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Improving yield and quality of water spinach (*Ipomoea aquatica*) through optimization of biochar and organic fertilizer application rates

Nguyen Tuan Khoi

Faculty of Agronomy, BacGiang Agriculture and Forestry University, Viet Yen town, Bac Giang province, Vietnam

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Corresponding Author: Nguyen Tuan Khoi

Abstract

This study investigates the effects of optimized biochar and organic fertilizer application rates on the yield and quality of water spinach (*Ipomoea aquatica*). A series of field experiments were conducted to determine the optimal combination of biochar and organic fertilizer that maximizes crop performance. Key parameters evaluated include plant height, leaf number, chlorophyll content, and overall biomass production. The results indicate that specific application rates of biochar and organic fertilizer significantly enhance both the growth and nutritional quality of water spinach. The findings suggest that the strategic use of biochar and organic fertilizers can be an effective agronomic practice for sustainable vegetable production. Future research should focus on long-term soil health impacts and economic viability of the optimized fertilization strategy.

Keywords: Water spinach, biochar, organic fertilizer, crop yield, plant quality, agricultural optimization

Introduction

Water spinach (*Ipomoea aquatica*), commonly known as morning glory or kangkong, is a widely cultivated leafy vegetable in tropical and subtropical regions. It is highly valued for its nutritional content, including vitamins A and C, iron, and calcium, as well as for its culinary versatility. Given the growing demand for sustainable agricultural practices, there is an increasing interest in enhancing the yield and quality of water spinach through environmentally friendly methods.

Biochar, a carbon-rich product obtained from the pyrolysis of organic materials, has gained attention for its potential to improve soil fertility and plant growth. Biochar application can enhance soil structure, water retention, and nutrient availability while also sequestering carbon, thus contributing to climate change mitigation. However, the optimal application rates of biochar for different crops and soil types remain to be fully understood.

Organic fertilizers, derived from plant and animal residues, provide essential nutrients to crops while improving soil organic matter and microbial activity. They are a key component of sustainable agriculture, offering a renewable alternative to synthetic fertilizers. The synergistic use of biochar and organic fertilizers has been suggested to further improve soil health and crop productivity, yet detailed studies on the precise optimization of these inputs are limited.

This study aims to fill this knowledge gap by investigating the effects of varying application rates of biochar and organic fertilizers on the yield and quality of water spinach. By systematically analyzing plant growth parameters, chlorophyll content, and overall biomass production, we seek to identify the optimal combination of these amendments for enhancing water spinach cultivation. The findings of this research will contribute to the development of sustainable agricultural practices that maximize both productivity and environmental benefits.

In the following sections, we present the materials and methods used in our experiments, the results obtained, and a discussion of their implications for water spinach production and broader agricultural practices.

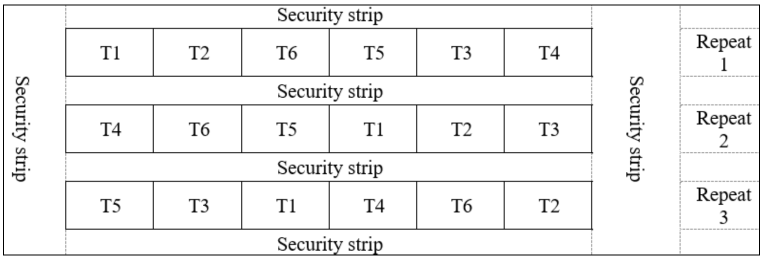
Materials and Research Methods

Materials

- **Biochar:** Sourced from coconut coir, pyrolyzed at 300 °C for 2 hours.
- **Organic fertilizer:** Produced from composted straw and peanut plant stems combined with Effective Microorganisms (EM) inoculant.

Methods

The experiment was designed according to the Randomized Complete Block Design (RCBD). Each experiment included 6 treatments with 3 replications. The total number of plots per experiment was 18, with each plot covering an area of 50 m², and the total experimental area was 900 m².



T_1: 5 tons of organic fertilizer/ha and 2 tons of biochar/ha (Control)
T_2: 6 tons of organic fertilizer/ha and 2 tons of biochar/ha
T_3: 7 tons of organic fertilizer/ha and 2 tons of biochar/ha
T_4: 5 tons of organic fertilizer/ha and 3 tons of biochar/ha
T_5: 6 tons of organic fertilizer/ha and 3 tons of biochar/ha
T_6: 7 tons of organic fertilizer/ha and 3 tons of biochar/ha

Fig 1: Scheme of the experiment

Data were analyzed using Excel and IRRISTAT 5.0 software to calculate basic statistical parameters and perform ANOVA on the experimental results.

Research Results and Discussion

Table 1: The effects of biochar and organic charcoal mixture on the growth duration of water spinach.

Formulas	Time from sowing to germination	Time from sowing to first harvest	Time from sowing to second harvest	Time from sowing to third harvest	Time from sowing to fourth harvest	Time from Sowing to final harvest	Total growth duration
T_1 (Control)	7	29	42	56	70	84	84
T_2	7	29	42	56	70	84	84
T_3	7	29	42	56	70	84	84
T_4	7	29	42	56	70	84	84
T_5	7	29	42	56	70	84	84
T_6	7	29	42	56	70	84	84

The germination period remained uniform across all treatments, and the variations in fertilizer application rates did not influence the harvest time for each cycle. Nonetheless, there were noticeable differences in growth and development indicators among the treatments.

Table 2: The effects of biochar and organic charcoal mixture on plant height and leaf number of water spinach at different harvest times

Formulas	First harvest		Second harvest		Third harvest		Fourth harvest		Final harvest	
	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves
T_1 (Control)	29,6	11,1	21	8,7	20,6	8,6	19,3	9,4	20,8	9,5
T_2	31,1	10,9	21,5	8,2	21,1	8,4	20,4	10,0	21,4	9,3
T_3	31,8	11	22,2	8,5	21,6	8,7	20,7	9,8	22,5	9,2
T_4	30,5	11,9	22,5	8,8	22,4	9,2	22,8	10,4	22,4	10,3
T_5	29,2	12,2	21,2	9,0	20,3	9,2	22,1	10,6	22,6	9,7
T_6	31,7	13,4	22,5	9,4	21,0	9,3	23.8	9,8	23,9	10,5
CV%	6,8	2,7	1,3	2,3	1,5	1,3	2,1	3,7	1,0	1,6
$LSD_{0.05}$	3,8	0,58	0,5	0,37	0,56	0,2	0,82	0,66	0,39	0,29

At the first harvest stage: The tallest average height was observed in T_3 (31.8 cm), which was 2.2 cm taller than the control. The shortest was in T_4 (29.2 cm), while the remaining treatments ranged from 29.6 cm to 31.7 cm in height. The highest average number of leaves was in T_6 (13.4 leaves/plant), significantly higher than the control (11.1 leaves/plant) with a 95% confidence level.
At the second harvest stage: The tallest average height was in T_6 (22.5 cm), significantly higher than the control (21 cm) with a 95% confidence level. The highest average number of leaves was also in T_6 (9.4 leaves/plant), significantly higher than the control (8.7 leaves/plant) with a 95% confidence level.
At the final harvest stage: The tallest average height was in T_6 (23.9 cm) and the shortest in T_1 (20.8 cm), with this difference being significant at the 95% confidence level. The heights of the other treatments were as follows: T_4 (22.6 cm), T_3 (22.5 cm), T_5 (22.4 cm), and T_2 (21.4 cm). The highest number of leaves per plant was in T_6 (10.5 leaves), followed by T_4 (10.3 leaves), and the lowest in T_3 (9.2 leaves).
Treatment 6, resulted in better outcomes compared to the control, with this difference being significant at the 95% confidence level.

Table 3: The effects of biochar and organic charcoal mixture on Leaf area and Leaf Area Index (LAI) of water spinach

Formulas	Leaf area (dm^2)			Leaf Area Index (LAI) (m^2 leaves/m^2 soil)		
	15 days after sowing	30 days after sowing	First harvest	15 days after sowing	30 days after sowing	First harvest
T_1 (Control)	1,6	4,2	6,8	0,32	0,84	1,4
T_2	1,3	4	5,8	0,26	0,8	1,2
T_3	1,4	4,1	7,3	0,28	0,82	1,5
T_4	1,6	4,2	7,1	0,32	0,84	1,5
T_5	1,5	4,4	7,4	0,30	0,88	1,5
T_6	1,8	4,5	7,8	0,36	0,9	1,56

At 15 days after planting, the T_6 treatment (0.9 m^2 leaves/m^2 soil) had the highest leaf area index (LAI), with negligible differences among the remaining treatments. At the first harvest stage, the highest LAI was also observed in T_6 (1.56 m^2 leaves/m^2 soil), while the lowest was in T_1 (1.4 m^2 leaves/m^2 soil).

Table 4: The effects of biochar and organic charcoal mixture on various physiological parameters of water spinach

Formulas	SPAD			Fresh plant weight (g)			Dry Matter Content (%)		
	15 days after sowing	30 days after sowing	First harvest	15 days after sowing	30 days after sowing	First harvest	15 days after sowing	30 days after sowing	First harvest
T_1 (Control)	7,39	19,6	65,16	26,8	28,0	13,6	31,8	38,3	46,4
T_2	8,17	18,74	74,33	25,7	23,7	12,4	31.8	38,7	45,2
T_3	8	19,75	70,65	25,5	27,6	12,6	31,7	38,3	47,2
T_4	7,94	19,03	83,2	24,3	27,2	11,1	31,2	39,3	47,5
T_5	8,1	18,24	72,75	25,8	28,5	11,7	31,1	38,4	46,5
T_6	8,14	20,31	76,96	26,17	23,9	11,73	31,6	38,8	47,8

SPAD index: At 15 days after planting, the T_4 treatment had the highest SPAD index (39.3). At the first harvest stage, all treatments had similar SPAD values, approximately 47.48, with a 95% confidence level.

Fresh plant weight: At 15 days after planting, the highest fresh weight was observed in T_6 (20.31 g), and the lowest in T_4 (18.24 g). At the first harvest stage, T_4 had the highest fresh weight (83.2 g) and T_1 had the lowest (65.16 g). All other treatments had significantly higher fresh weights compared to the control, with a 95% confidence level.

Table 5: The effects of biochar and organic charcoal mixture on pest and disease incidence in water spinach

Formulas	White rust		Leaf miners		Leaf yellowing	
	Rate of affected plants	Severity of damage	Rate of affected plants	Severity of damage	Rate of affected plants	Severity of damage
T_1 (Control)	2,67	1,87	1,63	1,60	1,50	1,60
T_2	2,67	1,93	1,80	1,67	1,67	1,73
T_3	3,13	1,93	1,77	1,67	1,27	1,53
T_4	2,17	1,93	2,01	1,80	1,53	1,80
T_5	1,60	1,67	1,73	1,73	1,60	1,67
T_6	2,93	2,00	1,63	1,73	1,73	1,80

Pests and diseases affecting water spinach are generally not severe and do not significantly impact economic yields; however, vigilance is essential. Regular monitoring is necessary, and if pests or diseases are detected, appropriate control measures should be implemented.

Leaf miners: These pests can affect both the yield and quality of water spinach. To manage leaf miners, manual removal or the application of garlic solution can help prevent damage and reproduction of the pests.

White rust: This disease manifests as yellow spots on both sides of the leaves. Over time, these spots develop into raised, wart-like lesions surrounded by a yellow halo. If only a few white spots are observed on the leaves, they should be removed and disposed of to prevent further spread.

Leaf yellowing: This condition may be caused by nutrient deficiencies, particularly nitrogen. In such cases, additional nitrogenous fertilizers should be applied. Yellowing may also result from prolonged rainfall leading to waterlogging. To address this, ensure proper drainage, remove and discard yellowing or decaying leaves to prevent disease spread, and trim any damaged branches caused by rain.

Table 6: The effects of biochar and organic charcoal mixture on the yield of water spinach

formulas	Number of harvested shoots per plant	Average shoot weight (g)	Individual yield (g/plant)	Harvested yield (t/ha)	Theoretical yield (t/ha)
T_1 (Control)	30	5,19	155,7	26,8	31,1
T_2	30	5,24	157,2	27,0	31,4
T_3	40	5,63	225,2	30,6	45,0
T_4	41	5,66	232,1	31,6	46,4
T_5	42	5,66	237,7	34,4	47,5
T_6	43	5,66	243,4	35,4	48,7
CV%	0,32	0,7	24,47		
$LSD_{0.05}$	0,5	7,2	6,6		

Average shoot weight: There is a noticeable difference in the average shoot weight among the treatments. The highest average shoot weight was observed in T_4, T_5, and T_6 (5.66 g/shoot), while the lowest was in T_1 (5.19 g/shoot). The other treatments ranged from 5.24 g to 5.63 g per shoot.

Yield per plant: The highest yield per plant was achieved in T_6 (243.4 g/plant), while the lowest was in T_1 (155.7 g/plant). This difference is statistically significant at the 95% confidence level.

Theoretical yield: The highest theoretical yield was recorded in T_6 (48.7 tons/ha), followed by T_4 (47.5 tons/ha), and the lowest was in T_1 (31.1 tons/ha).

Actual yield: The highest actual yield was obtained from T_6 (35.4 tons/ha), and the lowest from T_1 (26.8 tons/ha). The other treatments showed yields as follows: T_2 (27 tons/ha), T_3 (30.6 tons/ha), T_4 (31.6 tons/ha), and T_5 (34.4 tons/ha).

Increasing the application rates of organic fertilizer and biochar improved the quality compared to the control treatment, with the most pronounced effect observed in T_6.

Table 7: The effects of biochar and organic charcoal mixture on the quality indicators of water spinach in the first harvest

Formulas	Shoot length (cm)	Leaf length (cm)	Leaf width (cm)	Number of leaves per shoot	Shoot diameter (mm)
T_1 (Control)	21,82	12,92	1,92	9,40	6,1
T_2	21,45	12,99	1,88	9,87	6,2
T_3	22,32	13,06	1,91	10,60	6,1
T_4	22,21	13,39	1,91	10,80	6,2
T_5	21,51	13,42	1,91	10,47	6,3
T_6	22,03	13,09	1,90	11,07	6,4
CV%	0,9	0,4	0,13	0,68	0,3
$LSD_{0.05}$	2,3	1,7	3,7	3,6	2,6

Shoot length: The average shoot length was greatest in T_3 (22.32 cm) and smallest in T_2 (21.45 cm).

Shoot diameter: The average diameter was largest in T_6 (6.4 mm) and smallest in T_1 and T_3 (6.1 mm). The highest average number of leaves per shoot was observed in T_6 (11.07 leaves/shoot), while the lowest was in T_1 (9.4 leaves/shoot). This difference is statistically significant at the 95% confidence level. The average number of leaves in T_6 was significantly higher than in the other treatments.

Leaf length: The average leaf length was greatest in T_4 (13.42 cm), surpassing all other treatments.

Leaf width: The widest average leaf width was found in T_1 (1.92 cm), while the narrowest was in T_2 (1.88 cm).

Among the treatments, T_6 exhibited the best shoot quality with the longest shoot length (22.03 cm), the widest diameter (6.4 mm), the highest number of leaves (13.09 leaves), and the largest, greenest leaves. In contrast, T_1 had the shortest shoot length (21.82 cm) and the fewest number of leaves per shoot (9.4). Increasing the application rates of organic fertilizer and biochar led to better shoot quality compared to the control, with T_6 showing the most significant improvement. The increase in organic fertilizer and biochar application resulted in higher effectiveness at the 95% confidence level.

Conclusion

The germination period remained consistent across all treatments, and fertilizer application rates did not affect the harvest time for each cycle.

Treatment T_6 showed the best overall performance, with significant improvements in plant height, number of leaves, and leaf area index (LAI) at various growth stages compared to the control.

Fresh plant weight was highest in T_6 at 15 days after planting and showed significant differences across treatments at the first harvest stage, with T_4 having the highest weight.

Pests and diseases, though not severe, require regular monitoring and appropriate control measures to prevent significant impact on yields.

Theoretical and actual yields were highest in T_6, followed by T_4, with significant improvements in quality and yield parameters compared to the control.

Shoot quality, including length, diameter, and number of leaves, was significantly better in T_6, demonstrating that increased application rates of organic fertilizer and biochar resulted in higher effectiveness.

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