

Growth and yield performance of Cucumber (*Cucumis sativus*) under different intercropping patterns with Water spinach (*Ipomoea aquatica*)

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ABSTRACT

Intercropping has emerged as a sustainable agronomic strategy to enhance land-use efficiency and crop productivity through improved resource utilization and ecological balance. This study investigated the growth and yield performance of cucumber (*Cucumis sativus*) under different intercropping patterns with water spinach (*Ipomoea aquatica*). A field experiment was conducted using a randomized complete block design (RCBD) consisting of four treatments—monoculture, single-row intercropping, double-row intercropping, and alternating single-row intercropping—with three replications. Growth parameters (plant height and leaf number) and yield components (fruit length, diameter, weight, and number per plant) were measured. Results showed that intercropping patterns had a significant impact on cucumber growth and yield. The double-row intercropping system produced the highest plant height, number of leaves, and yield per hectare, statistically comparable to monoculture but superior to single-row and alternating patterns. Enhanced performance under the double-row system was attributed to improved light distribution, nutrient uptake, and soil moisture retention, which reduced interspecific competition and promoted photosynthetic efficiency. Conversely, single-row intercropping resulted in lower yield due to higher competition for resources. These findings suggest that the double-row intercropping pattern offers an ecologically efficient and productive alternative to monoculture, contributing to sustainable vegetable production systems. Implementing row-based intercropping could optimize land productivity while supporting agroecological resilience and resource-use efficiency in intensive vegetable cultivation.

Keywords: cucumber, water spinach, intercropping pattern, crop productivity, resource efficiency, agroecological management.

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, a gap remains 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 various intercropping patterns of cucumber and water spinach, as well as 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 primarily focused on intercropping systems that feature 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. A tropical climate characterizes this study. 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 (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 m × 1 m. 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 SmartStat XL V. software (Setiawan, 2023), and multiple treatments were compared using the Tukey test at a 5% significance level.

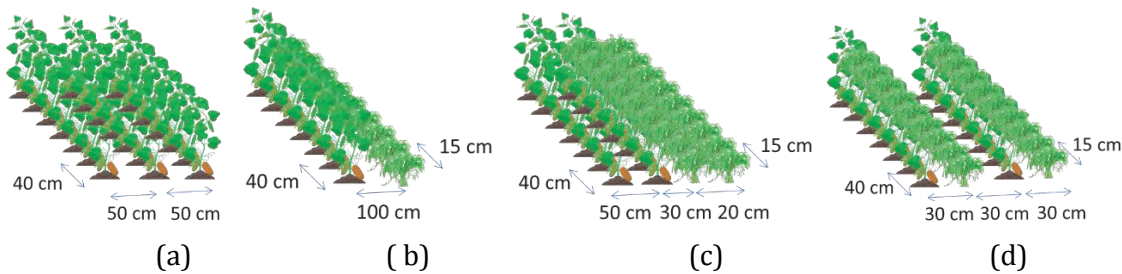


Figure 1. An intercropping pattern of cucumber and water spinach. Plot size: 3 m x 1 m. (a) Monoculture, population density of 24 cucumber plants; (b) single-row intercropping, population density of 5 cucumber plants and 22 water spinach plants; (c) double-row Intercropping, population density of 10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

System intercropping is employed to enhance land efficiency and optimize 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).

Table 1. Influence of different intercropping patterns with water spinach (*Ipomoea aquatica*) on cucumber plant length.

Treatment	14 DAP	28 DAP	42 DAP	56 DAP
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, Different letters within a column indicate significant differences according to Tukey's test ($p < 0.05$).

The results indicate significant differences between treatments, marked by different letters at each observation time. The research results highlight significant differences in plant height, depending on the intercropping patterns with water spinach, compared to monoculture (Table 1). At 14 days after planting, cucumbers grown in the monoculture system showed the highest growth (12.2 cm), results that differed significantly from plants grown in the intercropping treatments. Cucumber plants in monoculture do not face substantial competition for light and nutrients in their initial growth phase (Chaudhary *et al.*, 2022; Gou *et al.*, 2017). However, as the plants developed, differences emerged between the cropping systems, highlighting the influence of complex ecological interactions in intercropping systems. In the advanced growth phase (42 DAP and 56 DAP), the two-row intercropping system showed the highest growth. At 42 DAP, the height of cucumbers in the -row intercropping system reached 195.7 cm and was significantly different from the single-row intercropping system (152 cm). The same differences were evident at 56 days after

planting (DAP), where the length of cucumbers in the double-row intercropping system (254.7 cm) was significantly higher than in all other treatments (Table 1). 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 enables 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). The results showed that the single-row intercropping system produced the lowest growth rates of cucumber plants, especially after 28, 42 and 56 days after planting. 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.

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 interactions among ecological, physiological, and agronomic factors 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, along with economic analysis.

Table 2. Effect of different intercropping patterns with water spinach (*Ipomoea aquatica*) on the average number of leaves in cucumber (*Cucumis sativus*) at various growth stages.

Treatment	14 DAP	28 DAP	42 DAP	56 DAP
Monoculture	2.7 ± 0.8 ^a	23.5 ± 0.6 ^{ab}	13.3 ± 2.4 ^a	193.9 ± 3.5 ^a
Single-row Intercropping	2.0 ± 0.5 ^a	22.2 ± 1.9 ^a	32.3 ± 1.5 ^b	199.2 ± 7.0 ^{ab}
Double-row Intercropping	2.0 ± 0.5 ^a	27.2 ± 1.1 ^b	36.6 ± 4.1 ^b	218.8 ± 7.1 ^b
Alternating single-row intercropping	2.2 ± 0.3 ^a	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	-	**	**	**

DAP stands for Days After Planting, LS denotes Level of Significance, SD refers to Standard Deviation, CV indicates Coefficient of Variation, Different letters within a column indicate significant differences according to Tukey's test ($p < 0.05$).

The results of leaf number showed significant differences between the various intercropping patterns with water spinach and the monoculture system (Table 2). During the early growth phase (14 DAP), number of leaves did not show a significant difference between treatments, ranging from 2.0 to 2.7 leaves per plant. At 28 DAP, the double-row intercropping and the alternating single-row intercropping systems showed the highest leaf number (27.2 and 26.4 leaves) compared to the single-row intercropping system (22.2) and monoculture (23.5). This suggests that specific intercropping systems can enhance leaf production compared to monoculture systems, as supported by improved light efficiency and optimized nutrient utilization in the double-row intercropping pattern sequence (Gou *et al.*, 2017). At 42 DAP, the number of cucumbers leaves in the double-row intercropping and alternating single-row

intercropping reached 36.6 and 33.6 leaves, respectively, compared to 13.3 leaves in cucumber grown in the monocropping system (13.3) and single-row intercropping (32.3). The same significant differences were maintained at 56 DAP. The number of leaves in the two-row intercropping and single-row intercropping (218) was significantly higher than that in the monoculture (193.9) and single-row intercropping (199.2). The increase in the number of leaves in the two-row intercropping and single-row alternating intercropping can be attributed to several factors, including reduced competition, improved access to light (Gou *et al.*, 2017), improved nutrient uptake by roots (Qiang *et al.*, 2024), and more efficient groundwater management compared to monoculture systems.

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.

The results of the study revealed significant differences in several parameters of cucumber harvest results being influenced by the types of intercropping patterns with water spinach (Table 3). Regarding fruit length, the single-row intercropping showed significantly greater fruit length (23 cm).

This indicates that intercropping patterns can influence the development of cucumber fruit length, potentially through mechanisms related to light competition and the distribution of different nutrients in each system (Frąc *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. Effect of different intercropping patterns with water spinach (*Ipomoea aquatica*) on yield and fruit characteristics of cucumber (*Cucumis sativus*).

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, Different letters within a column indicate significant differences according to Tukey's test ($p < 0.05$).

In terms of fruit production per hectare, the monoculture and double-row intercropping recorded the highest yields (26.9 t.ha⁻¹ and 25.9 t.ha⁻¹), respectively and differed significantly from the yields recorded for cucumber grown in single-row intercropping (14.7 t.ha⁻¹). These findings suggest that a double-row intercropping model can enhance

cucumber productivity compared to single-row intercropping, likely due to the more efficient use of light and nutrient resources.

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

When considering fruit weight per fruit, the monoculture (260.8 g) and double-row intercropping (235.9 g) showed significantly higher fruit weights compared to single-row intercropping (193.4 g). The single-row intercropping (238.7 g) showed no significant difference from either the double-row intercropping or monoculture. These findings suggest that specific intercropping systems can enhance cucumber fruit size, with double-row intercropping yielding results comparable to monoculture in terms of fruit weight per plant. The number of fruits per plant was significantly higher in double-row intercropping (17) compared to all other crop types. The alternating single-row intercropping (14.3) also showed higher yields than monoculture and single-row intercropping (11.3). This significant difference indicates that double-row intercropping can increase the number of fruits produced per plant, which may be due to nutrient uptake and more optimal conditions (Li *et al.*, 2021). The study's results showed that double-row intercropping yielded comparable results to monoculture in terms of fruit weight per hectare and fruit weight per plant. Still, it had a significantly higher number of fruits per plant.

Additionally, alternating single-row intercropping also demonstrated promising results, particularly in terms of the number of fruits per plant and the weight of the 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 results of this study demonstrate that different intercropping patterns with water spinach (*Ipomoea aquatica*) significantly influenced the growth and yield performance of cucumber (*Cucumis sativus*). Among the evaluated systems, the double-row intercropping consistently exhibited superior performance, with the highest plant height (254.7 cm at 56 DAP), leaf number (218.8), and fruit yield (25.9 t.ha⁻¹). These results indicate that this arrangement optimizes light distribution, enhances nutrient uptake, and reduces competition between plants.

The alternating single-row intercropping also showed notable improvements in vegetative growth and yield components compared to monoculture, suggesting its potential as a productive and land-efficient alternative for small-scale farmers. In contrast, the single-row intercropping recorded the lowest growth and yield parameters, likely due to greater interspecific competition for light, nutrients, and soil moisture.

Overall, this study confirms that double-row intercropping represents the most effective and sustainable pattern for improving cucumber productivity while maintaining ecological balance. The findings highlight the potential of optimized intercropping arrangements as a viable strategy for enhancing land-use efficiency and promoting sustainable vegetable production systems.

REFERENCES

1. Andersen, M.K., 2005. Competition and complementarity in annual intercrops - the role of plant available nutrients, in: *The Royal Veterinary and Agricultural University, Copenhagen, Denmark, Department of Soil Science*. p. 123.
2. Chadfield, V., Hartley, S., Redeker, K., 2022. Associational resistance through intercropping reduces yield losses to soil-borne pests and diseases. *The New Phytologist*. 235: 2393–2405.
3. Chaudhary, M., Kumar, R., Yadav, A., Maurya, S.K., Sahu, S., Tiwari, A., 2022. Best Row Ratio Combinations of Agronomic Crops in the Intercropping System: An Overview. *International Journal of Plant & Soil Science*. 34(22): 645–654.
4. Chen, P., Song, C., Liu, X.-M., Zhou, L., Yang, H., Zhang, X., Zhou, Y., Du, Q., Pang, T., Fu, Z.-D., Wang, X.-C., Liu, W., Yang, F., Shu, K., Du, J., Liu, J., Yang, W., Yong, T., 2019. Yield advantage and nitrogen fate in an additive maize-soybean relay intercropping system. *The Science of the total environment*. 657: 987–999.
5. Feng, L., Raza, M., Chen, Y., Khalid, M., Meraj, T., Ahsan, F., Fan, Y., Du, J., Wu, X., Song, C., Liu, C., Bawa, G., Zhang, Z., Yuan, S., Yang, F., Yang, W., 2019. Narrow-wide row planting pattern improves the light environment and seed yields of intercrop species in relay intercropping system. *PLoS ONE*. 14(2): e0212885.
6. Frąc, M., Panek, J., Gryta, A., Oszust, K., Pertile, G., Siegieda, D., Mącik, M., Pylak, M., Imran Pathan, S., Pietramellara, G., 2023. Legume-cereal intercropping as a strategy of regenerative agriculture supporting reverse of biodiversity loss - relevance of microbiome-based research. *ARPHA Conference Abstracts*. 6: e108886.
7. Fu, Z.-D., Zhou, L., Chen, P., Du, Q., Pang, T., Song, C., Wang, X., Liu, W., Yang, W., Yong, T., 2019. Effects of maize-soybean relay intercropping on crop nutrient uptake and soil bacterial community. *Journal of Integrative Agriculture*. 18(9): 2006–2018.
8. Glaze-Corcoran, S., Hashemi, M., Sadeghpour, A., Jahanzad, E., Keshavarz Afshar, R., Liu, X., Herbert, S.J., 2020. Understanding intercropping to improve agricultural resiliency and environmental sustainability. *Advances in Agronomy*. 162: 199–256.
9. Gou, F., Ittersum, M., Simon, E., Leffelaar, P., Putten, P., Zhang, L., Werf, W., 2017. Intercropping wheat and maize increases total radiation interception and wheat RUE but lowers maize RUE. *European Journal of Agronomy*. 84: 125–139.
10. Jianxiong, H., Jian, P., Zhou, L., Dinghua, Z., Yuan, S., Chen, J.-F., Li, J., Qing, G., Lin, W., 2020. An improved double-row rubber (*Hevea brasiliensis*) plantation system increases land use efficiency by allowing intercropping with yam bean, common bean, soybean, peanut, and coffee: A 17-year case study on Hainan Island, China. *Journal of Cleaner Production*. 263: 121493.
11. Kumar, R., Bhushan, A., Samnotra, R., Sharma, S., Naik, R., Chheepa, M.S., Naga, V.K., 2022. Heritability Analysis for Horticultural Traits in Tomato under Low Cost Polyhouse Conditions of Jammu Subtropics. *International Journal of Environment and Climate Change*. 12(10): 737–741.
12. Li, C., Stomph, T., Makowski, D., Li, H., Zhang, C., Zhang, F., Van Der Werf, W., 2023. The productive performance of intercropping. *Proceedings of the National Academy of Sciences of the United States of America*. 120(2): e2201886120.
13. Li, X.-F., Wang, Z.-G., Bao, X.-G., Sun, J.-H., Yang, S.-C., Wang, P., Wang, C.-B., Wu, J.-P., Liu, X.-R., Tian, X.-L., Wang, Yu, Li, J.-P., Wang, Yan, Xia, H.-Y., Mei, P.-P., Wang, X.-F., Zhao, J.-H., Yu, R.-P., Zhang, W.-P., Che, Z.-X., Gui, L.-G., Callaway, R., Tilman, D., Li, L., 2021. Long-term increased grain yield and soil fertility from intercropping. *Nature Sustainability*. Nat Sustai(4): 943–950.
14. Liu, X., Rahman, T., Song, C., Su, B., Yang, F., Yong, T., Wu, Y., Zhang, C., Yang, W., 2017. Changes in light environment, morphology, growth and yield of soybean in maize-soybean intercropping systems. *Field Crops Research*. 200: 38–46.
15. Liu, X., Rahman, T., Song, C., Yang, F., Su, B., Cui, L., Bu, W., Yang, W., 2018. Relationships among light distribution, radiation use efficiency and land equivalent ratio in maize-soybean strip intercropping. *Field Crops Research*. 224: 91–101.
16. Lu, J., Dong, Q., Lan, G., He, Z., Zhou, D.-M., Zhang, H., Wang, X.-G., Liu, X., Jiang, C.-J., Zhang, Z., Wan, S., Zhao, X., Yu, H., 2023. Row ratio increasing improved light distribution, photosynthetic characteristics, and yield of peanut in the maize and peanut strip intercropping system. *Frontiers in Plant Science*. 14(14 Juli).
17. Maitra, S., Hossain, A., Brestič, M., Skalický, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J.B., Jena, J., Bhattacharya, U., Duvvada, S.K., Lalichetti, S., Sairam, M., 2021. Intercropping—A Low Input Agricultural Strategy for Food and Environmental Security. *Agronomy*. 11(2): 343.
18. Nweke, I., 2020. Potentials of Intercropping Systems to Soil - Water - Plant-Atmosphere. *Agricultural Science*. 2(1): 31–38.
19. Qiang, B., Fan, Z., Tang, N., Asad, M.S., Timbang, B.C., Ren, X., Chen, X., 2024. Improving the productivity of intercropping through above and below ground separation: A case study on photosynthetic characteristics and root distribution. *Industrial Crops and Products*. 222: 119506.
20. Rodriguez, C., Carlsson, G., Englund, J., Flöhr, A., Pelzer, E., Jeuffroy, M., Makowski, D., Jensen, E., 2020. Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate

- agroecosystems. A meta-analysis. *European Journal of Agronomy*. 118: 126077.
21. Setiawan, A., 2023. SmartstatXL Versi 3.6.5.4 [software].
 22. Stefan, L., Engbersen, N., Schöb, C., 2022. Rapid transgenerational adaptation in response to intercropping reduces competition. *eLife*. 11(Januari): 40.
 23. Toker, P., Canci, H., Turhan, I., Isci, A., Scherzinger, M., Kordrostami, M., Yol, E., 2024. The advantages of intercropping to improve productivity in food and forage production – a review. *Plant Production Science*. 27(3): 155–169.
 24. Yuhua, Fu, S., Zhang, X., Zhao, K., Chen, H., 2017. Intercropping improves soil nutrient availability, soil enzyme activity and tea quantity and quality. *Applied Soil Ecology*. 119: 171–178.