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THE EFFECT OF APPLYING BIOCHAR IN COMBINATION WITH MINERAL FERTILIZERS ON THE GROWTH, DEVELOPMENT, AND YIELD OF SOYBEAN VARIETIES DT20 AND DT26

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Abstract

Biochar is a stable carbonaceous material produced through the pyrolysis of biomass. It is commonly utilized to enhance soil functionality, mitigate greenhouse gas emissions, and augment crop yields. This study aimed to investigate the impact of varying doses of biochar application combined with mineral fertilizers on the growth and development of soybeans. The research was conducted in Bac Giang province, situated in northern Vietnam. Within the framework of the field experiment, the influence of two key factors, namely fertilizers and soybean genotype, was examined. Specifically, the effects of soybean varieties DT20 and DT26 were evaluated across replicated plots measuring 40m² each. The fertilization aspect, encompassing four distinct experimental treatments, was scrutinized within plots of 10 m², allocated within each larger 40 m² plot. Throughout the soybean growth phase, parameters relating to growth, development, and yield were meticulously recorded. Analysis of the experimental outcomes revealed that biochar application significantly impacted soybean growth, development, and yield, influencing parameters such as leaf area index, nodule mass and quantity, dry matter accumulation capability, total fruit count per plant, and soybean seed yield. Furthermore, it was ascertained that the most effective approach for integrating mineral fertilizers with biochar for soybean varieties DT20 and DT26 in the infertile soils of Bac Giang province was the application of 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 1 ton of biochar per hectare.

Keywords: biochar, fertilizers, soybeans, Vietnam, DT26 soybeans, DT20 soybeans.

I. INTRODUCTION

Vietnam is a country with a high level of agricultural development, upon which the livelihoods of the majority of Vietnamese depend. The intensive agricultural practices in Vietnam result in a significant amount of agricultural by-products, which serve as suitable raw materials for biochar production. The production of biochar from agricultural by-products represents a novel direction in scientific research. On one hand, biochar production addresses environmental pollution concerns.



On the other hand, biochar serves as a beneficial product for enhancing soil properties.

The objective of this study is to ascertain the optimal dosage of mineral fertilizers in conjunction with biochar for various new soybean varieties under winter conditions in Bac Giang province.

The study was conducted from September 2020 to January 2021 in Bac Giang province, Vietnam. Two soybean varieties, DT20 and DT26, were used in the study, with planting initiated on September 25, 2020.

As part of the field experiment, the influence of two factors was examined: fertilizers and soybean varieties. The impact of soybean varieties DT20 and DT26 was assessed on plots measuring 40 m², replicated three times. The fertilizer factor, comprising four experimental variants, was investigated on plots measuring 10 m² within each 40 m² plot. The fertilizers utilized included the mineral complex N₄₀P₁₂₀K₈₀ and biochar derived from rice husks. Biochar was applied ten days prior to sowing the seeds (September 15, 2020), while mineral fertilizers were applied to the soil after the emergence of 2-3 true leaves on the soybeans. The experimental treatments consisted of: fertilizer level 1 (PB1): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O (control without biochar); fertilizer level 2 (PB2): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 0.5 t/ha of biochar; fertilizer level 3 (PB3): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 1 t/ha of biochar; fertilizer level 4 (PB4): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 1.5 t/ha of biochar.

The soil in the study areas exhibited a granulometric composition ranging from sandy loam to loam, with a pH range from 5.01 to 5.29, and was classified as gray forest soil.

Throughout the soybean growing season, various parameters including growth duration, main stem height, node count, primary branch count, leaf area, leaf area index, nodulation capacity, and dry matter accumulation at different growth stages were assessed. At the conclusion of the soybean growing season, metrics such as total fruit count per plant, percentage of mature fruits per plant, ratio of three-seeded fruits, weight of 1000 seeds, and actual yield were determined.

The results of the experiment revealed notable differences in the main stem heights of the two soybean varieties under investigation. The greatest main stem height was observed in the PB4 treatment variant (1.5 t/ha of biochar), with DT26 reaching 47.9 cm and DT20 reaching 38.18 cm. Across all fertilizer treatments, DT26 consistently exhibited a greater main stem height compared to DT20.

The number of branches per plant tended to increase with escalating biochar application from the PB1 to PB3 treatment variants, but a further increase in biochar amount (PB4) resulted in a decrease in branch count.

The growth duration of both soybean varieties, DT26 and DT20, subjected to different fertilizer treatments, did not exhibit significant variation. The growth duration ranged from 88 to 92 days for DT20 and from 83 to 87 days for DT26.

The leaf area index exhibited a gradual increase with rising fertilizer amounts. Both soybean varieties displayed the lowest leaf area index in the PB1 treatment variant and the highest in the PB3 treatment variant. However, with increased fertilizer application up to PB4, the leaf area index declined. Across all experimental variants, the leaf area index for DT20 consistently showed lower values than for DT26 (at a 95% confidence level).

The accumulation of dry matter progressively increased from the onset of flowering, peaked during flowering, and reached its maximum during fruiting. During flowering and fruiting stages, dry matter accumulation was minimal in PB1 and maximal in PB3. Conversely, dry matter accumulation tended to decrease in the PB4 treatment variant. The ability of DT20 to accumulate dry matter was consistently lower than that of DT26 across all experimental variants.

Significant disparities were observed in the number and mass of nodules between the two soybean varieties, DT26 and DT20, under various fertilizer treatments. In the PB3 treatment variant, both DT26 and DT20 exhibited the highest nodule count and volume across all developmental stages, reaching a peak during the fruiting phase. However, an increase in biochar application to PB4 led to a reduction in nodule count and volume.

The yield of both soybean varieties, DT26 and DT20, increased with escalating biochar application. Nevertheless, excessively high biochar application (PB4) resulted in decreased yield.



Soybean is a crop that matures early and boasts high nutritional value. Its seeds find applications in human consumption, livestock feed, and various processing industries [1]. Furthermore, soybeans exhibit notable capabilities as soil fertilizers. The yield of soybeans is intricately linked to the fertilization regimen employed. Research by Saleh and Sumarno (2002) [2] indicates that fertilizing soils with low available phosphorus levels below 18 ppb significantly enhances soybean yield compared to non-fertilized conditions. A study on fertilizer dosage conducted in Queensland, Australia, by Dikson et al. (1987) [3] illustrated that soybean yield experiences a substantial increase upon phosphorus fertilization. The susceptibility of soybeans to phosphorus fertilizers is contingent upon soil acidity, organic matter content, and soil texture. Watanabe et al. (1986) [4] suggested that in order to achieve a soybean seed yield of 3 tons per hectare, an application of 60 kg of nitrogen per hectare is necessary.

There have been numerous studies examining the optimal dosage of NPK fertilizers for novel soybean varieties [5-9], yet investigations into the synergistic effects of combining NPK fertilizers with biochar to enhance soybean yield are relatively scarce. In Vietnam, biochar represents an emerging area of research. Various organic materials such as coconut fiber, rice husk, and straw are utilized in the production of biochar across different regions. Despite the rapid economic development, Vietnam continues to rely significantly on agriculture, which sustains the livelihoods of the majority of its population. The country's intensive agricultural practices generate abundant by-products that serve as viable feedstocks for biochar production. Despite the widespread recognition and utilization of biochar across various industrial sectors, comprehensive studies elucidating its properties remain limited.

According to the General Statistical Office of Vietnam [10], the winter soybean yield in Bac Giang province averages only 16-17 quintals per hectare (q/ha). The underlying causes of this low yield are attributed to incomplete and unbalanced fertilizer application, particularly concerning new soybean varieties. There is a notable dearth of research focusing on the optimal application rates of NPK fertilizer combined with biochar for winter soybeans cultivated in soil following the rice harvest in Bac Giang. Hence, the objective of this study is to ascertain the appropriate fertilizer application rates in conjunction with biochar supplementation for selected new soybean varieties under winter conditions in Bac Giang province.

II. MATERIALS AND METHODS

The study was conducted from September 2020 to January 2021 in Bac Giang Province, Vietnam. Bac Giang Province experiences a tropical monsoon climate characterized by four distinct seasons annually. The average humidity throughout the year stands at 83%. Certain months witness humidity levels exceeding 85%, while in drier periods, it ranges between 74% and 80%. The region enjoys an average of 1500 to 1700 hours of sunshine annually, facilitating the cultivation of tropical and subtropical crops [11]. Annual precipitation averages around 1533 mm, with maximum rainfall occurring between April and September. The average annual evaporation rate is approximately 1000 mm [11]. Prevailing winds are predominantly influenced by southeast winds during the summer and northeast winds during the winter [11]. The study was conducted on two soybean varieties, DT20 and DT26, which were developed and researched by the Vietnam Institute of Food and Food Plants. Soybeans were sown on September 25, 2020.

As part of the field experiment, the influence of two factors was examined: fertilizers and soybean variety. The impact of soybean varieties DT20 and DT26 was evaluated on plots measuring 40 m², each replicated three times, as depicted in Figure 1. The fertilizer factor, comprising four experimental treatments, was investigated on plots measuring 10 m², allocated within each 40 m² plot. Fertilizers utilized included a mineral complex of N₄₀P₁₂₀K₈₀ and biochar derived from rice husks (refer to Table 1). Biochar application occurred ten days prior to seed sowing, on September 15, 2020. Mineral fertilizers were administered to the soil after the emergence of 2-3 true leaves on the soybean plants. The experimental treatments consisted of the following fertilization levels: PB1 (fertilization level 1): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O (no biochar - control); PB2 (fertilization level 2): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 0.5 ton/ha biochar; PB3 (fertilization level 3): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 1 ton/ha biochar; PB4 (fertilization level 4): 40 kg N + 120 kg P₂O₅ + 80 kg K₂O + 1.5 ton/ha biochar.

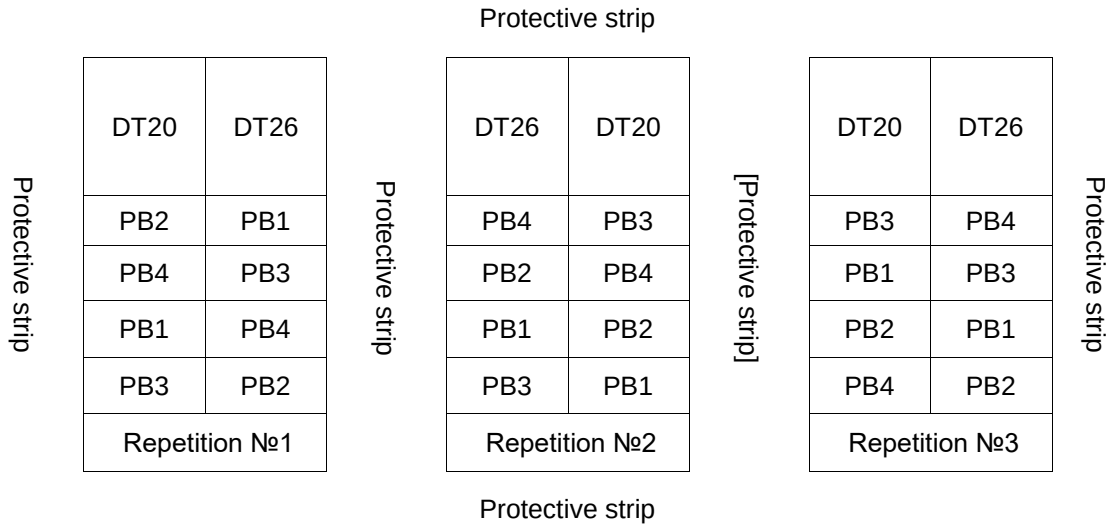


Fig. 1. Scheme of the experiment

[Table 1]

Substance content (%) in biochar obtained from rice husk

Parameter	pHKCl	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Value	6,380	42,790	0,568	0,152	0,531	0,183	0,088

The soil within the study areas is classified as poor gleysoic according to the FAO classification. Chemical analysis of the soil revealed its acidic nature (pH in H₂O ranging from 5.01 to 5.29, pH in KCl from 4.19 to 4.49). Soil absorption capacity varies from low to medium-low, ranging from 9.24 to 10.47 mg eq/100 g of soil. The soil's saturation with bases ranges only from 22% to 29%. The organic carbon and total nitrogen content in the arable soil layer were measured as average, at 1.21% to 1.53% OC and 0.12% to 0.15% N, respectively. The levels of total and readily available phosphorus in the soil in the arable layer ranged from rich to very rich (0.11% to 0.15% P₂O₅ and 10.09-23.48 mg P₂O₅/100 g soil). Conversely, the levels of total and easily digestible potassium in the topsoil layer were found to be very low (total potassium ranging from 0.19% to 0.58% K₂O, and readily available potassium ranging from 5.79 to 15.08 mg K₂O/100 g of soil) [12]. The granulometric composition of the soil ranged from sandy loam to loam. The proportion of clay particles in the surface layer ranged from 13% to 17%, while the content of clay particles in the surface layer varied from 16% to 20%. The density of the topsoil varied from 1.23 to 1.26 g/cm³, and the porosity ranged from 50% to 52%. Low organic matter and potassium content in gray soil represent two major limiting factors in agricultural production that require mitigation [12]. Throughout the soybean growing season, various parameters including growth duration, main stem height, node count, primary branch count, leaf area, leaf area index, nodulation capacity, and dry matter accumulation at different growth stages were evaluated. At the conclusion of the soybean growth cycle, assessments were made regarding the total fruit count per plant, proportion of mature fruits per plant, ratio of three-seeded fruits, weight of 1000 seeds, and actual yield.

The height of the main stem was measured from the node of the two cotyledons to the growing tip of the main stem and expressed in centimeters. The Leaf Surface Index (LSI) (m² leaves/m² soil) was calculated as the product of the area of one leaf of a plant and the density per 1 m² area. To determine dry matter (g), plant samples were dried to a constant weight in an oven maintained at a temperature exceeding 80°C, and 5 plants were weighed for each experimental treatment.



The total number of fruits was determined by randomly selecting 10 plants from each experimental treatment, and the average value per plant was calculated. To assess the percentage of mature fruits, 10 plants were randomly sampled from each plot, and the total number of mature fruits was counted, followed by the calculation of the average number per plant. Statistical data processing was conducted using MS Excel and IRRISTAT 5.0.

III. RESEARCH RESULTS AND DISCUSSION

[Table 2]

The effect of the fertilizer formula on the height, number of nodes, number of branches of two soybean varieties

Soy variety	Experience option	Plant height in (cm)	The number of internodes on the stem	Number of level 1 branches per plant	Total growing time
DT26	PB1	42,3	10,15	3,04	84
	PB2	43,7	10,21	3,82	83
	PB3	46,6	10,84	4,04	86
	PB4	47,9	10,36	3,18	87
DT20	PB1	34,64	7,02	2,19	88
	PB2	36,18	7,28	2,66	89
	PB3	37,34	7,59	2,86	91
	PB4	38,18	7,36	2,47	92
<i>LSD_{0,05}</i>		2,69	0,72	0,35	
<i>CV (%)</i>		4,00	4,30	5,60	

[Table 3]

Effect of fertilizers on the leaf area index of two soybean varieties (m^2 of leaves/ m^2 of soil)

Soy variety	Experience option	The beginning of the flowering period	The period of strong flowering	The period of large fruits
DT26	PB1	1,76	2,68	3,56
	PB2	2,14	3,36	4,13
	PB3	2,15	3,34	4,16
	PB4	2,04	3,02	3,99
DT20	PB1	1,55	2,36	3,04
	PB2	2,11	2,93	3,66
	PB3	2,13	2,97	3,68
	PB4	1,93	2,66	3,46
<i>LSD_{0,05}</i>				0,33
<i>CV (%)</i>				4,61



The experiment revealed a gradual increase in the soybean leaf area index from the flowering stage to the fruiting stage. This index exhibited a tendency to rise with increasing fertilizer application. Among the two soybean varieties, the lowest leaf area index was observed in experimental variant PB1, while the highest was recorded in experimental variant PB3. Notably, as fertilizer application increased to PB4, the leaf surface index displayed a decreasing trend.

Throughout all three periods, DT26 consistently exhibited the highest leaf area index. At the onset of flowering, the PB3 experiment reached its peak with a leaf area index of 2.15 m² of leaves/m² of soil. During the flowering stage, the PB2 treatment demonstrated the highest leaf surface index of 3.36 m² of leaves/m² of soil, while the PB3 treatment recorded the maximum value of 4.16 m² of leaves/m² of soil during the fruiting period. Overall, across all experimental variants, the leaf area index for the DT20 variety consistently displayed lower values compared to the DT26 variety, with statistical significance at a 95% confidence level.

Plant dry matter accumulation is contingent upon factors such as leaf area, photosynthetic efficiency, and the plant's capacity to absorb nutrients. This accumulation serves as a crucial indicator of plant growth and potential yield. The outcomes of monitoring dry matter accumulation in experimental treatments across different growth and development stages are presented in Table 4. The quantity of dry matter accumulated by soybean plants exhibited significant variability across all experimental treatments. Dry matter accumulation gradually increased from the onset of flowering, experienced a rapid surge during flowering, and peaked during the fruiting stage. Throughout the flowering and fruiting periods, dry matter accumulation was minimal in PB1 and maximal in PB3. Conversely, in the PB4 treatment, there was a tendency for decreased dry matter accumulation. Furthermore, across all experimental treatments, the DT20 variety consistently displayed a lower ability to accumulate dry matter compared to the DT26 variety.

[Table 4]

The effect of fertilizers on the accumulation of dry matter of two varieties of soybeans

Soy variety	Experiment option	The beginning of the flowering period	The period of strong flowering	The period of large fruits
DT26	PB1	2,79	6,89	17,85
	PB2	3,24	8,17	19,75
	PB3	3,43	8,22	20,31
	PB4	3,05	8,04	19,28
DT20	PB1	2,58	5,36	15,06
	PB2	3,15	7,58	18,27
	PB3	3,18	7,81	18,66
	PB4	2,96	7,12	17,43
<i>LSD</i> _{0.05}				1,42
<i>CV (%)</i>				4,0

Nodules on soybean roots form as a result of symbiosis between the bacterium *Rhizobium japonicum* and plant roots. This type of nodule bacteria possesses the capability to fix atmospheric nitrogen, converting it into a readily assimilable form for plants. The quantity and size of nodules serve as indicators of the symbiotic relationship and biological nitrogen fixation by bacteria. Bacterial activity is significantly influenced by soil conditions, external environmental factors, growth conditions, and the genetic characteristics of the soybean variety [14]. The findings regarding nodule formation in the experimental treatments are presented in Table 5. The experimental results demonstrated significant differences in the number and weight of nodules between the two soybean varieties, DT26 and DT20, under various fertilizer regimes.



In the PB3 treatment, both DT26 and DT20 exhibited the highest number and volume of nodules across all growth stages, peaking during the fruiting phase. With an increase in biochar application up to PB4, there was a tendency for the number and volume of nodules to decrease. Furthermore, across all fertilizer treatments, variety DT26 consistently exhibited a lower number and weight of nodules compared to DT20, with statistical significance at a confidence level of 95%.

[Table 5]

The effect of fertilizer treatment on the nodules of two varieties of soybeans

Soy variety	Experience option	The beginning of the flowering period		The period of strong flowering		The period of large fruits	
		Total number of nodules (nodes/plant)	weight (g/plant)	Total number of nodules (nodes/plant)	weight (g/plant)	Total number of nodules (nodes/plant)	weight (g/plant)
DT26	PB1	19,35	0,09	28,42	0,17	45,70	0,48
	PB2	28,32	0,15	38,71	0,31	58,68	0,76
	PB3	29,70	0,16	39,34	0,34	60,36	0,85
	PB4	21,70	0,12	32,70	0,28	54,84	0,60
DT20	PB1	31,32	0,17	44,64	0,36	58,14	0,94
	PB2	38,66	0,22	57,56	0,68	74,45	1,16
	PB3	41,13	0,26	60,72	0,92	85,13	2,04
	PB4	36,30	0,21	52,50	0,56	67,36	1,11
LSD _{0.05}		2,97		3,42		6,95	
CV (%)		5,20		4,10		5,80	

The total number of fruits per plant is indicative of soybean's fruit-bearing capacity. The results presented in Table 6 demonstrate that, under varying fertilizer levels, the two soybean varieties exhibit differing fruit yields. Throughout the experimentation, the DT26 variety consistently outperformed the DT20 variety in terms of fruit production, with statistical significance at the 95% confidence level. Notably, the PB3 treatment yielded the highest total number of fruits, with the DT26 variety yielding 51.42 fruits and the DT20 variety yielding 34.56 fruits. Monitoring results also indicated a high percentage of hard fruits per plant and a high percentage of three-seeded fruits for both varieties, with the PB3 treatment consistently yielding the highest values.

[Table 6]

Effect of fertilizer compositions on yield and yield components of two soybean varieties

Soy variety	Experience option	Total number of fruits/trees (fruits)	Percentage of hard fruits (%)	Percentage of three-seeded fruits (%)	weight of 1000 seeds (g)	Actual yield (c/ha)
DT26	PB1	43,19	93,15	17,44	160,76	17,89
	PB2	48,29	96,60	21,43	168,28	20,63
	PB3	51,42	97,52	22,67	170,16	20,72
	PB4	46,12	94,23	18,41	165,95	19,45
DT20	PB1	27,90	92,37	16,86	199,45	16,58
	PB2	32,82	95,85	20,13	211,94	18,78
	PB3	34,56	97,11	20,48	214,75	18,88
	PB4	31,98	94,68	18,45	203,82	18,33
LSD _{0.05}		3,87				1,27
CV (%)		5,61				5,32



IV. CONCLUSION

Based on the findings of the study, it was revealed that the combined application of biochar and mineral fertilizers yields greater efficiency compared to the use of fertilizers alone. Optimal outcomes across various soybean parameters were observed in the PB3 treatment, where 40 kg N, 120 kg P₂O₅, 80 kg K₂O, and 1 t/ha of biochar were applied. Consequently, in the PB3 treatment, the highest leaf area index was consistently observed across all three developmental stages of soybeans, surpassing other experimental treatments. Additionally, the PB3 treatment exhibited the highest number of nodules in both soybean varieties, with the DT26 variety displaying a greater number of nodules compared to the DT20 variety. Moreover, the volume of nodules in the PB3 treatment exhibited the highest values throughout the soybean growing season, spanning the onset of flowering, vigorous flowering, and fruiting stages. Remarkably, the PB3 treatment also resulted in the highest net soybean yield compared to other experimental treatments, reaching 20.7 quintals per hectare for DT26 and 18.84 quintals per hectare for DT20.

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ВЛИЯНИЕ ВНЕСЕНИЯ БИОЧАРА В СОЧЕТАНИИ С МИНЕРАЛЬНЫМИ УДОБРЕНИЯМИ НА РОСТ, РАЗВИТИЕ И УРОЖАЙНОСТЬ СОРТОВ СОИ DT20 И DT26

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Аннотация

Биочар - это стабильный углеродистый материал, получаемый в результате пиролиза биомассы. Он широко используется для улучшения функциональности почвы, снижения выбросов парниковых газов и повышения урожайности. Целью данного исследования было изучить влияние различных доз внесения биоугля в сочетании с минеральными удобрениями на рост и развитие сои. Исследования проводились в провинции Бак Гианг, расположенной на севере Вьетнама. В рамках полевого эксперимента изучалось влияние двух ключевых факторов, а именно удобрений и генотипа сои. В частности, влияние сортов сои DT20 и DT26 оценивалось на размноженных участках площадью 40 м². каждый. Аспект удобрений, включающий четыре различные экспериментальные обработки, был тщательно изучен на участках площадью 10 м², выделенных на каждом большом участке площадью 40 м². На протяжении всей фазы роста сои тщательно регистрировались параметры, связанные с ростом, развитием и урожайностью. Анализ результатов эксперимента показал, что применение биочара значительно повлияло на рост, развитие и урожайность сои, воздействуя на такие параметры, как индекс площади листьев, масса и количество клубней, способность накапливать сухое вещество, общее количество плодов на растении и урожайность семян сои. Кроме того, было установлено, что наиболее эффективным подходом к интеграции минеральных удобрений с биочаром для сои сортов DT20 и DT26 на неплодородных почвах в провинции Бак Гианг является внесение 40 кг N + 120 кг P₂O₅ + 80 кг K₂O + 1 тонна биочара на гектар.

Ключевые слова: биочар, удобрения, соя, Вьетнам, соя DT26, соя DT20.

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