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Cowpea, corn, and soybean yield using fertilizer based on the bone meal in the Eastern Amazon

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ABSTRACT: The objective of this study was to evaluate the efficiency of granulated formulations, made using calcined bone meal as a phosphorus source, on cowpea, soybean, and corn in the Amapá State, Eastern Brazilian Amazon. In the greenhouse, the treatments consisted of two soils with different clay contents (231 and 376 g kg^{-1}), three granulated NPK formulations (08-20-10, 02-20-10, and 01-20-00 prepared with bovine bone meal, monoammonium phosphate, ammonium sulfate, urea, and potassium chloride and phosphorite), and three crop successions (cowpea/corn/soybean, soybean/cowpea/corn, and corn/soybean/cowpea). In the field, treatments consisted of four levels of NPK 08-20-10 for corn and NPK 02-20-10 for soybean, in a Cerrado, and NPK 02-20-10 for cowpea, in both Cerrado and upland forest environments. NPK formulations fertilizer promotes greater soybean, cowpea, and corn shoot dry weight in the sandy loam compared to sandy clay soil. NPK promotes greater cowpea grain yield in the Cerrado than in the upland forest environment. The grain yield of the cowpea cultivar BRS Tumucumaque and corn BRS 206 responds linearly to the increase in fertilization with NPK formulations. The increasing levels of NPK formulation made with calcined bone meal do not affect soybean BRS Tracajá grain yield in the Cerrado environment.

Key words: agroindustrial residue; organomineral fertilizer; phosphorus fertilization

Produtividade de feijão-caupi, milho e soja utilizando formulações granuladas à base de farinha de ossos na Amazônia Oriental

RESUMO: O objetivo deste trabalho foi avaliar a eficiência de formulações granuladas, produzidas com farinha de osso calcinada como fonte de fósforo, em feijão-caupi, soja e milho. Em casa de vegetação, os tratamentos consistiram em dois solos com diferentes teores de argila (231 e 376 g kg^{-1}), três formulações NPK (08-20-10, 02-20-10 e 01-20-00 preparadas com farinha de osso bovino, fosfato monoamônico, sulfato de amônio, ureia e cloreto de potássio e fosforita) e três sucessões de culturas (feijão-caupi/milho/soja, soja/feijão-caupi/milho e milho/soja/feijão-caupi). No campo, os tratamentos consistiram em quatro níveis de NPK 08-20-10 para milho, e NPK 02-20-10 para soja, em cerrado, e de NPK 02-20-10 para feijão-caupi, em ambiente de cerrado e floresta de terra firme. A adubação com as formulações NPK promove maior massa seca da parte aérea da soja, feijão-caupi e milho no solo franco-argiloarenoso do que em solo argiloarenoso e maior produtividade de grãos de feijão-caupi em ambiente de cerrado do que em floresta de terra firme. A produtividade de grãos do feijão-caupi BRS Tumucumaque e do milho BRS 206 responde linearmente ao aumento da adubação com as formulações. O aumento da dose de adubação não afeta a produtividade de grãos da soja BRS Tracajá em ambiente de cerrado.

Palavras-chave: resíduos agroindustriais; fertilizante organomineral; adubação fosfatada

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Introduction

The increase in the productivity of Brazilian agriculture is directly related to the increase in the adoption of fertilizers by farmers and has provided an increase in the efficiency of land use (save land) in recent decades. Curiously, only 14% (728,542) of Brazilian agricultural establishments use some type of soil pH corrective, and only 42% (2,144,693) use fertilizers in their crops (chemical and/or organic) (IBGE, 2022a). Additionally, the lack of fertilizer application is identified as an important cause of the low productivity of Brazilian pastures (Strassburg et al., 2014). Nowadays, increases in productivity and reduction in the use of areas by agriculture through the expansion of use of correctives and fertilizers can be achieved in Brazil.

In 2020, Brazilian fertilizer production was 6.3 million tons, and 584 thousand tons of fertilizers and NPK formulations were exported (ANDA, 2022), and imports of fertilizers reached 38.3 million tons in 2021 (CONAB, 2021). The expansion of the use of fertilizers in Brazilian agriculture has occurred through the increase, 52% between the years 2017 and 2021, of imports. Considering that at the end of 2021 a ton of fertilizer cost approximately US$ 400.00 (CONAB, 2021), there was an investment of US$ 15.4 billion in fertilizer imports. In this context, fertilizers produced with locally available raw materials have been developed (Corrêa et al., 2018) to reduce dependence on imports, the deficit in Brazilian trade balance, as well as contribute to the development model based on a circular economy (Smol, 2019). Cowpea and cassava are the most important crops for small farms in the Brazilian Amazon. In the Amapá state besides cowpea and cassava, corn and soybean become very important in the last decade in the function of the Cerrado environment occupation by farmers who came from other regions of Brazil. The soybean planted area reached 21,250 ha in 2018 (IBGE, 2022a) and fertilizer demands are increasing.

The Brazilian cattle bovine and buffalo, in the last ten years (2009-2019) varied between 205 and 215 million heads. The average number of cattle slaughtered per quarter is 7.2 million (IBGE, 2022b), generating waste such as manure, blood, meat, hoof, horn, and bones, in high amounts throughout the national territory. Residues from livestock activities have been successfully used to produce fertilizers (Sá et al., 2017; Silvasy et al., 2021). Hoof and horn meal and bovine bone meal were effective as a source of phosphorus to promote the development and production of tomato and arugula (Cavallaro Júnior et al., 2009).

The most representative soil type in the Brazilian Amazon is Latossolo (Oxisol), with a high rate of weathering. Oxisol adsorbs most of the phosphorus applied as fertilizer forming highly stable complexes, reducing its availability to the plants (Silva et al., 2010), while most of the nitrogen applied as fertilizer is lost by leaching, due to the low energy linkage between nitrogen inorganic forms and soil colloids, both affecting plant growth and yield. The observance of the best land suitability, the management of soil organic matter, and the selection of applied phosphorus sources to the crops (organic, inorganic, phosphorus content, and solubility) contribute to increased availability and efficiency of phosphorus use, to the increased in grain yield, affect the leaching of forms of nitrogen in the soil (Grohskopf et al., 2020), and the rates of biological nitrogen fixation in the legumes, which may, in this case, contribute to the reduction of demand for nitrogen fertilizers (Borges et al., 2021). Then, the objective of this study was to evaluate the efficiency of granulated NPK formulations, produced using calcined bone meal as a phosphorus source, on both the growth and grain yield of cowpea, soybean, and corn in the Brazilian Eastern Amazon edaphoclimatic conditions.

Materials and Methods

The NPK formulations were produced in the Laboratory of Fertilizer Technologies of Embrapa Solos in Rio de Janeiro, Rio de Janeiro State, Brazil. The raw materials selected for the elaboration of the formulations were the bovine bone meal, urea, ammonium sulfate, monoammonium phosphate (MAP), phosphorite, and potassium chloride (KCl). The bovine bone meal used had 14.2% of P_2O_5 total and 7.03% of P_2O_5 soluble in citric acid. The raw materials were homogenized and placed in an inclined plate granulator with constant rotation and application of silicate solution over the mixture. The granules were sieved in 4.0 and 2.0 mm sieves and dried at 50 °C. After drying, the granules were sieved again in 4.0 and 1.0 mm sieves.

A three-crop greenhouse experiment was carried out in 2018, in the Fazendinha experimental area (0° 01' 01.51" S, 51° 06' 35.18" W) at Embrapa Amapá in Macapá, Amapá State, Brazil. The experiment design was a 3 × 3 × 2 factorial in randomized blocks with four replicates. The experimental plots consisted of pots with 5.0 dm^3 of soil. The treatments consisted of three NPK formulations, three crop successions, and two soils with different clay contents. It was evaluated the formulations NPK 08-20-10 and 02-20-10 (bovine bone meal, MAP, ammonium sulfate, urea, and KCl) and 01-20-00 (bovine bone meal and phosphorite) and the cowpea/corn/soybean, soybean/cowpea/corn, and corn/soybean/cowpea crop successions. Soils used were collected in Cerrado (Cerrado environment, 0° 23' 44" N and 51° 03' 31 W) and Mazagão (upland forest environment, 0° 07' 19.2" S and 51° 17' 57.4" W) experimental areas, located in the Macapá and Mazagão municipalities, respectively, and the soils in experimental areas are Latossolo Amarelo, according to the Brazilian soil classification system (Santos et al., 2018), i.e., an Oxisol. The soils used had the following characteristics at 0-20 cm depth: Cerrado pH = 5.5, OM = 14.3 g kg^{-1}, P available extracted by Mehlich 1 = 7.0 mg dm^{-3}, K^+ = 0.12 $cmol_c$ dm^{-3}, Ca^{+2} + Mg^{+2} = 1.7 $cmol_c$ dm^{-3}, Al^{+3} = 0 $cmol_c$ dm^{-3}, H^+ + Al^{+3} = 2 $cmol_c$ dm^{-3}, CEC = 3.8 $cmol_c$ dm^{-3}, texture sandy loam, sand = 665 g kg^{-1}, silt = 104 g kg^{-1}, and clay = 231 g kg^{-1}, and Mazagão pH = 4.4, OM = 23.8 g kg^{-1}, P available extracted by Mehlich 1 = 7 mg dm^{-3}, K^+ = 0.14 $cmol_c$ dm^{-3}, Ca^{+2} + Mg^{+2} = 0.7 $cmol_c$ dm^{-3}, Al^{+3} = 1.3 $cmol_c$ dm^{-3}, H + Al = 6.3 $cmol_c$ dm^{-3}, CEC = 7.1 $cmol_c$ dm^{-3}, texture sandy clay, sand = 485 g kg^{-1}, silt = 139 g kg^{-1}, and clay = 376 g kg^{-1}.

Five seeds per pot of the cowpea (*Vigna unguiculata*) BRS Tumucumaque, soybean (*Glycine max*) BRS Tracajá, and corn (*Zea mays*) BRS 206 cultivars were sown, and thinning was performed keeping two plants per pot. All pots received in each sowing the equivalent of 80 kg ha^{-1} of P_2O_5, 40 kg ha^{-1} of K_2O, and 32 kg ha^{-1} of N for cowpea and soybean, and 80 kg ha^{-1} of P_2O_5, 40 kg ha^{-1} of K_2O, and 50 kg ha^{-1} of N for corn. The amounts of N and K_2O were balanced among the three formulations using urea (44% N) and potassium chloride (60% K_2O). Cowpea plants were harvested at 43 DAS and soybean and corn at 55 DAS, at flowering. Shoots were oven-dried at 65 °C and weighed. The corn shoots were ground from which the P and K^+ contents were determined. In the end, soil samples were collected for analysis of the remaining P and K^+.

Four further field experiments were carried out in 2018, three in a Cerrado environment, (0° 23' 44" N and 51° 03' 31 W, Macapá, AP, Brazil), and the other in an upland forest environment (0° 07' 19.2" S and 51° 17' 57.4" W, Mazagão, AP, Brazil), to evaluate cowpea, soybean, and corn, responses to the NPK formulations levels. In the Cerrado environment according to the Köppen-Geiger classification, the climate is of the Ami type, with an average annual temperature of 26.3 °C and an average annual rainfall of 2,475 mm. In the upland forest environment according to the Köppen-Geiger classification, the climate is of the Am type, with an average annual temperature of 27.3 °C and an average annual rainfall of 2,410 mm.

Two well-defined climatic seasons are observed in both areas, the first, between December and July, is characterized as rainy (winter), where 90% of annual precipitation occurs and the second, between August and November, is characterized as drought (summer), where 10% of annual precipitation occurs, associated with high temperature and low relative humidity (Tavares, 2014). The sowing was carried out in the periods indicated as low climate risk, corresponding to the 15th and 16th tenths of year to the cowpea and 12th tenths of year to the soybean and corn.

The soils and the cultivars used were the same as used in the greenhouse experiment. A randomized block design with four replicates was adopted. The treatments consisted of four NPK formulations levels: 0, 200, 400, and 600 kg ha^{-1} of the 02-20-10 formulation for cowpea and soybean, and 0, 250, 500, and 750 kg ha^{-1} of the 08-20-10 formulation for corn. Was used plot with 2 × 3 m contained four 3.0 m lines, spaced at 0.5 m, with seven cowpea seeds per meter, plot with 2 × 2 m contained four 2.0 m lines, spaced at 0.5 m, with ten soybean seeds per meter, and plot with 4 × 3 m contained four 3.0 m lines, spaced at 1.0 m, with seven corn seeds per meter. At maturity, 60 DAS for the cowpea, and 120 DAS for the soybean and corn, grains were weighed to determine grain yield from the 2.0, 1.0, and 4.0 m^2 central of each plot, respectively.

Analysis of variance (ANOVA) was used and when confirming a statistically significant value in F test ($p \leq 0.05$) Tukey tests at 5% probability level were used to compare differences among NPK formulations, crop successions, and soils on shoot dry weight, P and K^+ shoot accumulation, and P and K^+ soil levels. Regression analysis was used to evaluate the effect of applied NPK formulations levels on grain yield. All statistical analyses were conducted using the software Sisvar (Ferreira, 2019).

Results and Discussion

There was a statistically significant effect of the interaction among crop succession, soil, and NPK formulation on the cowpea shoot dry weight (SDW) and a significant effect of three factors on soybean SDW. It was observed a greater cowpea SDW when cultivated in sandy loam soil with the NPK 08-20-10 than 01-20-00 NPK formulation for the cowpea-corn-soybean and corn-soybean-cowpea crop successions (Table 1). In sandy clay soil, there was not statistically difference among formulations, except for the soybean-cowpea-corn crop succession where the NPK 02-20-10 was superior to the NPK 01-20-00 formulation. For soybean SDW, no significant difference was observed among the formulations when cultivated in sandy clay soil. On the other hand, when cultivated in sandy loam soil, it was observed that the NPK 08-20-10 formulation was superior to the NPK 01-20-00 formulation, and the 02-20-10 and 01-20-00 formulations, in the soybean-cowpea-corn and corn-soybean-cowpea crop successions, respectively.

There was an effect of the interaction among crop succession, soil, and NPK formulation on the corn SDW, a significant effect of the crop successions, and the NPK formulations on the P accumulation, and the crop successions on the K^+ accumulation in the corn shoot. There was no

Table 1. Shoot dry mass (SDW – g per pot) of cowpea (*Vigna unguiculata*) BRS Tumucumaque and soybean (*Glycine max*) BRS Tracajá cultivars, grown in a greenhouse, as a function of NPK formulation (08-20-10, 02-20-10, and 01-20-00), made with bone meal, soil type (sandy loam, 231 g kg^{-1} of clay and sandy clay, 376 g kg^{-1} of clay) and crop succession (cowpea-corn-soybean, soybean-cowpea-corn, and corn-soybean-cowpea).

NPK formulation	Cowpea (g per pot)		Soybean (g per pot)	
	Sandy loam	Sandy clay	Sandy loam	Sandy clay
	Cowpea-corn-soybean			
08-20-10	9.53 a	6.43 a	5.68 a	2.38 a
02-20-10	9.18 a	6.03 a	4.78 a	1.78 a
01-20-00	6.10 b	4.65 a	4.60 a	0.93 a
	Soybean-cowpea-corn			
08-20-10	6.80 a	4.70 ab	8.75 a	5.48 a
02-20-10	4.58 b	5.68 a	8.38 ab	5.38 a
01-20-00	7.15 a	3.20 b	6.58 b	3.50 a
	Corn-soybean-cowpea			
08-20-10	7.53 a	5.33 a	8.38 a	4.98 a
02-20-10	5.68 ab	5.15 a	5.63 b	3.73 a
01-20-00	4.98 b	3.65 a	6.05 b	3.08 a

The coefficient of variation was 21.67% for the cowpea and 25.02% for the soybean. For each soil type and crop succession, means followed by the same letter within a column did not differ by Tukey test at 5% level.

significant difference for SDW and shoot P accumulation of corn when grown in sandy clay soil among the NPK formulations, except for shoot P accumulation in the corn-soybean-cowpea crop succession (Table 2). In the sandy loam soil, the NPK 08-20-10 formulation was superior to 02-20-10 and 01-20-00 formulations in cowpea-corn-soybean and corn-soybean-cowpea crop successions, and superior to both in the succession soybean-cowpea-corn for SDW, and the NPK 01-20-00 formulation promoted less shoot P accumulation than 08-20-10 and 02-20-10 formulations.

Many studies showed that weathered clayey soils adsorb most of the P applied as fertilizer, reducing its availability to plants, and consequently affecting growth and yield. Considering the average across the different crop succession and NPK formulations, a higher SDW of cowpea, soybean, and corn was observed when cultivated in sandy loam soil with lower clay content from the Cerrado environment. The soil from the upland forest environment evaluated had a higher content of clay, Al^{3+}, and SOM than the Cerrado soil. Sá et al. (2017) evaluated the agronomic and P recovery efficiency in sandy loam (100 g kg^{-1} clay) and clay loam texture soil (380 g kg^{-1} clay). The authors noted that in the first crop, the organomineral phosphate fertilizer (OPF) provided greater dry matter accumulation in corn plants than MAP, in the two analyzed soils, no effect significantly in the second and fourth cultivations, and a significant increased SDW yield in the sandy loam soil compared to clay loam soil in the third crop.

The decreasing sequence of SDW as a function of NPK formulations was 08-20-10 > 02-20-10 > 01-20-00 for cowpea, soybean, and corn, and 02-20-10>08-20-10>01-20-00 for P and 02-20-00 > 01-20-00 > 08-20-00 for K^+ accumulation in the corn shoot, in the present study. It is worth mentioning that the nitrogen and potassium rates were balanced among the three formulations using KCl and urea. The results show greater efficiency in the use of formulations containing NPK made with the calcined bone meal when compared with supplementation using KCl and urea for shoot dry mass and P accumulation. KCl supplementation provided greater K^+ accumulation in the shoots, but in a luxury consumption condition, not reverting to SDW. The grain of triticale and wheat and the green matter of maize contained higher phosphorus concentrations after the meat and bone meal application, in comparison to the plants receiving mineral fertilization (Nogalska & Zalewska, 2013).

There was a significant effect of the formulations and the soil on the P content and the three factors on the K^+ content remaining (Table 3). There was no significant difference

Table 3. Contents of P and K^+ in the soil after harvest of cowpea, corn, and soybean, grown in a greenhouse, as a function of NPK formulation (08-20-10, 02-20-10, and 01-20-00), made with bone meal, soil type (sandy loam, 231 g kg^{-1} of clay and sandy clay, 376 g kg^{-1} of clay) and crop succession (cowpea-corn-soybean, soybean-cowpea-corn, and corn-soybean-cowpea).

NPK formulation	Sandy loam	Sandy clay	Sandy loam	Sandy clay
	P (mg dm^{-3})		K^+ ($cmol_c$ dm^{-3})	
	Cowpea-corn-soybean			
08-20-10	20.75 b	17.50 a	0.0525 a	0.0625 a
02-20-10	28.25 ab	17.50 a	0.0550 a	0.0625 a
01-20-00	42.25 a	14.50 a	0.0725 a	0.0800 a
	Soybean-cowpea-corn			
08-20-10	25.75 a	15.25 a	0.0425 a	0.060 a
02-20-10	30.00 a	16.25 a	0.0425 a	0.045 a
01-20-00	37.75 a	30.25 a	0.0600 a	0.055 a
	Corn-soybean-cowpea			
08-20-10	10.75 b	18.00 a	0.0350 b	0.07 a
02-20-10	29.50 a	22.75 a	0.0625 a	0.07 a
01-20-00	21.50 ab	18.00 a	0.0625 a	0.08 a
	Crop successions average			
08-20-10	19.08 b	16.92 a	0.043 b	0.064 a
02-20-10	29.25 a	18.83 a	0.053 ab	0.061 a
01-20-00	33.83 a	20.92 a	0.065 a	0.072 a

The coefficient of variation was 43.61% for the P and 24.37% for the K^+. For each soil type and crop succession, means followed by the same letter within a column did not differ by Tukey test at 5% level.

Table 2. Shoot dry mass (SDW – g per pot), and P and K^+ shoot accumulation (mg per pot) of corn (*Zea mays*) BRS 206 cultivar grown in a greenhouse, as a function of the NPK formulation (08-20-10, 02-20-10, and 01-20-00), made with bone meal, soil type (sandy loam, 231 g kg^{-1} of clay and sandy clay, 376 g kg^{-1} of clay) and crop succession (cowpea-corn-soybean, soybean-cowpea-corn, and corn-soybean-cowpea).

NPK formulation	Cowpea-corn-soybean		Soybean-cowpea-corn		Corn-soybean-cowpea	
	Sandy loam	Sandy clay	Sandy loam	Sandy clay	Sandy loam	Sandy clay
			SDM (g per pot)			
08-20-10	16.68 a	12.13 a	18.05 a	12.60 a	15.55 a	14.38 a
02-20-10	13.28 b	11.93 a	14.15 b	12.28 a	15.78 a	13.10 a
01-20-00	13.68 ab	9.75 a	13.03 b	14.98 a	11.98 b	11.90 a
			P (mg per pot)			
08-20-10	21.04 a	18.19 a	27.14 a	22.05 a	17.61 a	19.37 a
02-20-10	21.90 a	18.25 a	26.72 a	20.44 a	17.34 a	21.25 a
01-20-00	14.13 b	15.21 a	16.57 b	18.92 a	10.42 b	11.56 b
			K (mg per pot)			
08-20-10	180.34 a	137.63 a	153.45 a	114.93 b	237.18 a	230.14 a
02-20-10	147.74 a	128.95 a	186.36 a	199.23 a	265.66 a	232.52 a
01-20-00	162.62 a	130.70 a	174.13 a	213.77 a	226.45 a	236.39 a

The coefficient of variation was 14.59% to the SDM, 15.50% to the P, and 25.89% to the K^+. For each soil type and crop succession, means followed by the same letter within a column did not differ by the Tukey test at 5% level.

among the formulations for the P and K^+ content in the sandy loam soil, and in the sandy clay soil, the P and K^+ content were higher when the formulations 02-20-10 and 01-20-00 were used compared to the 08-20-10 formulation. The NPK formulations application prepared with bone meal promoted an increase in soil P content, as observed by Nogalska & Zalewska (2013) to the meat and bone meal, especially in soil with lower clay content. The NPK formulations application made with calcined bone meal promoted an increase in soil P content after harvesting cowpea, soybean, and corn, as observed by Nogalska & Zalewska (2013) to the meat and bone meal, especially in soil with lower clay content. Sá et al. (2017) observed that the amount of available P in the soil for each crop of corn was higher in the sandy loam soil than in clay loam soil, regardless of the source of P.

Cowpea grain yield (GY) varied between 278 and 879 kg ha^{-1} and 1,285 and 1,775 kg ha^{-1} as a function of the applied rate of the NPK 02-20-10 formulation (Table 4), in upland forest and Cerrado environments, respectively. Cowpea GY in an upland forest environment ranged between 22 and 57% of the GY observed in a Cerrado environment. It was possible to adjust a linear equation as a function of the applied rates and, in the case of the upland forest environment, the GY observed for the rate of 600 kg ha^{-1}, equivalent to the 120 kg ha^{-1} of P_2O_5 application, was lower than 400 kg ha^{-1}, equivalent to the 80 kg ha^{-1} of P_2O_5 application. The P supply is extremely important to increase crop productivity, especially in tropical environments with weathered soils. The results achieved for cowpea GY observed in the present study using NPK formulation made with calcined bone meal corroborate the results previously reported in upland forest and cerrado environments, using superphosphate as a P source, as well as the linear response of cowpea to the increment of applied P. In a three-year field experiment in the upland forest environment Borges et al. (2021) observed cowpea grain yield varying from 373 to 984 kg ha^{-1}, when it was used increasing levels of P_2O_5 as triple superphosphate, in an Oxisol with 241 g kg^{-1} of clay. The maximum BRS Guariba and BRS Aracê cowpea cultivars GY were 1,376 and 2,165 kg ha^{-1}, respectively, when it was used increasing levels of P_2O_5 as triple superphosphate, in an Oxisol with 231 g kg^{-1} of clay, under Cerrado environment in the Maranhão State (Melo et al., 2018). Cowpea GY in an upland forest environment ranged between 22 and 57% of the GY observed in a Cerrado environment. This result is certainly related to climatic and edaphic conditions, especially due to the greater buffer capacity of the upland forest soil, determined by the clay and OM content. The place effect was more dominant than the season, inoculant, and P fertilization on cowpea growth and GY in field experiments conducted at three different agro-ecologies places in Mozambique (Kyei-Boahen et al., 2017).

Soybean GY observed here was high (4,029 kg ha^{-1}) and was not affected by increasing levels of the formulation 02-20-10. Soybean seed yield ranged between 1,932 and 3,507 kg ha^{-1} with a positive response to increasing levels of P in two growing seasons, in an Oxisol (Batistela Filho et al., 2013). The lack of response of soybean to fertilization has been reported in the literature (Lacerda et al., 2015, Ferreira et al., 2018). According to the authors, this behavior may be related to high soil fertility, and the amount of rain, and they argue that soybean is normally less responsive to soil fertility management than corn. The corn crop is highly demanding in nutrients and the response to P has been frequently reported, as observed in the Cerrado condition. In the present study, corn grain yield responded positively to doses of the NPK 08-20-10 formulation (Table 5), varying between 1,771 and 3,178 kg ha^{-1}. An increase of 1,356 kg ha^{-1} (57%) of GY was observed with the application of 250 kg ha^{-1} of the 08-20-10 formulation, corresponding to 50 kg ha^{-1} of P_2O_5, when compared with 0 kg ha^{-1}. The corn crop is highly demanding in nutrients and the response to P has been frequently reported. Corn responded linearly to P application up to a level of 120 kg P_2O_5 ha^{-1} in soil with 491 g kg^{-1} of clay (Silva et al., 2014). Ray et al. (2020) observed an increase in corn GY of 94.2% when applied 75% of the recommended rate of NPK (45 kg ha^{-1} of P_2O_5) compared to the control treatment (without NPK). In a long-term experiment, Ortasa & Islamb (2018) observed yields of 4,300 kg ha^{-1} in the control treatment and 5,600, 5,700, and 6,100 kg ha^{-1} with the 50, 100, and 200 kg ha^{-1}of P_2O_5 application, as triple superphosphate, respectively.

Table 4. Cowpea BRS Tumucumaque cultivar grain yield (kg ha^{-1}) cultivated in the upland forest (Mazagão) and cerrado (Macapá) environments, as a function of the application of increasing doses of the NPK (kg ha^{-1}) formulation 00-20-00, made with calcined bone meal.

NPK 02-20-10 levels	Macapá – Cerrado environment	Mazagão - upland forest environment
	(kg ha^{-1})	
0	1,285	278
200	1,390	565
400	1,544	879
600	1,775	864
CV (%)	13.87	21.44
Equation	$\hat{y}$ = 1,254.62 + 0.81*x	$\hat{y}$ = 336 + 1.04*x
R^2	0.97	0.87

Table 5. Corn BRS 260 cultivar and soybean BRS Tracajá cultivar grain yield (kg ha^{-1}) cultivated in Cerrado (Macapá) environment, as a function of the application of increasing rates of the NPK 08-20-10 and NPK 02-20-10 (kg ha^{-1}) formulations, made with calcined bone meal.

NPK 08-20-10 levels	Corn grain yield	NPK 02-20-10 levels	Soybean grain yield
	(kg ha^{-1})		
0	1,771	0	4,234
250	3,127	200	4,184
500	3,074	400	3,604
750	3,178	600	4,094
CV (%)	17.69	-	20.82
Equação	$\hat{y}$ = 2,162.11 + 1.67*x		$\hat{y}$ = $\bar{y}$= 4.03
R^2	0.63		-

The results found in the present study support previous findings that P fertilization has a positive effect on both grain yield and soil phosphorus availability (Kyei-Boahen et al., 2017; Melo et al., 2018), and the predictable behavior of NPK fertilizers made with bone meal on soil, shoot and GY. So, highlights the feasibility of using granular NPK fertilizers made with a bone meal for the different crops in the Brazilian Eastern Amazon edaphoclimatic conditions.

Conclusions

The relationship between phosphorus supply with NPK fertilizers made with bone meal, soil clay content, and environmental conditions on cowpea, corn, and soybean was investigated and we have demonstrated that: (i) fertilization with NPK formulations made with the calcined bone meal promotes greater soybean, cowpea, and corn SDW in the sandy loam compared to sandy clay soil, (ii) the grain yield of the cowpea cultivar BRS Tumucumaque and corn BRS 206 responds linearly to the increase in fertilization with NPK formulation made with calcined bone meal, and (iii) the increasing levels of NPK formulation made with the calcined bone meal do not affect soybean BRS Tracajá grain yield in the Cerrado environment.

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Compliance with Ethical Standards

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