OPTIMIZING PLANT SPACING TO IMPROVE GROWTH AND YIELD OF SWEET POTATO (*Ipomoea batatas* L.) UNDER LOW SOIL FERTILITY CONDITIONS

OPTIMALKAN JARAK TANAMAN UNTUK MENINGKATKAN PERTUMBUHAN DAN HASIL UBI JALAR (*Ipomoea batatas* L.) PADA KONDISI KESUBURAN TANAH RENDAH

Muzna Ardin Abdul Gafur*, Zulkarnain Sangadji, Desi Ratna Sari
Program Studi Agroteknologi, Fakultas Pertanian, Universitas Muhammadiyah, Sorong

*Correspondence : muznagafur@gmail.com

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ABSTRACT

Sweet potato (*Ipomoea batatas* L.) is an important food crop in tropical regions, but its productivity remains low on infertile soils where suboptimal agronomic practices, including inappropriate plant spacing, restrict plant growth and tuber development. This study evaluated the effect of different plant spacing arrangements on the growth and yield of sweet potato cultivated under low soil fertility conditions. A randomized complete block design with six spacing treatments J1 (40 × 30 cm), J2 (50 × 50 cm), J3 (75 × 30 cm), and J4 (75 × 50 cm) and three replications was used. Growth parameters and yield components were analyzed using analysis of variance followed by the Honest Significant Difference (HSD) test at the 5% significance level. Plant spacing significantly affected vegetative growth and tuber yield. The spacing of 75 × 50 cm produced the best overall performance, resulting in the highest plant height (278.83 cm), the greatest number of leaves (33.28 leaves plant^{-1}), the largest tuber diameter (5.49 cm), the highest tuber weight per plant (2.83 oz plant^{-1}), and the highest tuber weight per plot (4.53 kg plot^{-1}), equivalent to an estimated yield of 12.58 t ha^{-1}. The superior performance of this spacing is attributed to a more favorable balance between plant population and competition for light, water, and nutrients, thereby enhancing photosynthetic efficiency and assimilate partitioning to storage roots. These findings demonstrate that optimizing plant spacing is an effective and practical agronomic strategy for improving sweet potato productivity on low-fertility soils and may contribute to more sustainable sweet potato production in similar agroecological environments.

Keywords: sweet potato, plant spacing, low-fertility soil, tuber yield, agronomic management.

ABSTRAK

Ubi jalar (*Ipomoea batatas* L.) merupakan tanaman pangan penting di wilayah tropis, namun produktivitasnya masih rendah pada tanah kurang subur akibat praktik agronomi yang suboptimal seperti pengaturan jarak tanam yang tidak tepat yang menghambat pertumbuhan tanaman dan perkembangan umbi. Penelitian ini mengevaluasi pengaruh berbagai pengaturan jarak tanam terhadap pertumbuhan dan hasil ubi jalar yang dibudidayakan pada kondisi tanah dengan tingkat kesuburan rendah. Penelitian menggunakan rancangan acak kelompok lengkap dengan enam perlakuan jarak tanam J1 (40 × 30 cm), J2 (50 × 50 cm), J3 (75 ×

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30 cm), dan J4 (75 × 50 cm) serta tiga ulangan. Parameter pertumbuhan dan komponen hasil dianalisis menggunakan analisis ragam yang diikuti dengan uji Beda Nyata Jujur (BNJ) pada taraf signifikansi 5%. Jarak tanam berpengaruh nyata terhadap pertumbuhan vegetatif dan hasil umbi. Jarak tanam 75 × 50 cm menghasilkan performa terbaik secara keseluruhan, dengan capaian berupa tinggi tanaman tertinggi (278,83 cm), jumlah daun terbanyak (33,28 helai tanaman^{-1}), diameter umbi terbesar (5,49 cm), bobot umbi per tanaman tertinggi (2,83 oz tanaman^{-1}), dan bobot umbi per petak tertinggi (4,53 kg petak^{-1}), yang setara dengan estimasi hasil 12,58 ton ha^{-1}. Performa unggul pada jarak tanam ini disebabkan oleh keseimbangan yang lebih baik antara populasi tanaman dan kompetisi untuk mendapatkan cahaya, air, dan hara, sehingga meningkatkan efisiensi fotosintesis serta alokasi asimilat ke akar penyimpanan (umbi). Temuan ini menunjukkan bahwa optimalisasi jarak tanam merupakan strategi agronomi yang efektif dan praktis untuk meningkatkan produktivitas ubi jalar pada tanah kurang subur, serta dapat berkontribusi pada produksi ubi jalar yang lebih berkelanjutan di lingkungan agroekologi serupa.

Kata kunci: ubi jalar, jarak tanam, tanah kurang subur, hasil umbi, pengelolaan agronomi.

INTRODUCTION

Plant spacing is widely recognized as one of the most important agronomic practices influencing crop growth and productivity because it regulates competition for light, water, nutrients, and growing space within plant populations. In sweet potato (*Ipomoea batatas* L.), planting density affects canopy architecture, light interception, photosynthetic efficiency, biomass accumulation, and assimilate partitioning, which ultimately determine storage root formation and yield. Recent studies have demonstrated that optimizing planting density significantly improves photosynthetic performance, dry matter accumulation, storage root development, and commercial yield (Liang et al., 2024; Balázs et al., 2024). Conversely, excessively narrow spacing intensifies interplant competition for light and soil nutrients, whereas excessively wide spacing reduces land-use efficiency and may decrease yield per unit area (Liu et al., 2020). These findings highlight the importance of identifying an appropriate planting density that balances resource availability with plant population to maximize sweet potato productivity.

In addition to planting density, soil fertility plays a crucial role in determining sweet potato productivity because nutrient-deficient soils restrict vegetative growth, photosynthetic activity, biomass production, and storage root development (Asa et al, 2021., Liang et al., 2024; Okanlawon & Kolawole, 2023). However, most previous studies on planting density were conducted under moderate-to-high soil fertility or intensive crop management systems, which differ considerably from the nutrient-poor conditions commonly encountered in many tropical developing countries. Furthermore, variations in soil properties, climatic conditions, and local cultivation practices can substantially influence crop responses to planting density, making agronomic recommendations highly location-specific (Liang et al.,2024). Consequently, the optimum plant spacing for sweet potato under low-fertility tropical soils remains insufficiently understood. This knowledge gap limits the development of effective spacing recommendations for marginal production environments, highlighting the need for location-specific studies to identify optimum planting density for maximizing sweet potato growth and yield under low soil fertility conditions.

This study provides a novel contribution by evaluating planting spacing optimization for sweet potato under low soil fertility conditions in a tropical environment. It integrates vegetative growth parameters, yield components, and plant population density to identify the most efficient spacing for maximizing productivity. The findings are expected to contribute to the development of practical, site-specific agronomic recommendations for improving sweet potato production in marginal lands.

The study specifically aims to (1) analyze the effects of planting spacing on the growth and yield of sweet potato under low soil fertility conditions and (2) determine the optimal spacing for maximizing productivity. This study is particularly relevant to Sorong Regency, where agricultural lands are commonly characterized by acidic soils, low organic matter content, and limited macronutrient availability. These conditions constrain crop productivity and emphasize the need for appropriate agronomic interventions, including optimized planting spacing, to improve resource-use efficiency, land productivity, and sustainable agricultural production (Rosalina et al., 2019; Fajeriana et al., 2025; Gafur et al., 2025).

MATERIALS AND METHODS

The experiment was conducted from August to November 2025 in Aimas Village, Sorong Regency, Southwest Papua, Indonesia. The research site consists of marginal agricultural land dominated by Ultisols (Red-Yellow Podzolic soils), Oxisols (Latosols), and a smaller proportion of Inceptisols. These soils are generally characterized by acidic soil reactions, low organic matter content, low cation exchange capacity, low base saturation, and limited availability of essential nutrients, resulting in inherently low soil fertility and requiring appropriate soil management practices (Fajarindo & Limin, 2024). Ultisols exhibit low fertility due to highly acidic soil reactions, low organic carbon content, limited availability of phosphorus and potassium, low cation exchange capacity and base saturation, and high aluminum saturation; all these factors constrain crop productivity unless appropriate soil management practices are implemented.

The field experiment was arranged in a randomized complete block design (RCBD) consisting of four plant-spacing treatments: J1 (40 × 30 cm), J2 (50 × 50 cm), J3 (75 × 30 cm), and J4 (75 × 50 cm). The treatments were evaluated in three complete blocks, with each treatment randomly assigned once within each block, resulting in a total of 12 experimental units. Blocking was employed to minimize the effects of spatial variability across the experimental field. The experimental field was characterized by initially low soil fertility. Before planting, all experimental plots received a uniform basal application of chicken-manure bokashi at a rate of 1.5 kg m^{-2} (equivalent to 15 t ha^{-1}) to provide a common soil fertility baseline before treatment application. Data were analyzed using analysis of variance (ANOVA) for a randomized complete block design. The ANOVA consisted of treatment, block, and experimental error sources of variation with 3, 2, and 6 degrees of freedom for treatment, block, and experimental error, respectively. When treatment effects were significant, treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level.

The planting material consisted of a local purple-fleshed sweet potato cultivar commonly cultivated by farmers in the study area. Five sample plants were randomly selected from the central area of each plot to minimize border effects. Growth observations included plant height, number of leaves, and number of branches measured at 15, 30, 45, and 60 days after planting (DAP). Yield observations included number of tubers per plant, tuber length, tuber diameter, tuber weight per plant, and tuber weight per plot, measured at harvest.

Crop management practices included manual watering, hand weeding, and pest and disease control following local farmer cultivation practices throughout the growing period until harvest. The experimental data were analyzed using analysis of variance (ANOVA) for a randomized complete block design (RCBD). When the ANOVA indicated significant treatment effects, treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level.

RESULTS AND DISCUSSION

Soil Chemical Properties

The initial soil analysis at the experimental site in Aimas Village, Sorong Regency, indicated low to moderate fertility across several key parameters. The soil pH (6.07) was slightly acidic but still within the tolerance range for sweet potato growth, although it may influence nutrient availability. Organic carbon (1.76%) and total nitrogen (0.12%) were both classified as low, indicating limited nutrient supply for plant growth. Such conditions are typical of tropical soils with low organic matter accumulation. Soil organic matter plays a critical role in improving soil structure, increasing cation exchange capacity, and enhancing nutrient availability (Lal, 2020; Duque, 2023).

Table 1. Initial soil chemical properties before treatment application.

Soil property	Unit	Value
pH (H_2O)	–	6.07
pH (KCl)	–	–
Organic C (Walkley & Black)	%	1.76
Total N (Kjeldahl)	%	0.12
C/N ratio	–	15
Available P (Olsen-P_2O_5)	ppm	9.35
Exchangeable Ca	cmol(+) kg^{-1}	5.14
Exchangeable Mg	cmol(+) kg^{-1}	1.74
Exchangeable K	cmol(+) kg^{-1}	0.22
Exchangeable Na	cmol(+) kg^{-1}	0.27
Total exchangeable bases	cmol(+) kg^{-1}	7.00
Cation exchange capacity (CEC)	cmol(+) kg^{-1}	22.27
Base saturation	%	33

Available phosphorus (9.35 ppm) and exchangeable potassium (0.22 cmol(+)/kg) were also low, suggesting potential constraints on root development and tuber formation. Macronutrients such as N, P, and K are essential for vegetative growth, photosynthesis, and biomass accumulation in storage organs. Nutrient limitations in marginal soils have been shown to reduce sweet potato growth and productivity due to impaired photosynthetic efficiency and storage root development (Liang et al., 2024; Szarvas et al., 2018; Zewide et al., 2021). These findings indicate that the soil has limited capacity to support optimal crop growth, emphasizing the need for improved nutrient management.

The soil cation exchange capacity (CEC) was moderate (22.77 cmol(+)/kg), indicating a reasonable ability to retain nutrient cations, while base saturation was low (33%), reflecting limited availability of basic cations. This further confirms the overall low fertility status of the soil. Under such conditions, appropriate agronomic strategies particularly optimizing planting distance and nutrient management are essential to improve resource-use efficiency and enhance sweet potato productivity (Balázs et al., 2024; Zhao et al., 2025; Tittonell, 2013). Therefore, the soil characteristics provide a strong basis for evaluating optimal planting distance as a strategy to improve productivity in marginal soils.

Initial soil analysis indicated that the experimental field had moderately acidic soil (pH H_2O = 6.07), low organic carbon (1.76%), low total nitrogen (0.12%), low available phosphorus (9.35 ppm), low exchangeable potassium (0.22 cmol(+) kg^{-1}), moderate cation exchange capacity (22.27 cmol(+) kg^{-1}), and low base saturation (33%), indicating relatively low inherent soil fertility. Such conditions are commonly associated with limited nutrient availability and reduced nutrient-use efficiency, which may restrict sweet potato growth and storage-root development unless appropriate crop management practices are adopted (Pratamaningsih et al., 2024; Fajarindo & Limin., 2024; Anwar & Santosa., 2023). Under low-fertility conditions, optimizing plant spacing becomes an important agronomic strategy because appropriate plant density improves light interception, reduces interplant competition for water and nutrients, enhances canopy development, and ultimately increases storage-root yield. Recent studies demonstrated that plant spacing significantly affects vine growth, root size, marketable root yield, and total sweet potato productivity, particularly when integrated with balanced nutrient management (Balázs et al., 2024).

Plant Height

Further examination of the data presented in Table 3 demonstrates that plant spacing influenced the vegetative growth of sweet potato differently across the observation periods. During the early growth stage, plant spacing had no significant effect on plant height. At 15 DAP, the mean plant height ranged from 35.22 cm (J1) to 40.72 cm (J4), and statistical analysis indicated no significant differences among treatments ($F = 1.07$, $p > 0.05$). Similarly, at 30 DAP, plant height varied between 84.67 cm (J3) and 95.78 cm (J2), but these differences were also not statistically significant ($F = 0.60$, $p > 0.05$). These findings suggest that plant spacing had little influence on early vegetative development, likely because the canopy had not yet fully expanded and competition among plants for light, water, and soil nutrients remained minimal.

Table 2. Summary of analysis of variance (ANOVA) for the effect of plant spacing on sweet potato plant height at different observation times

Observation time	F-value	Probability (P)	Significance	CV (%)
15 DAP	1.07	P > 0.05	ns	11.19
30 DAP	0.60	P > 0.05	ns	11.63
45 DAP	9.25	P < 0.05	*	1.08
60 DAP	31.91	P < 0.01	**	0.86

Note: ns = not significant (P > 0.05); * significant at P < 0.05; ** highly significant at P < 0.01; CV = coefficient of variation. Data summarized from the RCBD ANOVA.

A different response was observed during the later growth stages. At 45 DAP, plant spacing significantly affected plant height ($F = 9.25$, $p < 0.05$). Plants grown under the widest spacing (J4) attained the greatest mean height (179.61 cm), followed closely by J3 (179.17 cm) and J2 (179.11 cm). According to Tukey's HSD test ($P \leq 0.05$), these three treatments were not significantly different from one another, but all produced significantly taller plants than J1 (172.55 cm). This result indicates that increasing plant spacing beyond the narrowest treatment promoted greater stem elongation once vegetative growth became more vigorous.

Table 3. Effect of plant spacing on sweet potato plant height at 15, 30, 45, and 60 days after planting (DAP)

Plant Spacing	15 DAP	30 DAP	45 DAP	60 DAP
J1	35.22 a	89.11 a	172.55 b	268.22 b
J2	36.95 a	95.78 a	179.11 a	268.72 b
J3	35.72 a	84.67 a	179.17 a	260.44 c
J4	40.72 a	92.06 a	179.61 a	278.83 a

Note: Means followed by the same letter within a column are not significantly different at P < 0.05 according to Tukey's HSD test.

The effect of plant spacing became even more pronounced at 60 DAP, when the analysis revealed a highly significant treatment effect ($F = 31.91$, $p < 0.01$). Treatment J4 consistently produced the tallest plants (278.83 cm) and was significantly superior to all other spacing treatments. Treatments J1 (268.22 cm) and J2 (268.72 cm) did not differ significantly from each other, whereas J3 produced the shortest plants (260.44 cm) and differed significantly from the remaining treatments. Overall, these findings demonstrate that wider plant spacing provided a more favorable growing environment during the later stages of crop development, thereby reducing interplant competition and enhancing vegetative growth under the low-fertility soil conditions of Sorong Regency.

Leaf Number

Plant spacing showed no significant effect on leaf number at 15, 30, and 45 days after planting (DAP) ($p > 0.05$), indicating that canopy development during early growth was not strongly influenced by plant density.

Table 4. Summary of analysis of variance (ANOVA) for the effect of plant spacing on leaf number at different observation times

Observation time	F-value	Probability (P)	Significance	CV (%)
15 DAP	1.17	P > 0.05	ns	8.42
30 DAP	1.20	P > 0.05	ns	4.61
45 DAP	2.00	P > 0.05	ns	4.54
60 DAP	5.11	P < 0.05	*	2.94

Note: ns = not significant (P > 0.05); * = significant at P < 0.05; CV = coefficient of variation

Table 5. Effect of plant spacing on number of leaves of sweet potato at 15, 30, 45, and 60 days after planting (DAP)

Plant Spacing	15 DAP	30 DAP	45 DAP	60 DAP
J1	6.11 a	15.39 a	24.33 a	30.50 b
J2	6.05 a	16.50 a	22.83 a	32.89 a
J3	6.78 a	16.05 a	24.22 a	31.94 ab
J4	6.22 a	16.17 a	24.94 a	33.28 a

Note: Means followed by the same letter within a column are not significantly different at P < 0.05 according to Tukey's HSD test

However, a significant effect was observed at 60 DAP ($p < 0.05$), where treatment J4 produced the highest leaf number (33.28 leaves plant^{-1}), while J1 recorded the lowest (30.50 leaves plant^{-1}). This suggests that the influence of plant spacing becomes more evident during the later vegetative stage as inter-plant competition increases. Leaf number increased progressively with plant age across all treatments, with clearer differentiation emerging between 45 and 60 DAP. This trend reflects active vegetative growth and indicates that spacing affects canopy expansion by regulating access to light, water, nutrients, and growing space. During early growth, the absence of significant differences suggests that plant development is primarily governed by internal factors such as genetic potential and stored assimilates rather than plant density (Hilty et al., 2021; Chapepa et al., 2020).

As plants develop, competition for environmental resources intensifies, making spacing effects more pronounced. Wider spacing improves light interception and photosynthetic efficiency, thereby enhancing vegetative growth (Zhou et al., 2024; Zhao et al., 2025). This condition also promotes better assimilate allocation, which may contribute to increased tuber size and weight under less competitive conditions, although higher plant density may still increase yield per unit area due to greater plant population (Motsa et al., 2015).

From a physiological perspective, leaf number reflects the plant's photosynthetic capacity, as leaves function as the main source organs in the source–sink system. Increased leaf number enhances assimilate production, which is subsequently allocated to storage root development (L. Li et al., 2016). Plant spacing influences this process by modifying canopy structure and light distribution, thereby affecting radiation interception and photosynthetic performance(Zhang et al., 2015).

Excessively high plant density intensifies competition for light, water, and nutrients, limiting leaf expansion, while excessively wide spacing may reduce land-use efficiency. Therefore, an optimal spacing balance is required to maintain efficient canopy development and storage root formation (Liang et al., 2024)). Similar findings indicate that the effect of plant density on vegetative growth becomes more apparent at later stages when canopy overlap increases (Bhattacharjee et al., 2023)). From an agronomic perspective, these results highlight the importance of spacing management in improving resource-use efficiency under low-fertility conditions. Proper plant density enhances light interception and nutrient utilization, leading to improved productivity in root and tuber crops (Szarvas et al., 2018). Moreover, spacing optimization supports sustainable intensification by improving crop performance without increasing external inputs (Xu et al., 2026)). Sweet potato productivity is not solely determined by leaf abundance, but rather by the efficiency of assimilate partitioning to storage roots, which is influenced by morphological traits and environmental adaptability (Pazos et al., 2021).

Overall, the findings demonstrate that plant spacing significantly influences leaf development during later growth stages and plays a crucial role in regulating canopy structure, photosynthetic efficiency, and ultimately sweet potato productivity under low-fertility soil conditions.

Number of Branches

The number of branches increased progressively with plant age across all treatments, with more pronounced development observed between 45 and 60 DAP.

Table 6. Summary of analysis of variance (ANOVA) for the effect of plant spacing on the number of branches at different observation times

Observation time	F-value	Probability (P)	Significance	CV (%)
30 DAP	0.54	P > 0.05	ns	14.84
45 DAP	0.64	P > 0.05	ns	9.35
60 DAP	2.40	P > 0.05	ns	7.34

Note: ns = not significant (P > 0.05); CV = coefficient of variation

Table 7 shows that plant spacing treatments did not significantly affect the number of sweet potato branches at 30, 45, and 60 days after planting (DAP), as indicated by the identical statistical grouping letters in each observation period. Although the average number of branches tended to increase with plant age across all treatments, the differences among spacing levels remained statistically insignificant. At

60 DAP, treatment J4 produced the highest average number of branches (5.33 branches plant^{-1}), followed by J1 (5.00), J2 (4.84), and J3 (4.56). This result suggests that the range of plant spacing tested provided relatively similar growing conditions, allowing plants to develop branches at comparable rates. The absence of a significant spacing effect indicates that branching in sweet potato is likely influenced more by genetic characteristics and environmental factors than by the differences in spacing applied in this study.

Table 7. Effect of plant spacing on number of branches of sweet potato at 30, 45, and 60 days after planting (DAP)

Plant Spacing	30 DAP	45 DAP	60 DAP
J1	2.22 a	3.89 a	5.00 a
J2	2.00 a	3.89 a	4.84 a
J3	1.95 a	3.61 a	4.56 a
J4	2.17 a	4.00 a	5.33 a

Note: Values followed by the same letters within a column are not significantly different according to the HSD test at the 5% level

This result suggests that under low soil fertility conditions, nutrient availability may be a more limiting factor for branching development than plant density. Similar findings indicate that morphological responses to spacing are often weak under nutrient-deficient conditions due to restricted vegetative growth (Zhang et al., 2022). Branch number in sweet potato is affected by environmental factors such as light intensity, with excessive shading significantly reducing branch formation (Jin et al., 2023).

Although spacing did not significantly affect branching in this study, plant density remains a key factor influencing competition for light, water, and nutrients among plants. Higher plant density may intensify light competition and induce morphological adjustments to optimize light interception. These responses are highly dependent on environmental conditions, particularly soil fertility and water availability.

From an agroecological perspective, the absence of significant differences suggests that sweet potato exhibits relatively stable morphological adaptation across spacing levels under marginal soil conditions. Similar responses have been reported in tuber crops grown under resource-limited environments (Liang et al., 2024)). This finding supports the concept that plant spacing primarily enhances resource-use efficiency and canopy distribution rather than directly influencing all vegetative traits (Xie et al., 2025).

From a practical standpoint, these results indicate that spacing adjustments alone may not significantly affect branching under low-fertility conditions. Therefore, determining optimal planting distance should consider broader agronomic factors, including yield, land-use efficiency, and management practicality (Balázs et al., 2024b). Optimizing plant density remains essential for improving resource-use efficiency and sustaining productivity in marginal environments (Zhao et al., 2025).

Overall, although plant spacing did not significantly influence branch formation, it remains a key component of sweet potato management. An adaptive spacing strategy that integrates soil fertility conditions is necessary to improve production efficiency and support sustainable cultivation systems in Sorong Regency

Tuber Length and Diameter

Plant spacing significantly affected tuber length and diameter (LSD 5%), indicating that plant density plays an important role in storage root development through its influence on resource competition and assimilate distribution. Treatment J4 produced the largest tuber diameter (5.49 cm) and the longest tubers (14.24 cm), while the lowest values were observed in J2. These results suggest that wider spacing provides more favorable growing conditions, allowing better root expansion and development.

Table 8. Summary of ANOVA for the effect of plant spacing on storage root size components of sweet potato

Variable	F-value	Probability	Significance	CV (%)
Length of the largest storage root (cm)	6.11	P < 0.05	*	3.12
Diameter of the largest storage root (cm)	10.88	P < 0.01	**	3.07

Note: ns = not significant ($P > 0.05$); * = significant ($P < 0.05$); ** = highly significant ($P < 0.01$); CV = coefficient of variation

Table 9. Effect of plant spacing on tuber length and tuber diameter of sweet potato

Plant Spacing	Tuber Length (cm)	Tuber Diameter (cm)
J1	13.01 b	4.92 b
J2	12.96 b	4.83 b
J3	13.28 b	4.97 b
J4	14.24 a	5.49 a

Note: Values followed by the same letters within a column are not significantly different according to the HSD test at the 5% level. Plant spacing significantly affected.

Plant spacing significantly influenced tuber length and diameter; however, the response was not strictly linear across treatments. Although J2 (50 × 50 cm) provided a wider growing space than J1 (40 × 30 cm), tuber length and diameter were slightly lower. Nevertheless, the differences between J1 and J2 were very small (0.05 cm for tuber length and 0.09 cm for tuber diameter), and both treatments belonged to the same statistical group according to Tukey's HSD test, indicating that these numerical differences were not agronomically meaningful. This finding suggests that sweet potato tuber development was not determined solely by increasing plant spacing, but rather by the interaction between within-row and between-row spacing, which influences canopy architecture, light interception, assimilate partitioning, and competition among plants. The superior performance of J4 (75 × 50 cm) indicates that this spacing configuration provided a more favorable balance between plant population and resource availability, resulting in significantly greater tuber length and diameter than the other spacing treatments.

The observed differences indicate that appropriate planting distance improves access to essential resources such as light, water, and nutrients, thereby enhancing photosynthetic performance and promoting assimilate allocation to storage roots. Similar findings were reported by Liang et al., (2024), who demonstrated that optimal plant density improves storage root yield and quality. Likewise, Zhang et al., (2022) showed that proper spacing enhances resource-use efficiency, particularly light interception and nutrient uptake, leading to greater biomass accumulation in yield-forming organs.

Conversely, excessive plant density can restrict root development due to increased competition for limited resources. Kivuva et al., (2021) reported that high plant density limits storage root expansion and reduces tuber size. Therefore, maintaining a balance between plant population and available growing space is essential for optimal root development.

From a theoretical perspective, these findings support the concept of optimum plant density, where productivity is determined by the balance between plant population and environmental resource availability (Yang et al., 2020). Under optimal spacing, improved radiation interception enhances assimilate accumulation in storage roots, directly influencing tuber size and yield potential.

From a practical standpoint, optimizing planting distance represents an effective strategy to improve both the size and quality of sweet potato storage roots, particularly in low-fertility soils such as those in Sorong Regency. Appropriate spacing reduces inter-plant competition and improves resource-use efficiency, thereby enhancing crop performance (Abdulai et al., 2021).

Overall, the results confirm that planting distance management plays a significant role in determining storage root morphology and represents a key agronomic strategy for improving sweet potato productivity under marginal soil conditions.

Number of tubers per planting, tuber weight per planting and tuber weight

Shows that plant spacing significantly affected the number of tubers per plant, tuber weight per plant, tuber weight per plot, and sweet potato yield. Treatment J4 produced the highest tuber weight per plant (2.83 × 100 g), tuber weight per plot (4.53 kg), and yield (12.58 t ha^{-1}). In contrast, the highest number of tubers per plant was recorded under treatment J3, with an average of 2.50 tubers per plant. These findings indicate that appropriate plant spacing can enhance sweet potato productivity by improving tuber development and overall yield performance.

Plant spacing significantly affected several yield components of sweet potato cultivated under low-fertility soil conditions. The J3 treatment produced the highest number of tubers per plant (2.50), while J4 resulted in the highest tuber weight per plant (2.83 oz $plant^{-1}$) and tuber weight per plot (4.53 kg $plot^{-1}$). These findings indicate that spacing arrangement influenced yield performance within the environmental conditions of the present study. However, because the experiment was conducted only under low-fertility soil conditions, comparisons with normal or fertile soils were beyond the scope of this study

Table 10. Summary of ANOVA for sweet potato yield components as affected by plant spacing

Variable	F-value	Probability	Significance	CV (%)
Number of storage roots per plant	11.08	$P < 0.01$	**	7.76
Storage root weight per plant	6.55	$P < 0.05$	*	7.22
Storage root weight per plot	24.04	$P < 0.01$	**	5.82

Note: ns = not significant ($P > 0.05$); * = significant ($P < 0.05$); ** = highly significant ($P < 0.01$); CV = coefficient of variation.

Table 11. Effect of Plant Spacing on Yield Components and Productivity of Sweet Potato Based on the HSD Test (5% Significance Level)

Plant Spacing	Number of Tubers /Plant	Tuber Weight/ Plant (100 g)	Tuber Weight/ Plot (kg)	Yield (kg ha^{-1})	Yield (t ha^{-1})
J1	1.89 b	2.33 b	3.33 b	9,250	9.25
J2	1.83 b	2.28 b	3.37 b	9,361	9.36
J3	2.50 a	2.33 b	3.30 b	9,167	9.17
J4	2.00 b	2.83 a	4.53 a	12,583	12.58

Note: Values followed by the same letters within a column are not significantly different according to the HSD test at the 5% level

The results of this study demonstrated that planting distance treatments significantly influenced several yield components of sweet potato, including the number of tubers per plant, tuber weight per plant, and tuber weight per plot. Treatment J3 produced the highest number of tubers (2.50 tubers plant^{-1}), whereas the highest tuber weight per plant and per plot were observed under treatment J4, reaching 2.83 oz plant^{-1} and 4.53 kg plot^{-1}, respectively. These findings indicate that a greater number of tubers does not necessarily correspond to higher total yield, as this relationship is strongly influenced by tuber size. In this case, J4 tended to produce larger tubers, highlighting the role of planting distance in regulating assimilate distribution toward storage organs.

Statistical analysis further confirmed that planting distance had a highly significant effect on the number of tubers per plant ($F = 11.08$; $p < 0.01$), with the highest value recorded in J3 and the lowest in J2. Tuber size parameters were also significantly affected, as reflected in tuber length ($F = 6.11$; $p < 0.05$) and tuber diameter ($F = 10.88$; $p < 0.01$), both of which reached their maximum values under J4.

Similarly, tuber weight per plant and per plot showed significant to highly significant responses ($F = 6.55$; $p < 0.05$ and $F = 24.04$; $p < 0.01$, respectively). These results confirm that planting distance plays a critical role in determining both yield quantity and quality through its influence on plant growth and tuber development.

From a physiological perspective, wider planting distances reduce intraspecific competition and promote better canopy development, thereby enhancing photosynthetic efficiency and biomass accumulation in storage organs (Li et al., 2021). Increased spacing also allows for more extensive root system development, improving nutrient and water uptake efficiency (Chen et al., 2022). These findings are consistent with previous studies which reported that optimal spacing improves tuber weight per plant by enhancing resource use efficiency. In contrast, high plant density intensifies competition for light, water, and nutrients, which can reduce photosynthetic performance and limit tuber development (Kivuva et al., 2021).

Several studies have reported that higher plant density can increase total yield per unit area while reducing individual tuber size. This reflects a trade-off between individual plant productivity and land productivity. Therefore, optimizing planting distance should consider both production objectives and agroecosystem conditions. In low-fertility soils, nutrient competition becomes more pronounced, making optimal spacing an important strategy to improve nutrient use efficiency (Abewoy, 2024)., (Saifullah et al., 2024). Overall, the findings of this study highlight that planting distance is a key determinant of sweet potato productivity through its effects on assimilate allocation, tuber formation, and resource use efficiency.

Optimal plant density enhances radiation interception, photosynthetic performance, and biomass partitioning toward economic yield (Tian et al., 2022; Liang et al., 2023). Therefore, appropriate spacing management represents an effective agronomic strategy to improve sweet potato productivity, particularly in marginal soils with low fertility.

The yield conversion analysis further shows that sweet potato productivity under different planting distance treatments ranged from 9.17 to 12.58 t ha^{-1}. Overall, these values remain lower than the national average productivity, which is reported to be approximately 15 t ha^{-1}. The relatively lower yield observed in this study is likely associated with the low soil fertility conditions at the experimental site, which may limit nutrient availability for crop growth and tuber development.

Despite these limitations, treatment J4 produced the highest productivity, reaching 12.58 t ha^{-1}, which was relatively closer to the national average compared with the other treatments. This result suggests that wider planting distance under the present conditions improved nutrient uptake efficiency, reduced inter-plant competition, and promoted better tuber formation in low-fertility soils. These findings further emphasize the importance of optimizing plant spacing as part of agronomic management strategies aimed at improving sweet potato productivity under suboptimal soil conditions.

The yield values were obtained through conversion of tuber weight per plot into a hectare-based production estimate. Among the treatments, J4 produced the highest yield, reaching approximately 12.58 t ha^{-1}. In contrast, treatment J2 produced 9.36 t ha^{-1}, followed by J1 with 9.25 t ha^{-1}, while the lowest yield was observed under treatment J3 with 9.17 t ha^{-1}. Overall, treatment J4 consistently produced higher yield compared with the other spacing treatments. This result indicates that appropriate planting distance can improve sweet potato productivity by providing sufficient growing space and reducing interplant competition for essential resources such as light, water, and soil nutrients.

From a theoretical perspective, these findings contribute to the development of plant density management concepts in root crop cultivation, particularly under marginal land conditions. The results demonstrate that optimizing planting distance can improve the efficiency of resource utilization in soils with limited fertility. In addition to its theoretical implications, the study also provides practical recommendations for farmers in Sorong Regency regarding the importance of appropriate spacing management in sweet potato cultivation. Implementing optimal planting distance may enhance crop growth and yield without necessarily increasing external inputs such as fertilizers or pesticides. Therefore, planting distance optimization can serve as an effective agronomic strategy to improve agricultural productivity while maintaining sustainable land management practices.

In areas characterized by low soil fertility, such as those found in Sorong Regency, proper planting distance becomes increasingly important for improving crop performance. Soils with limited nutrient availability often intensify competition among plants when population density is too high. Under such conditions, wider spacing may reduce competition and allow individual plants to utilize environmental resources more efficiently. This management approach aligns with the principles of sustainable agricultural intensification, which emphasize increasing crop productivity through improved management practices that are adapted to local environmental conditions (Tittonell, 2021).

Overall, the results of this study indicate that planting distance optimization plays a significant role in influencing both the growth and yield of sweet potato cultivated on low-fertility soils. Treatment J4 consistently produced the highest values across several growth and yield parameters, including plant height, final leaf number, tuber size, and tuber weight per plot. These findings suggest that the spacing applied in treatment J4 provided more favorable growing conditions that supported improved vegetative development and storage root formation.

Furthermore, the results reinforce the fundamental agronomic principle that plant density is a key factor determining the efficiency of resource utilization within cropping systems. Optimal plant density allows plants to access sufficient growing space, thereby reducing competition and improving photosynthetic efficiency. Recent studies have also demonstrated that appropriate spacing arrangements can enhance canopy light interception and increase biomass accumulation in root and tuber crops (Balázs et al., 2024). These findings are consistent with the present study, which showed that wider planting distance produced better vegetative growth responses during the later stages of sweet potato development.

CONCLUSION

This study demonstrates that planting distance management plays an important role in determining the growth and productivity of sweet potato (*Ipomoea batatas* L.) cultivated on low-fertility soils. The results indicate that variation in planting distance did not significantly affect vegetative growth during the early growth stages (15–30 days after planting). However, during the later growth stages (45–60 days after planting), planting distance treatments significantly influenced several growth and yield parameters.

The spacing treatment of 75 × 50 cm produced the best vegetative growth, characterized by the highest plant height (278.83 cm) and the greatest number of leaves (33.28 leaves per plant). In addition, this treatment also resulted in the largest tuber diameter (5.49 cm), the highest tuber weight per plant (2.83 oz plant^{-1}), and the highest tuber weight per plot (4.53 kg plot^{-1}), which corresponded to an estimated yield of 12.58 t ha^{-1}.

Based on these results, the 75 × 50 cm planting distance can be recommended as an optimal spacing strategy for improving sweet potato productivity under low soil fertility conditions such as those found in Sorong Regency.

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