



RESEARCH ARTICLE

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Optimization of Planting Distance for the Growth and Yield of Red Beetroot (*Beta vulgaris* L.) at Various Harvest Ages



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Abstract

Red beet (*Beta vulgaris* L.) is a horticultural crop whose production remains limited in Indonesia. Therefore, it is necessary to increase productivity by optimizing planting distance and harvest age. This study aimed to examine the interaction between planting distance and harvest age on the growth and yield of the red beet variety Ayumi 04. The research was conducted from March to June 2025 in Mojoroto Village, Pacet District, Mojokerto, using a Randomized Block Design (RBD) with two treatment factors: planting distance and harvest age. The first factor was planting distance (30x30 cm, 30x25 cm, 30x20 cm, 30x15 cm), and the second factor was harvest age (50, 60, and 70 days after sowing [DAS]). Observed parameters included plant length, leaf area, fresh tuber weight per plant, fresh tuber weight per plot, tuber weight per hectare, and leaf area index. The results showed that a planting distance of 30x15 cm combined with a harvest age of 70 DAS produced the best results, with fresh tuber weight per plot of 3.90 kg and per hectare of 27.06 tons/ha. These findings provide practical guidance indicating that a 30x15 cm planting distance and a 70 DAS harvest age are optimal for enhancing land-use efficiency and red beet production. Overall, appropriate planting distance and harvest timing can significantly improve the productivity and yield of red beetroot.

Keywords: Combination, Land Efficiency, Plant Competition, Productivity, Tuber Weight

1. Introduction

Beetroot (*Beta vulgaris* L.) is a horticultural crop from the Chenopodiaceae family that contains vitamin B, calcium, phosphorus, nutrients, iron, and anthocyanin compounds. Beetroot production in Indonesia remains limited, as evidenced by the high price of this commodity, caused by external factors such as inappropriate planting distance and the lack of a definitive harvest age for beetroot. Proper spacing and harvest age are essential to achieving an optimal balance between the quality and quantity of beetroot yields.

The distance between plants affects harvest time because it influences competition, development, and physiological maturity. Previous research conducted by Astuti and Murdono (2019) showed that optimal red beet yields were found at a planting distance of 20 x 15 cm with a harvest age of 55 days, which produced the highest tuber weight per plot, the highest number of tubers per plot, with tuber sizes that best suited market demand, and had the highest population numbers. The study aimed to determine

the effects of the combination of planting distance and harvest age on the growth and yield of red beet (*Beta vulgaris* L.) plants and to identify the combination treatment that maximizes land utilization and increases plant productivity.

Planting distance is a crucial aspect of plant cultivation that requires careful attention to maximize land utilization. Planting distance affects the efficiency with which plants access water, sunlight, and nutrients, thereby influencing crop production. Planting distance determines the population; the denser the spacing, the greater the population. Proper plant spacing can minimize competition between plants for nutrients, water, sunlight, and growing space. Proper plant spacing can also suppress weed growth, thereby preventing plant-weed competition (Setyowati et al., 2013). Suboptimal plant spacing results in less efficient plant growth due to an imbalance in resource use, such as light, water, and nutrients. Planting too close together increases intraspecific competition, reducing photosynthesis per plant and resulting in smaller yields,

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such as tubers or fruit. Conversely, excessive plant spacing reduces the plant population per unit area, underutilizing growing space and light energy and decreasing total yield per hectare.

A study (Kadam et al., 2018) showed that the spacing treatment had a positive effect on the growth and yield of red beet plants. The 30 cm x 15 cm spacing treatment produced the highest number of leaves per plant (15.64), the longest root length per plant (15.61 cm), and the highest tuber weight per plant (152.80g). The 30 cm x 15 cm spacing treatment also showed the highest plant yields for quality parameters, namely sugar content of 8.50% and anthocyanin content of 33.02 mg/100g.

Research (GAHARWAR et al., 2017) shows that the spacing treatment has a good effect on the growth and yield of red beet plants. The treatments used in this study were 30 cm x 10 cm, 30 cm x 20 cm, and 30 cm x 30 cm. The spacing treatment of 30 cm x 20 cm showed the highest average plant height of 41.17 cm and the largest tuber weight yield of 29.30 t/ha. The highest average tuber diameter per plant was also observed in the 30 cm x 20 cm spacing treatment at 6.66 cm. The 30 cm x 20 cm spacing treatment also showed the highest number of leaves at 17.54 strands.

Harvest time is the period required for optimal plant growth from planting to harvest. Determining harvest time depends heavily on plant type and variety, as well as environmental factors such as temperature, light, and rainfall. Harvesting must be done at the right time to achieve maximum yield quality and quantity, including size, flavor, nutritional content, and shelf life. (Wahditiya et al., 2024) . Harvest age is closely related to the plant's growth phase, reflecting the plant's physiological maturity and strongly influencing its production and nutritional content (Hariyani et al., 2015). According to Tafzi et al. 2021, harvest age also affects the physical appearance, color changes, texture, size, and shape of the fruit.

Research (Jannah, 2021) shows that harvest age treatment affects the quantity, namely tuber weight and tuber diameter, as well as the quality of beet tubers, namely sugar content and earthy aroma. The treatments in this study were harvest ages of 98 DAP, 88 DAP, 78 DAP, 68 DAP, and 58 DAP. The 98 DAP harvest age treatment produced an average tuber weight of 72.20 g, which was significantly higher than that of the other harvest age treatments. The 98 DAP harvest age treatment also produced the largest average diameter of 5.01 cm, which was significantly greater than that of other treatments. The 98 DAP harvest age treatment produced the highest average sugar content, significantly higher than that of other treatments, namely 2.15 °Brix.

Research (Astuti & Murdono, 2019) shows that there is an interaction between planting distance and harvest age on red beet yield. The planting distance treatments used in this study were 20 cm x 15 cm, 20 cm x 20 cm, and 20 cm

x 25 cm. Harvest age treatments included 35 HST, 45 HST, and 55 HST. The treatment with a harvest age of 55 HST and a planting distance of 20 cm x 25 cm produced a tuber weight per plant that was significantly higher than that of other treatments, namely 372.9 g/plant. At a harvest age of 55 days, a planting distance of 20 cm x 15 cm produced a tuber weight per plot that was significantly higher, namely 7584.2 g, than other treatments. The combination of a planting distance of 20x25 cm and a harvest age of 55 days produced a tuber diameter of 8 cm, which was larger than that of other treatments. The combination of 20x15 cm planting distance and 55 HST harvesting age produced the highest population per plot, namely 39.3 plants, compared to the 20x20 cm and 20x25 cm treatments. Based on this description, the author of this study sought to understand the interactions among different planting distances and harvesting age treatments. In addition, this study used red beet plants of the Ayumi04 variety, which were carried out in the Pacet area, Mojokerto. The combination of treatments applied in this study was planting distance (30x30 cm, 30x25cm, 30x20 cm, and 30x15cm) and harvesting age (50 HST, 60 HST, and 70 HST). The combination of treatments obtained better growth and results than previous studies.

2. Material and Methods

2.1. Place and Time

This research was conducted in March - June 2025 in the Agricultural Land of Mojoroto Petak Village, Pacet District, Mojokerto Regency, East Java Province, which is located at the coordinates 7° 38'52" S, 112° 32' 23" - 7.647778, 112.539722 with an average height of ±400 meters above sea level, has a temperature of 23° C- 31° C with rainfall of 1,500-2,000 mm per year.

2.2. Tools and materials

The tools used in this study were hoes, trowels, digital scales, wool thread, raffia rope, cameras, labels, wood, meters, stationery, and calipers. The materials used in this study were red beet seeds of the *Ayumi 04 variety*, seedling trays, NPK Mutiara 16:16:16 fertilizer, water, soil, compost, paper, manure, and Infraboard.

2.3. Research methods

This research is a factorial experiment arranged in a Randomized Block Design (RBD) with two treatment factors: plant spacing and harvest age. The first factor is plant spacing, with 4 levels: 30x30cm, 30x25cm, 30x20cm, and 30x15cm. The second factor is harvest age, with 3 levels: 50HST, 60HST, and 70HST. This experiment consists of 12 treatment combinations for both treatment factors, each with a predetermined level. Each treatment was repeated 3 times per experimental unit, yielding 36 experimental units with 3 sample plants per unit.

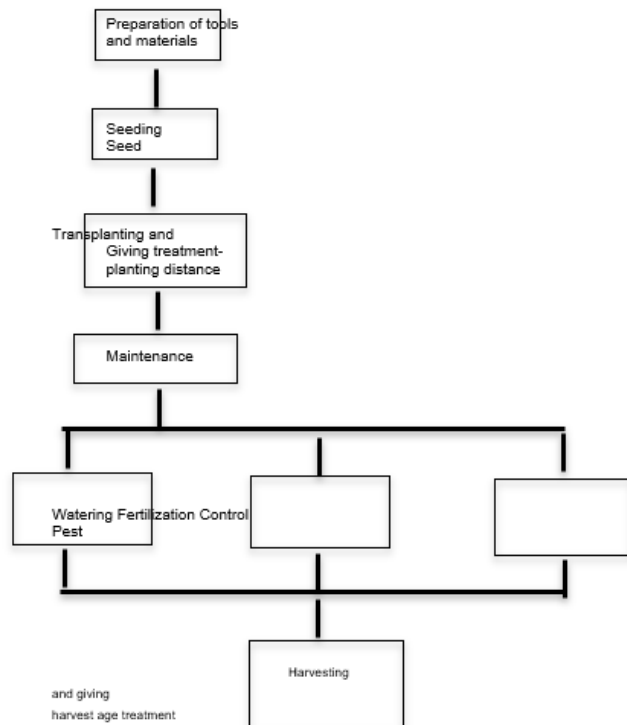


Figure 1. Research flow diagram

2.4. Observation Parameters

2.4.1. Plant Length (cm)

Plant length is measured with a meter stick, from the soil surface to the plant's longest part, in centimeters. Plant length measurements can be taken 7 days after transplanting, then weekly until the plants are 49 days after transplanting.

2.4.2. Leaf Area per Plant (cm²)

Leaf area observations were conducted 7 days after transplanting at 14-day intervals, ending when the plants were 42 days after transplanting. Leaf area measurements per plant were conducted by measuring the leaves that had opened, perfect using the length times width method, which is based on the following equation:

$$LD = P \times W \times kx \sum n$$

2.4.3. Fresh Weight of Tubers per Plant (g)

Tuber weight is monitored after harvest by weighing each plant using a weighing scale. The tubers to be weighed are first cleaned to remove any remaining soil or dirt.

2.4.4. Fresh Weight of Bulbs per Plot (kg)

Tuber weight per plot was measured after harvest by weighing tubers per plant and summing yields for each plot using a weighing scale. The tubers to be weighed were first cleaned to remove any remaining soil or dirt.

2.4.5. Fresh Weight of Tubers per Hectare (tons/ha)

Observations of tuber weight per hectare are carried out after harvest by weighing the tuber yield per plot, then dividing it by the plot area and multiplying it by 10,000. The tuber weight per hectare can be calculated using the following formula:

$$\text{Weight per Hectare} = \frac{\text{Weight per plot (kg)}}{\text{Plot Area (m}^2\text{)}} \times 10,000$$

2.4.6. Leaf Area Index

Leaf Area Index (LEI) is the ratio of the total leaf area of a plant to the unit area of land occupied by the plant. This index describes a plant's ability to capture sunlight for photosynthesis. The leaf area index is measured manually by calculating the area of each leaf using the formula length \times width \times leaf correction factor, then summing the plant's total leaf area and dividing by the area of land occupied. plant for obtaining the leaf area index value. The leaf area index can be calculated using the formula:

$$ILD = \frac{\text{Total Leaf Area}}{\text{The Area Occupied by Crops}}$$

3. Results and Discussion

3.1. Plant Length

The analysis of variance showed that the combination of plant spacing and harvest age treatments did not significantly affect the plant length parameter at 7-49 HST. The single factor of plant spacing treatment had an effect at 28-49 HST, while the single factor of harvest age treatment had no significant effect at any observation age. The results of the average length of red beet plants in the single treatment are presented in Table 1.

Table 1 shows that the spacing treatments were significantly different at the observation age of 28 HST, with the 30 \times 20 cm spacing significantly different from 30 \times 30 cm and 30 \times 25 cm, but not significantly different from 30 \times 15 cm. At 35 and 42 HST the spacing of 30 \times 25 cm was significantly different from the spacing of 30 \times 30 cm and 30 \times 15 cm, but not significantly different from the spacing of 30 \times 20 cm. At 49 HST the spacing of 30 \times 20 cm was significantly different from 30 \times 30 cm and 30 \times 25 cm, but not significantly different from the spacing of 30 \times 15 cm. Observations at the age of 28-49 HST had the longest average obtained from the 30 \times 15 cm spacing treatment with respective values of 26.15 cm, 32.92 cm, 36.03 cm and 39.19 cm. The lowest average plant length results were obtained at the age of 28 HST from the 30 \times 25 cm spacing treatment (22.22 cm), and at the age of 35-49 HST from the 30 \times 30 cm spacing treatment (29.77 cm, 33.82 cm, and 36.49 cm). These results are in line with research (GAHARWAR et al., 2017), which reported that a planting distance of 30 \times 20 cm resulted in an average plant height of 38.5 cm, higher than 40 \times 20 cm (34.2 cm) and 50 \times 20 cm (31.8 cm). In addition, research (Tamiru et al., 2017) showed that a planting distance of 20 \times 20 cm produced a plant height of 37.6 cm, while 30 \times 20 cm

produced 37.6 cm, and 40 × 20 cm only reached 33.4 cm and 30.9 cm.

Table 1. Average Length of Red Beet Plants in Planting Distance and Harvest Age Treatments 7-49 HST

Planting Distance	Plant Length (cm)						
	7 HST	14 HST	21 HST	28 HST	35 HST	42 HST	49 HST
30 x 30 cm	12.77 ± 1.45	15.74 ± 1.95	20.13 ± 5.74	23.89 ± 4.94 b	29.77 ± 1.74 a	33.82 ± 1.70 a	36.49 ± 1.41 a
30 x 25 cm	11.92 ± 5.11	16.58 ± 5.75	19.37 ± 1.35	22.22 ± 1.74 a	31.14 ± 1.83 b	35.07 ± 1.54 b	37.95 ± 1.33 b
30 x 20 cm	12.66 ± 1.48	14.61 ± 2.11	20.70 ± 1.06	25.96 ± 0.95 c	31.51 ± 1.99 b	35.18 ± 0.96 b	38.64 ± 1.62 c
30 x 15 cm	13.21 ± 2.43	14.53 ± 3.55	22.96 ± 1.89	26.15 ± 1.90 c	32.92 ± 1.63 c	36.03 ± 1.55 c	39.19 ± 1.78 c
BNJ 5%	tn	tn	tn	1.08	0.88	0.64	0.60
Harvest Age	Plant Length (cm)						
	7 HST	14 HST	21 HST	28 HST	35 HST	42 HST	49 HST
50 HST	13.12 ± 1.59	15.93 ± 4.55	21.04 ± 1.67	24.28 ± 2.71	31.16 ± 1.37	34.73 ± 0.51	37.80 ± 0.88
60 HST	13.02 ± 2.24	14.03 ± 1.68	21.09 ± 3.13	25.90 ± 2.61	31.72 ± 2.46	35.29 ± 1.43	37.67 ± 1.66
70 HST	11.78 ± 3.03	16.14 ± 1.36	22.96 ± 4.08	23.49 ± 4.02	31.14 ± 2.27	35.06 ± 2.28	38.74 ± 2.72
BNJ 5%	tn	tn	tn	tn	tn	tn	tn

Description: Numbers accompanied by the same letter for each treatment and the same age show no significant difference in the BNJ test at 5% level, tn = no significant difference.

The combination of planting distance and harvest time did not significantly affect the length of red beet (*Beta vulgaris* L.) plants. This finding is because the experimental field, which had sufficient light, water, and nutrients, produced almost the same plant length, regardless of whether the planting distance was close or wide. The harvest time factor generally affects final results, such as tuber weight and size, rather than vegetative characteristics in the early phase, so the interaction between harvest time and planting distance did not affect plant length. This result is consistent with research (Dhital et al., 2025), which found that the vegetative growth of beet is strongly influenced by environmental factors, particularly light and water availability. A single treatment of 30 x 15 cm planting distance significantly affected plant length. According to Asrori et al. (2023), a close planting distance

increases competition between plants, but in red beet plants, this competition remains tolerable, allowing each plant to grow optimally.

3.2. Leaf Area

The results of the analysis of variance showed that the combination of planting distance and harvest age did not significantly affect the leaf area of red beet (*Beta vulgaris* L.) plants at any of the observation ages (14, 28, and 42 HST). The single factor of planting distance treatment had a significant effect at the ages of 14, 28, and 42 HST, while the single factor of harvest age treatment had no significant effect at any observation age. The average value of the leaf area of red beet plants in the single treatment of planting distance and harvest age is presented in Table 2.

Table 2. Average Leaf Area per Plant in Planting Distance and Harvest Age Treatments at 14, 28, and 42 HST

Planting Distance	Leaf Area (cm ²)		
	14 HST	28 HST	42 HST
30 x 30 cm	111.44 ± 15.88 c	221.62 ± 18.62 c	354.03 ± 3.27 d
30 x 25 cm	105.27 ± 10.86 b	217.44 ± 12.40 c	334.16 ± 29.69 c
30 x 20 cm	103.22 ± 20.20 b	207.68 ± 3.86 b	304.47 ± 23.23 b
30 x 15 cm	93.13 ± 1.60 a	186.74 ± 7.15 a	278.85 ± 17.96 a
BNJ 5%	5.24	6.92	13.02
Harvest Age	Leaf Area (cm ²)		
	14 HST	28 HST	42 HST
50 HST	103.29 ± 12.02	207.16 ± 25.23	307.99 ± 53.41
60 HST	103.48 ± 13.31	208.30 ± 17.98	317.79 ± 46.71
70 HST	102.93 ± 21.41	209.65 ± 30.77	327.86 ± 48.98
BNJ 5%	tn	tn	tn

Description: The average number followed by the same letter at the same observation age shows no significant difference in the 5% BNJ test; HST: Days After Planting; tn= no significant effect

Table 2 shows that the observation age of 14 HST at a planting distance of 30 × 25 cm is significantly different from the planting distances of 30 × 30 cm and 30 × 15 cm, but not significantly different from the planting distance of 30 x 20 cm. At the observation age of 28 HST, the

treatment of planting distances of 30 × 30 cm and 30 x 25 cm gave a significantly larger leaf area compared to 30 × 20 cm and 30 × 15 cm. At 42 HST, the treatment with a planting distance of 30 × 30 cm produced the largest leaf area of 354.03 cm² and was significantly different from the

planting distances of 30 × 25 cm, 30 × 20 cm, and 30 × 15 cm, which produced the smallest leaf area of 278.85 cm². The single treatment of 50 HST harvest age for leaf area parameters was not significantly different from either 60 HST or 70 HST harvest age. Research by Dhital et al. (2025) reported that a spacing of 45 × 15 cm resulted in an average leaf number of 13.37 and a canopy diameter of 39.65 cm, indicating an increase in canopy size and potential leaf area at a relatively looser spacing.

The combination of planting distance and harvest age also had no significant effect on the leaf area of red beet (*Beta vulgaris* L.) plants. This finding is because leaf size in red beet plants is a morphological trait that tends to be controlled by genetic factors, so variations induced by environmental treatments, such as planting distance and harvest age, are relatively limited (Taiz et al., 2023).

Plant spacing influences leaf area of red beetroot plants because it is closely related to growing space and the level of competition for resources such as light, water, and nutrients. If the spacing is too narrow, plants will shade each other, reducing light intake and suboptimal photosynthesis. Conversely, wider spacing allows each plant to receive adequate light and nutrients, resulting in

better leaf growth. This variation in influence is evident at 14, 28, and 42 days after planting (DAP) because each growth phase has distinct physiological needs in relation to environmental factors (Susilo, 2024).

The results showed that the single-factor harvest age treatment had no significant effect on plant length, leaf area, number of tubers, or leaf area index. This finding is because the physiological development phase more influences beetroot growth than by the length of the harvest period. According to Zulfati et al. (2018), in the leaf area observation parameters, the red beet leaf canopy reached its maximum before harvest age, so that the harvest age treatment did not significantly increase leaf expansion.

3.3. Fresh Weight of Tubers per Plant (g)

The analysis of variance showed that the interaction between planting distance and harvest age significantly affected tuber fresh weight per plant. Separately, the single factor of planting distance and harvest age significantly affected tuber fresh weight per plant. The average fresh weight of tubers per red beet plant for the single factors of planting distance and harvest age are presented in Table 3.

Table 3. Average Fresh Weight of Red Beetroots per Plant in Combination of Planting Distance and Harvest Age Treatments

Planting Distance	Fresh Weight of Tubers per Plant (g)		
	Harvest Age (DAP)		
	50 HST	60 HST	70 HST
30 x 30 cm	146.89 ± 24.99 a	210.55 ± 9.68 b	304.77 ± 4.93 c
30 x 25 cm	144.17 ± 16.13 a	209.33 ± 2.42 b	303.81 ± 7.36 c
30 x 20 cm	137.86 ± 5.21 a	208.25 ± 2.07 b	244.37 ± 11.98 b
30 x 15 cm	130.33 ± 9.06 a	206.24 ± 4.93 b	244.03 ± 11.98 b
BNJ 5% 39.75			

Description: The average figures followed by the same letter in each treatment show no significant difference in the 5% BNJ test.

Table 3 shows that the harvest-age treatments differed significantly in tuber fresh weight per red beet plant. At a harvest age of 50 days after planting, all planting distance treatments were not significantly different. At a harvest age of 60 days after planting, tuber weight increased, but between planting distances remained unchanged. At a harvest age of 70 days after planting, there was a greater increase in tuber weight, especially at a planting distance of 30 × 30 cm (304.77 g), which was significantly greater than at 30 × 15 cm. The highest average yield of fresh tuber weight per plant was obtained in the combination treatment of a planting distance of 30 x 30 cm with a harvest age of 70 days after planting, namely 304.77 g. The lowest average yield of fresh tuber weight per plant was obtained in the combination treatment of a planting distance of 30 x 15 cm and a harvest age of 50 days after planting, namely 130.33 g. Research by Tamiru et al. (2017) reported that a planting distance of 40 × 30 cm resulted in a fresh tuber weight of 285.6 g, higher than that for 30 × 20 cm (243.7 g), further strengthening the evidence that planting density has a significant effect on tuber yield. In the treatment of

harvest age, the study by Kadam et al. (2018) reported that a longer harvest period (70–75 HST) was able to increase the weight of red beet tubers to 170.84 g compared to an earlier harvest (55–60 HST), which only reached 143.52 g, because at this phase, there was maximum accumulation of photosynthates towards the tuber tissue.

The combination of a 30 x 30 cm planting distance and a harvest time of 70 days after planting significantly affected tuber fresh weight per plant. This finding may be due to the fact that longer harvest times and wider planting distances result in greater tuber weight. Increased tuber weight at wider planting distances and longer harvest times can affect photosynthesis, particularly by altering the availability of light, H₂ O, and CO₂. This finding is in line with the opinion (Tegen & Jembere, 2021) that increasing growing space and the length of tuber filling time will increase photosynthate accumulation in storage organs.

A wide planting distance of 30 x 30 cm yields the highest tuber fresh weight per plant. This is because a wide planting distance allows each plant sufficient growing space to develop its canopy and roots, resulting in optimal

photosynthesis. Wide planting distances also reduce competition for sunlight, allowing photosynthate to be more efficiently allocated to tubers (Parajuli & Dhital, 2023).

The single factor of harvest age also influences tuber fresh weight per plant, reflecting the plant's physiological stage and biomass accumulation. The longer the plant ages before harvest, the more time it has for photosynthesis, so assimilated carbohydrates are allocated more to storage organs such as tubers, resulting in increased fresh weight (Wulandari et al., 2025).

3.4. Fresh Weight of Bulbs per Plot (kg)

The analysis of variance showed that the combination of planting distance and harvest age treatments significantly affected tuber fresh weight per plot. Separately, the single-factor planting distance treatment and the single-factor harvest age treatment significantly affected tuber fresh weight per plot. The average fresh weight of tubers per plot of red beet plants in the combination of planting distance and harvest age treatments is presented in Table 4.

Table 4. Average Fresh Weight of Bulbs per Plot of Red Beet Plants in Combinations of Planting Distance and Harvest Age Treatments

Planting Distance	Fresh Weight of Bulbs per Plot (kg)		
	Harvest Age (DAP)		
	50 HST	60 HST	70 HST
30 x 30 cm	1.40 ± 0.23 a	2.29 ± 0.19 b	2.31 ± 0.05 b
30 x 25 cm	1.63 ± 0.21 ab	2.40 ± 0.14 b	2.60 ± 0.15 b
30 x 20 cm	1.75 ± 0.38 ab	2.43 ± 0.13 b	3.89 ± 0.32 c
30 x 15 cm	2.30 ± 0.51 b	3.50 ± 0.35 c	3.90 ± 0.25 c
BNJ 5% 0.67			

Description: The average figures followed by the same letter in each treatment show no significant difference in the 5% BNJ test.

Table 4 shows that at the harvest age of 50 HST, the fresh weight of tubers per plot at a planting distance of 30 × 30 cm was significantly different from the planting distance of 30 × 15 cm. At the harvest age of 60 HST, there was an increase in tuber fresh weight, with a planting distance of 30 × 15 cm showing a significant difference compared with other treatments. At the harvest age of 70 HST, the fresh weight of tubers per plot increased further, where the planting distances of 30 × 20 cm and 30 × 15 cm were significantly different than the planting distances of 30 × 30 cm and 30 × 25 cm. The highest average yield of fresh tuber weight per plot was at a planting distance of 30 × 15 cm, with a harvest age of 70 HST, at 3.90 kg. The lowest average yield of fresh tuber weight per plot was obtained at a planting distance of 30 × 30 cm with a harvest age of 50 HST of 1.40 kg. The increase in results is in line with research (Kadam et al., 2018), who reported that a planting distance of 30 × 15 cm produced a tuber weight per plot of 3.68 kg, higher than a spacing of 45 × 15 cm, which only reached 2.95 kg, because the denser plant population increased the total yield per unit area. In addition, the study (Sinta & Garo, 2021) showed that increasing the harvest age from 60 to 75 HST increased the weight of red beet tubers from 2.81 kg to 3.74 kg per plot, due to increased photosynthate accumulation in storage organs.

The highest fresh tuber weight per plot was obtained with a 30 x 15 cm planting spacing at 70 days after harvest. This finding indicates that tuber weight per plot increases with increasing harvest age, and dense planting spacing provides higher productivity per plot. In line with the findings of Wulandari et al. (2025), photosynthates are allocated to storage organs, so the later the harvest, the larger the tuber size. Furthermore, dense planting spacing

can increase yield per unit area, even though tuber size per plant tends to be smaller (Fikre Limeneh et al., 2021). These results demonstrate that harvest age and planting spacing interact to determine the fresh weight of red beet tubers.

The single factor of harvest age also influences fresh weight per plot. During the vegetative growth phase and early tuber formation, plants continue to focus on leaf and stem development. As the harvest age increases, the growth phase shifts to the tuber-filling phase, during which photosynthates from the leaves are translocated to the tubers, thereby increasing the fresh weight of tubers per plant. Fresh tuber weight per plot and per hectare also increases because larger individual plant yields accumulate across the field population (Olfin Wombaibabo et al., 2021).

3.5. Fresh Weight of Tubers per Hectare (ton/ha)

The analysis of variance showed that the combination of planting distance and harvest age treatments significantly affected tuber fresh weight per hectare. Separately, the single-factor planting distance treatment and the single-factor harvest age treatment significantly affected tuber fresh weight per hectare. The average fresh weight of tubers per hectare of red beet plants in the combination of planting distance and harvest age treatments is presented in Table 5.

Table 5 shows that at the harvest age of 50 HST, the fresh weight of tubers per hectare at a spacing of 30 × 30 cm was significantly different from the spacing of 30 × 15 cm. At the harvest age of 60 HST, tuber fresh weight increased with a spacing of 30 × 15 cm, resulting in a significantly higher value than in other treatments. At the harvest age of 70 HST, the fresh weight of tubers per

hectare increased further, where the spacing of 30 × 20 cm and 30 × 15 cm was significantly higher than the spacing of 30 × 30 cm and 30 × 25 cm. The highest average yield of fresh tuber weight per hectare was obtained at a spacing of 30 × 15 cm, with a harvest age of 70 HST, yielding 27.06 tons/ha. The lowest average yield of fresh tuber weight per hectare was obtained at a spacing of 30 × 30 cm, with a

harvest age of 50 HST, at 9.72 tons/ha. These results are in line with research (Collins et al., 2021), which reported that a dense planting distance of 15 cm produced a fresh tuber weight of up to 32.74 tons/ha, compared to a planting distance of 20 cm, which reached only 24.32 tons/ha. This finding shows that plant density plays an important role in increasing yields per hectare.

Table 5. Average Fresh Weight of Red Beetroots per Hectare in Combinations of Planting Distance and Harvest Age Treatments

Planting Distance	Fresh Weight of Tubers per Hectare (tons/ha)		
	Harvest Age (DAP)		
	50 HST	60 HST	70 HST
30 x 30 cm	9.72 ± 1.57 a	15.86 ± 0.58 b	16.03 ± 0.39 b
30 x 25 cm	11.34 ± 1.61 ab	16.69 ± 0.80 b	18.08 ± 1.78 b
30 x 20 cm	12.16 ± 2.39 ab	16.85 ± 0.38 b	26.99 ± 3.66 c
30 x 15 cm	16.00 ± 3.55 b	24.27 ± 0.98 c	27.06 ± 4.24 c
BNJ 5% 4.62			

Description: The average number followed by the same letter in the treatment shows no significant difference in the 5% BNJ test.

The combination of 30 x 15 cm planting spacing and 70 days after planting significantly affected the average tuber weight per hectare. Tuber weight per hectare tends to increase with increasing harvest age and denser planting spacing. The results of the regression analysis showed that the highest tuber weight per hectare, 27.06 tons/ha, can be achieved at an optimum harvest age of 70 days after planting with a spacing of 30 x 15 cm. This result occurs because dense planting spacing increases the plant population per unit area, resulting in a greater total yield per hectare despite lower individual weights. Meanwhile, a longer harvest age provides sufficient time for photosynthate accumulation in the tubers. According to Wulandari et al. (2025), the interaction between plant density and harvest age affects the efficiency of light, water, and nutrient use, thus impacting yield per hectare.

The single-spacing treatment significantly affected tuber weight per hectare because spacing directly determines the plant population per unit of land area.

According to (Patel et al., 2015), increasing the number of plants per plot directly increases the weight of tubers per plot and the weight of tubers per hectare, even though the size of tubers per plant is lower, but increasing the plant population can compensate for the decrease in tuber weight per plant, so that the accumulated yield per hectare remains greater than with wider planting distances.

3.6. Leaf Area Index

The results of the analysis of variance showed that the combination of planting distance and harvest age treatments did not significantly affect red beet (*Beta vulgaris* L.) plants in the leaf area index observation parameter. Separately, the single-factor planting distance treatment had a significant effect, whereas the harvest age treatments (39, 40, 40) did not significantly affect the leaf area index. The average results of the leaf area index of red beet plants in the combination of planting distance and harvest age treatments are presented in Table 6.

Table 6. Average Leaf Area Index of Red Beet Plants in Planting Distance and Harvest Age Treatments

Planting Distance	Leaf Area Index		
	14 HST	28 HST	42 HST
30 x 30 cm	0.11 ± 0.04 a	0.25 ± 0.02 a	0.39 ± 0.03 a
30 x 25 cm	0.14 ± 0.02 b	0.29 ± 0.02 b	0.45 ± 0.03 b
30 x 20 cm	0.17 ± 0.03 c	0.35 ± 0.02 c	0.51 ± 0.04 c
30 x 15 cm	0.21 ± 0.01 d	0.41 ± 0.02 d	0.62 ± 0.03 d
BNJ 5% 0.01 0.01 0.01			
Harvest Age	14 HST	28 HST	42 HST
50 HST	0.16 ± 0.06	0.33 ± 0.12	0.48 ± 0.13
60 HST	0.15 ± 0.08	0.32 ± 0.12	0.49 ± 0.14
70 HST	0.16 ± 0.05	0.33 ± 0.10	0.51 ± 0.15
BNJ 5% tn tn tn			

Description: The average figures followed by the same letter in each treatment show no significant difference in the 5% BNJ test.

Table 6 shows that the spacing treatment gave a significant difference to the leaf area index of red beet

plants at all observation ages of 14, 28, and 42 HST, where the spacing of 30 × 30 cm was significantly different from

30 × 25 cm, 30 × 20 cm, and 30 × 15 cm. The highest average leaf area index was obtained from the spacing treatment of 30 x 15 cm at the age of 42 HST, with a value of 0.62, and the lowest average leaf area was obtained from the spacing treatment of 30 x 30 cm at the age of 14, with a value of 0.11. The harvest-age treatment did not show a significant difference at any observation age. Research by Sakti and Sugito (2018) reported that leaf area index at a narrow planting distance of 10x10 cm (6.2) was significantly greater than that at a wider planting distance of 10x25 cm (4.2).

The single-factor treatment of plant spacing



Figure 2. Comparison of Leaf Area in Planting Distance Treatments

Despite differences in harvest age, the leaf area index (ILD) did not increase because leaf area tends to stabilize after reaching the generative phase. Therefore, additional harvest time only increases tuber biomass accumulation, not canopy expansion. Furthermore, photosynthate allocation at later ages is directed more toward tuber enlargement than to new leaf formation, so the ILD remains relatively constant. Environmental factors such as light intensity and nutrient availability play a greater role than harvest age in determining these parameters. According to Nurholis et al. (2023), vegetative parameters such as ILD tend to be unresponsive to harvest age treatment.

significantly affected the leaf area index (ILD) of red beet plants at all observation ages. The ILD values obtained across all plant spacing treatments ranged <1, indicating that leaf area had not reached optimal conditions, so light assimilation remained limited (Susanti & Safrina, 2018). The denser the plant spacing, the higher the ILD value. This finding indicates that plant population density increases total leaf area through competition for light and growing space. At ILD values <1, plants still utilized available light for photosynthesis, although efficiency was not optimal.

4. Conclusion

This study shows that the 30 x 15 cm planting distance, alone or in combination with a harvest age of 70 HST, can significantly increase the growth and yield of red beet plants, especially in tuber fresh weight per plot and per hectare. In addition, the 30 x 15 cm planting distance yields the best results for plant length and leaf area index. The treatment at 70 HST harvest age yields the highest results for leaf area per plant and tuber fresh weight per plant. A 30x15 cm planting distance with a harvest age of 70 HST is recommended for farmers cultivating red beet plants of the Ayumi04 variety.

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