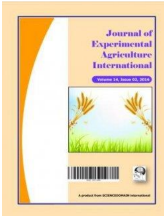

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Agronomic Efficiency of Bone Meal under Acidification in *Brachiaria ruziziensis* Dry Matter Production in Western Amazon

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Authors' contributions

This work was carried out in collaboration with all authors. Author JBDD led the experiment, through writing and statistical analysis. Author EF designed the conditions of the study and produced the bone meal. Authors CAS and JKDM offered technical support and assistance to the realization of the experiment. Authors RTG and ACNL accomplished the linguistic adequacy. Authors NPSF and CAFT carried out the final revision and support of the work. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this work was to evaluate the agronomic efficiency of the bone meal under acidification in the production of dry matter of *Brachiaria ruziziensis* in relation to a soluble source.

Study Design: The experiment was conducted in a completely randomized design with seven treatments and three replications. Treatments included a control, single superphosphate (SS), bone meal (BM), BM treated with 10% oxalic acid, BM treated with 10% acetic acid, and BM treated with 1% to 0.5% hydrochloric acid.

Place and Duration of Study: The experiment was carried out from October 2014 to February 2015, at the Experimental Farm of the Federal University of Rondônia (UNIR), located 15 km from the city of Rolim de Moura, Rondônia, Brazil.

Methodology: The bone meal used in the experiment was produced manually, where bovine bones were collected and burned for carbon removal and particle reduction. The oxalic acid, acetic acid and hydrochloric acid were used to increase the solubility of the bone meal for application to the soil for growth of *B. ruziziensis*. Parameters evaluated were the agronomic efficiency index (AEI), phosphorus conversion efficiency (PCE), shoot dry matter (SDM), and root dry matter (RDM).

Results: AEI obtained for acid treatments was above 60% and PCE satisfactory when compared to the soluble source, except for 0.5% hydrochloric acid and significantly above the BM without acid treatments. There was higher production of SDM and RDM with the soluble source (SS), however the acid treatments promoted dry matter production above the BM without acid treatments.

Conclusions: The application of acids in bone meal promoted satisfactory agronomic efficiency gains for *Brachiaria ruziziensis*.

Keywords: Phosphorus; forage; exploitation.

1. INTRODUCTION

Brazil is the second largest producer of beef in the world, behind only the United States, and according to the Brazilian Institute of Geography and Statistics [1], the herd surpasses 218 million heads. Approximately, 80% of the Brazilian herd is extensively raised under planted / natural pastures, since it is the most economical method of cattle feeding to cattle ranchers [2]. Of the fodder used for this purpose, those of the genus *Brachiaria* correspond to 70 - 80% of the area planted in Brazil. The *Brachiaria ruziziensis* is one of the most planted because of its high palatability, grazing support, and high dry matter production (6 to 15 t ha^{-1}) [3].

It is estimated, however, that about 70 to 80% of the pastures used for this purpose are degraded or in the process of degradation [4]. According to Dias-Filho [2], the main causes of this degradation are focused on the adopted management, such as fire use, low quality seeds, high stocking rates, and absence of fertilization. Among these, the absence and inefficiency of fertilization has been noted as a more aggravating factor of pasture degradation in Brazil [5,6]. As soil fertility decreases, there is a marked productive loss of fodder and, consequently, decrease in animal production [3].

When considering the Amazon region, the problem tends to be more pronounced, considering the prevailing most acidic soil characteristics, low cation exchange capacity, high aluminum saturation, and low nutrient reserves, mainly in phosphorus (P) (between 1 and 3 g dm^{-3}) [2]. Therefore, it is suggested that fertilization with this nutrient should be carried out in order to guarantee its adequate supply.

Phosphorus maintenance for pasture production has been performed with the use of liming and the use of soluble phosphorus sources, such as single superphosphate and triple superphosphate [7]. Although widely used, they come from the exploration of phosphate rocks, whose reserves are estimated to deplete in up to 100 years [8,9]. In this sense, it is necessary the study of new sources of phosphorus in order to guarantee the supply of this element [10,6].

Recently, studies by several authors have shown that the use of solid animal waste processed, bone meal (BM), have been pointed as potential source of phosphorus and calcium for plants [11,12]. Under heat action, bones can also supply magnesium, potassium and iron from the blood [13]. However, due to the chemical nature of the bones (hydroxyapatite), BM has low solubility of phosphorus in water (0.26% of P_2O_5) despite its high concentration, between 30.6 and 38.8% P_2O_5 [14]. However, it is necessary to study acidifying agents capable of readily releasing the available phosphorus in the bones, as tested for 2% citric acid, which provided 23% solubility to bone meal [15].

Thus, the objective of this study was to evaluate the agronomic efficiency of the bone meal under acidification in the production of dry matter of *Brachiaria ruziziensis* in relation to a soluble source.

2. MATERIALS AND METHODS

The experiment was conducted at the Experimental Sector of Agronomy of the Federal University of Rondônia - UNIR, Campus Rolim de Moura, RO - Brazil, located 11º 34'58.60" S and 61º46'22.30" W at an altitude of 277 m. The climate of the region, according to the classification of Koppen, is Aw type, with defined dry season, mean temperature of 28°C, mean annual precipitation of 2,250 mm, and relative humidity of 85% [16].

The study was conducted in open-air pots of 3.9 kg in a completely randomized design, with seven treatments and three replicates (Table 1).

The conduction of the open-air experiment aimed to study the effect of various treatments on plants under natural conditions (different from greenhouse conditions). As a source of phosphate fertilization, bone meal (37.5% P_2O_5) and simple superphosphate (18% P_2O_5) were used. For each source, the equivalent of 100 kg ha^{-1} of P_2O_5 was used, depending on the concentration of each source. For the evaluations under equal conditions, both P sources were subjected to grinding and sieving with 2.00 mm-mesh.

As substrate for the plants, the arable layer (0-20 cm) of the experimental area classified as Eutrophic Yellow Red Oxisol [17] was used, with the following chemical and physical characteristics: pH in water = 5.4; Organic matter = 3 dag kg^{-1}; P = 3.7 mg dm^{-3}; K = 102 mg dm^{-3}; S-SO^{-2} = 3.6 mg dm^{-3}, Ca = 4.1 $cmol_c$ dm^{-3}; Mg: 1.4 $cmol_c$ dm^{-3}; Fe = 88 mg dm^{-3}; Cu = 1.8 mg dm^{-3}; Zn = 1.5 mg dm^{-3}; Mn = 25 mg dm^{-3}; B = 0.14 mg dm^{-3}, Potential acidity = 4.8 $cmol_c$ dm^{-3}; Al = 0.12 $cmol_c$ dm^{-3}; Sum of bases = 5.7 $cmol_c$ dm^{-3}; Potential cation exchange capacity = 10.5 $cmol_c$ dm^{-3}; Bases saturation= 54%; Saturation by aluminum = 2%; Sand = 530 g kg^{-1}; Silt = 83 g kg^{-1} and Clay = 381 g kg^{-1}.

The bone meal was produced through burning for elimination of organic compounds and for maceration in smaller particles. For this, the bovine bones were arranged inside a masonry barbecue and accommodated in coin-type screens, using charcoal for the burning for approximately eight hours. After cooling for about 24 hours, the bones were ground with the use of gral and pistil and sieved in a 2.00 mm-mesh. The material was characterized in laboratory by the analysis of the contents of P and Ca, which were 37.5% P_2O_5 and 43.76% CaO.

As acid extractors of phosphorus, the oxalic acid, acetic acid and hydrochloric acids (PAs) were used. For oxalic and acetic acids, 10 ml of acid were diluted in 100 ml of distilled water. For hydrochloric acid's dilution, 1 and 0.5 ml were used for 100 ml of distilled water. The solutions were applied to 100 g of bone meal. Subsequently, the material was forced to air drying at 65°C for approximately 72 hours. The bone meal was homogenized to the soil and arranged in the experimental units (open-air pots of 3.9 kg).

The Brachiaria ruziziensis sprouts collected in the experimental area and standardized (12 cm in height and mean mass of 4.52 g) were used as indicator of the treatments. Three shoots of *B. ruziziensis* were planted in each experimental unit. In addition to the treatments, complementary fertilization with macro and micronutrients was applied as recommended for the forage by Costa et al. [3]. The water supply was performed by daily manual watering, applying 300 ml / pot / day. Cultural treatments were carried out regarding the manual removal of invasive plants from the soil seed bank.

Table 1. Treatments used in the experimentation

Treatments	Description	Symbol
1	Unmanaged control	Wit.
2	P (Simple superphosphate)	SS
3	P (Bone meal)	BM
4	(Bone meal + 10% oxalic acid)	Oxa $^{10\%}$
5	(Bone meal + 10% acetic acid)	Ace $^{10\%}$
6	(Bone meal + 1% hydrochloric acid)	HCl $^{1\%}$
7	(Bone meal + 0.5 % hydrochloric acid)	HCl $^{0,5\%}$

The plants were grown for 120 days, with shoot dry matter (SDM) at 60, 90 and 120 days. The forage was cut at 20 cm from the soil level and the SDM determined from drying in a forced circulation oven at 65ºC for approximately 72 hours. At the end of the periods the sum of the SDM produced in the three periods was calculated for the determination of the agronomic efficiency index (AEI) and phosphorus conversion efficiency (PCE).

The AEI was calculated from equation 1:

AEI (%) = [(Y2-Y1) / (Y3-Y1)] x 100 (Equation1)

where AEI = Agronomic efficiency index, Y1 = SDM obtained in the control, Y2 = SDM obtained with the treatments, Y3 = SDM obtained from the reference source (SS).

The PCE was calculated from equation 2:

PCE = (SDM Treatments – SDM Witness) / APA (Equation 2)

where PCE = Phosphorus conversion efficiency, SDM treatments = Dry matter of the Aerial Part Total obtained in each treatment, in mg; SDM control = Dry matter of the total aerial part obtained from the control; APA = Amount of phosphorus added.

The root dry matter (RDM) was obtained 120 days after treatments. For this, the roots were removed from the experimental units, washed and subjected to drying in forced circulation oven at 65ºC for approximately 72 hours. SDM and RDM were determined using a precision digital scale. Data obtained were subjected to an analysis of variance and the contrast of the means was realized by the test of Tukey using the statistical program ASSISTAT 7.7 was used.

3. RESULTS AND DISCUSSION

Total shoot dry matter (SDM) was significantly higher in the commercial soluble source (SS) of phosphorus (Table 1). However, acidification of bone meal (BM) with 10% acetic acid, 10% oxalic acid and 1% chloride promoted an increase of 224%, 231% and 249% in relation to treatment that did not receive acidification (BM). In relation to the control, the application of BM without acidification promoted increments of only 56.1%.

With the exception of the treatment with 0.5% hydrochloric acid, the other acid treatments promoted a significantly similar effect on the agronomic efficiency index (AEI), with the lowest AEI observed, confirming its natural phosphate characteristics. $Oxa_{10\%}$, $Ace_{10\%}$ and $HCl_{1\%}$ acidifying treatments promoted AEI on average 31% lower, taxing much lower by observing the AEI without acidification of BM Owing to the efficiency scale, it can be noted that the AEI decreased in the following order: SS> $HCl_{1\%}$ > $Ace_{10\%}$ > $Oxa_{10\%}$ > $HCl_{0.5\%}$ > BM (Table 2).

Phosphorus conversion efficiency (PCE) was significantly higher in the standard treatment (SS), however high PCE values were obtained with acid treatments, when compared to those that did not receive acidification (BM). Among the acid treatments, $HCl_{0.5\%}$ was the one with the lowest efficiency. The PCE showed the following order: SS > $HCl_{1\%}$ > $Ace_{10\%}$ > $Oxa_{10\%}$ > $HCl_{0.5\%}$ > BM (Table 2).

Table 2. Values of shoot dry matter (SDM) of *Brachiaria ruziziensis*, agronomic efficiency index (AEI) and phosphorus conversion efficiency (PCE) of bone meal (BM) under acidification

Treatments	SDM (g)	AEI (%)	PCE ($mg\ mg^{-1}$)
Witness	4,1 d	----	----
SS	23,1 a	100 a	223,13 a
BM	7,3 cd	16,84 d	37,58 c
BM+ Oxa $^{10\%}$	16,4 abc	64,73 b	144,45 abc
BM+ Ace $^{10\%}$	16,9 ab	67,36 b	150,32 abc
BM+ HCl $^{1\%}$	18,1 ab	73,68 b	164,41 ab
BM+ HCl $^{0,5\%}$	10,3 bcd	32,63 c	72,81 bc
C.V	8,28	7,03	23,09
F	182,7	166, 8	7,50
p	0,001	0,001	0,002

C.V: Coefficient of variation; BM: Bone meal; SS: Simple superphosphate; Oxa10%: Bone meal + 10% oxalic acid; Ace10%: Bone meal + 10% acetic acid; HCl1%: Bone meal + 1% hydrochloric acid; HCl 0,5%: Bone meal + 0.5 % hydrochloric acid

Due to the high solubility of simple superphosphate (SS) in water [18], shoot dry matter production (SDM) was substantially higher, given the high availability of phosphorus (P) in solution. The same behavior was observed by Simões et al. [19] when using SS compared to bone meal (BM) in Tifton grass. However, these same authors observed satisfactory results with BM.

In a study using bone meal and meat, Oliveira et al. [20] observed SDM of Tifton grass varying between 65 and 93% in relation to fertilization with SS, a fact not observed in this work, where the application of the alternative source of P resulted in about 30% and the extraction of the acids between 70.9 and 78%. In general terms, the production of dry matter with natural phosphate sources depends on the forage species and the BM production method.

The low natural solubility of BM may compromise the short-term response of annual crops, such as *B. ruziziensis*, and is not fully indicated for efficient production of SDM, especially in soils with pH above 5.0, where the reactions with phosphate naturally occur slowly and progressively [15].

Agronomic efficiency index data differ from those obtained in the studies by Balbino et al. [15] and Farias et al. [21], which showed high BM efficiencies when compared to the control (soluble phosphate) treatment. Compared with Arad phosphate and triple superphosphate, Balbino et al. [15] obtained an increase in the availability of P in the soil and in the production of sugarcane with the use of BM. However, in the present study low AEI was observed using this source of P.

The low efficiency index can be related to the pH considered high in the application of bone meal on the substrate, preventing the transformation of the bound Ca + P compounds from BM to available soil phosphorus [14]. Also, according to Damaceno et al. [6], raising the pH can reduce BM efficiency and increase SS efficiency.

Like the soluble sources that undergo acidic attacks in reaction with water, like 2% citric acid on triple superphosphate, the action of the acidic extractors was pronounced in this work. With the exception of 0.5% hydrochloric acid, the other extractors showed AEI above 60%, considered high by Silva et al. [22] when compared to the standard source, evidencing its potential use in increasing the solubility of natural phosphate. These same authors, when studying the dry matter production of pigeon pea (*Cajanus cajan*), obtained similar responses between the use of natural phosphate and triple superphosphate.

Due to the high availability of phosphorus from the soluble source (SS), high phosphorus conversion efficiency (PCE) was obtained, a result also observed by Zambrosi et al. [23], which obtained a superiority of 31% of the same source in relation to the use of a natural phosphate (thermophosphate) in millet. However, the application of the acids resulted in satisfactory phosphorus efficiencies in dry matter, when observing the behavior without its presence. The PCE is directly correlated with the capacity of the phosphate source to release the nutrient in the soil solution [23,6]. Therefore, the low capacity observed by the bone meal compromised the use of the nutrient by the forage.

Another fact intrinsic to PCE is the extent and efficiency of root system absorption, which responds to the available P in the soil. The distinction in the morphology and root physiology modifies the uptake of P and other nutrients, compromising PCE [23]. The difference mentioned can be observed in the distribution of roots of *B. ruziziensis* according to the phosphate source and the acid treatment used (Fig. 1).

According to Singh et al. [24], the increase in P availability in the soil allows root growth in depth and the emergence of lateral roots in grasses, such as *B. ruziziensis*. Therefore, when the opposite scenario is found, the result responds in the same way, as shown for root dry matter (RDM). The observed similarity between the control and the BM evidenced the low supply of available phosphorus, resulting in poor root architecture (Fig. 1). All acidic treatments provided an increase in weight and volume and in the presence of *B. ruziziensis* root hairs, both related to the increased availability of phosphorus for plants.

Observing the behavior of the root, aerial part, the acidification of BM provided a balance between what was produced in the aerial part and in the roots. This fact was reported by Taiz and Zeiger [25], arguing that values close to one represent balance between the photosynthetic rate benefited by adequate nutrition and root expansion promoted by the presence of nutrients in the soil.

Fig. 1. Root system of *B. ruziziensis* according to the treatments applied

4. CONCLUSION

The shoot dry matter and root dry matter from *B. ruziziensis* were positively influenced by bone meal treated with acids. Other than acidification with $HCl_{0.5\%}$, the other treatments provided AEIs above 60%. Acid treatments provided higher PCEs in the absence of acidification. It is recommended to use acid extractors to increase the availability of phosphorus from bone meal, which is an alternative to the shortage of fortified mineral sources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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