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Kale density grown in an organic production system

Sebastião Elviro de Araújo Neto*, Andressa Sampaio Marreiro,
Regina Lúcia Félix Ferreira, Luís Gustavo de Souza e Souza, Isadora Costa da Silva Brito

Federal University of Acre, Rio Branco, Acre, Brazil
*Corresponding author, e-mail: gustavo_souza_fj@hotmail.com

Abstract

The study aimed to assess the leaf yield and economic indicators of organic kale cultivation in relation to plant density. The experiment was conducted at the Seridó Ecological Site in Rio Branco, AC. The seedlings were produced using seeds, substrate, and plastic cups. Plants were grown in a plant nursery with 2 m of lateral ceiling height and 3.5 m of central ceiling height, covered with a 100 μ transparent film. Planting was performed at the densities of 3.6, 4.2, 5.0, 6.3, and 8.3 plants m^{-2}, in triple rows spaced 0.40 m from each other and 0.50 m between triple rows. Within the row, plants were spaced 0.30 m, 0.40 m, 0.50 m, 0.60 m, and 0.70 m. The following parameters were evaluated: leaf fresh mass, leaf fresh mass per plant, number of bunches, fixed, variable, and total costs, mean total cost, net and total revenues, family labor remuneration, profit rate, profitability index, production for full coverage, and benefit to cost ratio. The increase in plant density reduced the leaf fresh mass and the leaf fresh mass per plant and increased the leaf yield per unit area. The highest yield achieved with the increase in plant density linearly reduced the mean cost of kale leaf bunches while linearly increased the net and total revenues, the remuneration of family labor, the profit rate, the profitability index, the minimum yield for full cost coverage, and the variable and total costs.

Keywords: *Brassica oleracea* var. acephala. Organic agriculture. Spacing

Introduction

Kale (*Brassica oleracea* var. acephala) belongs to the family Brassicaceae. Its leaves are arranged continuously in a rosette around the stem (Filgueira, 2013) and have nutritional and nutraceutical properties, achieving their highest antioxidant potential with organic cultivation and dry heat leaf treatment (Rigueira et al., 2016).

Usual in conventional agriculture, synthetic nitrogen fertilizers are known to accelerate plant growth. However, in organic cultivation, without fertilizers of high concentration and solubility and in the absence of agrochemicals, farmed products have higher contents of vitamin C, antioxidants, phenolic compounds, minerals, and longer shelf life, with lower nitrate contents (Mditshwa et al., 2017). Moreover, fair prices are guaranteed for organic products when sold in short circuit trade networks (Darolt et al., 2016).

Organic fertilization is a conservationist technique that reduces production costs, both due to the direct effect of using organic inputs in replacement to external and more extensive inputs (Uchoa et al., 2021) and the indirect effect resulting from increased soil organic matter, favoring higher soil moisture and nutrient uptake, lower soil and nutrient losses, and less machinery use over time (Fortini et al., 2020).

In organic lettuce cultivation, both less and more expensive production techniques do not provide sufficient yields for higher economic return, and it is necessary to find a balance between increased costs with technological inputs and increased income as a response to higher yields, resulting in increased profitability (Tomio et al., 2021). From this perspective, in addition to technological inputs, plant growth-promoting factors, such as meteorological conditions, are also responsible for increasing the yield and, consequently, the economic

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income (Souza et al., 2019).

The reduced plant growth in organic agriculture, without chemical fertilizers, can be compensated by modifying growth-promoting elements and changing the farming system. In this scenario, the increase in plant density reduces the product mass due to intraspecific competition while increasing the yield per cultivated area, as observed for garlic (Marondin et al., 2020), tomato (Wamser et al., 2017), lettuce (Ferreira et al., 2016), carrot (Resende et al., 2016), and pepper (Paulus et al., 2015).

The decision to increase plant density should consider both the biological and economic aspects of plants since the ideal plant population should receive an appropriate level of photosynthetic radiation in order to increase net photosynthesis (Resende et al., 2016). However, if the additional cost with a higher plant density is higher than the additional income, its practice is not justified (Wamser et al., 2017), requiring a different plant density for each farming system, such as the organic system.

Therefore, this study aimed to assess the leaf yield and economic indicators of organic kale production in relation to plant density.

Material and Methods

The experiment was conducted at the Seridó Ecológical Site in Rio Branco, Acre, 9º 53' 16'' S and 67º 49' 11'' W, at an elevation of 170 m above sea level. The region has a hot and humid climate classified as *Am* according to the Köppen classification, with mean annual temperatures around 24.5 ºC, air relative humidity of 84%, and mean annual rainfall ranging from 1,700 to 2,400 mm. The soil of the experimental area is classified as an Alitic Plinthic OXISOL (ARGISSOLO AMARELO Alítico plintossólico, according to the Brazilian Soil Classification System). The nutrient contents of the 0 - 20 cm soil layer are: pH (H_2O) = 7.1; P = 130 mg.dm^{-3}; K = 2.9 mmol$_c$.dm^{-3}; Ca = 69.0 mmol$_c$.dm^{-3}; Mg = 25.0 mmol$_c$.dm^{-3}; Al = 0 mg.dm^{-3}, and H = 11 mmol$_c$.dm^{-3}; organic matter = 27 g.dm^{-3}; base saturation = 89.7.

The experimental design was in randomized blocks, with five treatments (plant densities) and four replications of 15 plants each. Planting was performed at the densities of 3.6, 4.2, 5.0, 6.3, and 8.3 plants m^{-2}, in triple rows spaced 0.40 m from each other and 0.50 m between the set of triple rows (plant beds). Within the row, plants were spaced 0.30 m, 0.40 m, 0.50 m, 0.60 m, and 0.70 m (Figure 1). The useful plot comprised the six central plants from each plot.

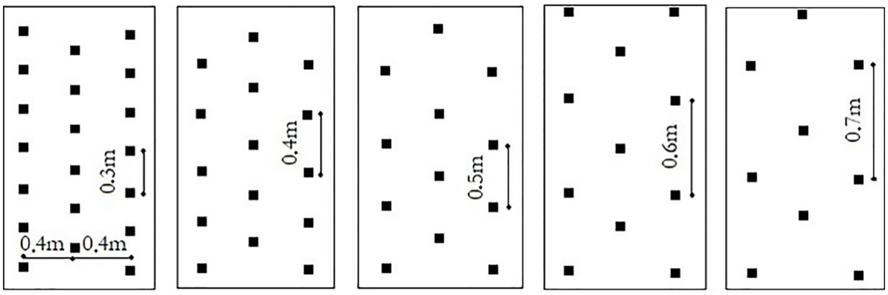

Figure 1. Detailed scheme of the planting spaces and arrangement of the plant beds.

The seed-produced seedlings of the kale cv. Georgia were grown in 128-cell polystyrene trays. Three seeds were sown per cell and thinned to two seedlings per cell eight days after sowing (DAS). The seedlings were then transplanted to 125 cm^3 plastic cups at 15 DAS and transplanted to the field at 45 DAS.

The substrate consisted of soil (33%), organic compost (33%), and a conditioner (33%), plus 1.0 kg m^{-3} of dolomitic limestone, 1.5 kg m^{-3} of thermophosphate, and 1.0 kg m^{-3} of potassium sulfate.

The soil was turned with a rotary hoe coupled to a compact tractor, making plant rows 1.20 m wide. In addition, the soil received dolomitic limestone (1,000 kg ha^{-1}), thermophosphate (500 kg ha^{-1}), and organic compost (15 t ha^{-1}).

A micro-sprinkler irrigation system was adopted, and the average daily water depth was 6 mm day^{-1}. The soil water content was increased to a level close to field capacity throughout the crop cycle.

Cultivation occurred in a plant nursery measuring 2.0 m of lateral ceiling height and 3.5 m of central ceiling height, covered with a 100 µ transparent film.

Pest control was performed with two applications of 1% neem tree oil, a microbial insecticide based on *Bacillus thuringiensis*, and one application of Bordeaux mixture. The area was hoed three times for weed control after transplantation, and the soil was covered with dry weeds after the first intervention. Biofertilization was split into four applications of 20 m^3 ha^{-1} as topdressing fertilization.

The plant material was harvested twice a week, beginning 20 days after transplantation and lasting six months.

The variables analyzed were: leaf fresh mass, leaf fresh mass per plant and per area, number of bunches, total fixed cost (CFT), total variable cost (CVT), total cost (CT), mean total cost (CTme), net revenue (RL), total revenue (RT), family labor remuneration (RMOF), profit rate (L), profitability index (IR), production for full coverage (Pct), and benefit to cost ratio(B/C).

After counting and weighing the leaves from the six central plants of the useful plot, the ratio of the number or mass of leaves to the number of plants was used to obtain the number of leaves per plant and the leaf fresh mass per plant (g plant^{-1}). The leaf fresh mass was obtained by the ratio between the mass and the number of leaves (g leaf^{-1}). The product of the fresh plant mass and plant density corresponded to the leaf fresh mass per m^2 (g m^{-2}).

The production cost comprised the fixed cost with greenhouse depreciation, irrigation materials, equipment, and administration (3%), variable costs with inputs and labor, the opportunity cost of land use (equivalent to the lease for beef cattle raising), and 6% of alternative costs (capital remuneration), as recommended by (Conab, 2010).

Depreciation (D) was calculated by equation 1 based on a linear function as the cost necessary to replace capital goods when rendered useless by either physical or economic wear, adapted from the equation proposed by Araújo Neto et al. (2012).

D= (Va-Vr)/Vu (Eq. 1)

Where: D – Depreciation (R$/year); Va – current value of the good (R$); Vr –residual value of the good (R$); Vu – lifespan, in years.

The table of agricultural production costs from Conab (2010) was used to determine the lifespan of materials and equipment and their respective residual values. Labor value was considered as the daily wage calculated based on the minimum monthly wage of a rural worker (R$ 1,045.00 - 2020), including 45.59% of labor benefits (INSS, FGTS, 13th wage, vacations, insurance, and child benefit) (Conab, 2010), divided by 23 monthly working days, resulting in the daily wage value of R$ 66.15 per person-day (HD).

The total cost (CT) was calculated by summing the fixed (CFT) and variable costs (CVT), including opportunity costs and excluding fixed (CopF) and variable operational costs (CopV). The ratio of costs to product yield indicates how much the product costs (mean total cost - CTMe) and should be lower than the price to result in profitability. Total revenue (RT) was obtained by the product between the price and the yield of kale bunches. Net revenue (RL) represents the income obtained with the activity minus the total cost (CT), calculated using equation 2.

RL=Total revenue – Total cost (Eq. 2)

The profit rate was calculated by the ratio between the net and total revenues, expressed as a percentage by equation 3.

L = Net revenue/Total revenue x 100 (Eq. 3)

The profitability index (IR) allows quantifying the net revenue (RL) in relation to the capital invested as a fixed investment (I) and the working capital (CG), expressed as a percentage and obtained by equation 4.

IR = [Net income/(investment + working capital)] x 100 (Eq. 4)

Family labor remuneration (RMOF) is the income referring to family labor in the activity. It indicates how much the system pays for a working day of the family, calculated by equation 5.

RMOF= Net income / days of work (Eq. 5)

The minimum yield to cover all production costs (Pct) was calculated by the ratio between the total cost and the average revenue (Eq. 6.), expressed as kg m^{-2}.

Pct = Total cost/average revenue (price) (Eq. 6)

The plant material was harvested throughout the experiment to determine the technical production coefficients. The cost with certification was not considered as family farmers in the region only adopt a social control for direct sale to consumers. Therefore, products are considered organic but have no official certification according to Law No. 10831 of 2003 (Brasil, 2003) and Normative Instruction No. 18 of June 20, 2014 (Brasil, 2014).

The data were analyzed for outliers by the Grubbs test, for normality of errors by the Shapiro-Wilk test, and homogeneity of variances by the Bartlet test. Subsequently, the analysis of variance was performed by the F-test. Regression analysis was performed when significance was identified.

Results and Discussion

Plant density influenced the leaf fresh mass per plant, the leaf fresh mass per area (Figure 2), the leaf fresh mass, and the number of bunches per area. However, this parameter did not change the number of leaves per plant (Figure 3). The economic indicators responded positively to the increase in plant density (Figures 4, 5, and 6).

The leaf mass per plant decreased with plant density, following a quadratic function with the minimum value of 1,365.89 g plant^{-1} at the density of 7.5 plants m^{-2}. In turn, the leaf fresh mass per area increased linearly at a rate of 861.66 g m^{-2}, reaching the maximum value of 11,271.6 g m^{-2} (Figure 2).

The mean leaf mass in this study was higher than the value found by Silva et al. (2016), of 19.9 g leaf^{-1} for organic kale grown at the single density of 2.22 plants m^{-2}. Since there was no reduction in the number of leaves per plant, the reduction in the leaf mass per plant is directly related to the competition for growth factors (water, light, and nutrients), as high plant densities result in smaller leaves.

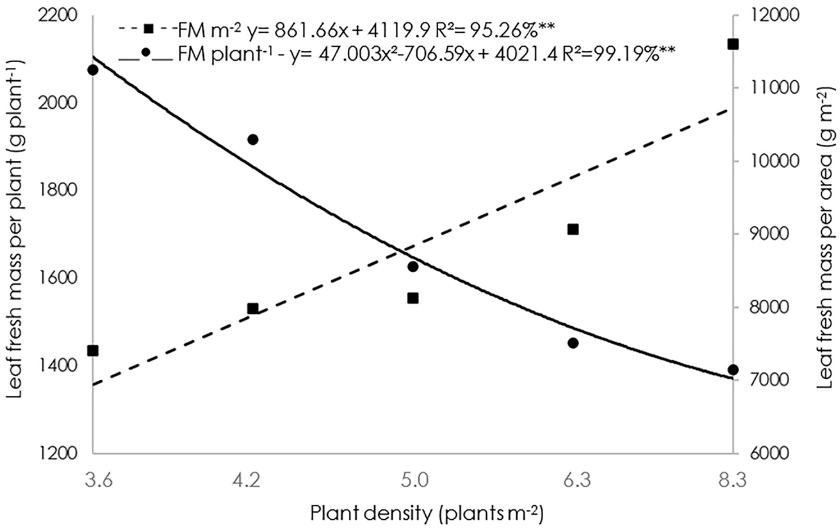

Figure 2. Leaf fresh mass per area (g m^{-2}) and leaf fresh mass per plant (g plant^{-1}). Rio Branco, AC, 2020.

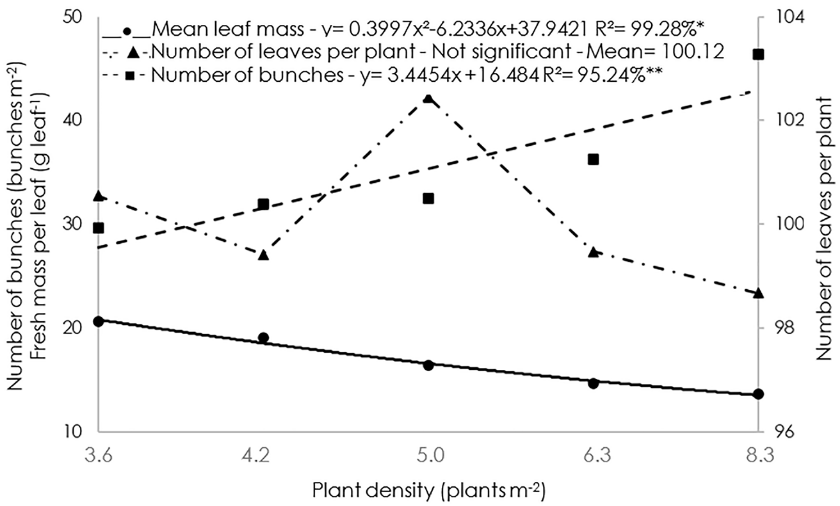

Figure 3. Number of bunches per area (bunches m^{-2}), fresh mass per leaf (g leaf^{-1}), and number of leaves per plant in relation to plant density. Rio Branco, AC, 2020.

The mean leaf fresh mass decreased with plant density following a quadratic function, with the minimum value of 13.64 g leaf^{-1} at the density of 7.8 plants m^{-2}. The highest leaf mass, 20.7 g leaf^{-1}, was obtained at the lowest density of 3.6 plants m^{-2} (Figure 3). The highest leaf mass in the present study was higher than the value recorded by Silva et al. (2016), who obtained a mean leaf mass of 19.9 g leaf^{-1} for organic kale grown at the single density of 2.22 plants m^{-2}.

The lower leaf mass (Figure 3) and mass per plant (Figure 2) are compensated by the higher number of plants per area (highest plant density), in which the number of marketable bunches increased linearly at a rate of 3.44 bunches for each additional plant per m^2, reaching a total value of 45.08 bunches m^{-2} at the density of 8.3 plants m^{-2} (Figure 3). The economic indicators also showed a linear increase with the increase in yield, even with higher production costs (Figures 4, 5, and 6).

This reduction in product mass and the higher yield per area are common behaviors when increasing plant density in vegetable crops, also occurring with garlic (Marondin et al., 2020), tomato (Wamser et al., 2017), lettuce (Ferreira et al., 2016), carrot (Resende et al., 2016), and pepper (Paulus et al., 2015). These authors observed that the mass of the product, whether root, bulb, leaf, or fruit, is reduced with plant density. However, more plants result in higher yields per area and contribute to intraspecific competition for growth factors, resulting in the lower mass of these products.

From the biological point of view, Resende et al. (2016) stated that an ideal plant population is necessary to properly distribute photosynthetic radiation on the leaves, increasing net photosynthesis. However, it is also necessary to assess plant density from an economic perspective. In that regard, Wamser et al. (2017) stressed that their highest tomato yield, obtained with 34,000 plants ha^{-1}, was not more economically efficient, with a better cost/revenue balance being achieved with 23,000 plants ha^{-1}.

Total production costs increased linearly with plant density at a rate of R$ 1.48 plant^{-1} m^{-2}, lower than the yield (3.44 bunches for each additional plant per m^{-2}), resulting in an economic situation of high profitability and financial returns (Figure 4). In this case, the cost increase was accompanied by the variable cost with seedlings and labor since the fixed costs with the land, plant nursery, irrigation system, and equipment did not change with plant density (R$4.71m^{-2}).

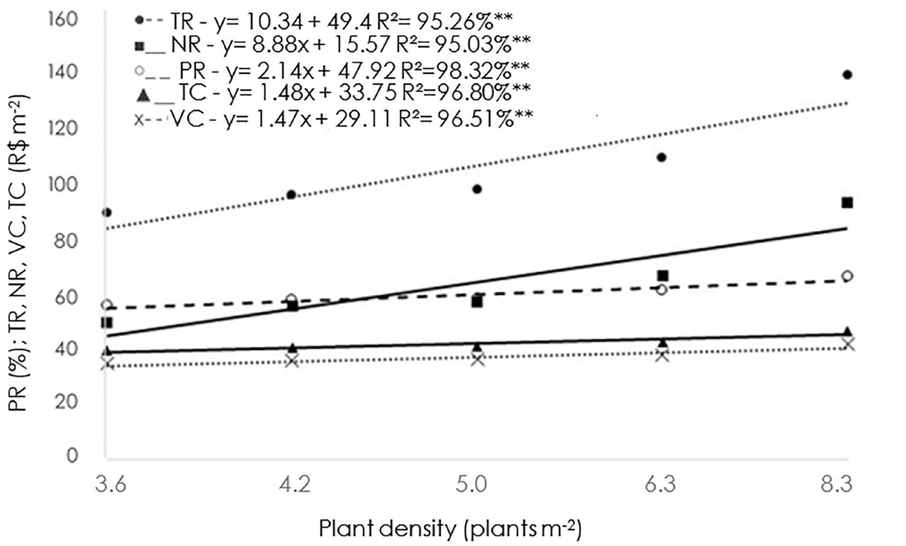

Figure 4. Net revenue (NR - R$ m^{-2}), total revenue (TR - R$ m^{-2}), profit rate (PR – percentage), variable cost (VC - R$ m^{-2}), and total cost (TC - R$ m^{-2}) in relation to kale plant density. Rio Branco, AC, 2020.

The lower production costs in conservationist agricultural systems result from the increase in soil organic matter, higher soil moisture, efficient nutrient uptake, less soil and nutrient losses, less workforce, and less machinery use over time (Fortini et al., 2020). These advantages contribute to reducing the production costs of organic agriculture. Also, organic inputs make the activity less dependent on external inputs and resources (Uchoa et al., 2021).

The low production costs of organic vegetable farming are related to the use of family labor in all stages of production, but especially to the manufacturing of inputs such as organic fertilizers. Moreover, these products have a prolonged residual effect, maintaining soil fertility in the medium and long term and increasing productivity (Souza et al., 2019).

The profit rate increased by 2.14% for each additional plant per m^{-2}, achieving the maximum value of 65.7% at the density of 8.3 plants m^{-2} in the six months of cultivation (Figure 4), equivalent to 10.95% p.m. This profit rate is higher than the return of saving accounts (2.11% p.y), CDI (2.75% p.y.), and national treasury tenders (7.20% p.y).

The high profit rate in olericulture activities is due to the high productivity, short cycle, and boosted by favorable growth factors and above average prices, with previously recorded profit rates of 69.0% for carrot (Martins et al., 2018), 59.1% for cilantro (Barros Junior et al., 2019), and 75% for lettuce (Souza et al., 2019).

The net and total revenues increased linearly by R$ 8.87 m^{-2} and R$ 10.34 m^{-2}, respectively, for each additional plant per m^2, reaching a net revenue of R$ 89.24 m^{-2} and total revenue of R$135.26 m^{-2} at the density of 8.3 plants m^{-2}, considering six months of cultivation (Figure 4). This result provided an also linear profitability rate that increased by 15.8% for each additional plant per m^{-2}, with the maximum value of 205.55% at the density of 8.3 plants m^{-2} (Figure 5). Profitability is high in olericulture, as previously observed for carrot, with R$ 5.18 m^2 (Martins et al., 2018), in addition to R$ 2.79 m^2 for cilantro (Barros Junior et al., 2019), R$ 6.28 m^2 for lettuce (Souza et al., 2019), and R$ 6.70 for arugula (PINTO et al., 2021).

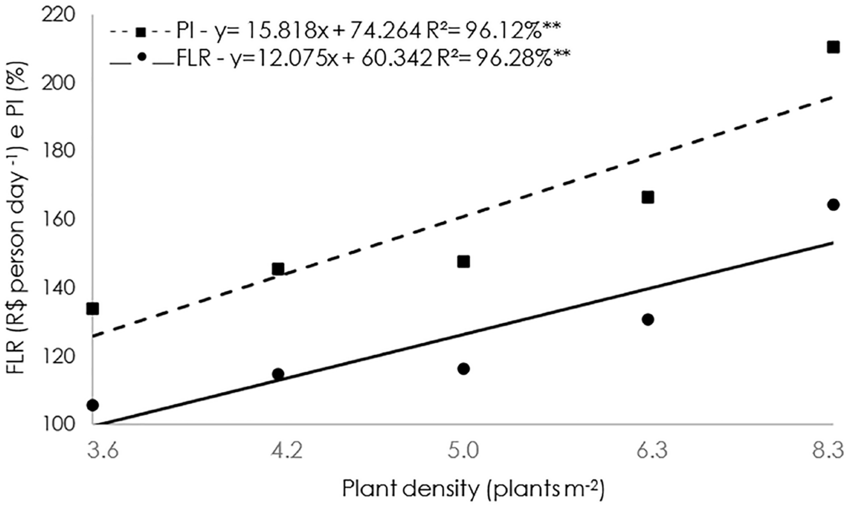

Figure 5. Family labor remuneration (FLR - R$ person day^{-1}) and profitability index (PI - percentage) in relation to kale plant density. Rio Branco, AC, 2020.

Family labor remuneration increased linearly at a rate of R$12.08 for each additional plant per m^2, reaching the maximum value of R$160.56 day^{-1} person, almost three times the daily pay of a rural worker (Figure 5).

This result is directly related to the total revenue increase caused by plant growth promotion and increased agricultural activity caused by density. In olericulture, it is not enough to supply additional inputs as it is also necessary to promote practices that, allied to other plant growth factors, will increase the yield and profitability (Souza et al., 2019).

The mean total cost of a marketable kale bunch decreased linearly with plant density at a rate of R$ -0.064 for each additional plant per m^2, reaching the minimum value of R$ 1.03 bunch^{-1} (Figure 6), well below the sale value (price) of R$ 3.00 bunch^{-1}. This reduction is directly related to the increase in yield, even with the cost increase due to plant density.

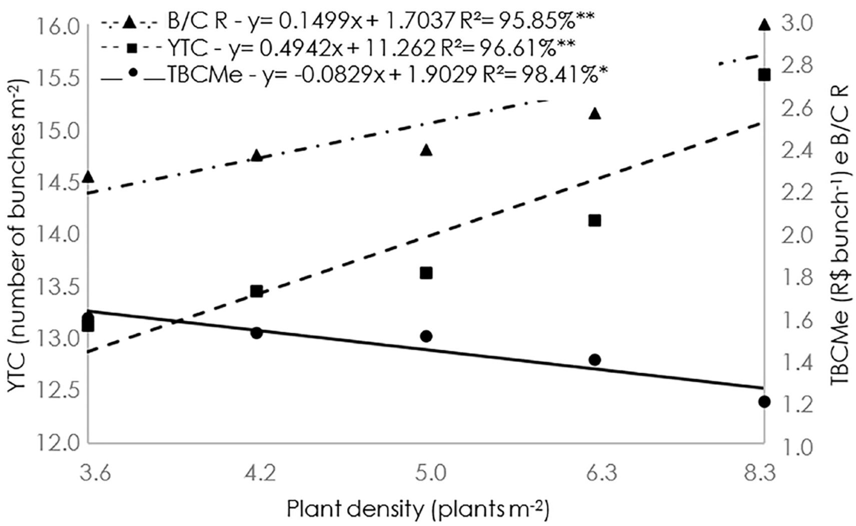

Figure 6. Yield for total cost coverage (YTC – number of bunches m^{-2}), total mean bunch cost (TBCMe - R$ bunch^{-1}), and benefit to cost ratio (B/C R) in relation to kale plant density. Rio Branco, AC, 2020.

The kale bunch price of R$ 3.00 bunch^{-1} is the value practiced in direct sales by organic product farmers at open markets or at home, below the conventional value found in local supermarkets but above the sale value obtained by farmers from their intermediaries. According to Darolt et al. (2016), this type of sale, called *short circuit trade*, guarantees a fair price for organic products based on consumer awareness with regard to healthy foods, creating a social connection with those who produce their food, especially when associated with family labor, diversified production, farmer autonomy, biodiversity preservation, and landscape appreciation.

Increased production costs with plant density demand higher yields, requiring a yield increase rate of 0.49 bunch for each additional plant per m^2, equivalent to 15.4 bunch m^{-2} at the density of 8.3 plants m^{-2} to cover production costs (Figure 6), an easily achievable yield at this plant density of 45.08 bunches m^{-2} (Figure 3).

Organic kale production is an economically viable activity, with a growing benefit to cost ratio at a rate of 0.15 for each additional plant per m^2, reaching the maximum value of 2.95 at the density of 8.3 plants m^2. Therefore, in addition to the actual economic efficiency as a growing agricultural activity in view of the ever-increasing demand for organic products, the trend is to expand the activity, encouraging other farmers to engage with organic kale production.

Conclusions

The increase in plant density from 2.6 to 8.3 plants m^{-2} reduced the leaf fresh mass, the leaf fresh mass per plant, and increased the leaf mass per unit area.

The highest yield obtained with the increase in plant density reduced the mean leaf bunch cost and increased the variable and total costs, the net and total revenues, the remuneration of family labor, the profitability index, and the production for full coverage.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.