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Growth and Yield Performance of Cucumber (*Cucumis sativus*) under Different Intercropping Patterns with Water spinach (*Ipomoea aquatica*)

R. Agustina [1]*, AF Indrazatmiko [1], S. Budi [1], ES Redjeki [1]

[1] **Department of Agrotechnology, Faculty of Agriculture, Universitas Muhammadiyah Gresik, East Java, Indonesia.**

*Corresponding author email: rohmatin@umg.ac.id

ABSTRACT

Intercropping is an agricultural practice that optimizes land use efficiency and enhances crop productivity by improving resource utilization. This study aimed to assess cucumber's growth and yield performance (Cucumis sativus) under various intercropping patterns with water spinach (Ipomoea aquatica). A field experiment was conducted using a randomized complete block design (RCBD) with four treatments: monoculture, single-row intercropping, double-row intercropping, and alternating single-row intercropping, each with three replications. Data were collected on plant height, leaf number, and yield components, including fruit length, fruit diameter, fruit weight per hectare, fruit weight per plant, fruit weight per fruit, and the number of fruits per plant. The results indicated that different intercropping patterns significantly influenced cucumber growth and yield. The double-row intercropping system exhibited the highest plant height and number of leaves 42 days after planting (DAP), demonstrating better growth performance than monoculture and other intercropping treatments. Regarding yield, the double-row intercropping system produced more fruits per plant and total fruit weight per hectare, comparable to monoculture but significantly higher than the single-row intercropping system. Meanwhile, the alternating single-row intercropping system showed moderate improvements in growth and yield, while the single-row intercropping system resulted in the lowest growth and yield due to increased resource competition. The double-row intercropping system was the most effective approach for enhancing cucumber growth and yield. This system optimized light distribution, nutrient uptake efficiency, and soil moisture conservation, contributing to sustainable crop production. The findings suggest that row-based intercropping could be a viable alternative to monoculture in improving cucumber productivity while promoting agroecological sustainability.

Keywords: *Cucumber, Water spinach, Intercropping, Crop Productivity, Sustainable Agriculture.*

INTRODUCTION

Cucumber (Cucumis sativus) is among the most widely cultivated vegetable crops due to its high nutritional value and economic significance. However, the efficiency of cucumber production is frequently challenged by factors such as land-use limitations, nutrient depletion, and pest infestations, which can adversely affect growth and yield. One sustainable solution to address these challenges is intercropping, a well-recognized agronomic practice that enhances land productivity, improves resource utilization efficiency, and reduces the occurrence of pests and diseases (Chadfield et al., 2022; Toker et al., 2024). Water spinach (Ipomoea aquatica), a fast-growing leafy vegetable, has been considered a potential companion crop for cucumbers in intercropping systems due to its capacity to improve soil structure, suppress weeds, and optimize nutrient cycling. Nevertheless, the impact of various intercropping patterns on cucumber growth and yield remains inadequately explored, making it crucial to investigate how different planting arrangements influence cucumber performance.

Existing research on intercropping systems has shown that various planting arrangements can significantly affect plant physiological responses, nutrient uptake efficiency, and overall productivity (Chen et al., 2019; Toker et al., 2024). Monocropping, while offering ease of management, often leads to nutrient depletion, higher susceptibility to pests, and inefficient resource use. In contrast, intercropping systems can boost biodiversity, enhance soil fertility, and create a more balanced agroecosystem, leading to greater sustainability in crop production (Glaze-Corcoran et al., 2020; Li et al., 2023; Maitra et al., 2021; Rodriguez et al., 2020). However, despite the acknowledged benefits, there remains a gap in understanding how intercropping patterns, particularly row-based and alternating systems, affect cucumber growth and yield compared to monoculture. This study aims to fill this gap by evaluating different intercropping patterns of cucumber and water spinach and their impact on plant growth parameters, leaf production, and yield performance.

The rationale for conducting this research arises from the need for innovative cropping systems that maximize land-use efficiency while ensuring high productivity. Previous studies have mainly concentrated on intercropping systems featuring cereal and legume crops, whereas research on vegetable intercropping, particularly involving cucumber and water spinach, is limited. Moreover, past findings have emphasized that row-based intercropping may offer improved light distribution, nutrient uptake efficiency, and better soil moisture conservation, resulting in enhanced growth and yield outcomes (Feng et al., 2019; Jianxiong et al., 2020; Lu et al., 2023). By comparing various intercropping arrangements, this study seeks to identify the most effective planting pattern that can sustainably boost cucumber production.

This research is of significant importance to the scientific community as it contributes to sustainable agricultural practices by identifying optimal intercropping arrangements that improve productivity and resource efficiency. The study also provides valuable insights into plant-plant interactions, soil fertility management, and ecological advantages associated with diversified cropping systems. By closing the knowledge gap in vegetable intercropping, the findings from this study can inform future research and agricultural policies aimed at enhancing food safety while reducing environmental degradation.

MATERIALS AND METHODS

The research was conducted at the Agrotechnology Study Program Laboratory, Faculty of Agriculture, Universitas Muhammadiyah Gresik, located in Klitih Hamlet, Wajik Village, Lamongan District, with geographical coordinates of 7°06′11″S and 112°22′32″E. This study is characterized by a tropical climate. Wajik is situated at an altitude of 8 meters above sea level, with a mean temperature of 26 °C. The site receives an annual precipitation of 1600 mm. The soil is classified as heavy clay Vertisol. The study employs a random group design with four intercropping pattern treatments: (1) monoculture, (2) single-row intercropping, (3) double-row intercropping, and (4) alternating single-row intercropping, with each treatment repeated three times, as shown in Figure 1. The measured variables include the growth and yield of cucumbers under different intercropping patterns. The experimental plot size for each treatment was 3 meters by 1 meter. The cucumber plant spacing was 50 cm x 70 cm, while the distance for water spinach was 15 cm x 20 cm. Results are expressed as the mean of three replications for each individual. Data were analyzed using two-way analysis of variance (ANOVA) with SmartstatXL V. software (Setiawan, 2023), and multiple treatments were compared using the Tukey test at a 5% error level.

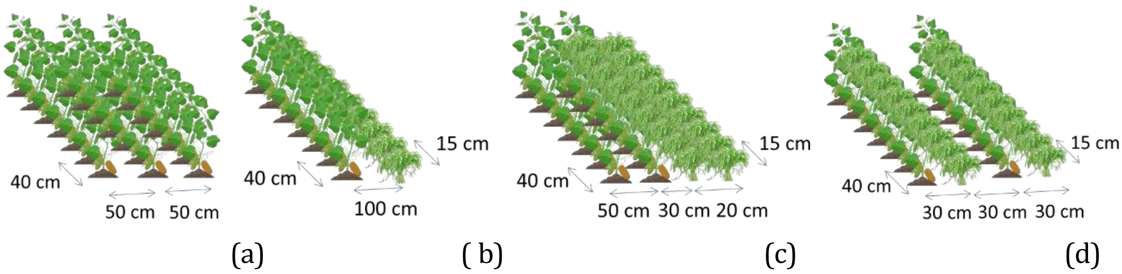

Fig 1. An intercropping pattern of cucumber and water spinach. Plot size: 3 m x 1 m. (a) Monoculture, population density of 24 cucumber plants; (b) single-row intercropping, population density of 5 cucumber plants and 22 water spinach plants; (c) double-row Intercropping, population density of 10 cucumber plants and 44 water spinach plants; (d) Alternating single-row intercropping, population density of 10 cucumber plants and 44 water spinach plants.

RESULTS AND DISCUSSIONS

Effect of Different Intercropping Patterns with Water spinach treatment on cucumber plant growth parameters

Table 1 Average plant length in Cucumber under Different Intercropping Patterns with Water spinach

Treatment	14 DAP ±SD	28 DAP ± SD	42 DAP ± SD	56 DAP ±SD
Monoculture	12.2 ± 1.2 b	127.8 ± 6.3 b	178.5 ± 8.6 ab	224.8 ± 18.4 a
single-row Intercropping	7.5 ± 1.0 a	116.2 ± 8.4 ab	152.0 ± 2.0 a	214.2 ± 11.3 a
double-row Intercropping	8.3 ± 0.7 a	109.3 ± 9.3 ab	195.7 ± 3.2 b	254.7 ± 17.6 b
Alternating single-row intercropping	7.5 ± 0.5 a	105.2 ± 5.5 a	178.6 ± 20.0 ab	220.7 ± 11.0 a
CV (%)	7.08	6.08	6.36	4.44
Tukey test	1.78	19.71	31.70	28.66
LS	**	*	*	*

DAP stands for Days After Planting, LS denotes Level of Significance, SD refers to Standard Deviation, CV indicates Coefficient of Variation, and NS signifies Non-Significant. An asterisk (*) represents the 5% Level of Significance, while two asterisks (**) denote the 1% Level of Significance. Figures with different letters in the treatment indicate significant differences.

System intercropping enhances land efficiency and optimizes plant interactions. In this study, long-plant cucumbers in monoculture were compared to various intercropping patterns with water spinach at 14, 28, 42, and 56 days after planting (DAP). The results of Tukey's test, with a 95% confidence level, indicate significant differences between treatments, marked by different letters at each observation time.

Research findings highlight the differences in long-plant cucumbers across various intercropping patterns with water spinach compared to monoculture (Table 1). At 14 DAP, monoculture produced long-plant cucumbers that were significantly taller (12.2 ± 1.2 cm) than in all intercropping patterns. Cucumber plants in monoculture do not face substantial competition for light and nutrients during their early growth phase (Chaudhary et al., 2022; Gou et al., 2017). However, as plant development continues, differences between the systems start to emerge, highlighting the influence of complex ecological interactions in system intercropping.

In the advanced growth phase (42 DAP and 56 DAP), the double-row intercropping system consistently demonstrates that long-plant cucumbers are significantly taller compared to other intercropping patterns. At 42 DAP, the height of cucumbers in the double-row intercropping system reached 195.7 ± 3.2 cm, differing from the single-row intercropping system (152.0 ± 2.0 cm). At 56 DAP, the length of cucumbers in the double-row intercropping system (254.7 ± 17.6 cm) was significantly taller than in all other treatments. The benefits of the double-row intercropping system for increasing long-plant cucumbers can be explained from physiological and agronomic perspectives. From a physiological standpoint, the double-row intercropping pattern allows for more even light distribution among plants, reduces shade competition, and enhances photosynthesis efficiency (Liu et al., 2018, 2017; Lu et al., 2023). From an agronomic perspective, this pattern promotes root stratification, which reduces direct nutrient competition, increases nutrient absorption efficiency, and improves soil moisture retention (Andersen, 2005; Glaze-Corcoran et al., 2020; Qiang et al., 2024).

Conversely, the single-row intercropping system consistently results in significantly shorter long-plant cucumbers compared to other patterns during later observations. This can be attributed to intense interspecific competition in dense planting patterns. Greater spacing between cucumbers and water spinach in the single-row intercropping system significantly increases competition for light, nutrients, and soil moisture, ultimately impeding optimal cucumber growth.

Interestingly, the alternating single-row intercropping system exhibited results that were not significantly different from monoculture during continued growth phases (42 DAP and 56 DAP). This suggests that the alternating single-row intercropping could be a promising alternative for farmers seeking to maintain comparable yields to cucumbers grown in monoculture while improving land efficiency through intercropping.

The study's results indicate that selecting an appropriate intercropping pattern, such as the double-row system, can significantly optimize the growth of primary plants without compromising land efficiency and sustainable production systems. The observed differences between treatments reflect the complex ecological, physiological, and agronomic interactions in the double-row planting system. However, to provide comprehensive and practical recommendations, the study will further integrate other aspects such as harvest outcomes, product quality, pest and disease dynamics, and economic analysis.

Table 2 Average number of leaves in Cucumber under Different Intercropping Patterns with Water spinach

Treatment	14 DAP ±SD	28 DAP ± SD	42 DAP ± SD	56 DAP ±SD
Monoculture	2.7 ± 0.8	23.5 ± 0.6 ^{ab}	13.3 ± 2.4 ^{a}	193.9 ± 3.5 ^{a}
single-row Intercropping	2.0 ± 0.5	22.2 ± 1.9 ^{a}	32.3 ± 1.5 ^{b}	199.2 ± 7.0 ^{ab}
double-row Intercropping	2.0 ± 0.5	27.2 ± 1.1 ^{b}	36.6 ± 4.1 ^{b}	218.8 ± 7.1 ^{b}
Alternating single-row intercropping	2.2 ± 0.3	26.4 ± 1.6 ^{b}	33.6 ± 4.3 ^{b}	218.8 ± 7.8 ^{b}
CV (%)	22.95	5.25	11.56	3.38
Tukey test	1.43	3.68	9.47	19.87
F-test	NS	**	**	**

DAP stands for Days After Planting, LS denotes Level of Significance, SD refers to Standard Deviation, CV indicates Coefficient of Variation, and NS signifies Non-Significant. An asterisk (*) represents the 5%

Level of Significance, while two asterisks (**) denote the 1% Level of Significance. Figures with different letters in the treatment indicate significant differences.

The results indicated a significant difference in the number of leaves of cucumber plants across various intercropping patterns with water spinach, compared to the monoculture system (Table 2). During the early growth phase (14 DAP), the number of leaves did not show a significant difference between treatments, ranging from 2.0 to 2.7 leaves per plant. However, as the plants developed, differences in leaf count between the systems began to emerge. At 28 DAP, the double-row intercropping and alternating single-row intercropping systems exhibited significantly more leaves (27.2 ± 1.1 and 26.4 ± 1.6) compared to the single-row intercropping system (22.2 ± 1.9) and monoculture (23.5 ± 0.6). This suggests that certain intercropping systems can enhance leaf production in comparison to monoculture systems, as supported by improved light efficiency and optimized nutrient utilization in the double-row intercropping pattern sequence (Gou et al., 2017). .

In the advanced growth phase (42 and 56 DAP), the double-row intercropping and alternating single-row intercropping consistently showed significantly higher leaf counts compared to monoculture and single-row intercropping. At 42 DAP, the number of cucumber plant leaves in the double-row intercropping and alternating single-row intercropping reached 36.6 ± 4.1 and 33.6 ± 4.3, both significantly different from the monoculture system (13.3 ± 2.4) and single-row intercropping (32.3 ± 1.5). At 56 DAP, the number of leaves in double-row intercropping and alternating single-row intercropping (218.8 ± 7.1 and 218.8 ± 7.8) was significantly higher than that of monoculture (193.9 ± 3.5) and single-row intercropping (199.2 ± 7.0). The increase in leaf count in double-row intercropping and alternating single-row intercropping can be attributed to several factors, including reduced competition, improved light access (Gou et al., 2017), enhanced nutrient uptake through roots (Qiang et al., 2024), and more effective groundwater management compared to monoculture systems.

On the other hand, the monoculture system showed significantly fewer leaves after 42 DAP, likely due to the increased shading effects among plants in a denser cropping system. The single-row intercropping also did not differ significantly from monoculture at 56 DAP, indicating that this system is less effective at increasing leaf numbers compared to pattern double-row intercropping and alternating single-row intercropping.

The significant difference in the increase in the number of leaves on cucumber plants in double-row intercropping and alternating single-row intercropping after 42 DAP, compared to monoculture, can be attributed to various synergistic agronomic and physiological factors. These factors include improved light management, enhanced efficiency, better nutrient uptake through root zone differentiation, reduced allelopathic effects, and a more stable groundwater balance (Fu et al., 2019; Nweke, 2020; Yuhua et al., 2017). Consequently, these two intercropping patterns offer greater agronomic benefits than monoculture systems, especially in promoting the vegetative growth of cucumber plants during advanced growth phase.

Effect of Different Intercropping Patterns with Water spinach treatment on cucumber plant yield parameters

The results of the study revealed significant differences in several parameters of cucumber harvest outcomes across various intercropping patterns with water spinach (Table 3). Regarding fruit length, the single-row intercropping (23.0 ± 0.6 cm) exhibited a significantly higher fruit length compared to the monoculture (19.4 ± 0.3 cm) and the alternating single- row intercropping (19.7 ± 1.1 cm), though it was not significantly different from the double-row intercropping (21.3 ± 1.0 cm). This indicates that intercropping patterns can influence cucumber fruit length development, potentially through mechanisms related to light competition and the distribution of different nutrients in each system (Gao et al., 2023). However, for fruit diameter, no significant differences were observed between treatments (5.1 - 5.6 cm), suggesting that fruit diameter is more affected by genetic factors than by environmental influences (Kumar et al., 2022). .

Table 3 Average yields in Cucumber under Different Intercropping Patterns with Water spinach

Treatment	Fruit Length (cm)	Fruit Diameter (cm)	Fruit Weight (t ha^{-1})	Fruit Weight Plant^{-1} (kg)	Fruit Weight Fruit^{-1} (g)	Number of Fruits Plant^{-1}
Monoculture	19.4 ± 0.3 ^{a}	5.3 ± 0.4	26.9 ± 7.2 ^{b}	2.8 ± 1.2 ^{a}	260.8 ± 51.2 ^{b}	11.3 ± 4.3 ^{a}
single-row Intercropping	23.0 ± 0.6 ^{b}	5.6 ± 0.0	14.7 ± 5.1 ^{a}	2.3 ± 1.1 ^{a}	193.4 ± 52.3 ^{a}	11.3 ± 4.3 ^{a}
double-row Intercropping	21.3 ± 1.0 ^{ab}	5.1 ± 0.0	25.9 ± 5.6 ^{b}	4.1 ± 1.2 ^{b}	235.9 ± 51.2 ^{b}	17.0 ± 4.4 ^{c}
Alternating single-row intercropping	19.7 ± 1.1 ^{a}	5.1 ± 0.1	23.0 ± 5.4 ^{ab}	3.9 ± 1.2 ^{b}	238.7 ± 50.5 ^{b}	14.3 ± 4.4 ^{b}
CV (%)	3.77	3.87	16.35	10.72	5.46	4.12
Tukey test	2.22	0.58	10.46	0.99	35.87	1.57
F-test	**	NS	*	**	**	**

DAP stands for Days After Planting, LS denotes Level of Significance, SD refers to Standard Deviation, CV indicates Coefficient of Variation, and NS signifies Non-Significant. An asterisk (*) represents the 5% Level of Significance, while two asterisks (**) denote the 1% Level of Significance. Figures with different letters in the treatment indicate significant differences.

When it comes to fruit weight per hectare, monoculture (26.9 ± 7.2 t ha^{-1}) and double-row intercropping (25.9 ± 5.6 t ha^{-1}) showed results that were not significantly different from each other but were significantly higher compared to single-row intercropping (14.7 ± 5.1 t ha^{-1}). Meanwhile, alternating single-row intercropping (23.0 ± 5.4 t ha^{-1}) produced results comparable to all other treatments. These findings indicate that a double-row intercropping pattern may enhance cucumber productivity compared to single-row intercropping, likely due to the efficient use of light and nutrients systems.

In terms of fruit weight per plant, double-row intercropping (4.1 ± 1.2 kg) and alternating single-row intercropping (3.9 ± 1.2 kg) were significantly higher compared to monoculture (2.8 ± 1.2 kg) and single-row intercropping (2.3 ± 1.1 kg). These results indicate that double- row intercropping and alternating single-row intercropping patterns can enhance the productivity of each cucumber plant, possibly due to improved space management and reduced competition between plants when compared to denser monoculture systems (Stefan et al 2022).

When considering fruit weight per fruit, the monoculture (260.8 ± 51.2 g) and double-row intercropping (235.9 ± 51.2 g) exhibited significantly larger fruit weights compared to single-row intercropping (193.4 ± 52.3 g). The alternating single-row intercropping (238.7 ± 50.5 g) showed no significant difference from either the double-row intercropping or monoculture. These findings indicate that specific intercropping systems can enhance cucumber fruit size, with double-row intercropping producing results similar to monoculture regarding fruit weight per fruit.

In terms of the number of fruits per plant, the double-row intercropping (17.0 ± 4.4) had a significantly higher number of fruits compared to all other treatments. The alternating single-row intercropping (14.3 ± 4.4) also showed higher yields than monoculture (11.3 ±

4.3) and single-row intercropping (11.3 ± 4.3). This significant difference indicates that double-row intercropping can increase the number of fruits produced per plant, which may be caused by an increase in the efficient absorption of nutrients and more optimal conditions (Li et al., 2021).
The results of the study showed that double-row intercropping had comparable yields to monoculture regarding fruit weight per hectare and fruit weight per plant, but it had a significantly higher number of fruits per plant compared to monoculture. Additionally, alternating single-row intercropping also demonstrated good results, particularly in the number of fruits per plant and the weight of fruits per plant. In contrast, single-row intercropping had the lowest yield compared to the other systems, which may have been caused by increased competition for resources due to the closer planting distance between cucumber and water spinach. Therefore, the intercropping system with the double-row pattern can be recommended as a more effective planting pattern for increasing cucumber productivity compared to other systems.

CONCLUSIONS

The research results indicate that intercropping systems significantly influence cucumber growth and yield compared to monoculture. The double-row intercropping exhibited the best performance in enhancing plant height, leaf production, and fruit yield, outperforming other intercropping patterns. At 42 and 56 days after planting (DAP), this system produced significantly higher plant heights and leaf counts than monoculture and single-row intercropping. In terms of yield, double-row intercropping also resulted in a greater number of fruits per plant and total fruit weight per hectare, similar to monoculture. The alternating single-row intercropping demonstrated improvements in leaf production and fruit yield compared to monoculture, although it did not surpass double-row intercropping. In contrast, single-row intercropping exhibited the lowest plant growth and yield, suggesting this planting pattern leads to greater resource competition than other intercropping systems. Overall, this study affirms that double-row intercropping is the most effective method for enhancing cucumber growth and yield, as it improves light distribution, increases nutrient uptake efficiency, and maintains soil ecosystem balance. Therefore, this system offers a more sustainable alternative to monoculture for optimizing cucumber production productivity.

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