



Yield and Profitability of Organic Radish Cultivation with Different between-Row Spacings

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SEAN and RLFF designed the study and performed the statistical analysis. Author LGSS managed the analyses of the study. Author AAP managed the literature searches. Authors GM and DFA reviewed the manuscript and suggested some alterations. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2022/v44i830838

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/87090>

Original Research Article

Received 25 February 2022

Accepted 05 May 2022

Published 10 May 2022

ABSTRACT

This study aimed to evaluate the yield and profitability of organic radish cultivation using different between-row spacings. The experiment was conducted at the Seridó Ecological Station in Rio Branco – AC in a randomized block design with five between-row spacings (0.05, 0.10, 0.15, 0.20, and 0.25 m) and four replications. Each plot consisted of four rows transverse to the plant bed at a density of 16.7 plants m⁻¹, spaced 0,06 m from one another, with the planting densities of 316.7, 255.7, 216.7, 166.7, 116.7, and 66.7 plants m⁻², respectively. The following agronomic variables were evaluated 35 days after sowing: shoot biomass, root yield, harvest index, root diameter, mean root mass, dry shoot mass, and the economic variables of mean total cost, cost-to-benefit ratio, yield to cover total costs, profitability, total income, net income, total cost, family labor remuneration, and profitability index. The smallest between-row spacing, increasing the planting density, increased the yield and reduced the root diameter without changing the mean root mass and the dry shoot mass. The increase in planting density increased the total cost and reduced the mean total cost, increasing the economic indicators of B/C ratio, profit rate, net and total income, profitability index, and family labor remuneration.

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Keywords: *Raphanus sativus* L.; Density; Organic agriculture.

1. INTRODUCTION

Radish (*Raphanus sativus*) belongs to the family Brassicaceae [1] and is consumed in salads or pickled, having a characteristic spicy flavor. The cultivation of this species is still incipient in the Brazilian state of Acre, where it is found in only four properties [2], which justifies the scarce knowledge about this species in the region generated by either research or empirical means.

Radish cultivation can contribute to generating jobs and income, yielding up to R\$ 34,845.84 ha⁻¹ at a profitability rate of 79.62% [3]. Moreover, the species can improve the nutrition and health of its consumers since, according to [4], the enzyme myrosinase, present in its roots, hydrolyze 4-methylthio-3-butenyl glucosinolate into the natural pungent agent 4-methylthio-3-butenyl isothiocyanate, which has antimicrobial, antimutagenic, and anticarcinogenic properties.

In addition, radish requires large amounts of nutrients in a relatively short period, especially N and K, the two nutrients usually required at larger volumes by agricultural crops [5], with 41.8 kg ha⁻¹ of N [6] and 103 kg ha⁻¹ of K being necessary to maintain high yields [5].

Ecological agriculture does not permit nitrogen supply through synthetic fertilizers. Instead, this nutrient is provided by the slow mineralization of soil humic substances and by the death of fungi, bacteria, protozoa, nematodes, earthworms, and arthropods, among others [7], with this slow N release resulting in slow vegetative growth in organic cultivation systems.

As a result, the fresh mass and the root yield of radish cultivated with nitrogen fertilization provided 100% by organic fertilizers are reduced by 9% compared to cultivation with 100% N provided by chemical inputs [8].

With slow growth, plants can be cultivated in smaller spacings. The increase in radish planting density increases the shoot biomass and reduces the root biomass due to the competition for water and nutrients. However, the lower root mass is compensated for by increasing the number of plants, thus increasing the crop yield [9]. Planting densities up to 0.05 m between plants in the row do not affect the net photosynthesis [10], thus maintaining the fresh root mass [11].

Most scientific articles conclude that the increase in radish planting density increases the yield, e.g., the article written by [10], in which the authors consider that 0.20 m between rows and 0.05 m between plants is the most productive spacing. However, other studies found no yield differences when changing the planting density, as observed in the cultivar Early Scarlet Globe for the between-row spacings of 0.15, 0.20, and 0.25 m and the between-plant spacings of 0.05 or 0.10 m.

For cultivars with less leaf area but with high productive efficiency, e.g., the Novella hybrid [12], it is possible to increase the planting density beyond the crop recommendations, both in the row and between rows. From this perspective, [13] recommend maintaining 0.05 m between plants and increasing the density in the planting row up to 0.10 m to obtain more commercial roots.

Therefore, this study aimed to evaluate the yield and profitability of organic radish cultivation in different between-row spacings.

2. MATERIALS AND METHODS

The experiment was conducted at the Seridó Ecological Station in Rio Branco, AC, Brazil, in an area under organic cultivation since 2008 and located at the following coordinates: 9° 53' 16" S and 67° 49' 11" W, at an elevation of 170 m above sea level. The climate of the region is hot, humid, and classified as Am according to the Köppen classification, with a mean annual temperature of 24.5 °C, relative air humidity of 84%, and annual rainfall ranging from 1,700 mm to 2,400 mm [14]. There was no rainfall during the experiment, from July 07 to August 11, 2021, and micro-sprinkler irrigation was necessary to supply the crop water requirements.

The soil is classified as a Plinthic Alithic RED YELLOW ULTISOL with a sandy-loam texture. The nutrients contents at the 0-20 cm depth layer are as follows: pH (H₂O)= 7.0, P= 49 mg dm⁻³, K= 1.1 mmolc dm⁻³, Ca= 49 mmolc dm⁻³, Mg= 11 mmolc dm⁻³, = H= 11 mmolc dm⁻³, O.M.=17 g dm⁻³, base saturation= 84.6%, SB= 61.1 mmolc dm⁻³ and CEC= 72.2 mmolc dm⁻³.

The experiment was conducted in a randomized block design with five treatments: 0.05, 0.10, 0.15, 0.20, and 0.25 m between rows, and four

replications. Each plot was composed of four rows transverse to the plant bed, holding a density of 16.7 plants m^{-1} spaced 0.06 m from one another.

The soil was prepared with a compact tractor and manual hoes to form plant beds 1.0 m wide and 0.20 m high fertilized with 15 t ha^{-1} of organic compost.

The planting density was defined based on conventional cultivation studies in which the between-row spacing ranged from 0.10 to 0.20 m, and the planting density was close to 0.05 m^{-1} [13 ;10], after which the planting density of 0.06 m^{-1} between plants and the between-row spacings of 0.05, 0.10, 0.15, 0.20, and 0.25 m were chosen, corresponding to 316.7, 255.7, 216.7, 166.7, 116.7, and 66.7 plants m^{-2} , respectively.

Sowing was performed directly in the plant beds using two seeds of the radish cultivar Novella per hole, with later thinning seven days after planting (DAP). Irrigation was performed with a micro-sprinkler system to maintain moisture at 80% of field capacity throughout the experiment. Aphids and fungal diseases were controlled with two applications of neem oil (1%) and fermented milk (5%).

Harvest was performed 35 days after sowing in the two central rows of each plot, after which the following agronomic variables were evaluated: shoot biomass ($kg\ m^{-2}$), root yield ($kg\ m^{-2}$), harvest index (HI), root diameter (mm), mean root mass (MRM - $g\ root^{-1}$), shoot dry matter (SDM - $g\ plant^{-1}$), and the economic variables of total mean cost (MeTC - $R\$\ kg^{-1}$), benefit-to-cost ratio (B/C), yield to cover total costs (YCT - $kg\ m^{-2}$), profitability (P - %), total income (TI - $R\$\ m^{-2}$), net income (NI - $R\$\ m^{-2}$), total cost (TC - $R\$\ m^{-2}$), family labor remuneration (FLR - $R\$\ dia^{-1}$), and profitability index (PI - %). In order to be considered proper for the organic market, the radish roots had to measure more than 20 mm in diameter.

After weighing the radish roots (diameter larger than 20 mm), the mean root mass was obtained by the ratio of the plot mass to the number of radish units ($g\ root^{-1}$). The shoot biomass was determined by the product between the fresh shoot mass and the planting density ($g\ m^{-2}$). The root yield was estimated by the product between the fresh root mass and the planting density ($kg\ m^{-2}$). The dry shoot mass was obtained after drying the material to constant weight in a forced-

air oven at 65 °C. The harvest index was obtained as the ratio of the fresh root mass to the total fresh plant mass, and the root diameter was measured with a caliper (mm).

The production cost was considered as the fixed cost with the depreciation of irrigation material, equipment, and management (3%), variable costs with inputs and labor, opportunity costs with land use (the equivalent to rental for beef cattle raising), and 6% of alternative costs (return on capital), as recommended by [15].

Depreciation (D) was calculated by equation 1 based on a linear function consisting of the cost necessary to replace capital goods when rendered useless by either physical or economic wear, using the equation adapted from [16].

$$D = (Va - Vr) / Vu \quad (1)$$

Where: D – Depreciation ($R\$\ ano^{-1}$); Va – current value of the good ($R\$$); Vr – residual value of the good ($R\$$); Vu – lifespan, in years.

The lifespan of the materials and equipment and the respective residual values were determined using the table of agricultural production costs proposed by [15]. The labor value was considered as the daily payment, calculated by considering the salaried pay of a rural worker on minimal wage ($R\$\ 1,100.00$ - 2021), including 45.59% of employment taxes (INSS, FGTS, 13th salary, vacations, insurance, and education salary) [15] divided by 23 monthly working days, resulting in the daily pay value of $R\$\ 69.63$ per man-day (MD).

The total cost (TC) was calculated by summing fixed (TFC) and variable costs (TVC), including opportunity costs (6% p.y.). The total income constitutes the product between the price and the radish yield ($R\$\ m^{-2}$). The net income represents the income obtained with the activity after subtracting the total cost ($R\$\ m^{-2}$) using equation 2.

$$NI = \text{Total income} - \text{Total cost} \quad (2)$$

The profitability index (PI) allows quantifying the net income (NI) based on the capital invested as fixed investment (P) and working capital (WC), expressed as a percentage and obtained by equation 3.

$$PI = [\text{Net income} / (\text{investment} + \text{working capital})] \times 100 \quad (3)$$

Family labor remuneration (FLR) is the income obtained by family labor in the agricultural activity, indicating how much the system pays the family for a working day (R\$ day⁻¹), calculated by equation 4.

$$FLR = \text{net income} / \text{working days} \quad (4)$$

The minimum yield to cover total production costs (Ytc) was calculated as the ratio of total costs to the mean income (price) (Eq. 5), expressed as kg m⁻².

$$Ytc = \text{Total cost} / \text{Mean income (price)} \quad (5)$$

The total cost (TC) was calculated by adding the total fixed cost (TFC) to the total variable cost (TVC), including the opportunity cost (Eq. 06), expressed as R\$ m⁻².

$$TC = TFC + TVC \quad (6)$$

The total mean cost (MeTC) was determined as the ratio of total costs (CT) to the yield (Eq. 07), expressed as R\$ kg⁻¹.

$$MeTC = TC / \text{yield} \quad (7)$$

The benefit-to cost ratio (B/C) was determined as the ratio of the total income (RT) to the total cost (CT) (Eq. 08).

$$B/C = TI / TC \quad (8)$$

The profitability rate (P) (Eq. 10) was determined as the ratio of the net income (RL) to the total income (RT), expressed as percentage.

$$P = (NI / TI) \times 100 \quad (9)$$

The technical coefficients of production were determined during the experiment. The cost with certification was not considered since the local family farmers only adopt social control for the direct sale of organic products to customers without a certifying seal as per Law N^o. 10,831 of 2003 [17] and Ordinance N^o 52 of March 15, 2021 [18].

The data were collected and checked for the presence of outliers by the Grubbs test, normality of residuals by the Shapiro-Wilk test, and homogeneity of variances by the Cochran test. After verifying the assumptions, the analysis of variance was performed by the F-test, and the treatments that showed significant effects at 5% probability were subjected to regression analysis.

3. RESULTS AND DISCUSSION

There was an effect of planting density caused by the difference in the between-row spacing on the following variables: shoot biomass, root yield (Fig. 1), root diameter (Fig. 2), mean total cost, B/C ratio, yield to cover total costs (Fig. 3), total and net income, total cost (Fig. 4), family labor remuneration, and profitability index (Fig. 5). On the other hand, plant spacing did not affect the harvest index (Fig. 1), mean shoot mass, and mean root mass (Fig. 2).

The shoot biomass and the root yield increased linearly with the increase in planting density at rates of 0.0052 kg m⁻² and 0.1737 kg m⁻², respectively, for each unit increase in planting density (Fig. 1). The harvest index was not significantly influenced by the increase in planting density (Fig. 1).

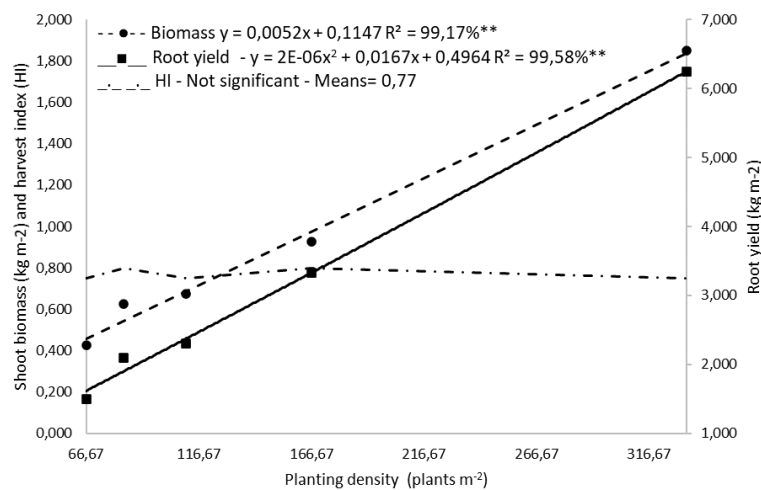


Fig. 1. Shoot biomass, harvest index (HI) and root yield of radish as a function of planting density changed by different between-row spacings. Rio Branco, AC, 2021

The dry plant mass and the fresh root mass were not significantly changed. However, the root diameter decreased linearly with the increase in planting density at a rate of $-0.0129 \text{ g root}^{-1}$ for every plant added to the planting density (Fig. 2). The smallest root diameter at the highest planting density (33.3 mm) was above the minimum required for the conventional radish market [19].

The maximum root yield of 5.92 kg m^{-2} was achieved at the highest planting density with the spacing of $0.05 \times 0.05 \text{ m}$, resulting from the increase in leaf biomass (Fig. 1) and the maintenance of the fresh root mass favored by the higher number of plants and roots (Fig. 1).

This yield of 5.92 kg m^{-2} is above the results found for the same cultivar [12] and others, whose yield might reach only 0.280 kg m^{-2} , e.g., the cultivar Apolo at the plant spacing of $0.30 \times 0.10 \text{ m}$ [20] and 7.4 kg m^{-2} for the variety Mino Early Long at the plant spacing of $0.40 \times 0.20 \text{ m}$ [20].

The fresh root mass can be either reduced [9], remain unchanged [11], or increased [13] with the increase in planting density, a phenomenon that can be probably changed by using different cultivars and environments.

The increase in planting density did not change the harvest index, which is favored by the lower leaf biomass of the hybrid Novella [12] by accepting the density increase without increasing

leaf biomass competition, thus maintaining the fresh root mass.

The mean total cost responded in a quadratic function with the minimum cost of $\text{R\$ } 3.37 \text{ kg}^{-1}$ at the estimated density of $286.9 \text{ plants m}^{-2}$ (Fig. 3), well below the regional market price of $\text{R\$ } 9.00 \text{ kg}^{-1}$. This situation covers all production and opportunity costs as more farms adhere to radish cultivation.

With this price above the mean total cost, the yield to cover total costs is reduced, which increases linearly with the increase in planting density, reaching the maximum value of 1.99 kg m^{-2} at the density of $316.67 \text{ plants m}^{-2}$ (Fig. 3). However, the yield was high at this density, resulting in 5.92 kg m^{-2} (Fig. 1), although there is a record of lower radish yields [21], including in organic cultivation [22,12].

The B/C ratio increased linearly with the increase in planting density, reaching the maximum value of 2.96 at the planting density of $316.67 \text{ plants ha}^{-1}$ (Fig. 3). The B/C ratio is high for radish grown under conventional cultivation, with 4:1 at the spacing of $0.30 \times 0.10 \text{ m}$ [8] and 4.95:1 at 0.20×0.05 [3]. The B/C ratio is favored by the increase in the yield to cover total costs. In that case, the B/C ratio of 2.96, lower than in conventional cultivation, is due to the increase in yield of the latter. According to [23], the production cost in organic vegetable cultivation is 8% lower than in conventional cultivation since fewer external inputs are used.

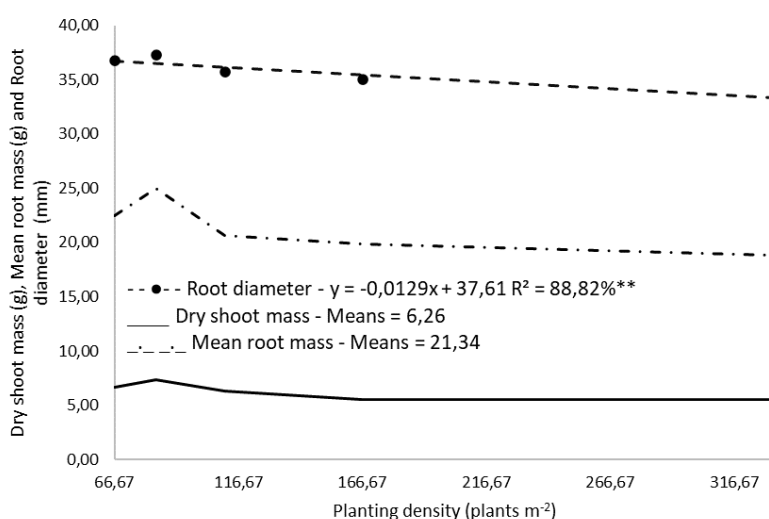


Fig. 2. Root diameter, mean root mass, and dry shoot mass of radish as a function of planting density changed by different between-row spacings. Rio Branco, AC, 2021

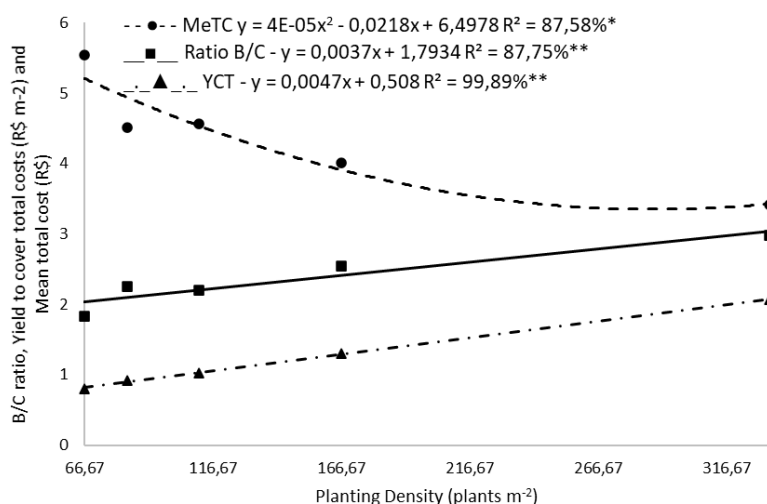


Fig. 3. Mean total cost (MeTC), benefit-to-cost ratio (B/C), and yield to cover total costs (YCT) of radish as a function of planting density changed by different between-row spacings. Rio Branco, AC, 2021

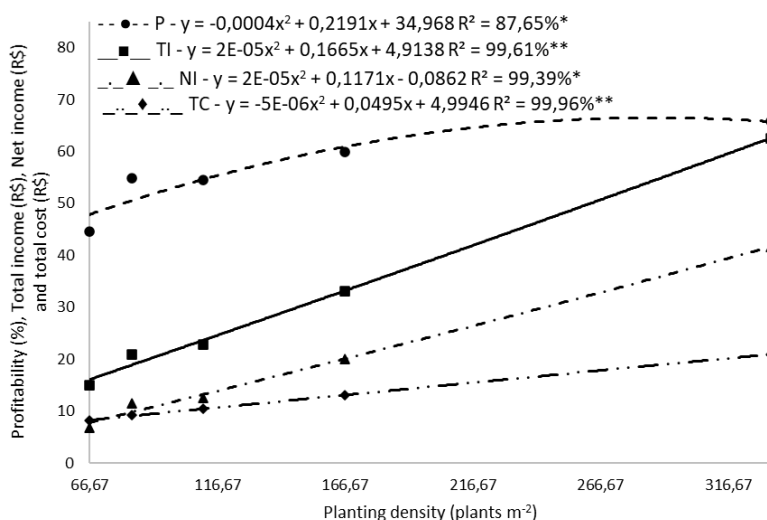


Fig. 4. Profitability (P), total income (TI), net income (NI), and total cost (TC) of radish as a function of planting density changed by different between-row spacings. Rio Branco, AC, 2021

The profitability rate (L) increased in a quadratic function with a maximum value of 64.97% at the density of 273.9 plants m⁻² (Fig. 4). The high yield, the short production cycle boosted by favorable growth factors (soil, climate, and planting density), and the price higher than the mean production cost provided high interest rates, e.g., the 69.0% with carrot cultivation [24], 59.1% with cilantro [25], and 75% with lettuce [26].

The total income, net income, and total cost responded in a quadratic function, with the

maximum values of R\$ 62.56 m⁻², R\$ 34.60 m⁻², and R\$ 20.17 m⁻², respectively, at the density of 316.67 plants m⁻² (Fig. 4). According to [23], the net income obtained in organic vegetable cultivation is R\$ 21,006.34 ha⁻¹, 80% higher than in the conventional system, which accounted for R\$ 11,450.44 ha⁻¹ but lower than the R\$ 291,340.00 ha⁻¹ referring to the R\$ 34.60 m⁻² of this study. However, these data cannot be sustained with the entry of a large number of producers into the activity, which will reduce the price with the increased supply.

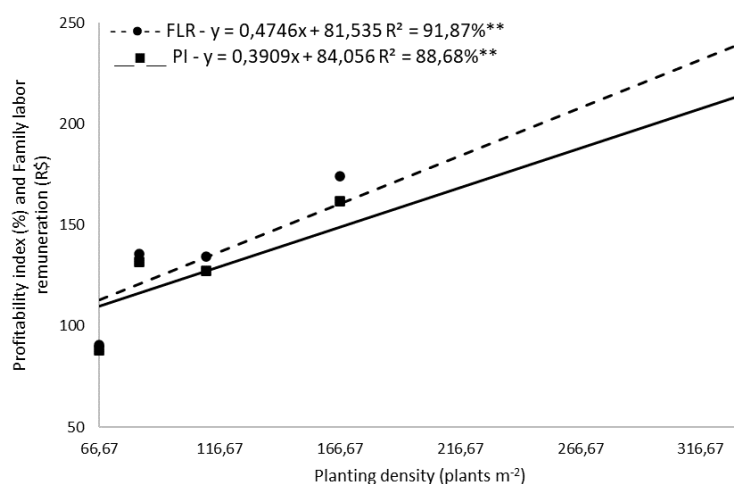


Fig. 5. Family labor remuneration (FLR) and profitability index (PI) of radish as a function of planting density changed by different between-row spacings. Rio Branco, AC, 2021

Family labor remuneration and the profitability index increased linearly, reaching the respective maximum values of R\$ 231.82 day⁻¹ and 207.84% (Fig. 5), above the daily pay of R\$ 69.63 day⁻¹ estimated for this study considering the current minimum wage and all labor rights [15].

Labor hiring increases production costs but is necessary to circulate and distribute the wealth produced. In that regard, when evaluating ten agricultural crops grown under organic cultivation, [23] identified a mean labor participation in vegetable cultivation costs of 38.5% and 40.2% in organic and conventional systems, respectively.

These high economic indicators are due to the higher price of the product (radish) compared to the mean total cost, which is caused by the lower production costs in organic agriculture [7,24], by the high yield of marketable roots, and by direct sale to the customer, without intermediaries and considering the short-circuit nature of the activity, which facilitates the access to the organic market and provides higher profitability to farmers [27].

The lower production costs of conservationist agricultural systems are due to the increase in soil organic matter, higher soil moisture, efficient nutrient uptake, lower losses of soil and nutrients, less manpower, and less use of machinery over time [28]. The use of organic fertilizers is a beneficial management to contribute to the accumulation of biomass and increase in radish productivity [29].

Although the price of organic radish is equivalent to the conventional radish commercialized in Rio Branco, AC at the end of 2021 (R\$ 9,00 kg⁻¹), organic vegetables are marketed at prices up to 57,8% higher, reflecting a higher gross income compared to conventional products [23] and contributing the increase the net income of organic products.

4. CONCLUSIONS

The smallest between-row spacing, increasing the planting density, increases the yield and reduces the root diameter without changing the mean fresh root mass and the dry shoot mass of radish plants.

The increase in planting density increases the total cost and reduces the mean total cost while increasing the economic indicators of B/C ratio, profit rate, total and net income, profitability index, and family labor remuneration.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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