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Yield and postharvest quality of 'common' arrowroot plants subjected to biofertilization

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Abstract

Arrowroot (*Maranta Arundinaceae* L.) is an unconventional vegetable crop with great economic potential but little knowledge regarding its mineral nutrition. This study aimed at assessing yield and postharvest of 'common' arrowroot subjected to different sources and doses of organic fertilizers. The split-plot experiment was laid out in four blocks of two main plots, each split into five sub-plots. The fertilizer sources (bovine and ovine manure) were applied to the main plots, whereas five doses of each liquid fertilizer (0; 300; 600; 900 and 1,200 mL plant^{-1} week^{-1}) were applied to the sub-plots. Number of rhizomes (NR), fresh mass of rhizomes (FMR), dry mass of rhizomes (DMR), average rhizome weight (ARW), rhizome yield (RY), rhizome length (RL), and rhizome diameter (RD) were measured. Better results for RY, FMR, and RL of 'common' arrowroot plants were observed for the bovine compared to the ovine biofertilizer. Fertilizer doses varying from 737 to 1,200 mL plant^{-1} week^{-1} are recommended to maximize yield and postharvest quality of 'common' arrowroot. RY of 212.51 t ha^{-1} and 207.1 t h^{-1} were achieved when 1,200 mL plant^{-1} week^{-1} of bovine and ovine manure were applied to pot-grown arrowroot plants, respectively.

Keywords: organic fertilizer, unconventional vegetable crop, rhizome

Introduction

Arrowroot (*Maranta Arundinaceae* L.) is an herbaceous, perennial, rhizomatous plant considered hardy (Souza et al., 2018). The arrowroot crop has a high versatility in use due to the unique properties of the starch extracted from its rhizome, which can be used as a texturizer, thickener, stabilizer, moisture retainer, and gelatinizer. Arrowroot is also appreciated for its medicinal benefits in treating gastrointestinal disorders, besides having good digestibility and being gluten-free (Maulani & Hidayat, 2016).

Because of arrowroot's high commercial value and the fact that arrowroot cultivation does not require high investments in technology due to the crop rusticity, the revival of arrowroot farming has been highly recommended to small-scale growers (Vieira et al., 2015).

The replacement of synthetic fertilizers by organic fertilizers in vegetable cultivation is considered a viable alternative from an economic point of view. Organic fertilization using animal manure, such as ovine manure, provides significant amounts of calcium and magnesium to the plants, which are considered adequate for vegetable growth and nutrition (Souza et al., 2014). Moreover, pH values of ovine manure are close to neutrality, favoring the supply of other nutrients, including nitrogen and phosphorus, to the crops (Souza et al., 2014).

In Brazil, crop fertilization with bovine manure has stood out due to its benefits in both vegetable yield and quality, highlighting its potential use to enhance yield of tuberous crops, especially those grown in nutrient-poor soils (Oliveira et al., 2017), as observed for the yam crop (Silva et al., 2012).

The use of biofertilizers from bovine and ovine manure can be an important nutrient source for plants, especially in small-scale farming areas (Souto et al., 2015).

Therefore, this work aimed to assess the influence

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of different sources and increasing doses of liquid biofertilizer on yield and postharvest quality of 'common' arrowroot.

Materials and Methods

The experiment was conducted at the Piróas' Research Farm Unit (PRFU) belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB), from November, 2018 to August, 2019. PRFU is located in the community Piroás, belonging to the district of Barra Nova, in the municipality of Redenção/CE.

The site comprises the biomes Caatinga and Atlantic Forest, and it is characterized by a hot, dry, semi-arid climate, with average temperatures of 27° C. Climatic data for the PRFU revealed average annual precipitations of 117.86 and 122.73 mm, for the 2018 and 2019 agricultural years, respectively.

For planting, 10cm-rhizomes of arrowroot (*Maranta arundinaceae* L.), variety 'common', obtained from the PRFU were used. The rhizomes were planted into 39.5 L-pots, with upper and lower diameters of 36.6 and 27.0 cm, respectively, and 50 cm in height. Pots were filled with a 5 cm n.1 gravel-layer to improve water drainage and a 38 cm-layer of a mixture of local soil and washed sand (2:1).

The local soil used in the pots was classified as sandy-clay (Santos et al. 2018). Soil chemical attributes of the 0−0.20 m layer were: $P_{\text{Mehlich 1 extractable}}$ 44 mg dm^{-3}; K, Ca, Mg, H + Al, sum of bases, and cation exchange capacity (CEC) 1.97; 21.36; 6.57; 2.00; 11.03; 31.9; 42.93 mmolc dm^{-3}, respectively; pH (1:2.5 soil/$CaCl_2$ suspension 0.01 mol L^{-1}) 6.06; Carbon 3.46; and organic matter 5.97 g kg^{-1}. Base saturation 74.66%; Exchangeable sodium percentage 4.33%; and electric conductivity 0.62 dS m^{-1}.

The experiment was arranged in split plot based on randomized block design, with four blocks and three useful plants per block, totaling 120 plants. Two organic sources of animal manure (bovine and ovine manure) were applied to the main plots, whereas five increasing doses of liquid biofertilizer (0; 300; 600; 900 and 1,200 mL plant^{-1} week^{-1}) were applied to the sub-plots.

Biofertilizers were produced by adding 100 L of fresh bovine or ovine manure (depending on the treatment), 30 L of chicken manure, 5 L of coal ash, and 270 L of water to 500 L- water tanks, followed by homogenization and decomposition for 30 days (Pereira et al., 2019). Chemical characterizations are shown in Table 1.

Table 1. Chemical characterizations of the biofertilizers.

Biofertilizer	------------- Macronutrients -------------						-------- Micronutrients --------					
	------------------------ g L^{-1} ------------------------						----------------- mg L^{-1} -----------------					
	N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B	Na
Bovine	1.06	0.47	0.05	1.91	0.49	0.01	194	6	2	27	1	205
Ovine	0.32	0.17	0.05	0.74	0.28	0.00	58	2	0	8	1	188

	EC (dS m^{-1})	----------------- % -----------------			
		C	O.M.	C/N	pH
Bovine	6.14	1.09	1.97	10	7.01
Ovine	7.47	0.17	0.31	5	6.91

Biofertilizer doses were applied to arrowroot plants twice a week with the use of a graduated container, starting on the 42nd day after planting (DAP). The liquid fertilizer was poured into 30 cm-long PVC pipes, placed inside the pots and next to the plants, at a depth of 10 cm. This technique improves fertilizer infiltration and hence absorption by roots.

Water was provided to plants through a drip irrigation system at an average flow rate of 8 L h^{-1}. A test to assess irrigation uniformity was performed according to the methodology proposed by Christiansen (1942). 92.45% was the irrigation uniformity recorded. Irrigation time was calculated according to the evaporation of the class A-pan in a daily frequency.

Plants were harvested 272 DAP when they reached the 50%-leaf senescence stage, indicated by the yellowing of leaves followed by leaf fall. Number of rhizomes (NR), rhizome length (RL), rhizome diameter (RD), fresh mass of rhizomes (FMR), dry mass of rhizomes (DMR), average rhizome weight (ARW), and rhizome yield (RY) were measured.

NR was quantified per plant. RL was measured using a ruler, and RD was measured using a digital caliper, both variables expressed in centimeters. For FMR, we weighed the rhizomes at harvest time using an analytical balance. After FMR measurements, rhizomes were dried out at 65-70° C in an air-forced circulation oven to constant weight to obtain DMR, expressed in grams. RY was based on FMR and plant stand, according to the spacing we adopted in this experiment. To calculate plant density, we divided 10,000 m^2 (1 hectare) by 0.098 m^2, which is the area occupied by each pot, so that plant stand was equal to 102,040 plants ha^{-1}. Arrowroot production fields often adopt 0.8 x 0.5 m between-row and in-row spacing, respectively, which is equivalent to 25,000 plants ha^{-1}.

To test the effects of fertilizer sources and doses as well as their interaction in the studied variables, NR, RL, RD, FMR, DMR, ARW, and RY data were subjected to analyses of variance. When significant by the F test (P<0.05), a mean comparison test was used for the qualitative factor (biofertilizer sources), and a regression analysis was used for the quantitative factor (biofertilizer doses).

Results and Discussion

The biofertilizer source effect was significant for RL (Table 2). The biofertilizer dose effect was significant for NR, DMR, and RD. FMR and RY showed significant effect for Source x Dose interaction (A) and biofertilizer doses (B). No significance between effects was found for ARW.

RL was 6.37% greater in bovine manure-based than in ovine manure-based biofertilizer treatments (Figure 1).

Table 2. Summary of the analyses of variance for number of rhizomes (NR), fresh mass of rhizomes (FMR), dry mass of rhizomes (DMR), average rhizome weight (ARW), rhizome yield (RY), rhizome length (RL), and rhizome diameter (RD) of ‘common’ arrowroot subjected to fertilization with different sources and doses of biofertilizers.

Source of variation	DF	Mean squares						
		NR	FMR	DMR	ARW	RY	RL	RD
Blocks	3	50.62^{ns}	0.040^{ns}	0.003^{ns}	0.0001^{ns}	409.24^{ns}	4.16^{ns}	2.19^{ns}
Bioertilizer sources (A)	1	1.74^{ns}	0.0001^{ns}	0.008^{ns}	0.0001^{ns}	0.56^{ns}	27.09*	9.12^{ns}
Error (A)	3	14.70	0.028	0.002	0.0001	289.92	1.96	1.28
Biofertilizer doses (B)	4	928.90**	2.80**	0.22**	0.0001^{ns}	29163.5**	10.09^{ns}	6.85**
Sources (A) x Bio (B)	4	48.26^{ns}	0.053*	0.001^{ns}	0.0001^{ns}	561.92*	5.21^{ns}	3.83^{ns}
Error (B)	24	32.22	0.014	0.003	0.0001	153.82	8.96	1.47
Total	39	-	-	-	-	-	-	-
CV(A) (%)	-	14.74	11.39	10.41	14.15	11.40	5.61	5.03
CV (B) (%)	-	21.82	8.30	12.42	16.39	8.30	12.01	5.40

DF: degrees of freedom; ** significant at 1% by the F test (p < 0.01); * significant at 5% by the F test (0.01 =< p < 0.05); ^{ns}: not significant by the F test.

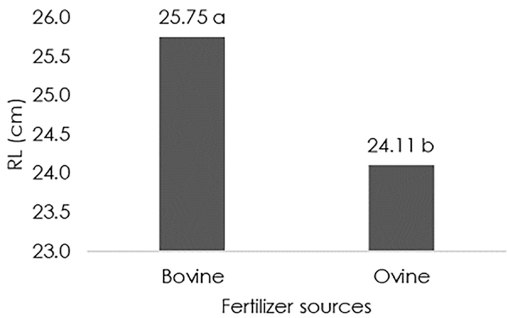

Figure 1. Rhizomes length (RL) of ‘common’ arrowroot as a function of bovine and ovine manure-based- biofertilizer sources.

It possibly happened because of the greater nitrogen concentration found for the bovine compared to the ovine biofertilizer. N concentration of the bovine biofertilizer was 1.06 g L^{-1}, whereas N concentration of the ovine biofertilizer was only 0.32 g L^{-1} (Table 1). N is a macronutrient that participates in several physiological processes in plant metabolism. According to Nunes et al. (2016), optimal N doses can favor root growth and hence influence the quality of tuberous roots due to increased leaf area, which maximizes photosynthetic efficiency. These factors may have led to an increase in carbohydrate flow to the roots, improving growth. Similar root length (23.35 cm) was verified by Vieira et al. (2015) in arrowroot plants grown under nutrient-rich soil.

Our results indicate that organic fertilization is a promising strategy for the development of tuberous vegetables. Nutrients of organic fertilizers become available to the plants throughout the growing cycle as they are mineralized. This makes organic fertilization more effective than mineral fertilization since losses by leaching and volatilization are avoided in the former (Rós et al., 2013).

The regression analysis for NR (Figure 2A) as a function of biofertilizer doses indicates that data fitted into an increasing linear model. NR varied from 10 to 38 rhizomes per plant, with the highest number (38 rhizomes) found for the highest biofertilizer dose applied (1,200 mL $plant^{-1}$ $week^{-1}$). DMR (Figure 2B) and RD (Figure 2C) data as a function of biofertilizer doses fitted into a quadratic polynomial model. Highest DMR (0.57 g $plant^{-1}$) was recorded at the 1,000 mL $plant^{-1}$ $week^{-1}$ dose. Highest RD (23.13 cm) was recorded at the 737.5 mL $plant^{-1}$ $week^{-1}$ dose.

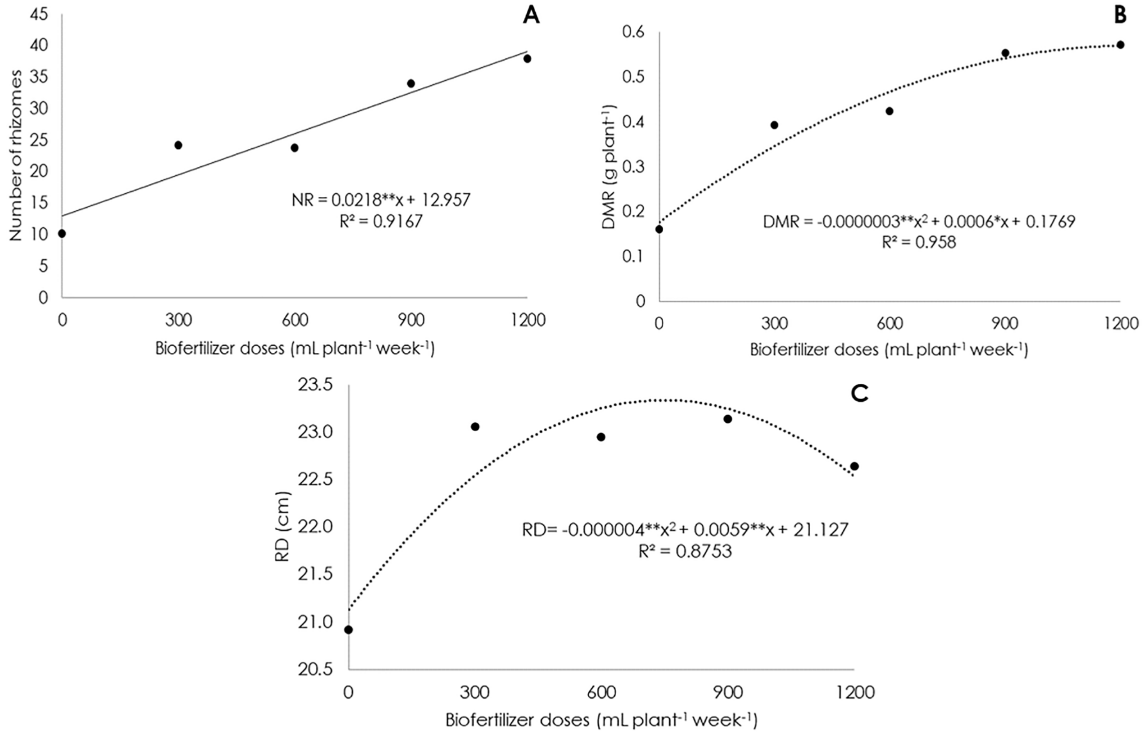

Figure 2. Number of rhizomes (NR) (A), dry mass of rhizomes (DMR) (B), and rhizome diameter (RD) (C) of 'common' arrowroot plants as a function of increasing doses of biofertilizers.

The increase in NR was proportional to the increase in the biofertilizer dose applied, probably because organic manure provides, in a balanced way, all nutrients a plant needs to maximize its productivity (Oliveira et al., 2013). NR may have been influenced by the adequate amount of P supplied to the crop by the biofertilizer solution since this nutrient is an important root growth stimulator (Dias et al., 2017).

The maximum NR obtained in this study (38 rhizomes) exceeded the maximum NR found by Vieira et al. (2015) at 150 DAP (18.9 rhizomes per plant). We believed that the low NR found by Vieira et al. (2015) could not be attributed to early harvesting because arrowroot rhizomes are formed at 105 DAP approximately. After this period, plants stop producing rhizomes and start rhizome filling (Pereira, 2019).

The response pattern observed for DMR may indicate that arrowroot plants are efficient in photoassimilate distribution as the source-drain relationship enabled its reserve organs, the rhizomes, to develop satisfactorily. Zárate et al. (2012) hypothesized that translocation of photosynthates to the mother rhizomes and from them to the daughter rhizomes occurs when leaves begin the natural senescence process. Increased DMR may be associated with the N supply from the animal manure. This nutrient plays an essential role in leaf development and expansion, resulting in greater photosynthetic efficiency and greater dry mass accumulation. Dias et al. (2020) reinforced the influence of nitrogen on DMR by pointing out that N also has a structural function besides being part of organic compounds such as amino acids and proteins.

The decrease in RD observed in biofertilizer doses higher than 737.5 mL plant^{-1} week^{-1} can be explained by micronutrient-caused toxicity. Based on the chemical characterizations (Table 1), we observed that the biofertilizers contain high levels of micronutrients, especially iron and sodium. According to Mantovani et al. (2017), high levels of organic matter in the soil can lead to nutritional unbalances, which can often lead to soil salinization. It impairs crop development due to unbalances on its metabolism. Another hypothesis is competitive inhibition, which occurs when two nutrients compete for the same absorption site.

Promising results were recorded in carrot plants subjected to bovine and ovine manure-based biofertilization (Cabral et al., 2019). Thus, we speculate that with the application of balanced doses of biofertilizer (both bovine and ovine manure-based biofertilizers), the rhizomes could have grown more significantly, but the limited space (pot) plants grew in did not allow the rhizomes to expand.

The Source x Dose interaction was significant for FMR and RY (Table 2). FMR and RY data on both fertilizer sources fitted into linear models (Figure 3). Highest FMR (2.02 g and 2.08 g for the ovine and bovine manure-based biofertilizers, respectively) were recorded at the 1,200 mL plant^{-1} dose (Figure 3A). Highest RY observed in the bovine source (212.51 T ha^{-1}), and the ovine source (207.1 t h^{-1}) were recorded at the biofertilizer dose of 1,200 mL plant^{-1} week^{-1}.

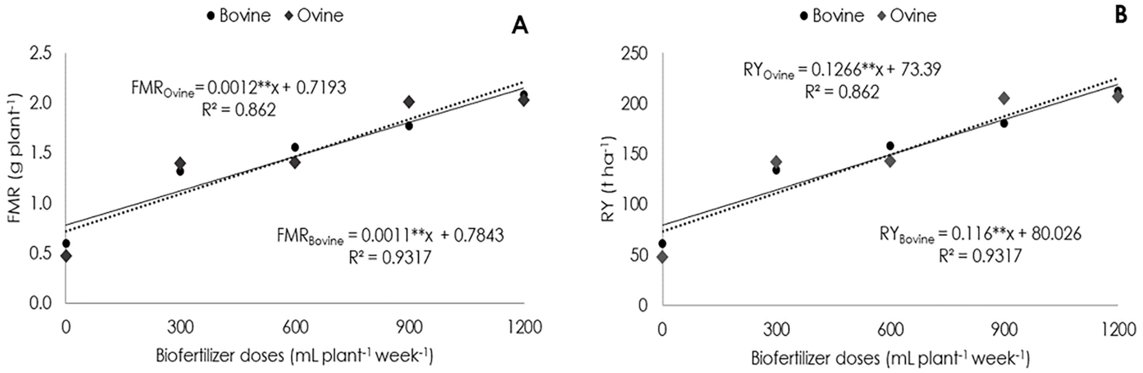

Figure 3. Fresh mass of rhizomes (FMR) (A) and rhizome yield (RY) (B) of 'common' arrowroot as a function of different sources and doses of biofertilizers.

FMR values recorded in this study are justified by the fact that the sources and doses of biofertilizer applied to the plants enabled their genetic potential to be expressed close to and/or at its maximum capacity. Pereira (2019) recorded 1.48 and 1.60 g planta^{-1} for the varieties Viçosa and Seta, respectively. Such lower values of FMR may also be associated with the intrinsic genetic characteristics of each cultivar, at which 'common' arrowroot stood out.

Barros Junior et al. (2019) attribute the effectiveness of organic fertilizer to its benefits to the soil, which can be direct, via nutrient supply, and indirect, via improvement of soil physical properties. Both benefits are crucial for roots to develop effectively and for the nutritional value of the arrowroot crop to increase.

RY of 'common' arrowroot increased by 71.1% with the application of 1,200 mL plant^{-1} week^{-1} of the bovine-based biofertilizer compared to the control (0 mL plant^{-1} week^{-1}). As for the ovine-based biofertilizer, RY increased by 76.7%.

RY for both biofertilizer sources is much greater in this study than in other studies performed for the arrowroot crop. We did not adopt the plant spacing commonly used in commercial arrowroot fields (0.8 m between rows and 0.5 m within rows), but the pot area (0.098 m^2) plants were grown, which makes the plant stand much larger. If RY were estimated using commercial plant spacing, it would be 52.06 and 50.74 t ha^{-1} for the bovine and ovine biofertilizer sources, respectively.

Although arrowroot cultivation in pots is still not widespread, it has great advantages. According to Melo et al. (2014), some of the advantages are better area usage, more efficient irrigation management, and better control of environmental conditions, which reduces problems with pests and diseases. In addition, growing arrowroot in pots results in better planting uniformity, as well as prevents competition for water and nutrients.

The yield value of the 'common' arrowroot recorded in this study suggests that the crop displays satisfactory performance when subjected to organic fertilization. Other works with organic fertilization in rhizomatous and tuberous plants have also shown its efficiency in increasing yield.

Silva et al. (2012), using organic fertilization based on bovine waste in yam cultivation, concluded that this type of fertilizer provides commercial rhizome yield, with maximum values between 22.8 and 24 t ha^{-1}, in which the highest dose of biofertilizer yielded high-quality rhizomes, considered adequate for exportation.

By comparing the efficiency of bovine manure compared to other non-organic nutrient sources in sweet potato cultivation, Leonardo et al. (2014) concluded that the use of bovine manure as nutrient source promoted commercial potato yields above the national average.

Silva et al. (2012) relate the increase in yield of starchy plants subjected to organic fertilization to the fact that the nutrient input achieved using animal manure improves the cation exchange capacity of soils. Considering that the adoption of organic fertilization in several works with tuberous vegetables maximized yield, we can infer that this method is an alternative not only to sustainable crop production but also to conventional farming.

Conclusion

The bovine manure-based biofertilizer is recommended over the ovine manure-based biofertilizer for arrowroot fertilization as it promotes better crop performance in terms of rhizome yield, fresh mass of rhizomes, and rhizome length.

The dose of 1,200 mL plant^{-1} week^{-1} of biofertilizer is indicated to maximize yield and postharvest quality attributes of 'common' arrowroot.

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