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Effects of organic fertilizer and biochar-based amendments on purple sweet potato under reduced synthetic fertilizationYugi R. Ahadiyat^{1*}, Ervina Mela², Ahmad Fauzi¹¹Laboratory of Agroecology, Department of Agrotechnology, Faculty of Agriculture, Universitas Jenderal Soedirman, Purwokerto, Indonesia²Department of Agricultural Technology, Faculty of Agriculture, Universitas Jenderal Soedirman, Purwokerto, Indonesia***Correspondence:** Yugi R. Ahadiyat (ahadiyat.yugi@unsoed.ac.id)**Article info:****Received:** 26 June 2026**Revised:** 9 September 2026**Accepted:** 19 September 2026**Available online:** 19 September 2026**Academic Editor:** Prof. Marina Piria, University of Zagreb Faculty of Agriculture, Croatia**How to Cite:**

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ABSTRACT

The objective of this study was to determine the effect of organic fertilizer application and biochar plus low-dose synthetic fertilizer application on physiological characteristics and purple sweet potato yield. A factorial Randomized Block Design consisted of two factors: biochar plus a dose of 8 t/ha, viz. biochar, biochar+liquid organic fertilizer (LOF), biochar+azolla, and organic fertilizers with a dose of 15 t/ha, viz., no organic fertilizer, goat organic fertilizer, and cow organic fertilizer. Synthetic fertilizer of N, P, and K was applied at a low dose of 50% of the recommendation. The physiological variables observed were stomata density and stomatal opening width, leaf chlorophyll content, and total soluble solids (°Brix). Yield components were observed on tuber diameter and length, tuber weight per plant, and harvest index. Stomatal density, stomatal opening width, and total soluble solids were not improved due to the application of biochar and organic fertilizer. In general, the application of organic fertilizer in combination with biochar, could increase chlorophyll contents in leaves. However, the application of organic fertilizer or the enrichment of biochar with LOF and azolla failed to increase sweet potato yields. This result indicates that local cultivar of purple sweet potato has low response to organic fertilization and biochar application under reduced synthetic fertilizers.

Keywords: Azolla; biochar; liquid organic fertilizer; organic fertilizer; sweet potato

INTRODUCTION

Sweet potatoes are an important food crop that contributes to the growth of the agricultural industry. Sweet potatoes can be preserved for longer periods and are more effective when processed into semi-finished products such as flour and starch (Hasmadi et al., 2021). Sweet potatoes are available in various varieties in Indonesia and contain fiber, antioxidants, minerals, and vitamins that can be used as food, medicine, and cosmetics (Kurnianingsih et al., 2021). Sweet potato production in Indonesia currently exhibits an unstable pattern, both in terms of planted area and harvest yield (Karuniawan et al., 2021). This situation has the potential to hinder the sustainability of supply and the development of downstream processing. Therefore, strategies to increase productivity are needed through the application of cultivation technology, the provision of superior varieties, and policy support that can ensure the sustainability of purple sweet potato production in various regions.

The long-term and continuous use of synthetic fertilizers and pesticides during fertilization and in controlling plant pests has been proven to cause serious problems such as water pollution, soil pollution, decreased soil fertility, and the development of biological elements (Bai et al., 2020; Beaumelle, 2023). Therefore, efforts to maintain crop production include the use of organic materials. According to Aytenew & Bore (2020), organic fertilizers are beneficial in improving soil aeration, nutrient retention, water-holding capacity, soil buffering capacity, and serving as an energy source for soil microbes. Organic fertilizers can improve soil structure and increase the availability of essential macro- and micronutrients for plants (Fan et al., 2023).

The application of organic fertilizers derived from cattle and goat manure offers significant advantages for sweet potato (*Ipomoea batatas* L.) growth and yield because these amendments provide essential nutrients, improve soil structure, enhance water-holding capacity, and stimulate microbial activity. Cattle manure contributes to increased soil organic matter and nutrient availability, leading to higher tuber production and improved nutrient uptake, while

goat manure is characterized by relatively rapid mineralization and has been reported to enhance agronomic traits and yield components of sweet potato. Long-term organic fertilization also promotes potassium accumulation in soil aggregates, thereby increasing potassium uptake and yield stability in sweet potato. Consequently, the utilization of cattle and goat manure represents an environmentally friendly and sustainable strategy for improving sweet potato productivity while maintaining soil fertility (Oliveira et al., 2010; Caruana & Cagasan, 2020; Yuan et al., 2023).

Another organic material that can be utilized in crop cultivation systems is biochar. Biochar improves root morphology, such as root biomass, volume, length, and diameter, which in turn enhances nutrient uptake, shoot growth, and yield in maize (Gaurav et al., 2025). Another study also revealed that biochar enhances soil nutrient retention and water-holding capacity, improves soil structure (aeration and root penetration), and leads to significantly higher tomato yield (Olasekan et al., 2025).

Biochar can eliminate soil pollution chemically and physically (Qiu et al., 2022), and the combination of organic fertilizer and biochar can create a synergy that enhances the benefits of each treatment, such as increasing nutrient availability and soil microbial health, thus supporting long-term soil fertility and nutrient utilization efficiency by plants (Ali et al., 2025). Biochar has the potential to improve agricultural physiology and yield (Naz et al., 2025). Several approaches to biochar's role include nutrient addition, the development of systemic insect resistance, and reduced aluminum (Al) toxicity caused by biochar's high pH (Deng et al., 2025).

Despite numerous studies reporting the beneficial effects of organic fertilizers, biochar, and plant-based amendments on sweet potato production, limited information is available regarding the integrated use of cow manure- and goat manure-based organic fertilizers in combination with biochar, as well as the synergistic effects of biochar enriched with liquid

organic fertilizer and *Azolla* on the growth, physiological characteristics, and yield of purple sweet potato (*Ipomoea batatas* L.). Previous studies have generally focused on the individual application of these amendments, whereas their combined effects on physiological and yield characteristics have not been comprehensively evaluated. Therefore, the novelty of this study lies in the comparative assessment of different organic nutrient management strategies involving animal manure-derived fertilizers, biochar, and biochar supplemented with liquid organic fertilizer and *Azolla*, with particular emphasis on their influence on physiological traits and tuber yield of purple sweet potato. This approach is expected to provide a more sustainable and environmentally friendly nutrient management alternative for enhancing purple sweet potato productivity. The objective of this study was to determine the effect of the application of organic fertilizer and biochar plus with low-dose synthetic fertilizer on the physiological characteristics and yield of purple sweet potatoes.

MATERIALS AND METHODS

The study was conducted in Bobosan Village, North Purwokerto District, Banyumas Regency, Central Java, Indonesia, with coordinates of Latitude -7.40809° S and Longitude 109.22214° E. The research period was carried out from April 2025 to August 2025.

A Factorial experiment in a Randomized Complete Block Design was applied, consists of two factors viz. the first factor of biochar-based amendment treatment consisting of Biochar at a dose of 8 t/ha (128 g/polybag), Biochar (128 g) + Liquid Organic Fertilizer (192 ml), and Biochar (128 g) + *Azolla* (12.8 g); and the second factor of organic fertilizer treatment at a dose of 15 t/ha (240 g/polybag) consisting of no organic fertilizer, goat organic fertilizer, and cow organic fertilizer were tested. All treatments were combined, resulting in nine combinations and each replicated three times. Each combination treatment consisted of four experimental units as subsamples in a total of 108 polybags. Four units in each treatment were averaged to obtain

a single data point. Therefore, each replication (block) had nine data points. A polybag of 40 cm x 50 cm was used and filled with dry soil weighing 17 kg.

Organic fertilizer of goat and cow manure was made using a standard fermentation method by adding bio-fermenter liquid and sugar. The mixed bio-fermenter and sugar solution was then poured onto the livestock waste and fermented for one month.

Biochar was made from corn cobs using pyrolysis method of open pit. The substrate was put into an open pit in the ground and started with a small fire at the bottom, then gradually added by corn cobs layer by layer. Oxygen was restricted by the walls of the pit and by covering the pit with green leaves and soil. This process took about 4 hours to complete, resulting in black charcoal. Biochar was then ground and filtered through a 2 mm sieve. Liquid Organic Fertilizer was made from banana stems, which were then chopped into small pieces. The chopped banana stems were then mixed with rice washing water and sugar, and then stored in a closed bucket for one month. Fresh Azolla was dried until its moisture content was a maximum of 15%, after which it was finely ground and filtered through a 2 mm sieve.

Biochar+liquid organic fertilizer (LOF) was made by dissolving biochar in a bucket containing LOF until evenly distributed. The media was mixed between biochar and LOF with a ratio of 1:1.5 (128 g biochar + 192 ml LOF per polybag), then dried to a maximum water content of 15%. For biochar+azolla, biochar and filtered dry azolla were mixed with a ratio of 10:1 (128 g biochar + 12.8 g azolla per polybag). The soil media used in polybags was 17 kg, with the application of 240 g each of organic cow or goat fertilizer and 128 g of biochar, biochar + 192 ml of LOF, and biochar + 12.8 g of azolla.

Prior to the experiment, the soil, organic fertilizer, and biochar were analyzed to determine their chemical characteristics. The measured characteristics included pH (electrometric method), organic C (spectrophotometric method), total N content (Kjeldahl method), P_2O_5

(spectrophotometric method), K_2O and CEC (AAS method), and moisture content (gravimetric method).

The treatments of biochar and organic fertilizer were applied at 7 days before planting by mixing them with soil, then put into polybag and added water to reach field capacity condition. Planting material was prepared from 25 cm length stem of a local cultivar of purple sweet potato regularly cultivated by farmers in Banyumas Regency. One single stem was planted into polybag after 7 days incubated. Crop management applied were fertilization, installing stakes, watering, weeding and pest control. Harvesting was carried out at 90 days after planting by cutting the sweet potato vines and subsequently digging the tubers out of the soil.

Fertilization was carried out in two stages, 14 days after planting and 30 days after planting. At a 50% fertilizer dose recommendation of 46 kg N/ha, 27 kg/ha P_2O_5 , and 25 kg/ha K_2O was applied. Based on the dose and number of populations per hectare (62,500 plants resulted from 40 x 40 cm planting space), the equivalent dose applied to the soil in each polybag (17 kg of dry soil) was 0.75 g of N, 0.45 g of P_2O_5 , and 0.4 g of K_2O .

The physiological variables observed included stomatal density and total stomatal number, which were determined from epidermal imprints and quantified under a light microscope following image analysis procedures commonly employed for stomatal characterization (Hill et al., 2021; Li et al., 2026). Using the nail polish approach, stomatal features were examined by putting nail polish to the leaf surface to create an imprint, waiting for the polish to dry, carefully removing the polish, looking at the leaf imprint using a light microscope, and taking and analyzing pictures (Pathoumthong et al., 2023). Each treatment in each block is represented by one sample plant. The leaf used is the second leaf from the flag leaf.

Referring to Lichtenthaler and Buschmann (2001) Chlorophyll content was measured using a spectrophotometer with acetone extraction. The levels of chlorophyll a and chlorophyll b can be calculated with the following equations:

$$\text{Chl.a } (\mu \text{ g/ml}) = 11.24 A_{661.6} - 2.04 A_{644.8}$$

$$\text{Chl.b } (\mu \text{ g/ml}) = 20.13 A_{644.8} - 3.96 A_{661.6}$$

Total soluble solids (°Brix) in storage roots were determined using a digital refractometer and expressed as °Brix, which represents soluble sugar accumulation and quality attributes (Jaywant et al., 2022). All physiological observations were conducted when the plants reached the early flowering stage.

Yield components included tuber diameter and tuber length, which were measured using a vernier caliper, while tuber weight per plant was determined using a digital balance immediately after harvest. Harvest index (HI) was calculated as the ratio between storage root fresh weight and total plant biomass, providing an estimate of assimilate partitioning efficiency to economic yield (Amao et al., 2018).

The observed data were statistically analyzed using the analysis of variance test with a $p \leq 0.05$ level to determine the effect of the treatments. If the analysis results showed a significant effect, the analysis was continued with Duncan's Multiple Range Test (DMRT) at a $p \leq 0.05$ level. The software used for statistical analysis was DSAASTAT ver. 1.514.

RESULTS

Chemical properties of soil, manure, biochar, and biochar plus

The soil used in the pot trial has pH 6.4, 20.19 me/100g CEC, 2.39% organic C, 0.40% Nitrogen, 1.75% P_2O_5 , 0.20% K_2O , and 19.05% water content. Organic fertilizer of goat manure was characterized as pH 8.22, 19.88% Carbon, 1.27% Nitrogen, 16.06 C/N ratio, 2.08 P_2O_5 , 0.95% K_2O , and 30.83% water content, while cow manure as pH 8.25, 19.33% Carbon, 1.31% Nitrogen, 15.08% C/N ratio, 2.42% P_2O_5 , 1.17% K_2O , and 30.35% water content. This chemical properties have meet the national standard of solid organic fertilizer in Indonesia except water content that over minimum standard (8-25%)

Chemical analysis for biochar has showed that pure biochar consisted of 6.67% organic C, 0.91% Nitrogen, 6.69% P_2O_5 , 10.12% K_2O , pH 9.7, and 11.22% water. Biochar plus LOF consisted of 11.78% organic C, 1.04% Nitrogen, 4.78% P_2O_5 , 6.34% K_2O , pH 9.1, and 40.57% water. Biochar plus azolla consisted of 8.46% organic C, 0.98% Nitrogen, 8.62% P_2O_5 , 21.81% K_2O , pH 9.5, and 28.75% water.

Physiological characteristics of purple sweet potato plants with liquid organic fertilizer and biochar plus application

Stomata density (number of stomata/mm²) and stomata opening width (μm)

Table 1 shows that the application of organic fertilizers and biochar had no significant effect on stomatal characteristics. Stomatal density remained statistically similar among plants receiving no organic fertilizer, goat manure organic fertilizer, and cow manure organic fertilizer, with values ranging from 170.51 to 198.46 mm². Likewise, the application of biochar alone, biochar combined with liquid organic fertilizer (LOF), and biochar combined with azolla did not significantly alter stomatal density, which varied between 167.71 and 194.27 mm². A similar trend was observed for stomatal width.

Neither the different sources of organic fertilizer nor the various biochar treatments caused significant differences in stomatal aperture, with values ranging from 12.22 to 14.17 μm for organic fertilizer treatments and from 12.72 to 14.03 μm for biochar treatments. These findings suggest that stomatal density and stomatal opening were relatively stable and were not markedly influenced by the application of organic fertilizers or biochar under the conditions of the present study.

Total soluble solids (°Brix)

The results revealed that all treatments had no significant effect on the total soluble solids (TSS) or sweetness level (°Brix) of the harvested products. Applications without organic fertilizer, as well as those receiving goat and cow organic fertilizers, produced statistically similar TSS values ranging from 10.49 to 11.05 °Brix. Likewise, the application of biochar alone, biochar combined with liquid organic fertilizer (LOF), and biochar combined with azolla resulted in no significant differences, with TSS values varying from 10.55 to 10.98 °Brix (Table 1).

These findings indicate that the different sources of organic fertilizer and biochar amendments did not markedly influence sugar accumulation, suggesting that the sweetness characteristics of the crop remained relatively stable across all treatments under the conditions of the present study.

Leaf chlorophyll a content (mg/kg)

The application of organic fertilizer and biochar showed a significant difference in leaf chlorophyll content. The high chlorophyll a content resulted from the application of biochar plus azolla, goat organic fertilizer, and biochar, and cow organic fertilizer, along with all treatments of biochar and biochar plus. Thus, the lower chlorophyll content resulted from goat organic fertilizer and biochar plus azolla, with an insignificant difference from other treatments, except for applications of goat organic fertilizer and biochar and cow organic fertilizer and biochar plus LOF (Table 2).

The results demonstrated that the application of organic fertilizer and biochar significantly affected leaf chlorophyll content. In general, treatments involving biochar, either applied alone or in combination with organic amendments, tended to enhance chlorophyll concentration. Higher chlorophyll content was observed in plants treated with biochar

combined with azolla, goat manure organic fertilizer plus biochar, cow manure organic fertilizer plus biochar, as well as all treatments containing biochar and biochar plus.

In contrast, relatively lower chlorophyll a content was recorded in plants receiving goat manure organic fertilizer and biochar plus azolla, although the values were not significantly different from most other treatments, except for goat manure organic fertilizer plus biochar and cow manure organic fertilizer combined with biochar plus liquid organic fertilizer (LOF). The overall findings suggest that the interaction between biochar and different organic fertilizer sources plays an important role in determining chlorophyll accumulation in leaves.

Leaf chlorophyll b content (mg/kg)

The results showed in Table 2 that chlorophyll b content tended to vary among treatments, although several treatments were statistically comparable. The highest chlorophyll b concentrations ($>480 \text{ mg kg}^{-1}$) were observed in plants receiving cow organic fertilizer combined with biochar plus liquid organic fertilizer (LOF), which did not differ significantly from the treatments of biochar plus LOF, goat organic fertilizer combined with biochar, and cow organic fertilizer combined with biochar.

In contrast, relatively lower chlorophyll b contents ($<470 \text{ mg kg}^{-1}$) were recorded in plants treated with biochar without organic fertilizer, and these values were not significantly different from those obtained with biochar plus azolla, goat organic fertilizer combined with biochar plus LOF, or biochar plus azolla, and cow organic fertilizer combined with biochar plus azolla. Overall, the findings suggest that the combination of organic fertilizers with biochar, particularly when supplemented with LOF, tended to promote greater chlorophyll b accumulation, whereas biochar applied alone or in combination with azolla generally resulted in comparatively lower chlorophyll b content.

Total leaf chlorophyll content (mg/Kg)

The total chlorophyll content varied among the different treatment combinations. Plants treated with cow organic fertilizer combined with biochar plus liquid organic fertilizer (LOF), as well as those receiving goat organic fertilizer combined with biochar, exhibited the highest total chlorophyll content, exceeding 2000 mg kg⁻¹. In contrast, all other treatment combinations produced total chlorophyll contents below 2000 mg kg⁻¹, indicating comparatively lower chlorophyll accumulation.

The interaction between organic fertilizer sources and biochar plays an important role in enhancing chlorophyll synthesis. In particular, the combination of cow organic fertilizer with biochar plus LOF and the combination of goat organic fertilizer with biochar provided the most favorable conditions for chlorophyll accumulation, resulting in superior total chlorophyll content compared with the other treatments.

Yield characteristics of purple sweet potato plants with organic fertilizer and biochar plus applications*Number of tuber (units)*

The number of tubers was not significantly affected by the application of organic fertilizer or biochar treatments, although numerical variations were observed among the treatments (Table 3). Under organic fertilizer application, the number of tubers ranged from 2.97 to 3.03 tubers per plant, while values under biochar treatments varied from 2.66 to 3.51 tubers per plant. Despite the relatively higher number of tubers recorded with biochar plus liquid organic fertilizer (LOF), the differences among treatments were statistically insignificant, indicating that the treatments had a comparable effect on tuber formation.

Tuber weight per plant (g)

Tuber weight per plant also showed no significant differences among the treatments, even though the recorded values varied considerably. Organic fertilizer treatments produced tuber weights ranging from 491.94 to 540.14 g plant⁻¹, whereas biochar treatments resulted in values between 455.37 and 591.39 g plant⁻¹ (Table 3). The highest tuber weight was observed with biochar plus LOF; however, this increase was not statistically different from that of the other treatments, suggesting that all treatments had a similar effect on tuber biomass accumulation. Tuber weight showed that in most treatments, the sweet potato tubers produced had an average weight in groups A and B, according to SNI quality standards. Some treatments showed a higher concentration of tuber weight in group A, which is an indicator of better tuber quality and readiness for harvest (Table 3).

Tuber diameter (cm)

Statistical analysis revealed that tuber diameter was not significantly influenced by either organic fertilizer or biochar applications, despite some numerical differences among treatments. Tuber diameter ranged from 3.530 to 3.814 cm under organic fertilizer treatments and from 3.419 to 3.834 cm under biochar treatments (Table 3). Although biochar plus Azolla and cow organic fertilizer tended to produce larger tuber diameters, these differences were not statistically significant, indicating that tuber enlargement occurred similarly across all treatments.

Tuber length (cm)

Likewise, tuber length did not differ significantly among the treatments, even though values ranged from 11.02 to 12.90 cm for organic fertilizer treatments and from 11.28 to 12.94 cm for biochar treatments (Table 3). The longest tubers were observed in plants treated with

biochar plus Azolla and in those without organic fertilizer; however, these values were statistically comparable to those obtained from the other treatments. This finding suggests that the different combinations of organic fertilizer and biochar had no marked effect on tuber elongation.

Harvest index

The harvest index was also not significantly affected by the application of organic fertilizer and biochar treatments. Although the values ranged from 0.39 to 0.42 under organic fertilizer treatments and from 0.37 to 0.42 under biochar treatments, the observed differences were statistically insignificant. Therefore, all treatments exhibited a similar efficiency in partitioning assimilates to storage roots, indicating that the allocation of biomass between vegetative growth and economic yield remained relatively stable regardless of the fertilizer and biochar combinations applied.

DISCUSSION

The present study demonstrated that the application of organic fertilizers and biochar-based amendments affected physiological responses of purple sweet potato more markedly than yield components. Stomatal density and stomatal opening width remained statistically unchanged across all treatments, indicating that neither goat manure, cow manure, biochar, liquid organic fertilizer (LOF), nor Azolla substantially modified leaf anatomical characteristics (Fig 1). Stomatal traits are generally considered conservative characteristics that are strongly regulated by genetic factors and environmental conditions rather than nutrient supply. Therefore, although biochar and organic amendments improved soil fertility, as mentioned by Elshony et al. (2025) that soil conditioners accelerate the process of soil recovery or improve soil quality and similar findings have been reported by several studies showing that biochar

mainly influences plant physiological processes through improved water availability, nutrient retention, and microbial activity rather than through alterations in leaf morphology (Agbede et al., 2024; Osman et al., 2023), they were insufficient to induce significant changes in epidermal development.

Interestingly, despite the absence of significant differences in stomatal characteristics, chlorophyll accumulation responded positively to the interaction between organic fertilizer and biochar. Treatments consisting of cow organic fertilizer combined with biochar plus LOF and goat organic fertilizer combined with biochar produced the highest chlorophyll a, chlorophyll b, and total chlorophyll contents. This result suggests that the beneficial effects of biochar are primarily associated with enhanced nutrient retention and increased availability of nitrogen, magnesium, and micronutrients involved in chlorophyll biosynthesis. Biochar possesses a highly porous structure and a large exchange capacity that improves nutrient use efficiency and stimulates microbial communities responsible for mineralization processes. Consequently, photosynthetic pigment synthesis was promoted, leading to increased chlorophyll concentration. Similar observations have been reported in sweet potato and other crops, where biochar-organic fertilizer combinations significantly improved chlorophyll content and leaf nutrient concentrations (Agbede et al., 2024; Antonious, 2024).

A possible improvement in light absorption ability is suggested by the rise in chlorophyll concentration, which might theoretically allow increased creation of carbohydrates. While chlorophyll b serves as an accessory pigment that expands the spectrum of light absorption, chlorophyll an is the main pigment involved in photosynthetic processes. enhanced pigment accumulation is shown by higher total chlorophyll content, but without gas exchange data, this cannot be directly taken as proof of enhanced photosynthetic rate or overall efficiency. Since liquid organic fertilizers provide easily accessible nutrients and growth-promoting compounds, the additional application of LOF seemed to promote chlorophyll production.

375 Additionally, animal manures supply organic carbon and vital nutrients required for pigment
376 formation, while Azolla adds biologically fixed nitrogen. Recent studies have shown that
377 integrated nutrient management involving biochar and organic amendments stimulates soil
378 microbial activity and nutrient cycling, thereby increasing chlorophyll concentration and
379 photosynthetic efficiency (Osman et al., 2023; Niedzbała et al., 2024; Zhang et al., 2024).

380 Nevertheless, the enhancement of photosynthetic pigments did not translate into
381 significant differences in tuber number, tuber weight, tuber diameter, tuber length, or harvest
382 index. Although numerical variations were observed, all treatments produced statistically
383 similar yield components. This phenomenon indicates that improvements in chlorophyll content
384 alone are insufficient to guarantee greater assimilation partitioning toward storage roots. Sweet
385 potato yield is determined not only by source strength (photosynthesis) but also by sink
386 strength, genetic factors, and environmental conditions. Similar results were reported by
387 Antonious (2024), who observed that biochar and organic fertilizers improved nutritional
388 quality without always producing significant increases in yield. Likewise, Zhang et al. (2024)
389 demonstrated that biochar enhanced nutrient availability and carbohydrate metabolism, but
390 yield responses depended on the application rate and soil conditions. Thus, According to
391 Adnyana et al. (2025), the better the soil structure, the easier it is for tubers to develop.
392 Therefore, under the conditions of the present study, the increase in photosynthetic pigments
393 likely improved physiological status without significantly altering storage-root formation.

394 The stability of total soluble solids (°Brix) further supports the notion that carbohydrate
395 accumulation in the storage roots remained relatively constant among treatments. Sweetness is
396 closely associated with sucrose and soluble sugar concentrations, which are products of
397 photosynthetic assimilation and translocation processes. Although chlorophyll concentration
398 increased in several treatments, the similar °Brix values suggest that sugar metabolism and
399 partitioning reached a physiological equilibrium. Transcriptomic studies by Zhang et al. (2024)

revealed that biochar influences genes involved in starch and sucrose metabolism without necessarily affecting starch quality. Furthermore, Antonious (2024) found that biochar and organic fertilizers improved the nutritional composition of sweet potato while maintaining relatively stable sugar concentrations. Therefore, the unchanged sweetness observed in this study indicates that biochar-based nutrient management preserved tuber quality while maintaining consistent sugar accumulation.

Another important observation was the absence of significant differences in harvest index. Values ranging from 0.37 to 0.42 indicate that the efficiency of assimilating partitioning between vegetative organs and storage roots remained relatively stable. Harvest index is often influenced by environmental conditions, genotype, and source-sink relationships. Since tuber weight and vegetative growth were proportionally similar among treatments, biomass allocation patterns were apparently unaffected by the nutrient amendments. Biochar has been shown to improve soil physical properties, moisture retention, and nutrient availability; however, these benefits are often expressed more strongly under nutrient-deficient or degraded soils. Consequently, in soils with moderate fertility, improvements in physiological processes may not necessarily lead to substantial changes in harvest index or yield components (Osman et al., 2023; Agbede et al., 2024).

Overall, the results suggest that integrated application of organic fertilizers and biochar primarily enhanced physiological characteristics, particularly chlorophyll accumulation, while maintaining relatively stable anatomical traits, tuber yield components, sweetness, and assimilate partitioning. Among the treatments, cow organic fertilizer combined with biochar plus LOF and goat organic fertilizer combined with biochar produced the most favorable physiological responses. These findings support the concept of integrated nutrient management as a sustainable strategy for sweet potato cultivation. Numerous studies conducted during the last decade have emphasized that biochar-organic fertilizer interactions improve soil health,

nutrient cycling, and plant physiological performance, although the translation of these improvements into higher yield is strongly influenced by cultivar, environment, soil conditions, and application rates. Therefore, further studies involving longer experimental periods and different combinations of biochar and organic fertilizers are needed to elucidate how enhanced photosynthetic capacity can be converted into greater storage-root productivity.

CONCLUSION

The present study demonstrated that the application of organic fertilizers combined with biochar-based amendments under a reduced synthetic fertilizer regime (50% of the recommended dose) enhanced chlorophyll accumulation while maintaining comparable tuber yield, harvest index, and sweetness of purple sweet potato. The combinations of cow organic fertilizer with biochar plus liquid organic fertilizer and goat organic fertilizer with biochar produced the highest total chlorophyll content, indicating improved physiological performance and nutrient utilization. Under a 50% synthetic fertilizer regime, some amendment combinations increased chlorophyll content while yield and quality parameters remained statistically comparable among treatments

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CRedit AUTHORSHIP CONTRIBUTIONS STATEMENT

Yugi R. Ahadiyat. designed research, performed research, coordinated research, and wrote the paper; Ervina Mela contributed new reagents/analytic tools and analyzed data; Ahmad Fauzi project administration, supervision, formal analysis, and investigation.

DECLARATION OF COMPETING INTEREST

We declare that all authors have no conflict of interest.

ETHICS AND PERMIT APPROVALS

We declare neither the lack of any ethical nor financial issues nor the need for permissions.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon reasonable request

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AI USE STATEMENT

The authors declare that they did not use artificial intelligence tools in developing this manuscript.

REFERENCES

- Adnyana I.M., Bimantara P.O., Roni N.G.K. (2025). Enhancing soil fertility through Azolla incorporation: Impacts on Nitrogen cycling and cation exchange capacity. *Org Farming* 11(1): 1-12. <https://doi.org/10.56578/of110101>
- Agbede T.M., Oyewumi A., Agbede G.K., Adekiya A.O., Adebiyi O.T.V., Abisuwa T.A., Ijigbade J.O., Ogundipe C.T., Wewe A.O., Olawoye O.D., Eifediyi E.K. (2024). Impacts of poultry manure and biochar amendments on the nutrients in sweet potato leaves and the minerals in the storage roots. *Sci Rep* 14, 16598. <https://doi.org/10.1038/s41598-024-67486-9>
- Ali A., Jabeen N., Chachar Z., Chachar S., Ahmed S., Ahmed N., Laghari A.A., Sahito Z.A., Farruhbek R., Yang Z. (2025). The role of biochar in enhancing soil health & interactions with rhizosphere properties and enzyme activities in organic fertilizer substitution. *Front Plant Sci* 16, 1595208. <https://doi.org/10.3389/fpls.2025.1595208>
- Amao P., Osunsanya S., Afolabi A. (2018). Yield evaluation and assessment of growth of five different varieties of sweet potato (*Ipomoea batatas* (L.) Lam). *J Agric Ecol Res Int* 15(1), 1-8. <https://doi.org/10.9734/JAERI/2018/40744>
- Antonious G.F. (2024). Impact of biochar and organic fertilizers on sweet potato yield, quality, ascorbic acid, β -carotene, sugars, and phenols contents. *Int J Environ Health Res* 34(11), 3708–3719. <https://doi.org/10.1080/09603123.2024.2318368>
- Aytenew M. Bore G. (2020). Effects of organic amendments on soil fertility and environmental quality: A review. *J Plant Sci* 8(5), 112–119. <https://doi.org/10.11648/j.jps.20200805.12>
- Bai Y.-C., Chang Y.-Y., Hussain M., Lu B., Zhang J.-P., Song X.-B., Lei X.-S., Pei D. (2020). Soil chemical and microbiological properties are changed by long-term chemical fertilizers that limit ecosystem functioning. *Microorganisms* 8(5), 694. <https://doi.org/10.3390/microorganisms8050694>

- Beaumelle L., Tison L., Eisenhauer N., Hines J., Malladi S., Pelosi C., Thouvenot L., Phillips H.R.P. (2023). Pesticide effects on soil fauna communities — a meta-analysis. *J Appl Ecol* 60, 1239–1253. <https://doi.org/10.1111/1365-2664.14437>
- Caruana R.J., Cagasan U. (2020). Effects of timing of goat manure and inorganic fertilizer application on productivity and profitability of sweetpotato (*Ipomoea batatas* (L.) Lam.). *Eurasian J Agric Res* 4(1), 1-10. <https://izlik.org/JA45NE64TM>
- Deng R., Lan Z., Xiao K., Shang X., Fang S. (2025). Biochar additions improve soil nutrient availability and biomass production of *Cyclocarya paliurus* via regulating soil bacterial community and pH value on the acidic soil. *J Soil Sci Plant Nutr* 25, 5751–5765. <https://doi.org/10.1007/s42729-025-02495-9>
- Elshony M., Farid I., Elkamar F., Abbas H., Ali I., Abbas M.H.H. (2025). Effects of organic amendments on soil productivity, its physical and chemical properties: A review of compost and biochar applications. *J Soil Sci Agr Eng* 2(1), 72-91. <https://doi.org/10.21608/bct.2025.372759.1002>
- Fan H., Zhang Y., Li J., Jiang J., Waheed A., Wang S., Rasheed S.M., Zhang L., Zhang R. (2023). effects of organic fertilizer supply on soil properties, tomato yield, and fruit quality: A global meta-analysis. *Sustainability* 15(3), 2556. <https://doi.org/10.3390/su15032556>
- Gaurav S., Diptanu B., Chandra M., Prasann K., Nishihara E., Inubushi K., Sudo S., Hayashida S., Patra P.K., Minkina T., Rajput V.D. (2025). Effects of biochar amendment at various soil depths on maize roots and growth indices. *Sci Rep* 15, 26310. <https://doi.org/10.1038/s41598-025-09218-1>
- Hasmadi M., Merlynda M., Mansoor A.H., Salwa I., Zainol M.K., Jahurul M.H.A. (2021). Comparative studies of the physicochemical and functional properties of sweet potato

- 519 (*Ipomoea batatas* L.) flour. Food Res 5(4), 145–152.
 520 [https://doi.org/10.26656/fr.2017.5\(4\).610](https://doi.org/10.26656/fr.2017.5(4).610)
- 521 Hill D., Nelson D., Hammond J., Bell L.W. (2021). Morphophysiology of potato (*Solanum*
 522 *tuberosum*) in response to drought stress: Paving the way forward. Front Plant Sci 11,
 523 597554. <https://doi.org/10.3389/fpls.2020.597554>
- 524 Jaywant S.A., Singh H., Arif K.M. (2022). Sensors and instruments for Brix measurement: A
 525 review. Sensors 22(6), 2290. <https://doi.org/10.3390/s22062290>
- 526 Karuniawan A., Maulana H., Ustari D., Dewayani S., Solihin E., Arifin M. (2021). Yield
 527 stability analysis of orange-fleshed sweet potato in Indonesia using AMMI and GGE
 528 biplot. Heliyon 7, e06881. <https://doi.org/10.1016/j.heliyon.2021.e06881>
- 529 Kurnianingsih N., Ratnawati R., Nazwar T.A., Ali M., Fatchiyah F. (2021). Purple sweet
 530 potatoes from East Java of Indonesia revealed the macronutrient, anthocyanin compound,
 531 and antidepressant activity candidate. Med Arch 75(2), 94–100.
 532 <https://doi.org/10.5455/medarh.2021.75.94-100>
- 533 Yuan J., Wang J., Ye J., Dai A., Zhang L., Jidong W., Li J., Zhang M., Zhang H., Chen D.,
 534 Zhang Y. (2023). Long-term organic fertilization enhances potassium uptake and yield of
 535 sweet potato by expanding soil aggregates-associated potassium stocks. Agric Ecosyst
 536 Environ 358, 108701. <https://doi.org/10.1016/j.agee.2023.108701>
- 537 Li Y., et al. (2026). Glutathione-gold nanoclusters enhance sweet potato thermotolerance
 538 through improved photosynthesis, redox homeostasis, and cellular integrity. BMC Plant
 539 Biol 26, Article 84. <https://doi.org/10.1186/s12870-026-08417-w>
- 540 Naz Z., Jahan S., Rashid A., Kamran A., Abd-Allah E.F., Avila-Quezada G.D., Hashem A.
 541 (2025). Efficacy of modified biochar for enhancing maize photosynthesis and yield under
 542 various irrigation regimes. Sci Rep 15, 32216. [https://doi.org/10.1038/s41598-025-](https://doi.org/10.1038/s41598-025-17700-z)
 543 [17700-z](https://doi.org/10.1038/s41598-025-17700-z)

- Niedzbała N., Lorenc-Grabowska E., Rutkowski P., Chęćmanowski J., Szymczycha-Madeja, A. (2024). Potential use of *Ulva intestinalis*-derived biochar adsorbing phosphate ions in the cultivation of winter wheat. *Bioresour Bioprocess* 11, 27. <https://doi.org/10.1186/s40643-024-00741-z>
- Olasekan A.A., Ogunbode T.O., Esan V.I., Adedokun O., Olatubi I.V., Ayegboyin M.H. (2025). Short term effects of biochar on soil chemical properties, growth, yield, quality, and shelf life of tomato. *Sci Rep* 15(1), 24965. <https://doi.org/10.1038/s41598-025-10411-5>
- Oliveira A.P., Santos J.F., Cavalcante L.F., Pereira W.E., Santos M.C.C.A., Oliveira A.N.P., Silva N.V. (2010). Yield of sweet potato fertilized with cattle manure and biofertilizer. *Hortic Bras* 28(3), 277–281. <https://doi.org/10.1590/S0102-05362010000300006>
- Osman A.I., Zhang Y., Lai Z.Y., Rashwan A.K., Farghali M., Ahmed A.A., Liu Y., Fang B., Chen Z., Al-Fatesh A., Rooney D.W., Yiin C.L., Yap P. (2023). Machine learning and computational chemistry to improve biochar fertilizers: A review. *Environ Chem Lett* 21, 3159–3244. <https://doi.org/10.1007/s10311-023-01631-0>
- Pathoumthong P., Zhang Z., Roy S.J., El Habti A. (2023). Rapid non-destructive method to phenotype stomatal traits. *Plant Methods* 19, 36. <https://doi.org/10.1186/s13007-023-01016-y>
- Qiu M., Liu L., Ling Q., Cai Y., Yu S., Wang S., Fu D., Hu B., Wang X. (2022). Biochar for the removal of contaminants from soil and water: a review. *Biochar*, 4, 19. <https://doi.org/10.1007/s42773-022-00146-1>
- Lichtenthaler, H.K. and Buschmann, C. (2001), Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy. In: *Current Protocols in Food Analytical Chemistry*, 1: F4.3.1-F4.3.8. John Wiley & Sons, Inc. <https://doi.org/10.1002/0471142913.faf0403s01>

569 Zhang J., Xu X., Li T., Lv Z., Zhu Y., Li J., Lu G. (2024). Transcriptome analysis reveals the
570 impact of short-term biochar application on starch and sucrose metabolism in sweet
571 potato tuberous roots. Ind Crops Prod 220, 120050.
572 <https://doi.org/10.1016/j.indcrop.2024.120050>
573

TABLES

Table 1. Effect of organic fertilizer and biochar plus application on stomatal density, stomatal opening width, and total soluble solids

Treatment	Stomata density (stomata/mm ²)	Stomata opening width (μm)	Total Soluble Solids (°Brix)
Organic fertilizer			
No organic fertilizer	177.49	14.17	11.05
Goat organic fertilizer	170.51	12.22	10.49
Cow organic fertilizer	198.46	13.41	10.85
Biochar			
Biochar	194.27	12.72	10.98
Biochar plus LOF	184.49	14.03	10.55
Biochar plus Azolla	167.71	13.05	10.86
CV (%)	13.97	16.78	5.56

Note: CV = Coefficient of Variance; LOF = liquid organic fertilizer.

Table 2. Effect of organic fertilizer and biochar plus application on content of chlorophyll a, b, and total

Treatment			chlorophyll a (mg/Kg)	chlorophyll b (mg/Kg)	Total chlorophyll (mg/Kg)
Organic fertilizer	Biochar				
No	Biochar	plus	1201.66 bc	299.88 c	1501.55 bc
organic	Biochar	plus	1354.20 bc	508.04 ab	1862.25 bc
fertilizer	LOF				
	Biochar	plus	1371.96 abc	467.17 bc	1839.14 bc
	Azolla				
Goat	Biochar	plus	1607.87 ab	562.08 ab	2169.95 ab
organic	Biochar	plus	1039.07 c	439.40 bc	1478.48 c
fertilizer	LOF				
	Biochar	plus	1263.63 bc	427.49 bc	1691.12 bc
	Azolla				
Cow	Biochar	plus	1454.55 abc	481.29 ab	1935.83 abc
organic	Biochar	plus	1888.90 a	666.92 a	2554.83 a
fertilizer	LOF				
	Biochar	plus	1369.50 abc	457.12 bc	1826.83 bc
	Azolla				
CV (%)			19.74	21.45	18.50

Note: Numbers followed by the same letter indicate no significant difference in the Duncan's Multiple Range Test (DMRT) at ($p>0.05$); CV = Coefficient of Variance; LOF = liquid organic fertilizer.

Table 3. Yield and yield components of sweet potato due to application of organic fertilizer and biochar plus.

Treatment	Number of tubers	Tuber Weight per plant (g)	Tuber diameter (cm)	Tuber length (cm)	Harvest Index
Organic fertilizer					
No organic fertilizer	3.03	521.06	3.530	12.90	0.42
Goat organic fertilizer	3.01	540.14	3.725	11.88	0.40
Cow organic fertilizer	2.97	491.94	3.814	11.02	0.39
Biochar					
Biochar	2.66	455.37	3.815	11.59	0.37
Biochar plus LOF	3.51	591.39	3.419	11.28	0.42
Biochar plus Azolla	2.83	506.39	3.834	12.94	0.41
CV (%)	22.33	15.20	12.40	18.10	14.06

FIGURE CAPTIONS

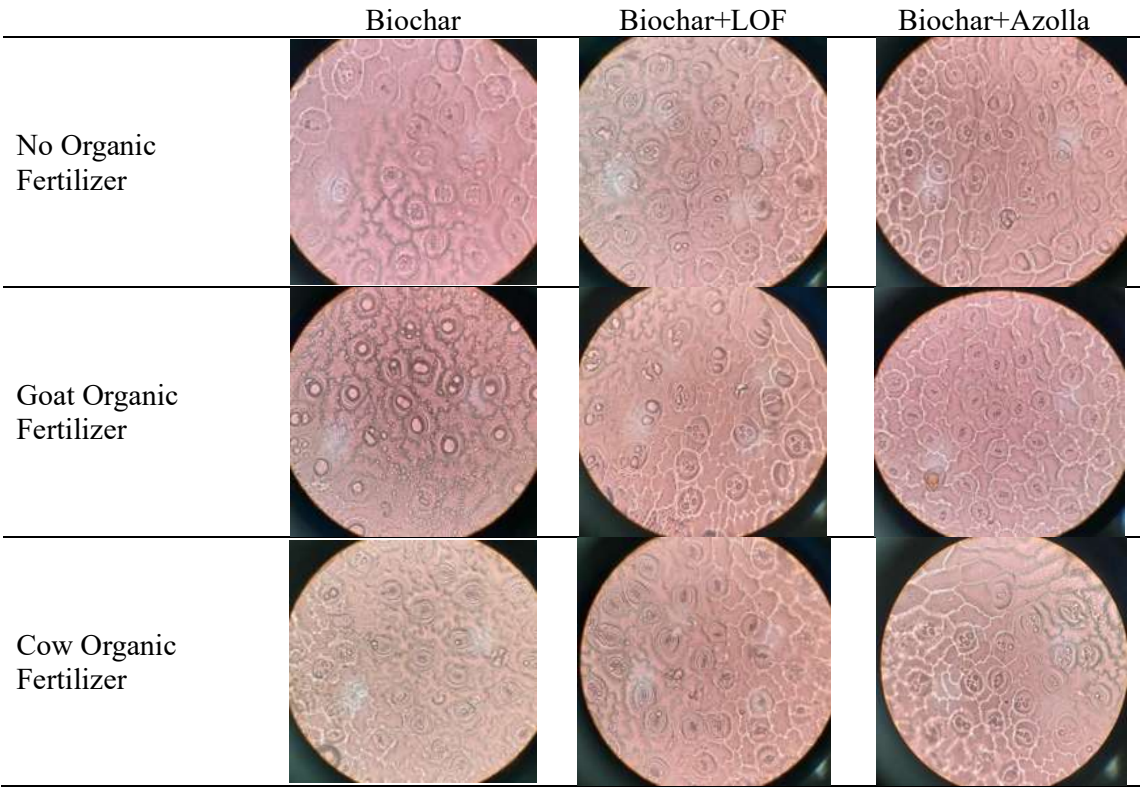


Figure 1. Stomata of purple sweet potato due to the treatment of organic fertilizer and biochar