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Scientific Article

Production of commercial branches of roselle with organic and mineral fertilization and plant architecture pruning

Produção de ramos comerciais de vinagreira com adubação orgânica e mineral e poda da arquitetura da planta

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ABSTRACT - Roselle (*Hibiscus sabdariffa* L.) cultivation in tropical and subtropical regions is carried out by family farmers without the use of technology and with low yields. This study aimed to evaluate the use of organic and mineral fertilizers in roselle growth and nutrition in São Luís, State of Maranhão, northeastern Brazil. The experiment was conducted in a randomized block design in a factorial scheme [(7x2)+1]. The treatments consisted of seven doses of poultry litter (0.0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 L), six percentages of NPK (100.0, 83.3, 66.3, 49.9, 33.2, and 16.5%), and an additional treatment (poultry litter plus PK at maximum doses), with three replications. Split harvests were conducted at 75, 105, 135, and 165 days after transplanting. Fresh phytomass and the number of primary, secondary, and commercial branches were evaluated in each harvest. Fertilization with poultry litter increased fresh biomass production and the number of commercial branches per plant. Phytomass and the number of commercial branches decreased with an increase in the cutting interval in the split harvests. The poultry litter enhanced the efficiency of mineral fertilization in crop management, standing out the combination of 1.0 L poultry litter plant^{-1} plus 66.3% of the recommended NPK dose.

Keywords: Unconventional vegetables. Phytomass. Fresh matter accumulation.

RESUMO - O cultivo da vinagreira nas regiões tropicais e subtropicais é realizado pelos agricultores familiares sem o uso de tecnologia, com baixo rendimento. O objetivo desta pesquisa foi avaliar o uso de adubação orgânica e mineral no crescimento e nutrição da vinagreira. O delineamento experimental foi de blocos casualizados em esquema fatorial [(7x2)+1]. Os tratamentos foram sete doses de cama de frango (0.0; 0.5; 1.0; 1.5; 2.0; 2.5 e 3.0 litros), seis percentagens de NPK (100.0%, 83.3%, 66.3%, 49.9%, 33.2%, 16.5 %), e um tratamento adicional (cama de frango mais PK, nas doses máximas) com 3 repetições. Foram feitas colheitas parceladas aos 75, 105, 135 e 165 dias após o transplante (DAT). Em cada colheita avaliou-se a fitomassa fresca e o número dos ramos primários, secundários e comerciais. A adubação com a cama de frango aumentou a produção de fitomassa fresca e o número de ramos comerciais por planta. Ocorreu diminuição da fitomassa e dos do número de ramos comerciais com o aumento do intervalo de corte na colheita parcelada. A cama de frango potencializou a eficiência da adubação mineral no manejo da cultura, com destaque para a combinação dose de 1.0 L planta^{-1} de cama de frango mais 66.3% da dose recomendada de NPK.

Palavras-chave: Hortaliça não convencional. Fitomassa. Acumulação de matéria fresca.

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INTRODUCTION

Roselle (*Hibiscus sabdariffa* L.) belongs to the group of unconventional vegetables and the family Malvaceae. It is an important crop in tropical and subtropical countries, including Brazil, India, Saudi Arabia, Malaysia, Indonesia, Thailand, Philippines, Vietnam, Sudan, Egypt, and Mexico (GOMES et al., 2018; ISLAM, 2019; AL-SAYED et al., 2020).

This species is considered an antioxidant due to its nutraceutical value (DA-COSTA-ROCHA et al. 2014; DJAENI et al., 2018; NASRABADI; ZARRINGHALAMI; GANJLOO, 2018), in addition to being used as an adjuvant in the treatment of hypertension and cancer (RIAZ; CHOPRA, 2018) and in food security and nutritional richness (SINGH; KHAN; HAILEMARIAM, 2017; COELHO; AMORIM, 2019; SILVA et al., 2018; ISLAM, 2019; SALAMI; AFOLAYAN, 2021). Furthermore, it has enormous potential as a source of dye for the food industry and the production of fibers for the manufacture of burlap (SILVA; RÊGO; LEITE, 2014).

Importantly, all parts of the plant are edible and can be used for human and animal consumption, as well as an ornamental and medicinal plant (BRASIL, 2010; KINUPP; LORENZI, 2014).

Roselle leaves are largely consumed as a vegetable in Brazil, mainly in the State of Maranhão, where they are a traditional basic ingredient of the main dish of local cuisine, called cuxá. This delicacy has been considered a Brazilian Intangible Cultural Heritage since 2000 (CASTRO; DEVIDE; SALLES, 2019).

Roselle is cultivated in this region of the humid tropics mainly by family farmers without the use of technology, with mineral or organic fertilization being rare and, occasionally, manure and vegetable residues being used in random quantities. Likewise, branches with leaves are not selected for sale (GOMES et al., 2018). The harvest in Maranhão is performed manually by collecting the branches when the plant reaches an age between 60 and 90 days after planting, and the branches are cut to 40–50 cm in length and tied into bunches (BRASIL, 2010; GOMES et al., 2018).

There is no criterion regarding the number of branches that must be collected at each harvest or during the plant cycle, resulting in low productivity in fresh phytomass production and number of commercial branches. It is necessary to provide roselle production with a competitive and economical cultivation system, focusing on the most appropriate cultural practices, aiming to increase the production capacity and longevity of the crop (PINHEIRO et al., 2013; SILVA et al., 2018).

Organic fertilization may be a good option for small producers, as it increases productivity. Furthermore, it promotes the sustainability of rural properties through soil recovery and conservation by increasing the degree of aggregation, total porosity, and soil microbial biomass, among other benefits (DI LIU et al., 2021).

Studies on organic and mineral fertilization in roselle have been carried out by different authors, including Sousa, Boyle, and Bonito (2010), Ahmed, Shalaby, and Shanan (2011), Ramos et al. (2011a), Ramos et al. (2011b), El Naim et al. (2017), Kahil, Hassan, and Ali (2017), Al-Sayed et al. (2020), and Di Liu et al (2021), but there is no report on research with organic fertilization using poultry litter in roselle in the State of Maranhão.

In this context, this study aims to evaluate the effect of organic and mineral fertilization and pruning on the plant architecture, fresh phytomass, and the number of commercial branches of roselle.

MATERIAL AND METHODS

The research was conducted in the experimental area of the Fazenda Escola of São Luis of the Agricultural Sciences Center of the State University of Maranhão. The municipality of São Luís is located between the geographical coordinates 2°31′47″ South and 44°12′10″ West, with an altitude of 64 m (IBGE, 2016).

The climate is classified as Aw according to the Köppen classification, that is, a hot and humid equatorial climate with two well-defined seasons: a rainy season (January to June) and a dry season, with a water deficit (July to December). The mean annual precipitation ranges from 1,800 to 2,010 mm. The highest rainfall events are between January and April, reaching a mean of 250 mm per month. The local mean temperature is around 26.1 °C, with the maximum temperatures varying from 30.4 to 37.0 °C and the minimum ones between 20.0 and 23.3 °C, with a mean relative humidity of 88% (INMET, 2009).

The experiment was set up on soil classified as an Ultisol (Argissolo Vermelho-Amarelo distrófico), according to the Brazilian Soil Classification System (EMBRAPA, 2006). Soil samples were collected at a depth of 0–20 cm for the chemical characterization of soil fertility (Table 1). Poultry litter samples were also analyzed (Table 2). The analyses were performed at the Laboratory of Soil Chemical and Physical Analysis at the Technological Center for Rural Engineering/CCA/UEMA and Laboratory of Soil Chemistry and Fertility at DSER/CCA/UFPB, following the methodologies by EMBRAPA (1997).

Table 1. Soil chemical characterization at a depth of 0–20 cm in the experimental area. São Luís, MA, Brazil.

OM	pH	P	H +Al	K	Ca	Mg	SB	CEC	V
g dm^{-3}		mg dm^{-3}	------------------------------------cmol$_c$ dm^{-3}------------------------------------						--%--
17	4.9	107	34	0.5	24	7	31.5	65.5	48

Extraction method: OM: sulfuric acid; pH: $CaCl_2$ solution; P, K, Ca, and Mg: resin; H+Al: SMP buffer. SB = sum of bases (Ca + Mg + Na + K); CEC = cation exchange capacity [SB + (H^{2++} Al^{3++})]; V = soil base saturation value (SB/CEC)100. Source: Laboratory of Soil Chemistry and Physics. Technological Center for Rural Engineering. CCA/UEMA.

Table 2. Chemical analysis of the poultry litter used to fertilize the roselle plants. Areia, PB, Brazil.

OM	pH	P	K	H +Al	Na	Al	Ca	Mg	SB	CEC	V
g kg^{-1}	Water	mg dm^{-3}		------------------------------------cmol$_c$ dm^{-3}------------------------------------							%
527	8.1	1.821	7.738	1.57	18.15	0.0	5.90	2.20	46.04	47.61	96.7

SB = sum of bases (Ca + Mg + Na + K); CEC = cation exchange capacity [SB + (H^{2++} Al^{3++})]; V = soil base saturation value (SB/CEC)100. Malavolta, Vitti, and Oliveira (1997). Source: Laboratory Soil Fertility of DSER/CCA/UFPB.

The poultry litter came from an intensive broiler rearing collected after the exit of the poultry flock, whose rearing period was approximately 35 days per cycle. The chickens were raised in a shed on wood shavings substrate. The poultry litter was previously cured for 45 days, after which chemical analysis was carried out; subsequently, it was incorporated into the soil.

The experimental area measured 2.176 m^2, where the three blocks were distributed, each with 15 plots of 36.0 m^2 (6.0 m wide x 6.0 m long), with a useful area of 14.4 m^2 (3.6 m wide x 4.0 m long).

The roselle plants were planted at a spacing of 1.20 m between rows and 1.00 m between plants, and each plot consisted of five rows of six plants. The useful area of the plot was represented by the 12 central plants.

Roselle seeds of the variety Talo Roxo (GOMES et al., 2018) used for seedling production were acquired in the Cinturão Verde region of the municipality of São Luís (MA). Three seeds were sown at a depth of 1.0 cm per black polyethylene bag with a capacity of 500 g filled with a substrate composed of a mixture of black earth and poultry manure in a 3:1 ratio (v/v). The bags were maintained on benches in a protected environment under 50% shading.

Emergence started three days after sowing (DAS). The first thinning occurred 10 days after emergence (DAE), and two seedlings were left per bag, choosing those that were uniform in size and well distributed in the container. The second thinning was performed at 20 DAE, leaving only one plant per bag.

All cultural treatments inherent to seedling production were carried out during the seedlings' stay in the protected environment. Irrigations were performed daily using a system suitable for plant propagation for a period of 30 days when they were at the transplanting point and had a root system forming a clod.

The planting area was prepared through plowing and harrowing. Dolomitic limestone (calcium carbonate equivalent equal to 90%) was broadcast applied at a dose of 0.508 t ha^{-1}, half the dose before plowing and the other half before harrowing, incorporated into the 0–20-cm layer 60 days before planting.

Subsequently, the area was demarcated, and holes were made for planting the seedlings, with a spacing of 1.20 m between rows and 1.00 m between plants. The planting holes measured 30 x 30 x 30 cm and fertilization, based on poultry litter and mineral fertilizer, was mixed with the soil, and returned to the hole.

Mineral fertilization consisted of NPK (40–120–240 kg ha^{-1}), with nitrogen in the form of ammonium sulfate, phosphorus in the form of single superphosphate, and potassium in the form of potassium chloride, incorporated into the soil with the poultry litter at a depth of 0.20 cm five days before transplanting in the plots corresponding to the treatments. Transplanting to the field was conducted 35 days after germination when the seedlings had two to three pairs of true leaves.

Manual and mechanical weeding was carried out during the experiment to keep the area free of weedy plants, avoiding competition with the roselle plant. A drip irrigation system was installed under the plant canopy, with watering shifts in two daily periods lasting three hours each, at a flow rate of 38.68 cm^3 per minute, using a uniform amount of water for all plants, except on rainy days.

The experimental design consisted of randomized blocks in a factorial scheme [(7 x 2) +1], represented by seven doses of poultry litter (0.0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 liters), six percentages of NPK (100.0, 83.3, 66.3, 49.9, 33.2, and 16.5%), and an additional treatment (poultry litter plus PK at maximum doses), with three replications. Isolate or combined fertilizer treatments are detailed below (Table 3):

Table 3. Description of treatments. São Luís, MA, Brazil.

Treatment	Specification	Dose
01	No poultry litter and no mineral fertilizer (Control)	0.0
02	Poultry litter	0.5
03	Poultry litter	1.0
04	Poultry litter	1.5
05	Poultry litter	2.0
06	Poultry litter	2.5
07	Poultry litter	3.0
08	Mineral fertilizer (NPK)	100%
09	Poultry litter + NPK	0.5 + 83.3%
10	Poultry litter + NPK	1.0 + 66.3%
11	Poultry litter + NPK	1.5 + 49.9%
12	Poultry litter + NPK	2.0 + 33.2%
13	Poultry litter + NPK	2.5 + 16.5%
14	Poultry litter + NPK	3.0 + 100%
15	Poultry litter + PK	Recommendation

Treatments 2 to 7 received increasing amounts of poultry litter (0.5 to 3.0 kg $hole^{-1}$). Treatments 9 to 14 received decreasing NPK doses, expressed as percentages of the total, associated with poultry litter. Treatment 15 (additional) received the maximum quantity of poultry litter (3.0 L) and maximum amounts of phosphate (P) and potassium (K), with 72.0 g of single superphosphate and 48.0 g of potassium chloride, respectively. In terms of composition, ammonium sulfate with 21% N, single superphosphate with 19% P_2O_5, potassium chloride with 60% K_2O, and poultry litter with 3% N were considered.

The split harvesting of roselle plants began 75 days after transplanting (DAT), which was the initial date for the characteristic cutting interval. Fresh mass was obtained fractionally, with four cuts at 30-day intervals (75, 105, 135, and 165 days) and harvests in the morning.

Branches from three plants per treatment were collected using pruning shears, totaling 45 plants per replication, totaling 135 plants. The plants that had their branches collected were previously marked randomly with yellow nonwoven fabric tape. The phytomass was evaluated considering the cutting interval.

The main stem was cut in the split harvest and quantified together with the primary branches. The plants in the field had a main stem with a height of 40.0 cm after pruning and the primary branches were pruned at a distance of 15.0 cm from the main stem (Figure 1). All materials considered commercial branches were tied into bundles of six branches and donated for human consumption. The following harvests of commercial branches (105, 135, and 165 days) were provided by the shoots of primary and secondary branches pruned to 15.0 cm in length.

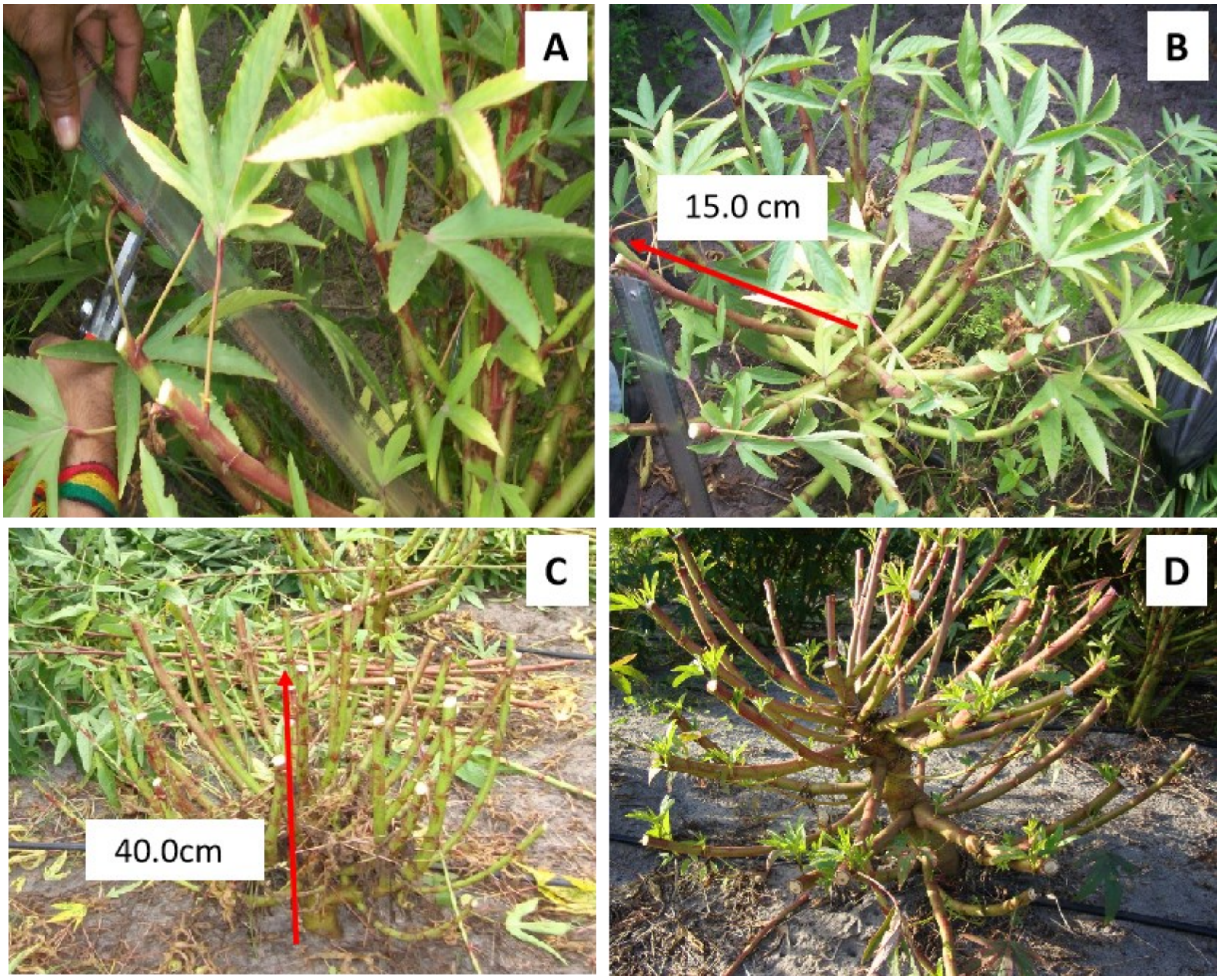

Figure 1. Detail of plant management: pruning of the main stem (A), shortening of the primary branches (B), main stem height (C), and sprouting of the primary branches after pruning (D) intended for the split harvests of roselle. São Luis, MA, Brazil.

Commercial branches produced from the primary branches were collected from three plants per treatment, ranging from 25 to 30 cm in length. Branches longer than 30 cm were reduced at the base to reach the appropriate measurement, which was taken from the stem apex. These branches were weighed on a 0.01g precision scale to obtain the fresh phytomass weight.

The branches produced from the primary branches that were within the measure adopted by producers for commercial branches were quantified.

The data were subjected to analysis of variance and regression analysis for poultry litter doses, testing linear, quadratic, and cubic effects. The mineral fertilizer was evaluated using the F-test. The analysis of variance was carried out after meeting the basic assumptions. Statistical analyses were processed by the software Statistical Analysis System – SAS (SAS, 2000).

RESULTS AND DISCUSSION

Number of commercial branches in the split harvest

The results of the analysis of variance for the number of commercial branches of roselle in the four harvests (75, 105, 135, and 165 DAT) showed a significant effect on the doses of poultry litter and the interaction between poultry litter versus mineral fertilizer. Only the mineral fertilizer at harvest at 75 days showed no statistical variation (Table 4).

Harvesting and counting of commercial branches started at 75 DAT (GOMES et al., 2018); the branches are marketed in bundles of three to four units. The mean was 33.00 branches plant^{-1} at this stage, in the absence of poultry litter (0.0 fertilization). Production at doses of 0.5 and 1.0 L poultry litter plant^{-1} was significant in favor of the combination of organic and mineral fertilizers. However, production increased from then on until the dose of 2.0 L plant^{-1} only using poultry manure, which reached 40.11 branches plant^{-1}, without differing from treatments combined with mineral fertilizer (Table 5).

Table 4. Summary of analyses of variance and mean squares of the number of commercial branches (NCB) of roselle in the split harvest at 75, 105, 135, and 165 DAT. São Luís, MA, Brazil.

Source of variation	DF	Mean square			
		Number of commercial branches (NCB)			
		75 DAT	105 DAT	135 DAT	165 DAT
Block	2	943.030**	3526.896**	669.119**	277.622**
Organic (Org.)	6	266.958**	465.571**	292.351**	91.482*
Mineral (Min.)	1	160.032^{ns}	1.657.531**	1194.794**	723.841**
Org. x Min.	6	104.735*	385.513*	257.368**	222.619**
ORG LINEAR	1	244.446*	38.335^{ns}	289.532*	8.643^{ns}
ORG QUADR	1	583.149**	960.333*	190.011^{ns}	44.024^{ns}
ORG CUBIC	1	225.148*	255.148^{ns}	10.704^{ns}	36.750^{ns}
Residual	28	41.161	154.358	72.533	38.630
CV (%)		18.46	42.92	41.05	44.11

^{ns}, *, and ** = not significant, significant at 5%, and significant at 1% probability, respectively, by the F-test. DAT: days after transplanting.

Table 5. Number of commercial branches of roselle plants as a function of poultry litter at the time of split harvest at 75, 105, 135, and 165 DAT. São Luís, MA, Brazil.

Poultry litter dose (L)	Number of commercial branches (NCB)							
	75 DAT		105 DAT		135 DAT		165 DAT	
	Without	With	Without	With	Without	With	Without	With
0.0	26.00b	33.00a	36.33b	104.67a	6.22b	24.89a	4.33b	18.22a
0.5	30.56b	37.22a	85.33a	80.33a	15.11a	15.78a	11.56a	11.11a
1.0	30.89b	37.44a	84.33b	129.67a	17.00b	30.33a	9.11b	24.44a
1.5	35.22a	33.00a	99.00a	88.67a	22.89a	19.33a	12.89a	11.89a
2.0	40.11a	35.00a	60.33a	74.33a	13.11a	18.11a	10.78a	10.33a
2.5	39.22a	42.00a	86.67a	100.00a	23.44a	26.56a	12.33a	17.56a
3.0	30.33a	30.44a	55.67a	82.33a	16.00a	21.89a	11.67a	12.67a

Means followed by the same letter in the row within each harvest season do not differ significantly from each other by the Tukey test at the 1% and 5% probability. DAT: days after transplanting. Without/With: without and with mineral fertilizer.

The number of commercial branches increased at 105 DAT, that is, 30 days after pruning to shorten the primary and secondary branches and change in the plant architecture, in response to the intense sprouting and the combination of organic and mineral fertilization. The treatment 1.0 L poultry litter plant^{-1} associated with mineral fertilizer (66.3% of the NPK recommendation dose) stood out at this stage, with a production of 129.67 branches plant^{-1} (Table 5).

A progressive decrease in the production of commercial branches in all treatments was observed in harvests at 135 and 165 DAT, which correspond to 4.5 and 5.5 months after planting, a fact also related to the beginning of plant senescence events. Likewise, the treatment 1.0 L poultry litter plant^{-1} associated with mineral fertilizer (66.3% of the recommended NPK dose) remained the most efficient in these two phases, producing 33.33 and 24.44 branches plant^{-1}, respectively (Table 5).

The results justify the use of organic fertilizer in roselle management, considering the obtained production and soil characteristics (sandy texture and low fertility) despite the rapid mineralization resulting from the region's hot and humid climate. In this particular case, poultry manure increased the mineral fertilizer use efficiency. The addition of poultry litter as top dressing at a rate of 10 t ha^{-1} influenced the antioxidant activity of *Hibiscus sabdariffa* L., regardless of the spacing (RAMOS et al., 2011a).

Similar studies but using legumes such as gliricidia have ensured ecological intensification in humid tropical soils with low natural fertility, providing ecosystem services such as biomass production, carbon sequestration, cation recycling, and increased N absorption (SENA et al., 2020).

El Naim et al. (2017) observed similar results in Egypt in research using organic fertilizers and spraying plants with humic acid. In addition, Ahmed, Shalaby, and Shanan (2011) conducted research in Egypt with soil mixed with compost or magnetic iron sprayed with humic acid and found a significant increase in commercial branches and the antioxidant activity of *H. sabdariffa* with organic fertilizer.

Kahil, Hassam, and Ali (2017) observed in Saudi Arabia that vegetative growth parameters, including the number of fruits per plant and sepal production were significantly increased with organic fertilization using biofertilizers *Azotobacter chroococcum* + *Azospirillum brasilense* as nitrogen-fixing bacteria and *Bacillus megaterium* var. *phosphaticum* + *Bacillus polymyxa* as phosphate solubilizing bacteria.

Ramos et al. (2011b) verified that the addition of poultry litter significantly increased the number of commercial branches per plant in Mato Grosso do Sul, Brazil, with branches reaching a linear growth of 32 cm compared to plants grown without poultry litter.

El Naim et al. (2017) conducted a study in Sudan using biofertilizers and observed that plants treated with organic fertilizers had a larger stem diameter, a higher number of leaves per plant, a higher number of commercial branches, a higher content of fresh and dry shoot phytomass, and a higher number of calyces per plant.

Regarding the regression, the mean number of commercial branches of roselle in the split harvest at 75 DAT was adjusted to the cubic model at a 5% probability level as a function of the poultry litter doses in the absence of mineral fertilizer. The maximum mean number for commercial branches was 40.11 branches, with an estimated maximum dose of 2.14 kg plant^{-1} (Figure 2A).

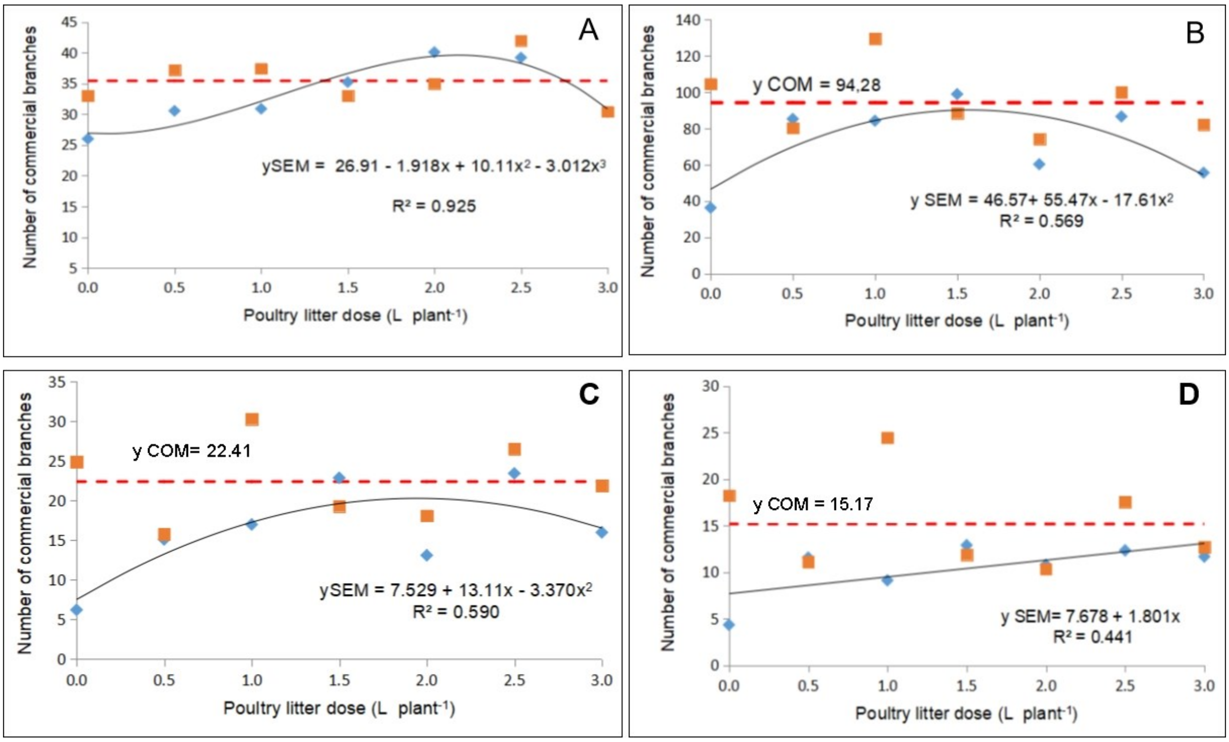

Figure 2. Number of commercial branches of roselle in the split harvest at 75 DAT (A), 105 DAT (B), 135 DAT (C), and 165 DAT (D) as a function of fertilization with poultry litter in São Luís, MA, Brazil.

The mean number of commercial branches of roselle in the split harvest at 105 DAT was adjusted to the quadratic model at a 5% probability level as a function of the poultry litter doses in the absence of mineral fertilization (Figure 2B). The maximum number of commercial branches at this stage of the crop was 99.00 branches per plant, with an estimated maximum dose of 1.57 kg poultry litter plant^{-1} (Figure 2B).

The mean number of commercial branches of roselle in the split harvest at 135 DAT was adjusted to the quadratic model at a 1% probability level as a function of the poultry litter doses in the absence of mineral fertilization (Figure 2C). The maximum number of commercial branches at this stage was 23.44 branches, with an estimated maximum dose of 1.95 kg poultry litter plant^{-1}.

The mean number of primary branches of roselle plants in the last harvest carried out at 165 DAT, was adjusted to the linear model as a function of the poultry litter doses without mineral fertilization. The highest value was 12.89 branches per plant, achieved by increasing doses of poultry litter (Figure 2D). The progressive decrease in the production of commercial branches is confirmed between 135 and 165 DAT.

Fresh phytomass of commercial branches in the split harvest

The results of analysis of variance for the fresh phytomass of commercial branches of roselle in the four harvests (75, 105, 135, and 165 DAT) were significant at the 1 and 5% levels for the poultry litter doses, poultry litter associated with mineral fertilization, and the interaction between poultry litter versus mineral fertilizer. No significant difference was observed for mineral fertilizer doses at 75 DAT and the interaction at 105 DAT (Table 6). In general, the behavior of this variable was similar to that observed for the number of commercial branches, as the fresh phytomass refers to the harvested branches depending on the treatments.

Table 6. Summary of analysis of variance, regression analysis, and mean squares of fresh phytomass of commercial branches of roselle in the split harvests at 75, 105, 135, and 165 DAT in São Luís, MA, Brazil.

Source of variation	DF	Mean squares			
		Commercial branch phytomass			
		75 DAT	105 DAT	135 DAT	165 DAT
Block	2	0.952**	0.284**	0.060**	0.015**
Organic (Org.)	6	0.360**	0.047**	0.028**	0.012**
Mineral (Min.)	1	0.245^{ns}	0.190**	0.176**	0.089**
Org. x Min.	6	0.190*	0.021^{ns}	0.027**	0.020**
ORG LINEAR	1	0.757**	0.004^{ns}	0.006^{ns}	0.001^{ns}
ORG QUADR	1	0.745**	0.083**	0.014^{ns}	0.013*
ORG CUBIC	1	0.163^{ns}	0.030^{ns}	0.020^{ns}	0.005^{ns}
Residual	28	0.067	0.012	0.007	0.003
CV (%)		19.10	34.64	36.53	32.63

^{ns}, *, and ** = not significant, significant at 5% probability, and significant at 1% probability, respectively, by the F-test. DAT: days after transplanting.

The fresh phytomass of commercial branches of roselle plants was significantly affected by mineral fertilization associated with organic fertilizer at the beginning of harvest (at 75 DAT) compared to the absence of organic fertilization (0.0 L poultry litter plant^{-1}). This situation was repeated in the treatment of 1.0 L poultry litter plant^{-1} associated with mineral fertilization at the same stage and 1.0 L poultry litter plant^{-1} associated with mineral fertilization at 135 and 165 DAT (Table 7).

Table 7. Fresh phytomass of commercial branches of roselle as a function of poultry litter in the split harvest at 75, 105, 135, and 165 DAT. São Luís, MA, Brazil.

Poultry litter dose (L)	Fresh phytomass of commercial branches (kg plant^{-1})							
	75 DAT		105 DAT		135 DAT		165 DAT	
	Without	With	Without	With	Without	With	Without	With
0.0	0.97b	1.26a	0.17	0.31	0.11b	0.27a	0.07b	0.20a
0.5	1.22a	1.31a	0.29	0.30	0.18a	0.20a	0.13a	0.14a
1.0	1.18b	1.49a	0.28	0.48	0.19b	0.39a	0.13b	0.29a
1.5	1.48a	1.26a	0.31	0.33	0.22a	0.22a	0.16a	0.15a
2.0	1.39a	1.42a	0.24	0.28	0.15a	0.21a	0.14a	0.15a
2.5	1.45a	1.68a	0.31	0.39	0.23a	0.26a	0.15a	0.19a
3.0	1.31a	1.19a	0.24	0.30	0.19a	0.24a	0.14a	0.16a

Means followed by the same letter in the row within each harvest season do not differ significantly from each other by the Tukey test at the 1% and 5% probability. DAT: days after transplanting. Without/With: without and with mineral fertilizer.

This variable maintained the already observed trend of higher roselle production efficiency with the strategy of combining organic with mineral fertilizers, standing out the treatment of 1.0 L poultry litter plant^{-1} plus NPK (66.3% of the recommended dose). A decrease was also observed in the harvested phytomass production throughout the crop cycle in all treatments (Table 7).

Sousa, Boyle, and Bonito (2010) observed significant effects of fertilization with poultry litter on the phytomass production of commercial branches, plant height, and the number of fruits per plant in a study carried out in Roraima, Brazil.

Al-Sayed et al. (2020) also observed similar results in Egypt in research carried out with biofertilizers, with an increase of 5.89% in the fresh phytomass of commercial branches and a significant increase in growth, nutrient uptake, yield, and quality of plants.

El Naim et al. (2017) and Ahmed, Shalaby, and Shanan (2011) reported a significant increase in the fresh phytomass of commercial branches and the anti-oxidant activity, while Di Liu et al. (2021) reported significant effects on the phytomass of commercial branches using an organic compost.

A quadratic model was observed for the adjustments of the regression curves of the mean fresh phytomass of commercial branches at 75, 105, and 165 DAT, whereas a linear model was observed at 135 DAT (Figures 3A, B, C, and D).

The maximum mean phytomass of commercial branches in the split harvest carried out at 75 DAT was 1.48 kg plant^{-1}, with a maximum dose estimated by derivatives of 2.08 kg poultry litter plant^{-1} without mineral fertilizer (Figure 3A).

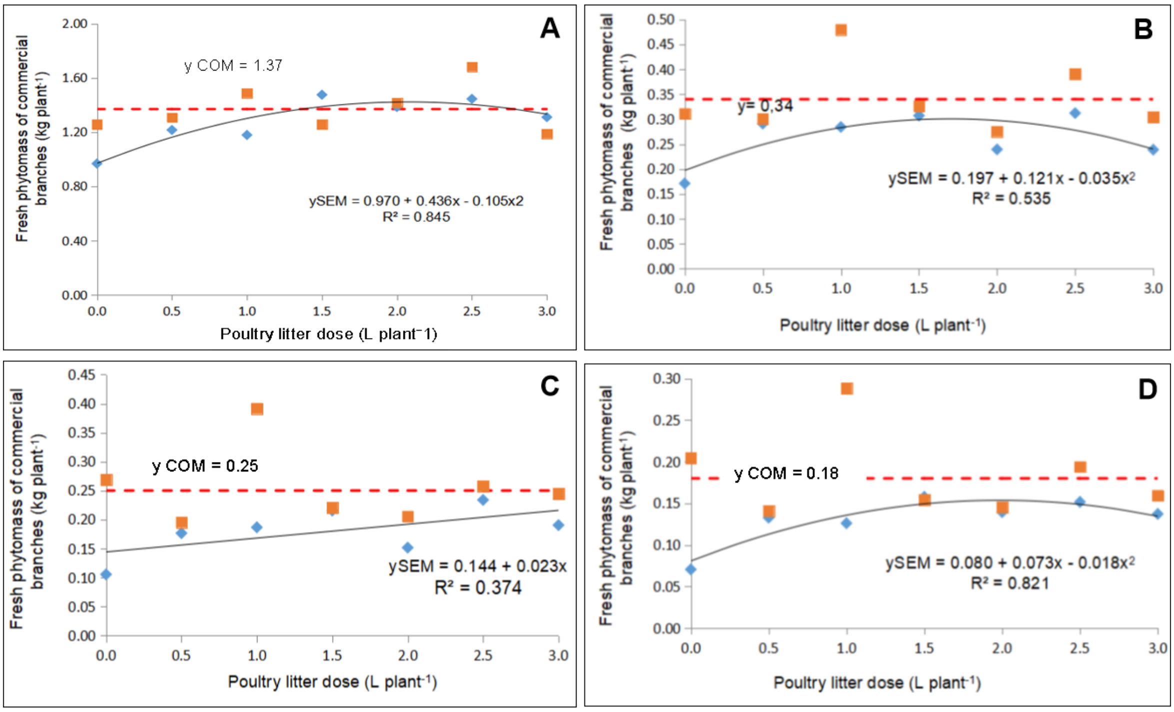

Figure 3. Fresh phytomass of commercial branches of roselle in the split harvests at 75 DAT (A), 105 DAT (B), 135 DAT (C), and 165 DAT (D) as a function of fertilization with poultry litter in São Luís, MA, Brazil. DAT: days after transplanting.

The maximum mean phytomass of commercial branches was 0.31 kg plant^{-1} in the harvest carried out at 105 DAT, with an estimated maximum dose of 1.73 kg poultry litter plant^{-1} without mineral fertilizer (Figure 3B). The linear model as a function of poultry litter doses showed that the maximum phytomass of commercial branches of roselle at 135 DAT was 0.23 kg plant^{-1}, achieved by increasing doses of poultry litter (Figure 3C).

The mean fresh phytomass of commercial branches of roselle plants in the split harvest at 165 DAT was adjusted to the quadratic model at a 5% probability level as a function of the poultry litter doses without mineral fertilizer. The maximum mean phytomass of commercial branches was 0.16 kg plant^{-1} at this stage, with an estimated maximum dose of 2.03 kg poultry litter plant^{-1} (Figure 3D).

The highest productivity was achieved 105 days (3.5 months) after planting for the adopted management, following pruning to shorten the primary and secondary branches.

CONCLUSION

Poultry litter promoted a significant increase in phytomass and the number of commercial branches of roselle in doses between 1.5 and 2.0 L plant^{-1}. Poultry litter enhanced the efficiency of mineral fertilization in crop management, standing out the combination of the dose of 1.0 L poultry litter plant^{-1} plus 66.3% of the recommended NPK dose. The production of phytomass and commercial branches reduced as the harvest time increased.

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