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ORGANIC FERTILIZATION ON THE PRODUCTIVITY OF BIOFORTIFIED SWEET POTATO

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ABSTRACT - Sweet potato (*Ipomoea batatas* (L.) Lam.) is a widely grown vegetable in Brazil. The application of organic fertilizers of animal origin is considered a useful and economical practice for producers because it enhances soil fertility and ensures conservation. The objective of this study was to evaluate the commercial potential and total productivity of biofortified sweet potato based on the concentration of applied tanned bovine manure. This study was conducted from February to July 2020 in the experimental area of the Center for Agricultural and Environmental Sciences, Federal University of Maranhão (UFMA), Brazil. The experimental design used was randomized blocks with six treatments (0, 10, 20, 30, 40., and 50 Mg ha^{-1} of tanned bovine manure) and five replicates. The following agronomic characteristics of sweet potatoes were evaluated: fresh and dry biomass of the shoot (Mg ha^{-1}), fresh and dry biomass of the tuberous root (Mg ha-1), number of commercial roots, and damage galleries (and holes) caused by insects. Bovine manure can be used as a source of organic fertilizer in the range of 10.0-20.0 Mg ha^{-1} to improve the productivity of biofortified sweet potato 'Beauregard'. The yield was 7 Mg ha^{-1} with 10 Mg ha^{-1} of bovine manure, and this yield is higher than the average yield for the state of Maranhão.
Keywords: *Ipomoea batatas* (L.) Lam, Eastern Maranhense, olericulture, tuberous.

ADUBAÇÃO ORGÂNICA NA PRODUTIVIDADE DE BATATA-DOCE BIOFORTIFICADA

RESUMO - A batata-doce (*Ipomoea batatas* (L.) Lam.), é uma hortaliça muito popular no Brasil. A utilização de adubos orgânicos de origem animal é considerada uma prática útil e econômica para os produtores, pois, favorece a fertilidade e conservação do solo. Desta forma, objetivou-se avaliar a produtividade comercial e total da batata-doce biofortificada, em função de concentrações de esterco bovino curtido. O estudo foi conduzido no período de fevereiro a julho de 2020, na área experimental do Centro de Ciências Agrárias e Ambientais, pertencente a Universidade Federal do Maranhão (UFMA). O delineamento experimental utilizado foi blocos ao acaso, com 6 tratamentos (0, 10, 20, 30, 40 e 50 Mg ha^{-1}) de esterco bovino curtido, 5 repetições. Foram avaliadas as características agronômicas da cultura, como, biomassa fresca (Mg ha^{-1}) e seca da parte aérea (Mg ha^{-1}), biomassa fresca (Mg ha^{-1}) e seca da raiz tuberosa (Mg ha^{-1}), número de raízes comerciais e danos (galerias e furos) causados por insetos. O esterco bovino pode ser utilizado como fonte de adubo orgânico, na faixa de 10,0 a 20,0 Mg ha^{-1}, obtendo assim, produtividade de raízes de batata-doce cv. Beauregard biofortificada de 7 Mg ha^{-1}, superior à média do estado do Maranhão.
Palavras-chaves: *Ipomoea batatas* (L.) Lam, Leste Maranhense, olerícola, tuberosa.

INTRODUCTION

In Brazil, sweet potato (*Ipomoea batatas* (L.) Lam.) is one of the most planted vegetables, occupying the 5th place, with approximately 52,928 ha of cultivated area, annual production of 741,000 thousand tons, and an average productivity of 14,000 kg ha^{-1} (IBGE, 2019). According to IBGE (IBGE, 2020), 6 ha of sweet potato were grown in the state of Maranhão in 2020, and a production of 18 tons and an average productivity of 3,000 kg ha^{-1} were obtained, accounting for 26% of the planted area in the northeast, characterized predominantly with family production (NASCIMENTO, 2013).

The low levels of sweet potato cultivation in the planted area over decades is attributable to the lack of knowledge of the productive potential of the crop, technical and scientific information regarding its cultivation and fertilization, and unavailability of adequate instruments to producers (RÓS et al., 2014). Low productivity is a historical trend, owing to the lack of technical assistance and access to science and technology to small producers; there is a lack of appropriate cultural treatments, adapted insums, and availability of cultivars (MELO et al., 2011). In recent years, sweet potato production chain has received attention from researchers, especially regarding genetic improvement. These researchers aim to increase the productive potential and quality of roots (KIST et al., 2019).

According to Samborski et al. (2020), sweet potato cultivation is considered an excellent socioeconomic

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alternative for small and medium farmers because of its nutritional importance, such as high calorie content and high concentrations of vitamins, minerals, and beta-carotene, making it an important food for improving the nutrition of people with dietary restrictions. The plants used were biofortified 'Beauregard', an American cultivar developed by the Louisiana Agricultural Experiment Station in 1981. In Maranhão, it has a vegetative cycle of 90-130 days, with elongated and uniform roots, purplish-red bark, and a smooth surface. The pulp has an intense orange color, which is indicative of a high beta-carotene content (VIZZOTTO et al., 2018).

In the State of Maranhão, the plants are grown using a monoculture system, accompanied by localized fertilization with NPK, applied according to the demand for the aforementioned nutrients. However, for smallholder farmers, such a practice is expensive; thus, fertilization is not a constant practice. Among the forms of nutrient supply, organic fertilization is rarely used by Maranhão producers. According to IBGE data (2018), only 2% (6,131) and 0.85% (1,789) of agricultural establishments provide organic and mineral/organic fertilizers, respectively, for cultivating sweet potatoes, but 4.7% (9,988) of them use chemical fertilizers. Most establishments (92.45%) do not sell any type of fertilizer for this crop, contributing significantly to the low agricultural productivity in the State (IBGE, 2018).

The use of organic fertilizers is an alternative way of reducing production costs and increasing productivity in crops that are not chemically fertilized. Bovine manure is a source of organic fertilizers because of its high availability, low cost, and high use in the production of vegetables, along with goat and poultry manure (MANTOVANI et al., 2017). The nutrient levels of bovine manure vary widely and are related to the cattle production methods. Usually, the nutrient values found in cattle manure are as follow: 40–60% moisture, 3–22 g kg^{-1} nitrogen (N), 3–18 g kg^{-1} P_2O_5, and 5–15 g kg^{-1} K_2O (RAIJ, 2011).

Fertilization management research for sweet potato cultivation, elaborated from local experimental trials, has become important, especially regarding the use of organic fertilizers. The objective of this study was to evaluate the commercial potential and total productivity of the sweet potato 'Beauregard' after applying various concentrations of bovine manure.

MATERIAL AND METHODS

The experiment was conducted between February and July 2020 in an experimental area of the Center for Agrarian and Environmental Sciences of the Federal University of Maranhão (UFMA), located in the municipality of Chapadinha/MA (geographic coordinates: 3°44'30"S, 43°21'37"W; altitude: 105 m). According to the Köppen classification, the climate *is type Aw*, predominantly humid tropical, with an average maximum temperature of 37 °C minimum sums of 21 °C and an annual precipitation of 2100 mm.

Figure 1 shows the average monthly rainfall, temperature, and precipitation data collected throughout the experimental period and provided by the station 82382 of the National Meteorological Institute (INMET), located 7 km from the experimental area.

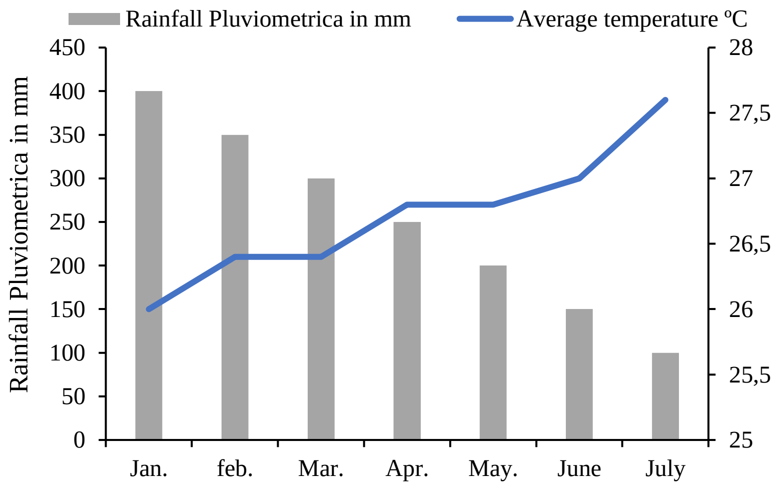

FIGURE 1 - Monthly precipitation and temperature values for the municipality of Chapadinha - MA during the experimental period. Source: INMET (2020).

The experimental area was prepared, phighing with a leveling grid, approximately 30 days before the sweet potato was planted. Soil samples were collected before soil preparation for chemical analyses. The soil was classified as DYSTROPHIC YELLOW LATOSOL, according to Santos et al. (2013), with the following chemical characteristics: pH in $CaCl_2$ = 4.5; available phosphorus = 3.5 mg dm^{-3}; potassium = 0.07 cmol dm^{-3}; aluminum = 0.18 cmol dm^{-3}; calcium + magnesium = 1.19 cmol dm^{-3}, and organic matter = 13.4 g kg^{-1}. Soil correction of the area with dolomitic limestone was performed using the following: CAO 31.4%, MGO = 18.5%, sum of oxides = 49.9%, PN = 102, and PRNT = 93.8%.

Bovine manure was acquired in December 2019 and stored in burlap bags for tanning. A pile of 2 m long, 1.5 m wide, and 80 cm high was formed with the material and wet daily with 15 L of water. This was performed every two days for 30 days until it was ready for use. The manure used in the study has the following chemical characteristics: N = 22.7 g kg $^{-1}$; P = 2.5 g kg^{-1}; P_2O_5 = 5.8 g kg^{-1}; K = 0.6 g kg^{-1}; K_2O = 0.7 g kg^{-1}; Ca = 4.7 g kg^{-1}; Mg = 1.0 g kg^{-1}; Fe = 5.0333 mg $^{kg-1}$; Cu = 0.0435 mg kg^{-1}; Zn = 0.0952 mg kg^{-1}, and Mn = 0.2195 mg kg^{-1}.

The experimental design used was randomized blocks containing six treatments (Table 1) and five replicates, making a total of 30 plots. The area of the plots was 7.84 m², consisting of three 2.8 m trees spaced 0.80 m between them. Planting was conducted at a spacing of 0.3 m between plants, that is, 8 plants/leira, totaling 720 plants.

TABLE 1 - Experimental treatments on sweet potato 'Beauregard' cultivation.

Treatments	
T1	No use of bovine manure (DYSTROPHIC YELLOW LATOSOL)
T2	Bovine manure (10 Mg ha^{-1})
T3	Bovine manure (20 Mg ha^{-1})
T4	Bovine manure (30 Mg ha^{-1})
T5	Bovine manure (40 Mg ha^{-1})
T6	Bovine manure (50 Mg ha^{-1})

An area of 1.68 m² was considered and used for evaluation, that is, the central leira of the experimental plot. Sweet potato plants ('Beauregard') were cultivated and used for the experiment. The seedlings were obtained via asexual/cutting propagation, using mini cuttings containing 2 gems, sectioned from young branches and freshly harvested from the Federal Institute of Maranhão (IFMA), Maracanã campus. Before they were taken to the field, the mini-cuttings were deposited and kept in disposable cups (150 mL), with one yolk above and another below the substrate, filled with substrate mixture, and prepared based on soil (DYSTROPHIC YELLOW LATOSOL) + bovine manure (1:1 v/v). The propagules were kept in benches of the seedling nursery in the experimental area of the institution, and irrigation was performed once a day early in the morning on the first week and 2 times a day (morning and afternoon) after the second week until transplantation [30 days after transplantation (DAP)].

The planted trees were manually raised to a height of 30 cm using hoes. Transplantation was performed on the same day as the application of the treatments (organic fertilization to toss) in the late afternoon at 16 h. During the first week in the field, the plants with defects were replaced by healthy seedlings, and frequent manual weeding was performed around and between the trees to keep them free from competition with weeds. In addition, denim oil (dilution: 1.5%, v/v) was sprayed to control white cochineal (*Planococcus citri).*

After 120 days, the tuberous roots were harvested, and phytotechnical characteristics, such as fresh and dry shoot biomass, fresh and dry biomass of the tuberous root, number of commercial roots, and damage caused by insects (such as holes and galleries) were determined.

Shoot and root samples were collected to determine the dry biomass of shoots and roots. They were collected in an area of 0.56 m², in the center of the useful area of the plots, bounded by a structure of 0.70 m long and 0.80 m wide, made with a PVC pipe of 20 mm. The entire aerial part contained inside were harvested. Thereafter, the samples were cleaned (the weeds were removed), weighed on an analytical scale (four decimal places), packed in identified paper bags according to treatments, and dried in a greenhouse with forced air circulation at 65±1°C) until they reached a constant mass.

The length and diameter of the commercial roots were measured using a digital caliper and a graduated ruler. During this period, the total productivity was determined based on the tuberous roots of the useful area of each harvested plot. This was conducted by putting the tuberous roots into bags that were properly labeled, washed, and then left in a laboratory environment under a condition of 20±2°C) until they lost the excess moisture acquired during washing. Thereafter, the samples were weighed to obtain the productivity (Mg ha^{-1}).

To evaluate the damage caused by soil insects, a scale of notes, established by Miranda et al. (1983) was used: 1 = damage-free roots, with desirable commercial aspects; 2 = roots with little damage, losing a little in relation to the commercial aspect, with the presence of some galleries and holes in the roots; 3 = roots with damage verified without much visual effort, with the presence of galleries and holes in the roots in greater intensity, with impaired commercial aspect; 4 = roots with many damages, practically unfeasible for commercialization, with the presence of many galleries, holes, and rots; and 5 = totally unviable roots for commercial purposes, full of galleries, with holes, and more advanced rot.

The data obtained were subjected to analysis of variance, and significance was tested using the F-test, with a 5% probability of error. When significant treatment effects were found, the data were subjected to orthogonal polynomials for treatment responses using a statistical program.

RESULTS AND DISCUSSION

Fresh shoot biomass, fresh root biomass, and dry root biomass of tuberous plants did not show any significant difference among the treatments (organic fertilizer) (Table 2). However, there was a positive effect on the dry biomass of the aerial parts of sweet potato plants, adjusted in a linear model with R^2 = 0.45 (Figure 2).

Under a concentration of 50 mg ha^{-1} of bovine manure (Table 1), the values for fresh biomass corresponded to 0.410 kg m^{-2}, and is lower than the results obtained by Andrade Junior et al. (2012). This result may be related to the final phase of the cycle, when there is accumulation of photoassimilates by tuberous roots and leaf area and a tendency for stabilization and then decline. As the leaf area is important for the efficiency of photosynthesis, the faster the plant reaches its maximum leaf area index, the faster the photosynthetic rate.

TABLE 2 - Summary of analyses of fresh shoot biomass (BFPA), shoot dry biomass (BSPA), fresh root biomass (BFR), and dry root biomass (BSR) of biofortified sweet potato plants according to bovine manure concentrations.

Concentrations of bovine manure (Mg ha^{-1})	BFPA (Mg ha^{-1})	BSPA (Mg ha^{-1})	BFR (kg m^{-2})	BSR (kg m^{-2})
0	0,368	0,076	0,154	0,041
10	0,308	0,050	0,105	0,027
20	0,380	0,091	0,145	0,041
30	0,390	0,086	0,145	0,041
40	0,354	0,127	0,125	0,033
50	0,410	0,094	0,108	0,032
		Calculated F values		
Treatments	0.45^{ns}	3,89*	1.28^{ns}	2.41^{ns}
Blocks	0.47^{ns}	0.86^{ns}	1.14^{ns}	0.51^{ns}
Linear regression	0.67^{ns}	8,75*	1.17^{ns}	0.70^{ns}
Quadratic regression	0.10^{ns}	0.09^{ns}	0.23^{ns}	0.48^{ns}
CV (%)	31,68	32,52	31,15	23,07

CV = coefficient of variation, ns = not significant at 5% probability of error, * = significant at 5% probability of error, by the f-test.

An average of 0.127 kg m^{-2} of BSPA of sweet potato plants was obtained with a concentration of bovine manure of 40 Mg ha^{-1}, with an increase of 67% compared to that of the control (Figure 2). This behavior of accumulated phytomass by the leaves in relation to the time was expected because of the gradual release of nutrients. The variation in dry biomass is directly related to the leaf area of the plant, and its temporal variation, in general, increased to a maximum, which was maintained for some time and then decreased due to the senescence of the old leaves (SANTOS et al., 2010).

After harvesting, the dry biomass of the plants decomposes, mineralizes the nutrients present, improves the chemical characteristics of the soil by providing nutrients for the next cycle, and improves the physical and structuring components of the soil. The addition of organic matter to the soil promotes positive effects because it promotes improvements in exchange capacity of the bases and greater availability of nutrients to the plant for a long period, and these effects are evidenced in soils with low cation exchange capacity (CTC) (SILVA, 2018).

The BFR values of tuberous roots presented an average value of 0.154 kg m^{-2} in the control and did not differ from that of other treatments (Table 2). The production of sweet potato plant is linked to the accumulation of biomass in the roots. The beginning of early tuberization and high rate and longer period of biomass accumulation in the roots contributed to the increased productivity. This increase in the average biomass of tuberous roots may be associated with organic sources, that is, the increased addition of bovine manure. Moreover, the soil physical properties were improved (OLIVEIRA et al., 2013).

A mean BSR of 0.41 kg m^{-2} was obtained using 20 mg ha^{-1} of bovine manure (Table 2), and the value was not different from that of the control. This value is possibly related to the balanced supply of nutrients provided by the bovine manure applied. Generally, the nutrients present in organic fertilizers, especially N and P, are released slowly, depending on the mineralization of organic matter, ensuring availability of nutrients over time (OLIVEIRA et al., 2010).

Table 3 shows the total productivity, commercial productivity, root diameter, root length, number of commercial roots, and insect damage of sweet potato. Figure 3 shows that the data were adjusted to the quadratic model with $R^2 = 0.82$. The total yield of the roots (small and large) of sweet potato, obtained with the use of 10 Mg ha^{-1} of bovine manure, was 25.23 Mg ha^{-1}. The results obtained in the present study were higher than those found by Rós et al. (2014), when they used poultry manure and combined organic and mineral fertilizations in the production of tuberous roots. The yield of 25.23 Mg ha^{-1} obtained in this study resulted in an increase of 10.68% or 2.67 Mg ha^{-1} compared to the productivity obtained with the control treatment and other treatments with concentrations higher than 10 Mg ha^{-1} of bovine manure, respectively.

The positive results obtained from the use of bovine manure may be related to the predominant role of organic matter in nutrient supply, elevation of soil moisture, improvement of soil structure, and increase in cation exchange capacity. The stabilization and decrease in sweet potato yield may be related to the increase in manure concentrations and consequently the excess nutrients supplied to the crop, enhancing the growth of branches excessively at the detriment of tuberous root formation (SANTOS et al., 2006).

There was no significant difference in the concentrations of bovine manure used for the commercial productivity of sweet potato roots. The application of 10.0 Mg ha^{-1} of bovine manure resulted in the best mean, which was 7.0 Mg ha^{-1} for CP, (Table 3). The low root yield may be related to the high rainfall index that occurred in the first month of crop development during the experiment. Even though there was no difference between the concentrations used, the productivity of 7.0 Mg ha^{-1} obtained with the application of 10.0 Mg ha^{-1} of bovine manure was higher than that obtained in Maranhão (only 3.0 Mg ha^{-1}), which is low compared to the national productivity of the crop (IBGE, 2018). The commercial yield values of sweet potato roots were comparable to the values found by Oliveira et al. (2013), who obtained an average of 8.0 Mg ha^{-1} of sweet potato, using organic fertilizer, poultry, and cattle manure.

TABLE 3 - Summary of the analysis of variance of total productivity (PT), commercial productivity (CP), root length (CR), root diameter (DR), number of commercial roots (NRC), and insect damage (ICD) of sweet potatoes.

Concentrations of bovine manure (Mg ha^{-1})	EN (Mg ha^{-1})	PC (Mg ha^{-1})	CR (cm)	DR (mm)	NRC (1x10^3 ha^{-1})	DCI (mm)
0	22,55	6,07	7,78	56,38	50,00	1,00
10	25,23	7,02	13,31	47,61	79,76	1,00
20	17,73	5,05	12,49	53,70	57,14	2,00
30	21,48	6,19	13,87	56,54	58,33	1,00
40	20,29	5,65	14,08	48,90	58,33	1,00
50	15,71	4,64	12,98	61,14	55,95	1,00
Calculated F values						
Treatments	0.98^{ns}	0.54^{ns}	5,20*	1.36^{ns}	1.41^{ns}	2.69^{ns}
Blocks	1.68^{ns}	1.22^{ns}	0.31^{ns}	2.00^{ns}	2.12^{ns}	1.01^{ns}
Linear Regression	2.98^{ns}	1.11^{ns}	11,90*	0.69^{ns}	0.22^{ns}	0.00^{ns}
Quadratic Regression	0.13^{ns}	0.16^{ns}	9,48*	1.56^{ns}	0.80^{ns}	4,79*
CV (%)	37,37	44,47	18,49	18,10	32,05	33,11

CV = coefficient of variation, ns = not significant at 5% probability of error, * = significant at 5% probability of error, by the F-test.

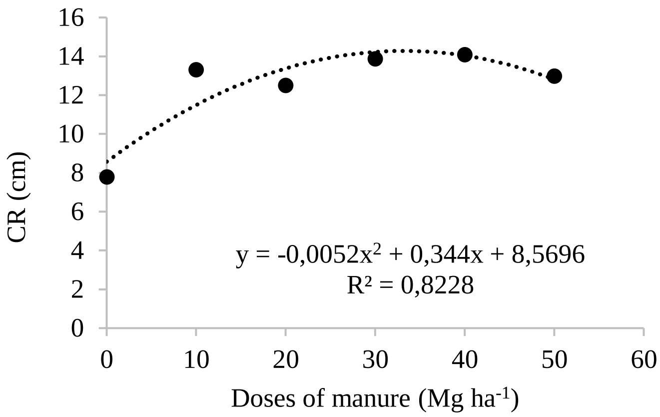

FIGURE 2 - Length of tuberous roots (CR) of sweet potato according to different concentrations of bovine manure used in the production.

The value of CR obtained with the use of 40.0 Mg ha^{-1} of bovine manure was 14.08 cm (Figure 3), and this fit into the pattern of the Brazilian consumer (between 13 and 15 cm), because very large or small sweet potato roots are not desirable. The dose of 40.0 Mg ha^{-1} resulted in better root development, because the bovine manure improved the physicochemical characteristics of the soil and resulted in favorable conditions for root development.

For DR, there was no difference between the concentrations of manure used; however, 50.0 Mg ha^{-1} improved the soil conditions to increase the diameter of the roots (Table 3). DR was influenced by the high rainfall index during the period and resulted in the formation of thin and elongated tuberous roots, because the crop does not tolerate excess moisture in the soil (ERPEN et al., 2013). The NRC obtained with the use of 10.0 Mg ha^{-1} of bovine manure reached an estimated maximum value of 79,760, a value higher than the estimated values of 48,100–73,500 units ha^{-1} obtained by Rós et al. (2013) in an area where soil tillage was reduced and under several production systems.

Regarding the damage caused by insects, there was no difference between the manure concentrations used. There was a greater number of roots free of damage and had desirable commercial aspect, a factor of paramount importance, because consumers observe the visual aspect of product at the time of purchase before making the decision to buy or not. Goto and Hora (2010) reported that 70% of the decisions to purchase fruits and vegetables are based on the visual aspect of the product. The low rate of attack or deformation of the roots is related to the good management of the crop during the production cycle.

The use of bovine manure fertilization in sweet potato production is a practice of paramount importance to improve the productive potential of the crop; therefore, it is necessary to develop this area to have accurate doses that are scientifically recommended for producers, especially family producers.

CONCLUSIONS

Bovine manure can be used as a source of organic fertilizer in the range of 10.0-20.0 Mg ha^{-1}.

The manure at 10.0 Mg ha^{-1} concentration resulted in sweet potato ('Beauregard') root yield of 7 Mg ha^{-1}, which was higher than the average yield in the state of Maranhão, Brazil.

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