dry bean mass. The results also corroborate those obtained by Bonfim-Silva et al. (2017) that, when evaluating the growth of bean plants, concluded that the dose of 24 g/dm^3 of WA provided a greater growth of shoots.

These results can be explained by the composition of WA, which has essential nutrients (Ca, Mg, P and K) (Table 2) for plant growth and development, in addition to containing elements capable of neutralizing soil acidity (Nnadi et al., 2019), as previously presented (Item: soil acidity) and also reduce aluminum toxicity.

With the correction of soil acidity, the nutrients present in the WA become available for absorption by the plant roots. Among the nutrients benefited, phosphorus stands out, which has a high rate of adsorption by acidic tropical soils, and which is present in WA in high concentrations (Table 2).

For the ORM-G, the lowest values of shoot dry mass production are observed when compared to WA and ORM (Fig. 3). This limited effect of ORM-G on the production of shoot dry mass may be due to the effect of fertilizer granulation, which may have delayed the release of nutrients to the plant

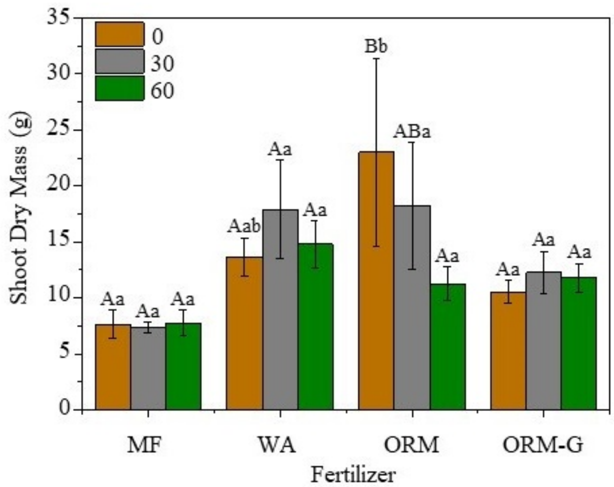

Figure 3. Shoot dry mass of cowpea fertilized with four types of fertilizers: mineral (MF), wood ash (WA), organomineral (ORM) and granulated organomineral (ORM-G); and three levels of base saturation: 60% (60) and 30% (30) of base saturation and control treatment without liming (0). Lowercase letters compare fertilizer sources within each base saturation level, uppercase letters compare base saturation levels within each fertilizer source, according to Tukey test ($p < 0.05$)

during the experiment. Similar results on the slow release of nutrients to the soil were reported by Wang et al. (2010) for short-term granulated wood ash. However, as these authors concluded, granulated ash is likely to have more pronounced positive effects over time and can be used for long-term nutrient compensation.

Grain dry mass and number of grains

For the number of cowpea grains, there was no significant effect of the treatments applied (Fig. 4 (A)). While there were significant effects on the dry grain mass produced by cowpea (Fig. 4 (B)). When analyzing the fertilizers, it is observed that the highest production of dry grain mass (14.5 g/pot) was obtained in the ORM, in the absence of liming (0). Followed by the WA treatment with a grain yield of 12 g/pot also in the treatment that did not receive liming.
These results allow us to guarantee a high capacity of soil neutralization with the use of wood ash and of supplying nutrients to the cowpea grains. Several authors point out that the elements are highly soluble, which facilitates their uptake and absorption by plant roots (Romdhane et al., 2021).
The ORM and WA fertilizers contributed to improve the production quality of the bean grains produced, since it was only observed the effect of the fertilizers on the weight of the grains and not on the number of grains (Fig. 4 (A)).
WA contains several macro and micronutrients in its composition, including zinc, which can contribute to improving the quality of cowpea grains (Almeida et al., 2020). A study carried out in the United Kingdom investigated zinc fertilization in cowpea and concluded that the use of zinc fertilizer significantly improved crop yield and cowpea grain quality (Manzeke et al., 2017).
Despite the addition of nutrients at the dose recommended by the region's fertilizer bulletin, MF fertilization showed low production rates when compared to WA, ORM and ORM-G fertilizers, even when the base saturation is increased to levels recommended for the cowpea crop. Despite possible small increases in productivity, fertilizer doses above the recommended dose are unfeasible, as they practically do not bring economic gains (Vieira et al., 2020).

Number and nodules dry mass

The number and nodules of dry mass showed a statistical difference for the levels of saturation by bases and fertilizers (Fig. 5). Analyzing the interaction levels of saturation by bases and fertilizers, it is observed that the highest production of nodules was observed in the use of WA and in the absence of liming. Soil liming had an inhibitory effect on nodulation, with lower numbers of nodules when base saturation was increased to 60% in WA (Fig. 5 (A)). Liming reduced cowpea nodulation by 70% when comparing the 0 to 60% base saturation level.

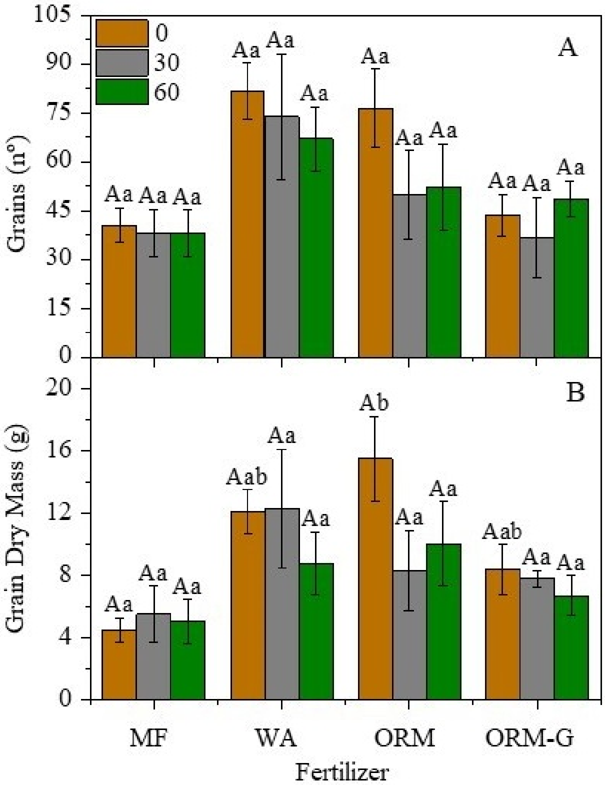

Figure 4. Number of grains (A) and grain dry mass (B) of cowpea fertilized with four types of fertilizers: mineral (MF), wood ash (WA), organomineral (ORM) and granulated organomineral (ORM-G); and three levels of base saturation: 60% (60) and 30% (30) of base saturation and control treatment without liming (0). Lowercase letters compare fertilizer sources within each base saturation level, uppercase letters compare base saturation levels within each fertilizer source, according to Tukey test ($p < 0.05$).

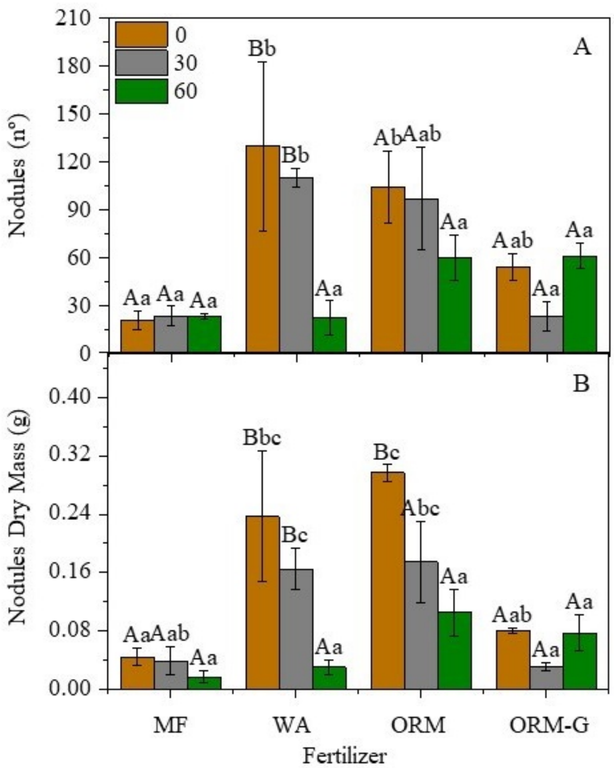

Figure 5. Number of nodules (A) and nodules dry mass (B) of cowpea fertilized with four types of fertilizers: mineral (MF), wood ash (WA), organomineral (ORM) and granulated organomineral (ORM-G); and three levels of base saturation: 60% (60) and 30% (30) of base saturation and control treatment without liming (0). Lowercase letters compare fertilizer sources within each base saturation level, uppercase letters compare base saturation levels within each fertilizer source, according to Tukey test ($p < 0.05$).

In the ORM, there was a significant difference in the number of nodules when the levels of base saturation were compared (Fig. 5 (A)). Similar to what occurred in WA, the highest nodulation was observed in the absence of soil liming, followed by 30% base saturation. ORM-G showed low nodulation when compared to WA and ORM fertilizers. The lowest numbers of nodules (23 nº/pot) were observed in the MF treatment.

The nodules' dry mass showed a similar tendency to the response of the number of nodules to the treatments (Fig. 5 (B)). Higher production of nodules dry mass of 0.23 and 0.30 g/pot, observed in the absence of liming in treatments WA and ORM, respectively. Even though inoculation was not carried out in the implantation of the experiment, the soil collected, in an area of native Cerrado, has native bacteria capable of nodulating and carrying out biological nitrogen fixation.

Soil chemical factors such as pH and nutrient concentrations can influence plant and rhizobia growth (Ferguson et al., 2013) and nodule establishment (Mendoza-Soto et al., 2015). Indeed, soil acidity alone is responsible for significant losses in global legume production, resulting from decreased nodule development and nitrogen fixation (Ferguson et al., 2013; Mendoza-Soto et al., 2015). What can be observed in the present study with low nodulation in treatments in which soil acidity was not corrected (Figs. 2, 5).

Under acidic soil conditions, there is an interruption in the signal exchange between the host plant and the nodulating bacteria. Reduction in plant flavonoid secretion decreases rhizobium Nod gene induction and restricts the excretion of NF and Nod metabolites (Phares et al., 2020). And this disruption affects subsequent nodulation processes, such as the attachment of rhizobia to root hairs and root colonization, leading to reduced nodule formation (Ferguson et al., 2013; Phares et al., 2020).

In soils with acidic pH, a reduction of more than 90% in the formation of nodules and a reduction of 50% in the nodules dry mass of species such as soybeans, beans and peas have been reported (Alva et al., 1990).

In addition, increasing soil pH favors greater availability of nutrients that influence the nodulation process, such as phosphorus and potassium, which are present in wood ash (Table 2 and Table 3). Phosphorus acts in the accumulation of energy by plants and is responsible for the transfer of adenosine triphosphate, so it is extremely important in biological nitrogen fixation (Phares et al., 2020). Soil pH has a great influence on phosphorus availability in tropical soils, pH value above 7 can reduce phosphorus availability due to precipitation of Ca phosphate and Mg phosphate (Job et al., 2022). In this way, the liming performed in our study caused the soil pH to rise to 6.5 in WA and ORM, which is the pH that maximizes the availability of P in the soil (Brady and Weil, 1999). This is very important, as the reduction of P can impair the nodulation and nitrogen fixation of the common bean.

Potassium is another very important element in the bean nodulation process, since it is an enzymatic activator, acting in several processes in the plant metabolism, including the supply of photosynthates from the plant to the nitrifying bacteria, directly affecting the development of rhizobia (Taiz et al., 2021). Duke and Collins (1985) found that nitrogen fixation increased with the addition of potassium and this effect could be attributed to increased nodulation, nodule productivity or both.

4. Conclusion

Wood ash application reduced soil acidity and increased production and nodulation of cowpea grown in naturally acidic soil. When organomineral fertilizer with wood ash is used, liming is unnecessary. The transformation of wood ash by combining it with mineral fertilizers into an organomineral fertilizer product proved to be a promising step in converting a solid waste into a commercially viable agricultural fertilizer. Regarding organomineral fertilizers (organomineral and granulated organomineral), studies are still necessary to evaluate the release of nutrients over a longer period.

Authors contributions
The authors confirm the study conception and design: Edna Maria Bonfim-Silva, Tonny José Araújo da Silva, Rackel Danielly de Souza Alves; data collection: Rackel Danielly de Souza Alves; analysis and interpretation of results: Rackel Danielly de Souza Alves, Edna Maria Bonfim-Silva, Jakeline Rosa de Oliveira, Luana Aparecida Menegaz Meneghetti; draft manuscript preparation: Jakeline Rosa de Oliveira, Jholian Maicon Ribeiro-Santos, Luana Aparecida Menegaz Meneghetti. The results were evaluated by all authors, and the final version of the manuscript was approved.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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