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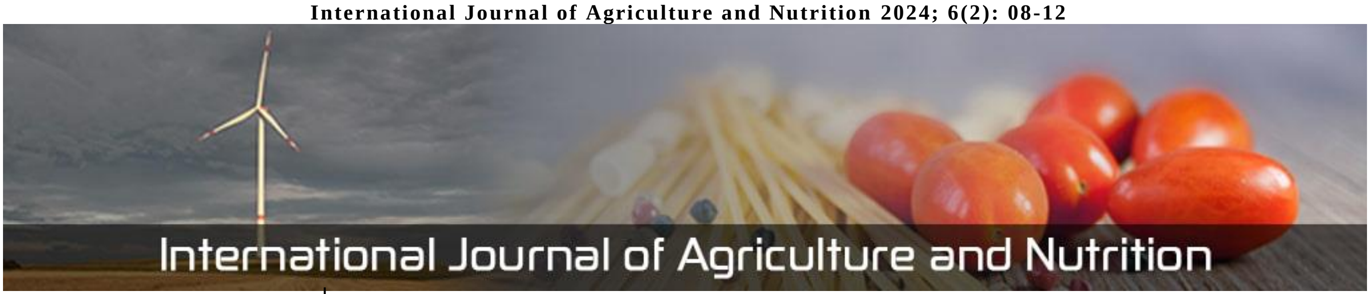

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A study on replacing chemical fertilizers with a mixture of biochar and rare earth elements for cultivating various Choy sum (*Brassica chinensis* L) varieties in foam boxes

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Abstract
The excessive use of chemical fertilizers in agriculture has led to significant environmental concerns, necessitating the exploration of more sustainable alternatives. This study investigates the potential of using a mixture of biochar and rare earth elements (REEs) as a replacement for chemical fertilizers in the cultivation of various choy sum varieties in foam boxes. Over a controlled growing season, experimental groups were treated with either traditional chemical fertilizers or the biochar-REE mixture. Key metrics such as plant growth, yield, and soil health were systematically measured and analyzed. The results indicated that the biochar-REE mixture provided comparable plant growth and yield to conventional chemical fertilizers. Moreover, soil health parameters, including microbial activity and nutrient retention, showed significant improvement with the biochar-REE treatment. These findings suggest that biochar and REEs can serve as effective and sustainable alternatives to chemical fertilizers, promoting environmentally friendly agricultural practices. Further research is recommended to optimize application rates and to evaluate the long-term impacts on soil ecosystems.

Keywords: Biochar, REEs, choy sum, chemical fertilizers, rare earth elements

Introduction
The global agricultural industry faces mounting pressure to adopt sustainable practices in response to environmental concerns associated with intensive chemical fertilizer usage. In this context, exploring alternative fertilization methods becomes imperative to ensure long-term agricultural productivity while mitigating adverse ecological impacts.

This study focuses on investigating the feasibility of replacing chemical fertilizers with a combination of biochar and rare earth elements (REEs) for cultivating various choy sum varieties in foam boxes. Choy sum, a popular leafy vegetable in Asian cuisine, presents an ideal model for this investigation due to its rapid growth cycle and adaptability to controlled environments.

Biochar, derived from the pyrolysis of organic materials, has garnered attention for its potential to improve soil fertility, water retention, and carbon sequestration capabilities. Additionally, rare earth elements, although traditionally associated with industrial applications, have shown promise in enhancing plant growth and nutrient uptake when applied judiciously.

The utilization of foam boxes for cultivation provides a controlled environment conducive to studying the efficacy of alternative fertilization methods. Through meticulously designed experiments, this study aims to evaluate the impact of biochar-REE mixtures on choy sum growth, yield, and soil health parameters compared to conventional chemical fertilizers.

By elucidating the potential of biochar and REEs as sustainable fertilization alternatives, this research contributes to the advancement of environmentally friendly agricultural practices. Moreover, insights gained from this study may inform policymakers and agricultural practitioners on strategies to reduce dependency on chemical fertilizers while maintaining or enhancing crop productivity.

Materials and Research Methods

Research materials

- **Biochar:** Pyrolyzed from coconut fiber at 400°C for 2 hours.
- **Rare earth (Excilerite):** Originated from the USA, a product of US Rare Earth Minerals, exclusively distributed in Vietnam.
- **Choy sum (*Brassica chinensis* L) Varieties:** Sourced from Japan, distributed in Vietnam by Rang Dong Seed Company, including the following varieties: Samurai VA.68, Koros 612, Rado 320.
- **Chemical fertilizer:** Slow-release NPK fertilizer (Minro 15-5-20) developed and produced by Maka Garden Company.
- **Styrofoam boxes:** Dimensions of 70 cm x 45 cm x 20 cm.

Research methodology

The experiment, involving two factors, was arranged in a randomized block design with three replications, as follows:

Factor A (Fertilizer): Comprises Minro fertilizer and a mixture of biochar and rare earth. Minro fertilizer has an NPK content of 15-5-20. The fertilizer mixture of biochar and rare earth was applied at a total rate of 3 tons/ha, mixed at the following ratios:

- **A1:** 1/3 Biochar + 2/3 Rare Earth, equivalent to 31.5g Biochar + 63g Rare Earth per styrofoam box
- **A2:** 1/2 Biochar + 1/2 Rare Earth, equivalent to 47.25g Biochar + 47.25g Rare Earth per styrofoam box
- **A3:** 2/3 Biochar + 1/3 Rare Earth, equivalent to 63g Biochar + 31.5g Rare Earth per styrofoam box
- **A4 (Control):** NPK Fertilizer (Minro 15-5-20), without using the biochar and rare earth mixture

Factor B (Variety): Three choy sum varieties used in the experiment are specified as follows:

- **B1:** Samurai VA.68
- **B2:** Koros 612
- **B3:** Rado 320

Security strip	**Security strip**												Security strip	
	A3B2	A2B2	A1B2	A3B1	A4B2	A2B1	A2B3	A1B3	A4B3	A4B1	A3B3	A1B1		Repeat 1
	Security strip													
	A4B1	A1B3	A3B2	A2B3	A4B3	A1B2	A4B2	A3B1	A3B3	A1B1	A2B1	A2B2		Repeat 2
	Security strip													
	A1B2	A4B1	A4B2	A3B2	A3B3	A2B1	A1B3	A1B1	A2B3	A3B1	A2B2	A4B3		Repeat 3
	Security strip													

Fig 1: Scheme of the experiment

The experiment was repeated three times, with each combination of Factor A and Factor B being tested in each replication.

- Each block contains all treatments (combinations of Factors A and B).
- Each combination is replicated three times within each block.
- Number of treatments (combinations of A and B): 4x3=12 treatments
- Number of replications: 3
- Total number of styrofoam boxes: 12x3=36 styrofoam boxes per block
- Each experimental unit is a styrofoam box with the specified treatment.
- Each box is planted with 24 choy sum plants.
- Planting distance within each box is 9 × 9 cm.

The experimental design ensures that each combination of treatments is tested under similar conditions, allowing for accurate comparisons and analysis of the effects of the different fertilizers and varieties. Data were processed using IRRISTAT 5.0 statistical software

Results and Discussion

Table 1: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on plant height

Factor A	Factor B			Average of factor A
	Samurai VA.68 (B1)	Koros 612 (B2)	Rado 320 (B3)	
A1	31,66^{de}	32,05^{cde}	32,73^{cd}	32,15^{B}
A2	29,89^{ef}	25,77^{g}	26,75^{g}	27,47^{C}
A3	27,64^{fg}	27,24^{g}	26,73^{g}	27,20^{C}
A4 (Control)	40,01^{a}	34,40^{bc}	35,87^{g}	36,76^{A}
Average of factor B	32,30^{A}	29,87^{B}	30,52^{b}	
CV = 4,26				

The data in Table 1 indicate that the effects of combining biochar and rare earth elements on the plant height of three varieties of choy sum at harvest time vary across different treatments. The tallest plant height (40.01 cm) was observed in the Samurai VA.68 variety grown with factor A4 (Minro chemical fertilizer), while the shortest plant heights (25.77 – 26.73 cm) were observed in the Koros 612 and Rado 320 varieties grown with factors A2 and A3 (biochar-rare earth mixture). The data also show that factor A4 has a significant effect on the plant height of the three choy sum varieties, with these differences being statistically significant at the 95% confidence level. During stem and leaf development, crops in general, and choy sum in particular, require a prioritization of NPK. Minro chemical fertilizer (A4) has a significantly higher NPK content compared to the biochar and rare earth mixture (A1, A2, A3), which results in the tallest plant heights in the experimental treatments using chemical fertilizer. The differences in plant height among the experimental treatments are statistically significant at the 95% confidence level.

When considering the average height among the choy sum varieties in factor A, there is no significant difference between factors A2 and A3. Similarly, when considering the average height among the choy sum varieties in factor B, there is no significant difference between factors B2 and B3. This similarity is statistically significant at the 95% confidence level.

Table 2: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on leaf number

Factor A	Factor B			Average of factor A
	Samurai VA.68 (B1)	Koros 612 (B2)	Rado 320 (B3)	
A1	6,21^{a}	6,21^{a}	6,12^{a}	6,18^{AB}
A2	5,76^{a}	5,49^{a}	5,67^{a}	5,64^{B}
A3	5,58^{a}	5,52^{a}	5,67^{a}	5,59^{B}
A4 (Control)	7,02^{a}	6,66^{a}	6,66^{a}	6,78^{A}
Average of factor B	6,14^{A}	5,97^{A}	6,03^{A}	
CV(%) = 8,03				

The data in the table indicate that, when using chemical fertilizers and a biochar-rare earth mixture, the highest number of leaves was observed in treatment A4B1 (chemical fertilizer with Samurai VA.68 variety) with 7.02 leaves per plant, and the lowest number of leaves was observed in treatment A2B2 (biochar-rare earth mixture with Koros 612 variety) with 5.49 leaves per plant. However, there were no statistically significant differences among the treatments at the 95% confidence level.
When considering the averages for the fertilizer factor (A) and the variety factor.
(B), the results also showed no statistically significant differences. This means that no fertilizer type or plant variety proved to be more effective than the others in terms of the number of leaves per plant at the 95% confidence level. All these similarities are statistically significant at the 95% confidence level, confirming that the use of chemical fertilizers or the biochar-rare earth mixture does not result in statistically significant differences in the number of leaves per plant.

Table 3: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on leaf area index (LAI)

Factor A	Factor B			Average of factor A
	Samurai VA.68 (B1)	Koros 612 (B2)	Rado 320 (B3)	
A1	8,00^{a}	5,99^{b}	5,95^{b}	6,65^{AB}
A2	5,98^{b}	5,73^{b}	6,05^{b}	5,92^{B}
A3	5,87^{b}	6,57^{ab}	5,97^{b}	6,14^{B}
A4 (Control)	8,33^{a}	7,24^{ab}	7,11^{ab}	7,56^{A}
Average of factor B	7,05^{A}	6,38^{A}	6,27^{A}	
CV = 6,36				

The data on the leaf area index show that it ranges from 5.73 to 8.33 m² leaf/m² ground, with the highest value observed in treatment A4B1 (chemical fertilizer with Samurai VA.68 variety) and the lowest in treatment A2B2 (biochar-rare earth mixture with Koros 612 variety). The interaction between the variety and fertilizer factors resulted in differences in the leaf area index among the three choy sum varieties, but these differences were not statistically significant among the treatments.
When considering the average of the fertilizer factor (A), the results show a variation in the leaf area index of the three choy sum varieties at harvest time, but this variation is not statistically significant at the 95% confidence level. Similarly, when considering the average of the variety factor (B), the results also show no significant impact on the leaf area index of the three choy sum varieties at harvest time with a 95% confidence level. In summary, although there are differences in the leaf area index when using different fertilizers and choy sum varieties, these differences are not statistically significant, confirming that changes in fertilizer or variety do not result in significant differences in the leaf area index at the 95% confidence level.

Table 4: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on plant biomass

Factor A	Factor B			Average of factor A
	Samurai VA.68 B1	Koros 612 B2	Rado 320 B3	
A1	42,83^{c}	42,14^{c}	41,85^{c}	42,27^{B}
A2	37,53^{d}	28,13^{f}	33,03^{e}	32,90^{C}
A3	33,6^{e}	28,80^{f}	29,11^{f}	30,50^{D}
A4 (Control)	53,61^{a}	47,33^{b}	49,29^{b}	50,08^{A}
Average of factor B	41,89^{A}	36,60^{C}	38,32^{B}	
CV = 3,81				

The data on the average plant biomass of three choy sum varieties show that the interaction between the variety and the growth medium created distinct differences among the treatments. The average plant biomass ranged from 28.13 grams per plant to 53.61 grams per plant, with the highest value in treatment A4B1 (chemical fertilizer with Samurai VA.68 variety) and the lowest in treatment A2B2 (biochar-rare earth mixture with Koros 612 variety).
When considering the average of the fertilizer factor (A), the results show a clear difference in the average plant biomass of the three choy sum varieties at harvest time. The highest average plant biomass was observed in A4 (chemical fertilizer) with 50.08 grams per plant, followed by A1

(biochar-rare earth mixture) with 42.27 grams per plant, A2 with 32.90 grams per plant, and the lowest in A3 with 30.5 grams per plant. These differences are statistically significant at the 95% confidence level.

The average of the variety factor (B) also affected the average plant biomass of the three choy sum varieties at harvest time. The Samurai VA.68 variety (B1) had the highest average biomass with 41.89 grams per plant, followed by the Rado 320 variety (B3) with 38.32 grams per plant, and the lowest in the Koros 612 variety (B2) with 36.60 grams per plant. These differences are also statistically significant at the 95% confidence level.

In summary, the combination of variety and fertilizer type resulted in statistically significant differences in the average plant biomass of choy sum. Chemical fertilizer (A4) and the Samurai VA.68 variety (B1) showed the highest effectiveness, while the biochar-rare earth mixture and the Koros 612 variety (B2) had the lowest results.

Table 5: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on theoretical yield

Factor A	Factor B			Average of factor A
	Samurai VA.68 (B1)	Koros 612 (B2)	Rado 320 (B3)	
A1	45.68[ab]	44.77[abc]	43.86[bc]	44.77[A]
A2	44.00[bc]	44.90[abc]	43.13[c]	44.01[A]
A3	38.71[d]	37.69[d]	37.18[d]	37.86[B]
A4 (Control)	46.45[a]	43.25[c]	44.61[abc]	44.77[A]
Average of factor B	43.71[A]	42.65[B]	42.20[B]	
CV = 4,11				

The data on theoretical yield, an indicator of potential crop productivity, consistently exceeds actual yield. Research from Table 5 demonstrates significant interaction between variety and growth medium in terms of theoretical yield across treatments. The theoretical yield ranges from 37.18 tons/ha (A3B3 - biochar-rare earth mixture with Rado 320 variety) to 46.45 tons/ha (A4B1 - chemical fertilizer with Samurai VA.68 variety), with this difference being statistically significant at the 95% confidence level.

The average of the fertilizer factor (A) shows variations in theoretical yield among the three choy sum varieties at harvest time. The averages for formulas A1, A2, and A4 range from 44.01 tons/ha to 44.77 tons/ha, with no statistically significant differences at the 95% confidence level. Similarly, the average of the variety factor (B) influences the theoretical yield of the three choy sum varieties at harvest time. The highest theoretical yield is observed in the Samurai VA.68 variety (B1) with 43.71 tons/ha, followed by the Koros 612 (B2) and Rado 320 (B3) varieties with 42.65 tons/ha and 42.20 tons/ha, respectively. The theoretical yield between the Koros 612 and Rado 320 varieties (B2 and B3) is statistically equivalent at the 95% confidence level.

In conclusion, the combination of crop variety and fertilizer type results in statistically significant differences in theoretical yield. Chemical fertilizer (A4) and the Samurai VA.68 variety (B1) exhibit the highest effectiveness, while the biochar-rare earth mixture with the Rado 320 variety (A3B3) shows the lowest results. Formulas A1, A2, and A4 demonstrate equivalent theoretical yields, and the difference between the Koros 612 and Rado 320 varieties is not significant.

Table 6: Comparison of the effects of chemical fertilizers and a Biochar-Rare Earth mixture on actual yield

Factor A	Factor B			Average of factor A
	Samurai VA.68 (B1)	Koros 612 (B2)	Rado 320 (B3)	
A1	36.91[a]	35.06[bc]	34.36[c]	35.44[A]
A2	36.28[ab]	34.47[c]	33.78[c]	34.84[A]
A3	31.28[d]	29.52[e]	29.12[e]	29.97[B]
A4 (Control)	37.53[a]	33.89[c]	34.95[bc]	35.46[A]
Average of factor B	35.50[A]	33.23[B]	33.05[B]	
CV = 3,12				

The data on actual yield shows that the interaction between variety and growth medium has led to significant differences in actual yield across treatments. Actual yield ranges from 29.12 tons/ha (A3B3 - biochar-rare earth mixture with Rado 320 variety) to 37.53 tons/ha (A4B1 - chemical fertilizer with Samurai VA.68 variety). This difference is statistically significant at the 95% confidence level.

The average of the fertilizer factor (A) also resulted in significant differences in the actual yield of the three choy sum varieties at harvest time. Formulas A1, A2, and A4 achieved actual yields ranging from 34.84 to 35.46 tons/ha, which are higher than the actual yield of formula A3 (29.97 tons/ha) by 16.25% to 18.32%. This difference is statistically significant at the 95% confidence level. Formulas A1, A2, and A4 show equivalent actual yields with 95% confidence.

Similarly, the average of the variety factor (B) also influenced the actual yield of the three choy sum varieties at harvest time. The Samurai VA.68 variety (B1) achieved the highest actual yield of 35.50 tons/ha, which is higher than the yield of both Koros 612 (B2) and Rado 320 (B3) varieties, with actual yields of 33.05 tons/ha and 33.23 tons/ha, respectively. This difference is statistically significant at the 95% confidence level.

In conclusion, the combination of crop variety and fertilizer type has resulted in statistically significant differences in actual yield. Chemical fertilizer (A4) and the Samurai VA.68 variety (B1) demonstrate the highest effectiveness, while the biochar-rare earth mixture with the Rado 320 variety (A3B3) shows the lowest results. Formulas A1, A2, and A4 exhibit equivalent actual yields, and the Samurai VA.68 variety has significantly higher actual yield compared to the Koros 612 and Rado 320 varieties.

Conclusion

Chemical fertilizer Minro (A4) resulted in the tallest mustard greens, particularly the Samurai VA.68 variety (B1), with a height of 40.01 cm. In contrast, the biochar and rare earth mixtures (A1, A2, A3) produced shorter plants, especially for the Koros 612 (B2) and Rado 320 (B3) varieties, which only reached heights of 25.77 cm to 26.73 cm. This difference is statistically significant at the 95% confidence level, indicating that chemical fertilizer is superior in terms of plant height.

The A4B1 combination (chemical fertilizer with the Samurai VA.68 variety) yielded the highest number of leaves (7.02 leaves/plant), whereas the A2B2 combination (biochar and rare earth mixture with the Koros 612 variety) had the fewest leaves (5.49 leaves/plant). However, this difference is not statistically significant at the 95% confidence level, suggesting that there is no substantial difference between the use of chemical fertilizer and the biochar + rare earth mixture in terms of the number of leaves per plant.

The highest leaf area index was also achieved with the A4B1 combination and the lowest with the A2B2 combination. Although there are differences in leaf area index between the formulas, these differences are not statistically significant. This indicates that the biochar and rare earth mixture can replace chemical fertilizers in terms of leaf area index without causing significant differences.

The highest average plant weight was achieved with the A4B1 combination (53.61 grams/plant), while the A2B2 combination had the lowest weight (28.13 grams/plant). This difference is statistically significant at the 95% confidence level, confirming that chemical fertilizers still outperform the biochar and rare earth mixture in terms of average plant weight.

The highest theoretical yield was obtained with the A4B1 combination (46.45 tons/ha) and the lowest with the A3B3 combination (37.18 tons/ha). Although the average theoretical yields of the A1, A2, and A4 combinations are similar, the differences between the formulas are statistically significant. This suggests that chemical fertilizers are still a better choice when considering theoretical yield.

The highest actual yield was also obtained with the A4B1 combination (37.53 tons/ha) and the lowest with the A3B3 combination (29.12 tons/ha). This difference is statistically significant at the 95% confidence level, indicating that chemical fertilizers outperform the biochar and rare earth mixture in terms of actual yield.

Overall conclusion: The biochar and rare earth mixture (A1, A2, A3) can be used as an alternative to chemical fertilizers (A4) for growing mustard greens. However, their effectiveness in terms of plant height, average plant weight, and yield has not yet matched or surpassed that of chemical fertilizers. For criteria such as the number of leaves and leaf area index, the biochar and rare earth mixture shows no significant difference compared to chemical fertilizers. However, when considering overall effectiveness, chemical fertilizers still provide better results

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