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Effect of Combined Organic and Inorganic Fertilizer Application on Soil Attributes, Yield and Quality of Sweet Potato (*Ipomoea batatas* L.)*

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Abstract

The use of organic fertilizers in adequate doses is an alternative to reduce the use of inorganic inputs, improving the soil chemical attributes, and increasing the production and quality of sweet potato. In this perspective, the objectives of this study were: (i) to evaluate the effects of fertilization with poultry and bovine manure, Ribumin®, and of conventional fertilization on soil attributes, production, and quality of sweet potato; and (ii) to evaluate the residual effect of organic fertilization on the production components and quality of sweet potato, in the second crop cycle. The two experiments were developed in the 2018/2019 crop year at the Agrotechnical School of the Federal University of Roraima (UFRR), Brazil. The treatments were arranged in a randomized block design with three replications, using a (2 × 5 × 2) + 1 factorial arrangement referring to two manure sources (bovine and poultry manure) and five doses, aiming at increasing the content of soil organic matter (1.35%) to 2.35; 3.35; 4.35, and 5.35%, in the absence and presence of Ribumin®, and an additional treatment referring to organomineral fertilization. For the evaluation of the second cycle, the residual effect of the manure was evaluated by applying only Ribumin® and conventional fertilizers. In the first cycle, the addition of 50.4 t ha^{-1} of bovine manure without Ribumin® provided the highest values of total (14.7 t ha^{-1}) and marketable yield (14.6 t ha^{-1}). However, the addition of poultry manure associated with the application of Ribumin® provided no increments in the sweet potato production components. Under the same experimental conditions, chemical fertilization can be replaced by fertilization with organic sources.

Keywords: poultry manure; bovine manure; inorganic fertilizer; Ribumin®; soil chemical attributes; smallholder farmers

1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a horticultural species of the family Convolvulaceae, being the seventh most consumed carbohydrate-rich food source in the world (Chueyen and Eun, 2013). The world production of sweet potato in 2017 was 184,867,095 t, with China ranking as the main producer (72,031,782 t) and Brazil (776,285 t) occupying the tenth position in the global ranking (Faostat, 2016). The Northeast, South, and Southeast regions of Brazil are the largest national producers of sweet potato, with 251,901 t, 250,618 t, and 214,230 t, respectively. In 2018, the state of Roraima alone produced 1,486 tons, the equivalent to 0.20% of the national production (IBGE, 2018).

The importance of this crop includes nutritional and health benefits related to the consumption of the tuberous root. According to Chueyen and Eun (2013), sweet potato possesses phenolic compounds, anthocyanins, sporamins, carotenoids (Hussein et al., 2014), vitamins A, B, C, K, and E, which are important in the prevention of several diseases, contributing to food security in some regions (Low et al., 2017; Iese et al., 2018). Furthermore, sweet potato is a highly energetic food due to its high starch content, and can also be used in the biodiesel and bioethanol industry (Silva et al., 2018a). In Brazil, besides these benefits, the crop is also important for generating jobs and income for smallholder farmers.

In the state of Roraima, although sweet potato cultivation prevails in rural settlement areas, such as the Nova Amazônia Settlement Project, producers perform fertilization, in most cases, using synthetic inputs (ammonium sulfate, urea, and potassium chloride). Despite the potential of the crop and the availability of organic inputs (bovine and poultry manure) in the region, there still a lack of scientific data on the management of organic fertilization, contributing to rising production costs with the application of doses beyond the required by the crop and reducing the yield, profitability, and quality of harvested products (Oliveira et al., 2006; Rós et al., 2014) since nutritional imbalances, especially nitrogen excess, can compromise the formation of tuberous roots in the sweet potato crop. In this perspective, it is necessary to seek alternatives that can reduce production costs, increase the yield, and improve the soil chemical attributes.

One of the alternatives is the replacement of high-cost mineral fertilizers by plant and animal origin products that are available in the field, which, besides having more affordable prices, exert a positive influence on soil properties (Silva et al., 2016a), also featuring less aggressive environmental effects (Kuzucu, 2019; Ciaccia et al., 2019). In the last few years, new technologies available on the market, such as correctives and fertilizers, if used inefficiently, may pose environmental risks that are potentialized by anthropic action, such as groundwater contamination. From this perspective, it is essential to adopt practices that can reduce the environmental and ecological risks caused by conventional agriculture, using more intensely the natural resources in the properties and surrounding areas (Yu-Kui., 2009).

Besides these aspects, it is necessary to consider that, in the last few decades, Brazilian and global consumers are increasingly demanding products obtained from crops cultivated with less synthetic fertilizers (Kikuchi-Uehara et al., 2016; Khan and Mohsin, 2017). In this regard, agroecological production has considerably increased the use of organic fertilizers in partial and sometimes even total replacement to mineral fertilizers. Among the organic fertilizers, bovine and poultry manure and Ribumin® are highlighted (Santos et al., 2010a; Nsa et al., 2013; Silva et al., 2016b).

The use of manure in vegetable cultivation contributes positively to improve the mineral composition and productivity of agricultural crops (Mueller et al., 2013; Adeyeye et al., 2016; Singh et al., 2017), also improving the soil chemical attributes (Mantovani et al., 2017). Besides the supply of manure, the application of humic substances, such as Ribumin®, can stimulate the improvement of soil attributes (Mellek et al., 2010), resulting in higher root activity, production, and quality of harvested products. However, for the proper supply of adequate sources and doses, it is essential to consider the type of crop under cultivation, the edaphoclimatic conditions of the region, and the quality of the organic material provided.

In view of this, the objectives of this study were: (i) to evaluate the effects of fertilization with poultry and bovine manure, Ribumin®, and of conventional fertilization on soil attributes, production, and quality of sweet potato; (ii) to evaluate the residual effect of organic fertilization on the production components and quality of sweet potato, in the second crop cycle.

2. Material and Methods

The study was conducted in the Olericulture Sector of the Agrotechnical School of the Federal University of Roraima (UFRR), Campus Murupu, municipality of Boa Vista-RR

(03°04'01.3' N 60°48'45.6" W). The climate of the municipality is classified as *Aw*, which means rainy tropical, hot and wet (Alvares et al., 2013), presenting a well-defined rainless period (October to March) and a rainy season (April to September).

The experiment was performed in the 2018/2019 crop year, with two sweet potato cultivations: the first from June 15 to October 3, 2018 (rainy season), and the second from December 18, 2018, to April 08, 2019 (dry season). The data referring to the daily air temperature (Figure 1A, B) and precipitation (Figure 1C, D), in the periods mentioned above, were collected with an automatic weather station of the National Meteorology Institute (INMET, 2019). The mean air temperature and precipitation values in the first and second experiments were 27.4 and 29.7 °C, and 1,170.4 and 16.2 mm, respectively (Figure 1).

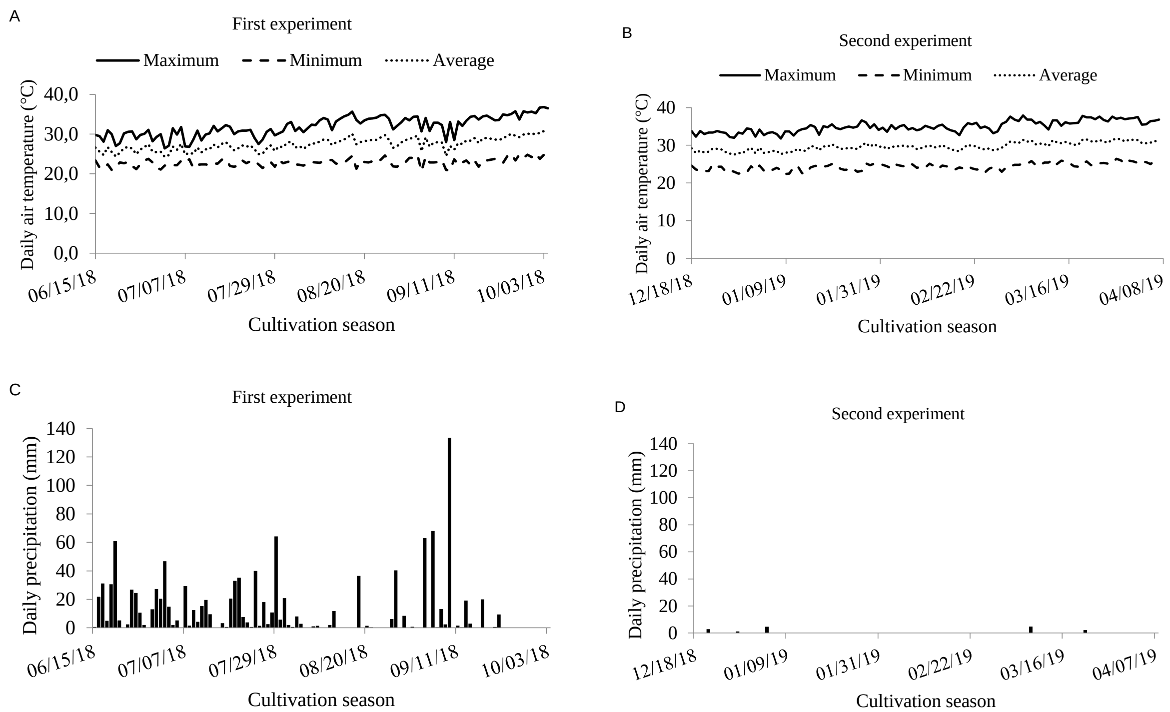

Figure 1. Daily air temperature (A, B) and precipitation (C, D) in the municipality of Boa Vista-RR, in the first experiment (A, C), during the rainy season, and in the second experiment (B, D), during the dry season

Before the installation of the experiment, soil samples were collected at 0-20 cm depth with the aid of a Dutch auger and sent to the Laboratory of Soil Analyses of Viçosa LLC, in Viçosa-MG, for the evaluation of the chemical (Table 1) and physical attributes, following the methodology by Embrapa (2011). The pH was determined in a soil: liquid (H_2O) suspension; the organic carbon was determined by wet oxidation of organic matter with potassium dichromate in a sulfuric medium; the cation exchange capacity and the exchangeable bases were determined by the KCl 1 mol L^{-1} method; the exchangeable acidity referred to the acidity released by the reaction with a non-buffered solution of KCl, and the potential acidity was obtained by extraction with a buffered solution of calcium acetate 1 mol L^{-1} pH 7.0. The particle size analysis was determined by the pipette method. The soil of the experimental area was classified as an Acrisol (WRB, 2014).

Table 1. Soil chemical attributes (0-20 cm) before the preparation of the planting piles in the experimental area of the Agrotechnical School of the UFRR, Campus Murupu

pH	P	K^+	S	Ca^{+2}	Mg^{+2}	Al^{+3}	H^++Al^{+3}	SB	CEC	V	SOM
H_2O	-----mg dm^{-3}-------			----------------------cmol$_c$ dm^{-3}----------------------						--%--	g kg^{-1}
5.20	6.00	26.00	4.00	0.50	0.20	0	1.49	0.80	2.30	34.0	13.50

Note. SB = Sum of bases (Ca^{2+} + Mg^{2+} + K^+ + Na^+); CEC = Cation Exchange Capacity [SB + (H^+ + Al^{3+})]; V = Saturation by exchangeable bases (SB/CEC)100; SOM = Soil organic matter.

The contents of sand, silt, clay, clay dispersed in water, and soil and particle density were, respectively, 76.6 %, 8.4 %, 15.0 %, 0.065 kg kg^{-1}, 1.20, and 2.76 g cm^{-3}, which allowed classifying the soil as of sandy-loam texture. Regarding the dry matter of the poultry and bovine manures, the following values were determined: macronutrient content, C/N ratio, density (D), organic matter content (MO), and moisture (U), with values of N = 1.94 and 3.33%; P = 0.22 and 1.53%; K = 1.68 and 2.08%; Ca = 0.70 and 11.06%; Mg = 0.32 and 0.41%; S = 0.25 and 0.44%; C/N = 13.98 and 3.41; OM = 467.8 and 196.1 (g kg^{-1}); D = 0.34 and 0.77%, and U = 29.36 and 5.41%, respectively.

The treatments (Table 2) were arranged in randomized blocks, with three replications, in a (2 × 5 × 2) + 1 factorial arrangement referring to two manure sources (bovine and poultry manure) and five doses, aiming at increasing the content of soil organic matter from 1.35% (Table 1) to 2.35; 3.35; 4.35, and 5.35%, in the absence and presence of Ribumin®, and an additional treatment referring to organomineral fertilization. Ribumin® is a peat-based material with high contents of humic substances, and, according to the manufacturer, it contains 2% nitrogen, 3% potassium oxide, 5 % NPK, and 3% of total organic carbon. In both experiments, the product was applied twice at the dose of 20 mL L^{-1}, and each planting hole received 100 mL of the mixture in each application, at 15 and 50 days after transplantation. The experimental plot was constituted by three planting piles with 240 cm length, spaced 80 cm in the row, and 30 cm between plants, totaling 24 plants per plot, in which the plants of the central pile were evaluated.

Table 2. Description of the treatments used in the experiment

Treatments	Cicle	Type of manure	% of soil organic matter	Ribumin®	Cicle	Type of manure	% of soil organic matter	Ribumin®
1	First	Bovine	1.35	Without	Second	Residual effect	Residual effect	Without
2	First	Bovine	1.35	With	Second	Residual effect	Residual effect	With
3	First	Bovine	2.35	Without	Second	Residual effect	Residual effect	Without
4	First	Bovine	2.35	With	Second	Residual effect	Residual effect	With
5	First	Bovine	3.35	Without	Second	Residual effect	Residual effect	Without
6	First	Bovine	3.35	With	Second	Residual effect	Residual effect	With
7	First	Bovine	4.35	Without	Second	Residual effect	Residual effect	Without
8	First	Bovine	4.35	With	Second	Residual effect	Residual effect	With
9	First	Bovine	5.35	Without	Second	Residual effect	Residual effect	Without
10	First	Bovine	5.35	With	Second	Residual effect	Residual effect	With
11	First	Poultry	1.35	Without	Second	Residual effect	Residual effect	Without
12	First	Poultry	1.35	With	Second	Residual effect	Residual effect	With
13	First	Poultry	2.35	Without	Second	Residual effect	Residual effect	Without
14	First	Poultry	2.35	With	Second	Residual effect	Residual effect	With
15	First	Poultry	3.35	Without	Second	Residual effect	Residual effect	Without
16	First	Poultry	3.35	With	Second	Residual effect	Residual effect	With
17	First	Poultry	4.35	Without	Second	Residual effect	Residual effect	Without
18	First	Poultry	4.35	With	Second	Residual effect	Residual effect	With
19	First	Poultry	5.35	Without	Second	Residual effect	Residual effect	Without
20	First	Poultry	5.35	With	Second	Residual effect	Residual effect	With
21	First	Additional	Additional	Additional	Second	Additional	Additional	Additional

Note. Additional: Increase of the soil organic matter content to 3.35% with the application of 12.6 t ha^{-1} of bovine manure and 24.0 t ha^{-1} of poultry manure in addition to the mineral fertilization with urea (20 kg ha^{-1} of N), single superphosphate (250 kg ha^{-1} of P_2O_5), and potassium chloride (110 kg ha^{-1} of K_2O).

Due to the soil pH value and the low content of nutrients, especially calcium and magnesium, soil correction was performed with the application of 1.7 t ha^{-1} of dolomitic limestone, 30 days before planting. The piles were raised manually using hoes. Fertilization at planting was performed based on the supply of the sources and doses that were pre-established in the experimental design, which was provided 20 days before planting the sweet potato crop. For the calculation of the manure doses applied in the first experiment, the equation proposed by Bertino et al. (2015) was adopted:

$$M = \frac{(MOD - MOI) \times V \times Ds \times U}{MOE} \quad (1)$$

In which: M: Organic matter content to be applied per planting hole (g kg^{-1}); MOD: Desired organic matter content (g kg^{-1}); MOI: Existing organic matter content in the soil (g kg^{-1}); V: volume of the hole in the pile (cm^{3}); Ds: Soil density (g cm^{-3}); U: Manure moisture (%); MOE: Organic matter content of the manure (g kg^{-1}).

For the calculation, the volume of each planting hole in the pile was 9,000 cm^{-3}, considering the planting hole dimensions of 30 cm × 10 cm × 30 cm (length, width, and depth, respectively), providing 0, 12.6, 25.2, 37.8, and 50.4 t ha^{-1} of bovine manure and 0, 24.0, 48.0, 72.0, and 96.0 t ha^{-1} of poultry manure to increase the soil organic matter content to the values defined in the experimental design, based on the attributes of each input. For the additional treatment, in both experiments, 20 kg ha^{-1} of N was applied using urea as a source (45% N), 250 kg ha^{-1} of P_2O_5 using single superphosphate (18% P_2O_5, 16% Ca, and 8% S), and 110 kg ha^{-1} of K_2O using potassium chloride (60% K_2O). The soil organic matter content was increased to 3.35% by applying 50% of bovine manure (12.6 t ha^{-1}) and 50% of poultry manure (24.0 t ha^{-1}). For the second experiment, the residual effect of the organic sources was evaluated by applying only Ribumin® and the mineral fertilizers in the additional treatment.

The collection of the vines of the sweet potato cultivar ‘Brazlândia Roxa’ was performed one day before transplantation, and the vines were selected containing, on average, eight internodes each. One vine was planted per planting hole, buried by the base with the aid of a small hook, at a depth of 10 to 12 cm, in holes opened at the top of the piles.

Water was provided by sprinkler irrigation in the second experiment. The water volume applied was calculated in order to maintain soil moisture close to field capacity. During the conduction of field activities, in both experiments, heaping and weed and phytosanitary controls were performed using natural resources (garlic (*Allium sativum*) and onion extract (*Allium cepa*); neem extract (*Azadirachta indica*)).

Immediately before the harvest of the first experiment, soil samples were collected at 0-20 cm depth to evaluate the soil chemical attributes according to the previously described methodologies (Embrapa, 2011). After the first cultivation cycle, in the same experimental plots, the piles were reconstructed for the cultivation of the second sweet potato cycle, aiming at evaluating the residual effect of the sources applied. No manure was applied in the second experiment, although Ribumin® was applied following the same criteria adopted for the first experiment. The additional treatment received the contents of inorganic fertilizers predefined in the first cycle.

In both experiments, the plant material was collected at 110 days after planting the vines, and the roots were stored in type-K plastic crates, being afterward transported to the laboratory to assess the number of roots and the mass of marketable and non-marketable roots. Marketable roots were defined as all those with mass above 80 g and below 400 g (Embrapa, 1995). After the classification and weighing of the roots, the results obtained were estimated for t ha^{-1}. For the post-harvest evaluation of the sweet potato, in both experiments, the pH and soluble solids were evaluated. The pH was determined with the aid of a DMPH-2 Digimed potentiometer. A Hanna HI 9680 digital refractometer was used to determine of soluble solids, using two drops of the juice resulting from root maceration (Adolf Lutz Institute, 2005).

2.1 Statistical Data Analysis

The results were subjected to analysis of variance by the F-test; the means referring to the application of manure sources and Ribumin® were compared by the F-test, which is conclusive for two factors, and the relative doses of manure were compared by polynomial regression. The contrast was performed by comparing the factorial effect with the additional treatment, and Dunnett's test was performed to compare the additional treatment with all remaining treatments. Data processing was performed using the statistical software SAS®, version 9.3 (SAS®, 2011).

3. Results and Discussion

The interaction of the type of manure × Ribumin® application × doses exerted influence on the sweet potato production components (total and marketable yield) in the two crop cycles, besides exerting a significant effect on soil attributes at the end of the first cultivation cycle. Except for the organic matter contents, the contrast between the factorial and the additional treatment (organic and mineral fertilization) presented a significant difference for all variables studied (Table 3).

Table 3. Summary of the analysis of variance, by the mean square, for the total yield (PT), marketable yield (PC), soil pH (pH – soil), and soil organic matter (SOM) cultivated with the sweet potato cultivar 'Brazlândia Roxa' in the first (June to October, 2018) and second cycles (December 2018 to April 2019) as a function of fertilization with organic and mineral sources

SV	DF	First cycle		Second cycle		First cycle	
		PT	PC	PT	PC	pH - soil	SOM
Block	2	17.22^{ns}	4.46^{ns}	46.59^{ns}	48.83*	0.10*	0.007^{ns}
Manure (E)	1	387.07**	230.33**	390.59**	259.00**	19.49**	0.491**
Ribumin (R)	1	9.34^{ns}	11.70^{ns}	5.479^{ns}	31.28^{ns}	0.38**	0.017^{ns}
Doses (D)	4	31.33*	33.87**	102.50**	89.51*	2.54**	0.735**
E × R	1	1.36^{ns}	4.15^{ns}	29.96^{ns}	55.60^{ns}	0.12^{ns}	0.006^{ns}
E × D	4	61.10**	54.58**	39.61^{ns}	33.77^{ns}	1.63**	0.167**
R × D	4	15.76^{ns}	14.29^{ns}	2.41^{ns}	5.06^{ns}	0.19**	0.020^{ns}
E × R × D	4	31.33**	33.87**	102.50**	89.51**	2.54**	0.735**
Factorial × Additional	1	198.73**	212.53**	746.11	472.94	0.44**	0.011^{ns}
Residue	40	9.46	6.21	16.28	14.58	0.03	0.008
Total	62						
CV %		4.18	4.31	11.37	14.01	2.62	7.48
				Contrast estimation			
Factorial × Additional		-8.34 t ha^{-1}	-8.62 t ha^{-1}	-16.15 t ha^{-1}	-12.86 t ha^{-1}	0.39	-

Note. SV = Source of variation; DF = Degree of freedom; CV = Coefficient of variation; ^{ns}, ** and *: not significant and significant at 1 and 5% by the F test ($p < 0.05$), respectively.

Contrast estimation indicated that the mean values of total and marketable yield, in the first sweet potato cycle of the factorial analysis (sources versus doses), were inferior in 8.34 and 8.62 t compared to the additional treatment (15.29 t ha^{-1} and 13.99 t ha^{-1}, respectively). This difference was even greater in the second cycle, with values of 16.15 and 12.86 t ha^{-1}, respectively. The mean soil pH value, in all treatments, was superior in 0.39 compared to the pH value of the additional treatment (Table 2).

In the first sweet potato cultivation cycle, regardless of the organic matter content added to the soil and of Ribumin® addition, the total yield was higher in the treatments fertilized with bovine manure (Figure 2A and 2B). The addition of bovine manure linearly increased the total yield to the level of 2.8967 and 1.2635 t per unitary increment in the soil organic matter content, in the treatments without (Figure 2A) and with (Figure 2B) Ribumin®, with maximum estimated values of 14.7 t ha^{-1} and 12.56 t ha^{-1}, respectively, at the highest dose of bovine manure (50.4 t ha^{-1}). In the treatments with poultry manure, in the absence of Ribumin®, the increase in the soil organic matter content promoted an increase in the total yield up to the estimated value of 6.7 t ha^{-1} in the percentage of soil organic matter of 3.17% (Figure 2A). In the presence of Ribumin®, the data did not adjust to any regression model tested, with a mean total yield of 4.65 t ha^{-1} (Figure 2B).

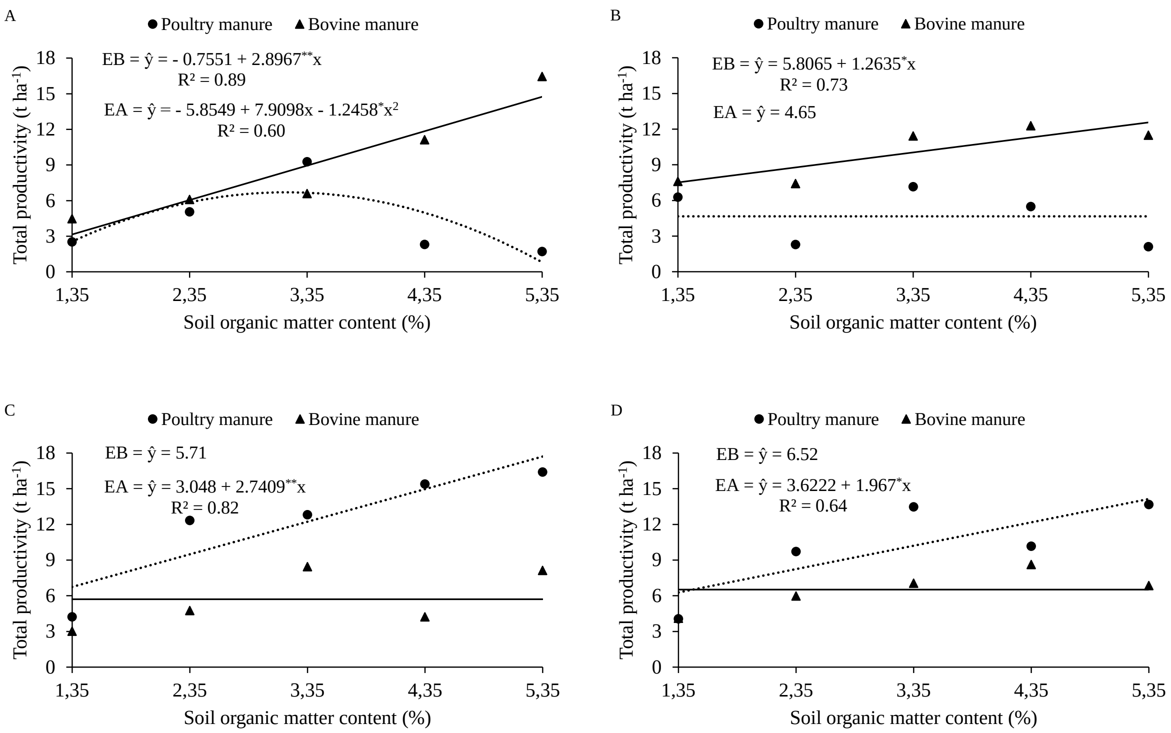

Figure 2. Total yield in the first (A, B) and second (C, D) cycle of the sweet potato cultivar 'Brazlândia Roxa' as a function of the soil organic matter content, provided through poultry (EA) and bovine manure (EB), in the absence (A, C) and presence (B, D) of Ribumin®

The trend of the results was inverse in the second crop cycle, registering the highest values of total yield in the treatments fertilized with poultry manure (Figure 2C and 2D), regardless of the absence or presence of the organomineral fertilizer. For both situations, the data of total yield in the treatments without (Figure 2C) and with (Figure 2D) Ribumin® and fertilized with bovine manure did not adjust to the tested regression models, with mean values of 5.71 and 6.52 t ha^{-1}, respectively. In the treatments without and with Ribumin®, the total yield values of the treatments that received the highest dose of poultry manure were 17.7 t ha^{-1} (Figure 2C) and 14.14 t ha^{-1} (Figure 2D).

Resembling the total yield, the marketable yield of sweet potato in the first cultivation cycle, in the treatments fertilized with bovine manure, was higher with the application of the maximum dose, regardless of the absence or presence of Ribumin® (Figure 3A and 3B). When relating the marketable yield values of 3.04 t ha^{-1} and 5.75 t ha^{-1} in the treatments without the application of bovine manure, in the absence and presence of Ribumin®, respectively, it was verified that the organic mineral input resulted in an 89.1% increase in the marketable yield (Figure 3A and 3B).

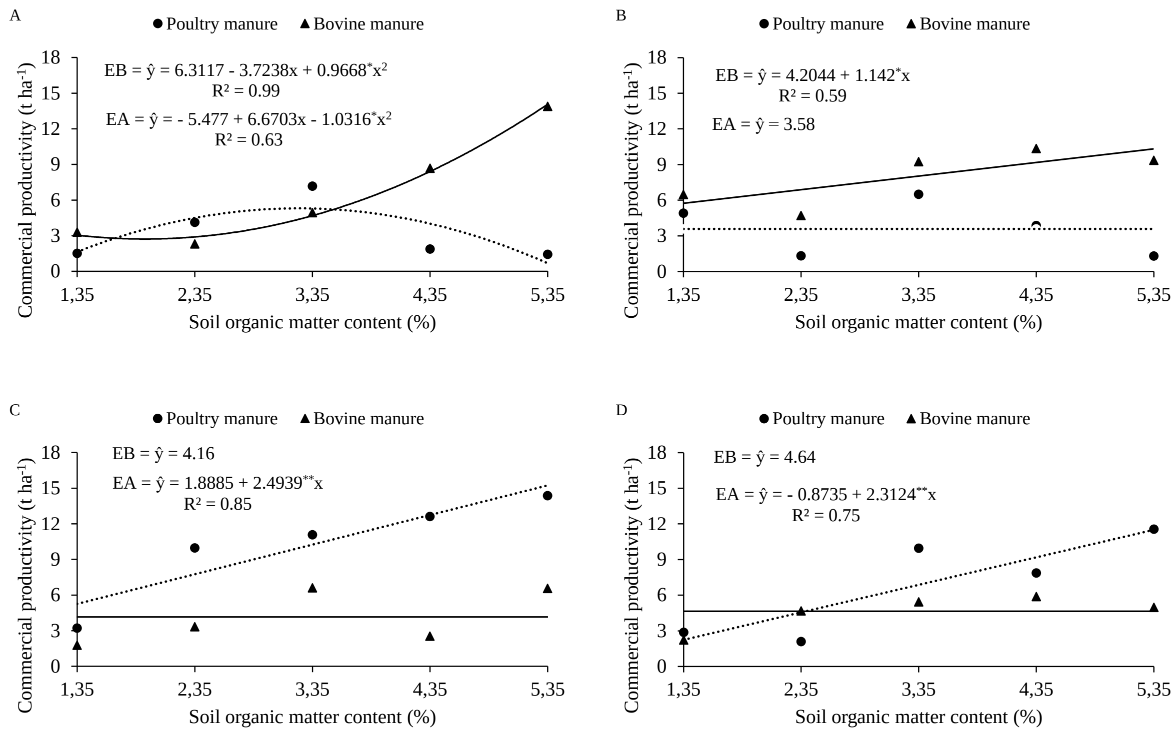

Figure 3. Marketable yield of the first (A, B) and second cycle (C, D) of the sweet potato cultivar ‘Brazlândia Roxa’ as a function of the soil organic matter content provided through poultry (EA) and bovine manure (EB), in the absence (A, C) and presence (B, D) of Ribumin®

The residual effect of the organic fertilization with poultry manure was also significant to increase the marketable yield of sweet potato in the second crop cycle. In the treatments without (Figure 3C) and with (Figure 3D) Ribumin®, the maximum marketable yield values of 15.2 t ha^{-1} and 11.5 t ha^{-1} were registered with the application of the highest dose of poultry manure (96 t ha^{-1}).

In the first sweet potato cultivation cycle, in the treatments with the highest dose of bovine manure, the total yield values were similar to the value registered for the national average (14.5 t ha^{-1}). In the second cycle, fertilization with poultry manure resulted in a yield above the Brazilian average, but the values were similar to that obtained in the state of Roraima (19.5 kg ha^{-1}) in production systems that prioritize the use of synthetic inputs (IBGE, 2018). This situation evidences that the use of fertilization with manure is promising and might be an alternative to the replacement of fertilization with inorganic inputs (Table 5).

The higher yield values obtained in the first cycle, with the application of bovine manure, result from the chemical improvement of soil attributes (Figure 4) since the soil presented, before the installation of the experiment, low organic matter contents (Table 1). Sweet potato is considered a rustic plant, although it responds to organic fertilization (Agbede, 2010; Nicoletto et al., 2017). However, the higher nitrogen availability in the first cycle, due to the high contents of poultry manure and the application of Ribumin®, may have contributed to the growth of the vegetative part of the plants to the detriment of the roots, since, in addition to the amount of input supplied to the soil having been higher, the poultry manure had a higher nitrogen content (3.33%) and a lower C/N ratio (3.41) compared to the bovine manure (Table 1). These attributes justify the values obtained in Figure 2 and express the cultivation potential of the sweet potato crop in a production system that prioritizes the maximum use of the existing resources in the property (Table 5).

Adeyeye et al. (2016), studying the application of 10 t ha^{-1} of three organic fertilizers (poultry manure, bovine manure, and organic compost) and fertilization with synthetic fertilizers on the production components of sweet potato, in Nigeria, verified that there was no difference between the application of inorganic and organic fertilizers on sweet potato yield. However, the highest yield value (4.0 t ha^{-1}) was registered for the plants fertilized with urea, followed by the treatments with poultry manure, organic compost, and bovine manure, although this yield value is still below the maximum values obtained in the present study. Silva et al. (2018b), studying the intercropping of sweet potato with rattlepod and the application of poultry manure (20 t ha^{-1}), registered a yield 16 t ha^{-1}, a similar value to that obtained in the first and second cycles (Figure 2, Table 5).

Except for the treatments fertilized with bovine manure, at the end of the first cycle, the soil pH was increased with the supply of manures, regardless of the absence (Figure 4A) or presence (Figure 4B) of the peat-based input. In the treatments without Ribumin®, the increase in soil pH was equivalent to 31.5% when comparing the values of the treatment that did not receive poultry manure (5.97) with the treatment that received the highest dose (7.81) of poultry input (Figure 4A). In the absence of Ribumin® (Figure 4B), although the two manure sources contributed to the increase of soil pH, the values were superior with the application of poultry manure (7.6), compared to bovine manure (6.3).

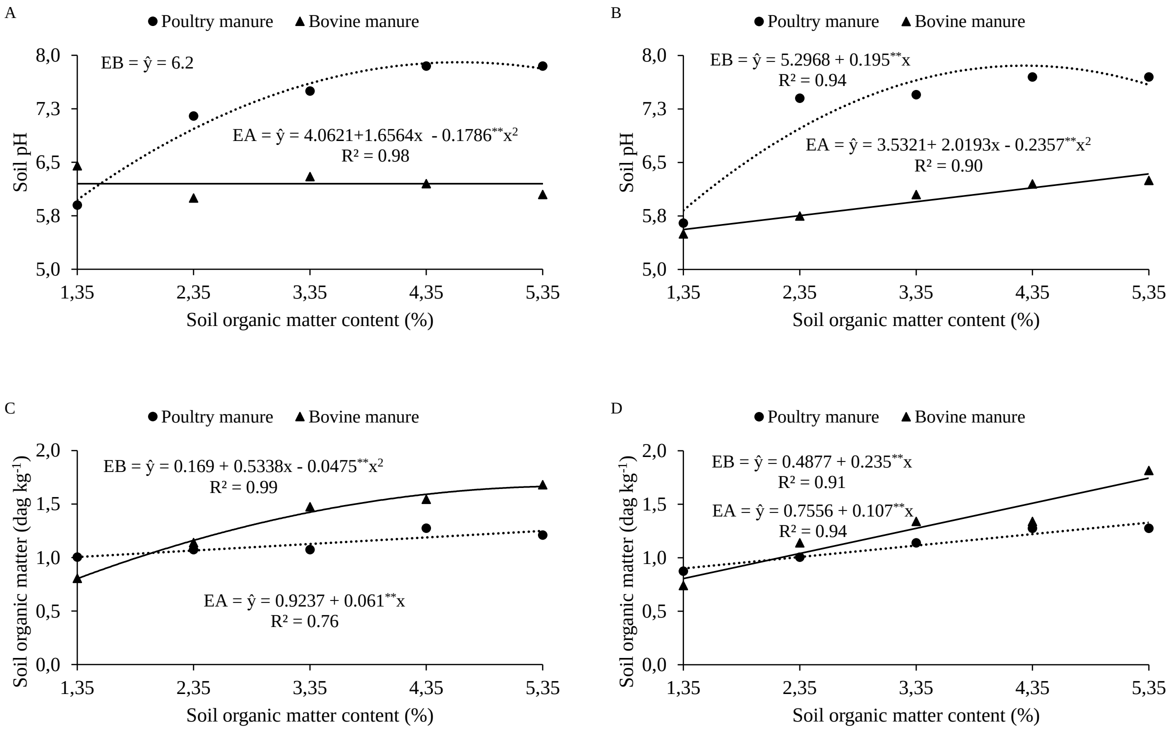

Figure 4. Soil pH (A, B) and organic matter (C, D) at the end of the first cultivation cycle of the sweet potato cultivar 'Brazlândia Roxa' as a function of the content of soil organic matter provided with poultry (EA) and bovine manure (EB), in the absence (A, C) and presence (B, D) of Ribumin®

When evaluating the content of soil organic matter at the end of the first experiment (Figure 4C and 4D), it was verified that the values obtained in all treatments were below those defined in the experimental design. However, the application of the manure doses contributed to the increase of the soil organic matter contents in the treatments without (Figure 4C) and with (Figure 4D) Ribumin®, with superiority in the treatments that received the peat-based input.

When relating the values of 1.74 dag kg^{-1} and 1.66 dag kg^{-1} of the treatments that received the highest dose of bovine manure with and without Ribumin®, respectively, it was verified that the organic mineral input increased promoted a 4.8% in the soil organic matter content. When relating the values of the treatments with poultry manure, it was verified that the superiority reached 6.4%.

When considering: (i) the dynamics of organic matter in tropical and subtropical soils, in which the carbon fraction lost in the system may reach 10% (0.10 year^{-1}); (ii) that this rate can be influenced by climatic conditions (Figure 1) (Silva et al., 2008); and (iii) the amounts of manure added to the soil in the installation of the experiment, most of the inputs were possibly mineralized and used by the plants or lost to the system, after the first cultivation cycle (Figure 4C and 4D). The results, however, evidence the importance of organic fertilization on soil attributes (Figure 4), including the increase in pH (Figure 4A and 4B), which may have occurred due to the reduction in H^+ activity, the mineralization of organic forms of nitrogen, and the denitrification and decarboxylation of organic acids (Silva et al., 2008). The supply of 100% of the manure doses, in the first cycle, contributed to the stimulation of the microbial population and, consequently, given the nutritional demand by the decomposing microbiota, mineral nutrients, such as NO_3^-, became immobilized by the new biomass. In the second cycle, due to the time factor, there was an increase in the mineralization of the material as a consequence of the reduction in microbial activity, with an increase in nutrient availability in the soil and an in the contents of soil organic matter (Figure 4), contributing to the retention of water and cations in the system by organic binders and improving the quality of the soil (Moreira and Siqueira, 2006).

Due to the greater addition of poultry manure, the positive effects of fertilization with this input were also better expressed in the second cycle, revealing the residual effect of the organic fertilization with poultry manure. According to Santos et al. (2010b), the residual effects of organic fertilization are usually better expressed in the second year of cultivation and in association with Ribumin®, which works as a soil conditioning, promoting the increase of production components (Silva et al., 2016b).

The summary of the analysis of variance for the post-harvest variables of sweet potato indicates that for the two cycles studied, both for the pH of the pulp and soluble solids, there was a significant effect of the interaction between the type of manure × doses × Ribumin® (Table 3). For the variables of the first cycle, it is verified that the contrast between the factorial and the additional treatment was only significant for the soluble solids of the pulp, in which the mean of the factorial (7.34 °Brix) was 0.85 °Brix inferior in relation to the additional treatment. In the second cycle, there was a significant effect for both variables analyzed; however, the pH (6.55) and soluble solids (6.60 °Brix) of the sweet potato pulp of the factorial analysis were superior in 0.12 and 1.14 °Brix, respectively (Table 4).

Table 4. Summary of the analysis of variance for the pH and soluble solids of the pulp in the sweet potato cultivar ‘Brazlândia Roxa’, in the first (June to October 2018) and second cycles (December 2018 to April 2019), as a function of fertilization with organic and mineral sources

SV	DF	First cycle		Second cycle	
		pH-1	SS-1	pH-2	SS-2
Block	2	0.04004^{ns}	0.334^{ns}	0.003^{ns}	0.167^{ns}
Manure (E)	1	0.60000^{**}	17.604^{**}	0.382^{**}	6.468^{**}
Ribumin (R)	1	0.00112^{ns}	0.073^{ns}	0.022^{*}	0.840^{*}
Doses (D)	4	0.101405^{**}	0.736^{**}	0.024^{**}	3.416^{**}
E × R	1	0.00002^{ns}	0.104^{ns}	0.002^{ns}	0.204^{ns}
E × D	4	0.20374^{**}	0.368^{ns}	0.031^{**}	1.783^{**}
R × D	4	0.01803^{ns}	0.287^{ns}	0.006^{ns}	0.568^{**}
E × R × D	4	0.10140^{**}	0.736^{**}	0.024^{**}	3.416^{**}
Factorial × additional	1	0.04903^{ns}	2.088^{**}	0.044^{*}	3.724^{**}
Residue	40	0.016	0.160	0.004	0.125
Total	62				
CV %		2.24	5.42	0.99	5.39
		Contrast estimation			
Factorial × Additional		-	-0.855 °Brix	0.12	1.14

Note. SV = Source of variation; DF = Degree of freedom; pH-1= pulp pH in the first cycle; SS-1= soluble solids of the pulp in the first cycle; pH-2= pulp pH in the second cycle; SS-1= soluble solids of the pulp in the second cycle; CV = Coefficient of variation; ns, ** and *: not significant and significant at 1 and 5% by the F test ($p < 0.05$), respectively.

Despite the significant effect of the triple interaction, in this first cycle, the data referring to the pulp pH in the treatments that received bovine manure did not adjust to any regression model tested, with a mean value of 5.6 in the treatments without Ribumin® (Figure 5A) and 5.7 in the treatments with Ribumin® (Figure 5B). Regardless of the application of this input, the supply of poultry manure to the soil reduced the pulp pH of sweet potato, with the highest values of 6.10 (Figure 5A) and 6.34 (Figure 5B).

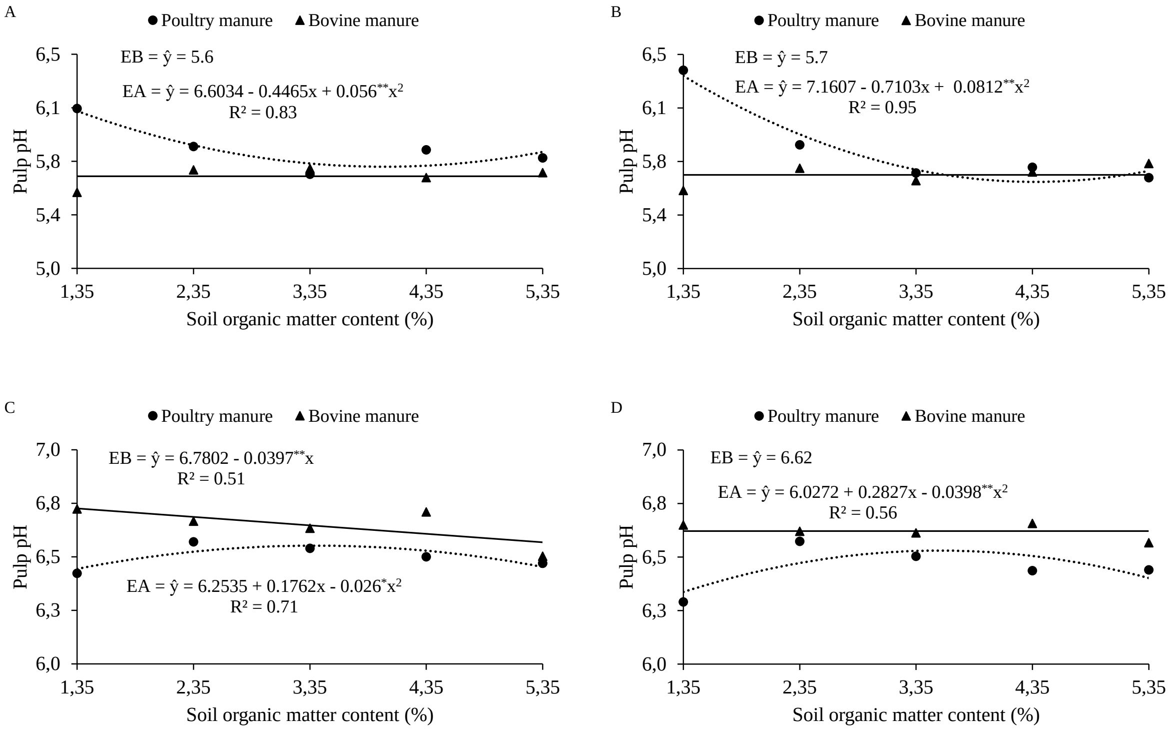

Figure 5. Pulp pH of the first (A, B) and second cultivation cycles (C, D) of the sweet potato cultivar 'Brazlândia Roxa' as a function of the content of soil organic matter provided through poultry (EA) and bovine manure (EB), in the absence (A, C) and presence (B, D) of Ribumin®

In the second cycle, the values of pulp pH in the treatments with poultry manure, unlike the first cycle, were increased with the application of the poultry input, reaching maximum values of 6.5 with soil organic matter contents of 3.38% (Figure 5C) and 3.55% (Figure 5D). The application of bovine manure in the treatments without Ribumin® reduced the pH of the sweet potato pulp from 6.73 to 6.56 from the lowest to the highest dose (Figure 5C), and in the presence of the organomineral input, the mean value obtained was 6.62 (Figure 5D).

The reduction of the pulp pH in sweet potato, in the treatments fertilized with poultry manure, in the first cycle, and in the treatments fertilized with bovine manure, without the application of Ribumin® (Figure 5), indicates that the addition of manure to the soil can favor the production of sweet potato with a slightly acid pulp, although the values are still within the range considered adequate for the crop (Uchôa et al., 2015). Pulp pH is an important attribute in sweet potato since acid values lead to losses in color intensity and in the activity of provitamin A. Marques et al. (2010) verified that the application of bovine manure to the soil does not affect the pH in beetroot (*Beta vulgaris esculenta*). The pulp pH results of sweet potato obtained in this research are within the range from 5.04 to 7.26 registered by Ali et al. (2015), when evaluating the physical-chemical characterization of two sweet potato cultivars (Adu and Barkume), in Ethiopia.

The supply of Ribumin®, associated with manure application, in both cycles, reduced the values of soluble solids in the sweet potato pulp (Figure 6B and 6D), although the values were superior to the first cycle, with values of soluble solids in the treatments without manure equivalent to 8.20 and 7.15 °Brix (Figure 6B). In the treatments without Ribumin®, the mean values obtained in the first cycle were 6.88 and 7.88 ºBrix, in the treatments with bovine and poultry manure, respectively (Figure 6A). For the second cycle, the mean value of soluble solids obtained for the sweet potato pulp grown in the soil fertilized with bovine manure was 7.11 °Brix, and the application of poultry manure also reduced the soluble solids (Figure 6C).

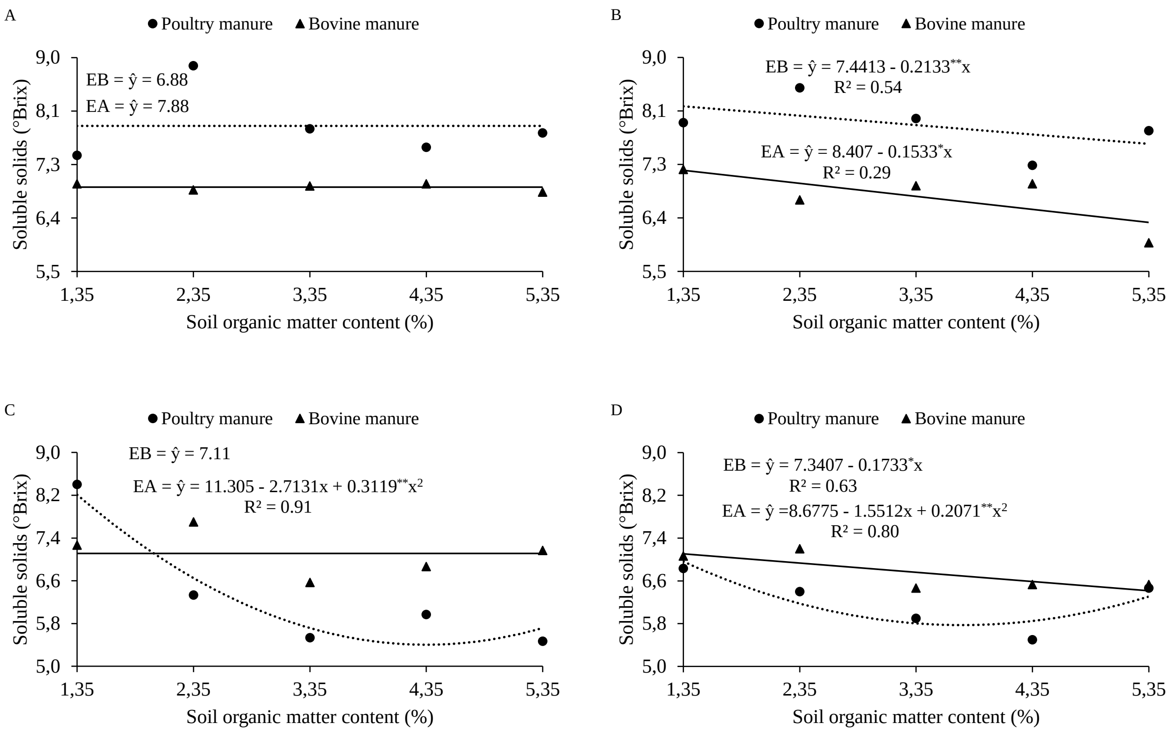

Figure 6. Soluble solids in the pulp of the sweet potato cultivar 'Brazlândia Roxa', in the first (A, B) and second cycles (C, D), as a function of the initial content of soil organic matter provided through poultry (EA) and bovine manure (EB,), in the absence (A, C) and presence (B, D) of Ribumin®

The soluble solids indirectly represent the content of sugars and organic substances, such as acids and tannins, in a specific sweet potato sample, determining the degree of sweetness of the vegetable. This quality attribute can be a determining factor for the consumer to purchase the product again with a smallholder farmer. Despite the reduction of soluble solids in the sweet potato pulp with the addition of manure, in both cycles (Figure 6), the mean values are within the range from 6.43 and 11.25 °Brix registered by Panja et al. (2016), when studying eight sweet potato cultivars for two years in India, although being below the mean value of 12.63 °Brix obtained by Ali et al. (2015) when studying the physicochemical characterization of two sweet potato cultivars in Ethiopia.

Table 5 presents, for all treatments, the mean values of each variable analyzed in both cycles and the significance level of Dunnett's test. In the first cycle, in treatments 6, 7, 8, 9, and 10,

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with bovine manure, there were higher values of total and marketable yield, not differing statistically from the additional treatment, using organic and synthetic fertilizers. Treatment 9 (50.4 t ha^{-1} of bovine manure without Ribumin® application) registered a numerically higher total yield (16.45 t ha^{-1}) compared to the additional treatment (15.29), and, in these same treatments, the marketable yield (13.89 t ha^{-1}) was similar to that of treatment 21 (13.99 t ha^{-1}).

Table 5. Mean values of total yield (PT1), marketable yield (PC1), soil pH (pH-soil), soil organic matter (SOM), pulp pH (pH-1), and soluble solids (SS-1) in the first cycle (June to October 2018), and total yield (PT2), marketable yield (PC2), pulp pH (pH-2), and soluble solids (SS-2) in the second cycle (December 2018 to April 2019) of the sweet potato cultivar 'Brazlândia Roxa' as a function of fertilization with organic and mineral sources

Treatments				First cycle						Second cycle			
T	E	SOM	R	PT1	PC1	pH-soil	SOM	pH -1	SS1	PT2	PC2	pHp2	SS2
				----t ha^{-1}----			dag kg^{-1}		°Brix	----t ha^{-1}----			°Brix
1	Bovine	1.35	Without	4.48*	3.3*	6.45^{ns}	0.81*	5.53^{ns}	6.93*	3.02**	1.78**	6.72*	7.27*
2	Bovine	1.35	With	7.60*	6.48*	5.5*	0.74*	5.55^{ns}	7.17*	4.11**	2.23**	6.65*	7.07*
3	Bovine	2.35	Without	6.10*	2.31*	6.00^{ns}	1.14^{ns}	5.69^{ns}	6.83*	4.75**	3.33**	6.67*	7.7*
4	Bovine	2.35	With	7.41*	4.71*	5.75*	1.14^{ns}	5.7^{ns}	6.67*	5.98**	4.68**	6.62*	7.2*
5	Bovine	3.35	Without	6.59*	4.93^{ns}	6.3^{ns}	1.48^{ns}	5.7^{ns}	6.9*	8.44**	6.61**	6.63*	6.57*
6	Bovine	3.35	With	11.42^{ns}	9.25^{ns}	6.05^{ns}	1.34^{ns}	5.62^{ns}	6.9*	7.05**	5.45**	6.61*	6.47*
7	Bovine	4.35	Without	11.12^{ns}	8.68^{ns}	6.2^{ns}	1.55*	5.64^{ns}	6.93*	4.22**	2.54**	6.71*	6.87*
8	Bovine	4.35	With	12.28^{ns}	10.36^{ns}	6.2^{ns}	1.34^{ns}	5.68^{ns}	6.93*	8.63**	5.89**	6.66*	6.53*
9	Bovine	5.35	Without	16.45^{ns}	13.89^{ns}	6.05^{ns}	1.68*	5.67^{ns}	6.8*	8.13**	6.55**	6.5^{ns}	7.17*
10	Bovine	5.35	With	11.48^{ns}	9.36^{ns}	6.25^{ns}	1.82*	5.74^{ns}	5.97*	6.85**	4.98**	6.57^{ns}	6.53*
11	Poultry	1.35	Without	2.52*	1.52*	5.90^{ns}	1.01*	6.12*	7.4^{ns}	4.22**	3.21**	6.42^{ns}	8.4*
12	Poultry	1.35	With	6.28*	4.92*	5.65*	0.88*	6.39*	7.93^{ns}	4.06**	2.88**	6.29^{ns}	6.83*
13	Poultry	2.35	Without	5.05*	4.13*	7.15*	1.08^{ns}	5.85^{ns}	8.87^{ns}	12.33**	9.96^{ns}	6.57^{ns}	6.33^{ns}
14	Poultry	2.35	With	2.28*	1.33*	7.4*	1.01*	5.87^{ns}	8.5^{ns}	9.71**	2.10**	6.57^{ns}	6.4*
15	Poultry	3.35	Without	9.27^{ns}	7.17*	7.5*	1.08^{ns}	5.66^{ns}	7.83^{ns}	12.81**	11.07^{ns}	6.54^{ns}	5.53^{ns}
16	Poultry	3.35	With	7.15*	6.49*	7.45*	1.14^{ns}	5.67^{ns}	8.00^{ns}	13.47**	9.95^{ns}	6.5^{ns}	5.9^{ns}
17	Poultry	4.35	Without	2.30*	1.88*	7.85*	1.28^{ns}	5.83^{ns}	7.53^{ns}	15.39^{ns}	12.6^{ns}	6.5^{ns}	5.97^{ns}
18	Poultry	4.35	With	5.47*	3.88*	7.70*	1.28^{ns}	5.71^{ns}	7.23^{ns}	10.17**	7.88**	6.44^{ns}	5.5^{ns}
19	Poultry	5.35	Without	1.71*	1.44*	7.85*	1.21^{ns}	5.77^{ns}	7.77^{ns}	16.4^{ns}	14.36^{ns}	6.47^{ns}	5.47^{ns}
20	Poultry	5.35	With	2.10*	1.31*	7.70*	1.28^{ns}	5.64^{ns}	7.8^{ns}	13.66**	11.55^{ns}	6.44^{ns}	6.47*
21	AD	AD	AD	15.29	13.99	6.25	1.28	5.62	8.2	24.83	19.35	6.43	5.47

Note. T = Treatment; E = Manure; SOM = Soil organic matter; R = Ribumin; ^{ns} and *, express non-significance and significance, respectively, by Dunnett's test at 5% of probability for comparisons with the additional treatment (21) (AD – Additional treatment).

Except for treatment 11 (without the application of poultry manure and absence of Ribumin®), all soil pH values in the treatments fertilized with poultry manure (12 to 20) were superior to the value registered for the additional treatment (6.25). Regardless of the presence (1.82 dag kg^{-1}) or absence (1.68 dag kg^{-1}) of Ribumin®, the supply of 50.4 t ha^{-1} of bovine manure provided soil organic matter values above those of treatment 21 (1.28 dag kg^{-1}). Treatments 11 and 12 (without poultry manure) registered high pulp pH values in the first cycle compared to the additional treatment (5.62). All values of soluble solids in the sweet potato pulp, obtained in the first cultivation with bovine manure, were inferior to the additional treatment (8.2 °Brix).

The highest values of total (24.83 t ha^{-1}) and marketable yield (19.35 t ha^{-1}) were registered in the second cycle, with the additional treatment. Only treatments 17 (15.39 t ha^{-1}) and 19 (16.4 t ha^{-1}), for the total yield, and treatments 16, 17, 19, and 20, for the marketable yield, were statistically equal to the additional treatment, and all were treated with poultry manure. The treatments that received the highest doses of bovine manure (9 and 10) and all those that received poultry manure presented a similar pulp pH to that registered for treatment 21 (6.43). All treatments fertilized with bovine manure presented contents of soluble solids in the sweet potato pulp above the mean value of the treatment with organic and mineral fertilization (5.47 °Brix), as well as treatments 11 (8.40 °Brix), 12 (6.83 °Brix), 14 (6.40 °Brix), and 20 (6.47 °Brix), which received poultry input (Table 5).

These results indicate the possibility of smallholder farmers in the Nova Amazônia Settlement Project in practicing more sustainable agriculture using the existing resources in their community, reducing or eliminating the dependence on inorganic inputs, reducing the deleterious effects to the environment, with a sweet potato production of higher quality and added value, without yield losses, and increasing the income and quality of life of sweet potato producers in the state of Roraima.

4. Conclusions

In the first cycle, the addition of 50.4 t ha^{-1} of bovine manure, without the application of Ribumin®, provided the highest values of total (14.7 t ha^{-1}) and marketable yield (14.6 t ha^{-1}). In the cultivation during the rainy period, the addition of poultry manure associated with the application of Ribumin® provided no increments in the production components of sweet potato; however, in the second cycle, the residual effect of fertilization increased the yield of *Ipomoea batatas* L. The application of organic inputs improved the soil chemical attributes and provided a sweet potato production with adequate quality for the consuming Brazilian market. Under the same experimental conditions, chemical fertilization can be replaced by fertilization with organic sources.

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