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Effects of biochar–goat manure application rate and cutting stage on growth and dry matter yield of *Panicum maximum* in Sudan Savannah zone of Nigeria

***[1]Idowu, W., [1]Musa, I., [1]Ayuba, I., [1]Garba, M.G., [1]Ghazali, A.A., [1]Yusuf, A., [2]Sani, R. T. and [3]Akinde, S.T.**

[1]*Department of Animal Science, Federal University, Dutsin-Ma, Nigeria*
[2]*National Animal Production Research Institute, Shika, Zaria, Nigeria.*
[3]*Department of Agricultural Technology, Federal Polytechnic Ayede, Oyo State, Nigeria.*
***Corresponding author:** waheedidowu@fudutsinma.edu.ng

Abstract

Low soil fertility and erratic rainfall limit forage production in the Sudan Savannah zone of Nigeria, resulting in persistent dry-season feed shortages and reduced livestock productivity. Soil amendments such as biochar and goat manure have the potential to improve soil water retention and fertility. This study evaluated the combined effects of biochar–goat manure (B–G) application rates and cutting stage on growth performance and biomass dry matter yield (DMY) of Guinea grass (Panicum maximum). The experiment was arranged in a randomized complete block design with three B–G rates (3, 6, and 9 t ha^{-1}) replicated three times, while cutting stages (6, 8, and 10 weeks after planting [WAP]) were assessed as repeated measures. No significant interaction between amendment rates and cutting stages was observed ($P > 0.05$). Varying the B–G application rate did not significantly affect the measured agronomic traits or DMY ($P > 0.05$), indicating no additional benefit of higher application rates under the conditions of this study. In contrast, cutting stage had a significant effect on all measured traits, with 10 WAP producing the highest biomass yield (16.27 t ha^{-1}), plant height (154.87 cm), and canopy development. These results indicate that harvest timing is a stronger determinant of forage productivity than increasing organic amendment rates beyond moderate levels. Therefore, optimizing cutting at 10 WAP is critical for maximizing biomass production of Panicum maximum under semi-arid tropical conditions.

Keywords: Biochar, organic amendment, cutting stage, dry matter yield, forage productivity
Running title: Biochar–manure effects on biomass

Effets du dosage d'application de biochar et de fumier de chèvre et du stade de coupe sur la croissance et le rendement en matière sèche de Panicum maximum dans la zone de savane soudanaise du Nigeria

Résumé

La faible fertilité des sols et les précipitations irrégulières limitent la production fourragère dans la zone de savane soudanaise du Nigeria, ce qui entraîne des pénuries alimentaires persistantes pendant la saison sèche et une baisse de la productivité du bétail. Les amendements du sol tels que le biochar et le fumier de chèvre ont le potentiel d'améliorer la rétention d'eau et la fertilité du sol. Cette étude a évalué les effets combinés des doses d'application de biochar et de fumier de chèvre (B–G) et du stade de coupe sur les performances de croissance et le rendement en matière sèche (DMY) de la biesse (Panicum maximum). L'expérience a été menée selon un plan en blocs aléatoires complets avec trois doses de B–G (3, 6 et 9 t ha^{-1}) reproduites trois fois, tandis que les stades de coupe (6, 8 et 10 semaines après la plantation [WAP]) ont été évalués comme mesures répétées. Aucune interaction significative entre les taux d'amendement et les stades de coupe n'a été observée ($P > 0,05$). La variation du taux d'application de B–G n'a pas eu d'effet significatif sur les caractéristiques agronomiques mesurées ni sur le DMY ($P > 0,05$), indiquant qu'il n'y a pas d'avantage supplémentaire à des taux d'application plus élevés dans les conditions de cette étude. En revanche, le stade de coupe a eu un effet significatif sur tous les caractères mesurés, le stade 10 SAP produisant le rendement en biomasse (16,27 t ha^{-1}), la hauteur des plantes (154,87 cm) et le développement du couvert végétal les plus élevés. Ces résultats

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indiquent que le moment de la récolte est un facteur déterminant plus important pour la productivité fourragère que l'augmentation des apports d'amendements organiques au-delà de niveaux modérés. Par conséquent, il est essentiel d'optimiser la coupe à 10 semaines après la plantation (WAP) pour maximiser la production de biomasse de Panicum maximum dans des conditions tropicales semi-arides.

Mots-clés: biochar, amendement organique, stade de coupe, rendement en matière sèche, productivité fourragère

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Introduction

Agricultural activities such as staple food production and livestock constitute the primary means of livelihood in the Sudan Savannah zone of Nigeria (Abdullahi *et al*., 2022; Akanwa *et al*., 2023). Livestock production in this region has been negatively affected by various factors. These factors include cattle rustling, climate change, feed shortages, outbreaks of diseases and parasites, inadequate technical knowledge among pastoralists, insufficient livestock extension services (Lelenguyah *et al*., 2023). One of the most serious of all is the unpredictable seasonal variation in precipitation and poor soil nutrient fertility, which result in acute feed scarcity for the grazing animals especially during the dry seasons of the year (Cooke *et al*., 2025; Nketsang *et al*., 2025). *Panicum maximum* is a high-yielding tropical grass characterized by a high leaf-to-stem ratio, good palatability to livestock and wildlife, and favorable nutrient composition depending on growth stage (Idowu *et al*., 2025). However, forage yield is a function of interaction among the different components of the ecosystem such as soil nutrients, moisture/precipitation, soil acidity, and solar radiation (Lodygin *et al*., 2023). Unfortunately, soils in the Sudan Savannah zone are generally poor in nutrient status, which often results in low forage yield and quality (Singh *et al*., 2024). As a result, there is a need for soil amendments that increase soil nutrients availability, conserve soil moisture and reduce soil acidity in order to improve nutrient uptake and increase the quality and quantity of the forage produced (Burezq, 2024; Wróbel *et al*., 2025). Goat manure is one of the readily available alternative soil amendment sources due to its lower competition when compared with poultry manure (Washaya and Washaya, 2023; Rana and Roy, 2024). It is known to contain an appreciable amount of Nitrogen, potassium and phosphorus which are the basic needs of forage grasses (Washaya and Washaya, 2023). Biochar is the end product of pyrolysis of plant materials under high temperature and oxygen-limited conditions (Kuryntseva *et al.*, 2023; Lamichhanae *et al*., 2025), Biochar has been shown to increase soil porosity, enhance infiltration rate, increase the soil water holding capacity, reduce soil acidity and contributes to carbon sequestration to reduce emissions of greenhouse gases (Kang *et al*., 2022; Li *et al*., 2022). It was hypothesized that the combination of biochar and goat manure, together with appropriate cutting stage will increase the growth and yield of *Panicum maximum* for livestock feeding in the Sudan Savannah zone of Nigeria. The objective of this study was to evaluate the effects of biochar–goat manure application rates and cutting stage on the growth characteristics and dry matter yield of *Panicum maximum* in the Sudan Savannah zone of Nigeria.

Materials and Methods

Experimental site

The experiment was conducted at the Prof. Lawal Abdu Saulawa Pasture Unit, Livestock Teaching and Research Farm, Department of Animal Science, Federal University Dutsin-Ma, located along the Kankara–Funtua Road in Dutsin-Ma, Katsina State, Nigeria (Google Earth Pro. 2026).

The area lies within the Sudan Savannah ecological zone at Latitude 12°27′18″N and Longitude 7°27′29″E, with an elevation of 542.08 m above sea level. Dutsin-Ma has a tropical savannah climate. The mean annual temperature is approximately 33.2°C, and annual rainfall ranges from 600–900 mm (NiMet, 2019).

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Meteorological data of experimental site

Weather observations during the experimental period were collected at the meteorological station of the Department of Geography and Urban Planning, Federal University Dutsin-Ma.

Soil sampling and analysis

Composite soil samples were collected from the four corners and the center of the experimental field at a depth of 0–15 cm using a soil auger. Samples were analyzed for physical and chemical properties following standard procedures described by (FAO, 2020). Laboratory analyses were conducted at the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria.

Collection and preparation of planting materials, biochar and goat manure

Seed of Guinea grass (*Panicum maximum*) was sourced from the Feeds and Nutrition Research Programme of the National Animal Production Research Institute (NAPRI), Shika, Zaria. Biochar, produced from shea butter tree (Vitellaria paradoxa) wood residues was purchased from commercial vendor at the Dutsin-Ma Wednesday market, Katsina State. The material was locally produced using traditional methods; however, the production conditions (temperature, and residence time) were not available. The biochar was used as purchased without further characterization, this represents a limitation and may partly explain the lack of significant response to amendment rate. Goat manure was obtained from the Goat Production Unit of the Professor Lawal Abdu Saulawa Livestock Teaching and Research Farm, Federal University Dutsin-Ma. The goat manure was air-dried. Both the biochar and goat manure were ground to fine particles and thoroughly mixed at a 1:1 weight ratio. The mixture was applied at total rates of 3, 6 and 9 t ha^{-1}, corresponding to 1.5 + 1.5, 3 + 3 and 4.5 + 4.5 t ha^{-1} of biochar and goat manure, respectively. The amendment was applied basally and incorporated into the soil to a depth of 15 cm approximately two weeks prior to sowing.

Field layout and experimental design

The experiment was arranged in a randomized complete block design (RCBD) with three biochar–goat manure (B–G) application rates (3, 6, and 9 t ha^{-1}) as treatments, replicated three times. Cutting stage (6, 8, and 10 WAP) was evaluated as a repeated measure over time within each plot.

Each experimental plot measured 4 m × 6 m and was separated by 0.5 m alleys, with a 1 m border maintained around the experimental area. The total experimental area measured 19.5 m × 27.5 m. Rows were spaced 0.5 m apart with an intra-row spacing of 0.2 m. Planting was carried out using the drilling method.

Growth and yield measurements were taken at 6, 8, and 10 WAP. At each sampling time, forage was harvested from a 0.5 m² quadrat placed at different locations within each plot to avoid resampling previously harvested areas. Thus, each plot was measured repeatedly over time, generating three observations per plot corresponding to the three cutting stages.

Data collection

Plant growth and dry matter yield

Data on yield and crop phenology was collected at 6, 8 and 10 WAP. Five plants were randomly selected and tagged A, B, C, D and E per plot for the measurements of various agronomic parameters using the standard procedure (Tarawali *et al*., 1995). The plant height was determined by measuring from the base of the plant to the tip of the uppermost leaf on the plant with the aid of a tape rule on the five randomly selected plants per plot.

Leaf length was measured from the ligule to the tip of the leaves in the five randomly selected and tagged plants with the use of 30cm ruler at 6, 8 and 10 WAP. Leaf width was determined by measuring the width of the leaf at its midpoint with the aid of 30cm ruler. Leaf area was estimated following the method of (Nakanwagi *et al*., 2018). Leaf area per leaf was calculated as the product of leaf length (LL) and maximum leaf width (LW) multiplied by a correction factor of 0.704. Total leaf area per plant was obtained by multiplying leaf area per leaf by the number of leaves per plant. Leaf area index (LAI) was then calculated as the ratio of total leaf area per plant to the ground area occupied by each plant, determined as the product of inter-row and intra-row spacing (Watson, 1952).

Total fresh forage was harvested from each sub-plot using a 0.5 m² quadrat at a cutting height of 15 cm above ground level. A sub-sample (150–200 g) was weighed and oven-dried at 65°C for 48 h to constant weight to determine dry matter content. Dry matter yield was calculated as: DMY (kg ha^{-1}) = TFW × (DWss / FWss) × 20, where TFW is the total fresh weight harvested from 0.5 m² (g), DWss is the dry weight of the sub-sample (g), and FWss is the fresh weight of the sub-sample (g) (Tarawali *et al*., 1995).

Statistical analysis

Data were analyzed using SAS (SAS Institute Inc., 2005). Biochar–goat manure rate was treated as a fixed effect, while block was treated as a random effect. Cutting stage (6, 8, and 10 WAP) was considered a repeated measure over time within each plot. Least square means were separated using Duncan's Multiple Range Test at $P \leq 0.05$.

Results and Discussion

Table 1. Physico-chemical properties of the composite soil sample collected at 0-15cm

Soil properties	0-15cm
Particle size (%)	
Clay	28.00
Silt	26.00
Sand	46.00
Textural class	**Loam**
Chemical properties	
Total Nitrogen (%)	0.18
Organic carbon (%)	0.58
Available phosphorus (ppm)	4.53
pH (H_2O)	6.36
pH (0.01M $CaCl_2$)	5.30
Exchangeable cation (meq/100g of soil)	
Ca^{2+}	3.90
Mg^{2+}	0.67
K^+	0.33
Na^+	0.70
Exchangeable Acidity (H-Al^{3+})	0.40
Cation Exchange Capacity (CEC)	6.40

The soil at the experimental site was classified as loam, comprising 46% sand, 26% silt, and 28% clay. It exhibited low fertility status, with low organic carbon (0.58%), total nitrogen (0.18%), available phosphorus (4.53 ppm), and cation exchange capacity (6.40 meq/100 g), suggesting limited nutrient reserves and retention capacity. The soil pH was slightly acidic (6.36 in H_2O; 5.30 in $CaCl_2$), which is generally suitable for forage production but may reduce phosphorus availability. Exchangeable calcium was moderate, while magnesium and potassium were relatively low, and sodium was slightly elevated but not at a critical level. The low exchangeable acidity (0.40 meq/100 g) indicates minimal risk of aluminum toxicity. Overall, the soil conditions suggest low inherent fertility but a high potential responsiveness to organic amendments such as biochar and goat manure, which could improve nutrient availability and enhance biomass production (Acharya et al., 2022).

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Table 2. Chemical composition of goat manure

Parameter	Unit	Value
Macronutrients		
Total Nitrogen (N)	%	3.95
Phosphorus (P)	%	0.85
Potassium (K)	mg kg^{-1}	24,045.73
Micronutrients		
Iron (Fe)	mg kg^{-1}	2,892.5
Manganese (Mn)	mg kg^{-1}	217.5
Copper (Cu)	mg kg^{-1}	63.0
Zinc (Zn)	mg kg^{-1}	350.0
Total micronutrients	mg kg^{-1}	4,900.10

The chemical composition of the goat manure used in this study (Table 2) indicates a nutrient-rich organic amendment with significant potential to improve soil fertility. The manure contained relatively high total nitrogen (3.95%), suggesting its suitability as a source of nitrogen for plant growth and biomass production. The phosphorus content (0.85%), although moderate, is particularly important given the low available phosphorus status of the experimental soil, indicating that manure application could help alleviate phosphorus limitation. The potassium concentration (24,045.73 mg kg^{-1}) was notably high, highlighting the manure as an excellent source of potassium, which plays a critical role in plant physiological processes such as water regulation and enzyme activation (Rana and Roy, 2024).

In addition, the manure supplied appreciable quantities of essential micronutrients, including iron (2,892.5 mg kg^{-1}), manganese (217.5 mg kg^{-1}), copper (63.0 mg kg^{-1}), and zinc (350.0 mg kg^{-1}), with a total micronutrient concentration of 4,900.10 mg kg^{-1}. These micronutrients are vital for enzymatic activities and overall plant metabolism and may contribute to improved forage quality. The combined presence of macro- and micronutrients, alongside organic matter, suggests that goat manure can enhance nutrient availability, improve soil biological activity, and increase nutrient retention when applied to low-fertility soils (Ayamba *et al*., 2021). This supports its use in combination with biochar as a strategy to improve soil productivity and sustain higher biomass yields.

Biochar composition

Shea butter tree (*Vitellaria paradoxa*) biochar has been widely reported as an effective soil amendment due to its alkaline nature, high carbon content, and porous structure, which collectively enhance soil physicochemical properties (Zubairu *et al*., 2023). When produced under pyrolytic conditions, such biochar often exhibits high surface area and appreciable cation exchange capacity (CEC), contributing to improved nutrient retention and reduced leaching losses, particularly in coarse-textured or low-CEC soils (Antonangelo *et al*., 2025). It may also contain base cations such as potassium, calcium and magnesium, which can increase soil pH and nutrient availability, while its porous structure can support microbial activity and improve soil moisture retention (Oyedeji *et al*., 2018). However, biochar is typically low in available nitrogen, making its combined application with nutrient-rich organic amendments such as goat manure more effective (Kammann *et al*., 2016). The integration of biochar with manure has been shown to enhance nutrient use efficiency by adsorbing and gradually releasing nutrients, thereby improving plant growth and biomass yield (Peng *et al*., 2021). These reported characteristics provide a basis for interpreting

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the response observed in the present study, although the specific properties of the biochar used were not determined.

Table 3. Statistical summary (p-values) for the effects of biochar–goat manure application and cutting stage on plant growth and yield parameters.

Variable	**B/G Rate**	***CUTSTG (WAP)***	***B/G × CUTSTG***
Plant Height (PH)	0.338	< 0.001**	0.996
Leaf Length (LL)	0.380	0.001**	0.997
Leaf Width (LW)	0.346	< 0.001**	0.993
Number of Leaves (NOL)	0.771	0.031*	0.981
Tiller Number (TN)	0.781	0.700	0.988
Dry Matter (DMS)	0.895	< 0.001**	0.861
Leaf Area Index (LAI)	0.339	< 0.001**	0.960
Dry Matter Yield (DMY)	0.889	< 0.001**	0.863

Note: *B/G = Biochar–Goat manure application rate; CUTSTG = Cutting stage; WAP = Weeks after planting. Results derived from two-way ANOVA. * Significant at p < 0.05; ** Significant at p < 0.01.*

Table 4. Main effects of biochar–goat manure and cutting stage on agronomic traits and dry matter yield of *Panicum maximum*.

B-G (t ha^{-1})	**PH (cm)**	**LL (cm)**	**LW (cm)**	**NL (stand^{-1})**	**TN (stand^{-1})**	**LAI**	**DMY (t ha^{-1})**
9	132.57	92.45	3.74	32.10	6.19	3.85	8.78
6	116.00	84.99	3.49	29.42	5.75	2.84	8.51
3	114.87	82.60	3.44	28.50	5.42	2.96	7.61
SEM (±)	8.09	4.59	0.12	2.86	0.65	0.46	1.62
Cutting Stage (WAP)							
10	154.87^{a}	103.29^{a}	4.25^{a}	35.96^{a}	6.31	5.34^{a}	16.27^{a}
8	117.48^{b}	85.84^{b}	3.33^{b}	32.47^{a}	5.67	2.71^{b}	6.40^{b}
6	91.09^{c}	70.89^{c}	3.09^{b}	21.58^{b}	5.39	1.59^{c}	2.23^{c}
SEM (±)	8.09	4.59	0.12	2.86	0.65	0.46	1.62

Means within a column followed by different superscripts differ significantly at P ≤ 0.05. B–G = biochar–goat manure application rate; PH = plant height; LL = leaf length; LW = leaf width; NL = number of leaves; TN = tiller number; LAI = leaf area index; DMY = dry matter yield. No significant B–G × cutting stage interaction was observed for any trait (P>0.05).

Plant height

Plant height was not significantly (P > 0.05) affected by the biochar–goat manure (B–G) mixture across application rates (Table 4). Although numerical differences were observed, with the highest mean value at 9 t ha^{-1} (132.57 cm), these variations were not statistically meaningful. The lack of significant response may be attributed to the short duration of the experiment and the relatively slow mineralization rate of organic amendments, which can delay nutrient release compared to inorganic fertilizers (Singh et al., 2024; Idowu et al., 2025). This finding is consistent with reports indicating that plant height responses to organic inputs are often limited or delayed in the early stages of growth, particularly under low nutrient availability.

Cutting time had a stronger influence on plant height than amendment rate. Growth parameters increased progressively from 6 to 10 WAP, reflecting normal canopy development over time. This is a direct physiological response to extended growth duration, allowing

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greater internode elongation and stem development (Gómez et al. 2013). Comparable trends have been documented in *Panicum maximum*, where delayed cutting consistently resulted in taller plants due to prolonged vegetative growth (Jimoh *et al*., 2019).

Leaf dimensions (leaf length and width)

Amendment rate had no significant effect (P > 0.05) on leaf width or leaf length. Although the highest numerical leaf width was observed at 9 t ha⁻¹, these differences were not statistically meaningful. In contrast, cutting time significantly influenced leaf traits, with lower leaf width at 6 and 8 WAP compared to 10 WAP, and a progressive increase in leaf length, reaching maximum values at 10 WAP. This trend likely reflects the effect of plant age on leaf expansion, as continued growth allows for greater cell division and elongation (Baidalina *et al*., 2023; Idowu *et al*., 2025). The absence of a significant response to amendment rate suggests that nutrient release from the biochar–goat manure mixture may not have provided sufficient readily available nutrients within the experimental period to influence leaf development. Similar patterns of increased leaf size with delayed cutting have been reported in tropical grasses.

Number of leaves and tiller production

The biochar–goat manure (B–G) application rate had no significant effect (P > 0.05) on number of leaves or tiller number. In contrast, number of leaves was significantly influenced by cutting stage, with higher values at 8 and 10 WAP compared to 6 WAP. However, tiller number was not significantly affected by cutting stage. This pattern reflects the effect of plant age, as extended growth duration promotes leaf production, which contributes to greater assimilatory surface and potential biomass accumulation (Ojo et al., 2013). The lack of response to amendment rate may be associated with the gradual nutrient release from organic inputs, which may not have influenced these traits during the experimental period (Singh et al., 2024; Cannavo et al., 2022).

Leaf area index (LAI)

Leaf area index (LAI), which integrates leaf size and leaf number, was not significantly affected (P > 0.05) by amendment rate, although the highest numerical value was observed at 9 t ha⁻¹. This trend likely reflects minor variation in leaf expansion rather than changes in tiller production. In contrast, LAI increased significantly with cutting stage, reaching its maximum at 10 WAP, indicating progressive canopy development with plant age.

The increase in LAI with delayed cutting is consistent with previous reports in forage grasses, where extended growth duration promotes leaf expansion and canopy formation. The absence of a significant amendment effect suggests that nutrient release from the biochar–goat manure mixture may have been insufficient within the experimental period to substantially influence canopy development.

Dry matter yield

Dry matter yield (DMY) was not significantly affected (P > 0.05) by amendment rate, despite some numerical increases at higher application levels. The lack of response may be attributed to the short duration of the study, which may have limited the mineralization and release of nutrients from the organic amendments (Cannavo et al., 2022; Ferreira et al., 2022). It is also possible that baseline soil fertility was sufficient to support biomass production under the prevailing conditions (Munzeiwa et al., 2025).

In contrast, DMY was significantly influenced by cutting stage, with the highest yield recorded at 10 WAP. This response is consistent with the observed increases in plant height and leaf area index, indicating that extended growth duration allowed greater canopy development and biomass accumulation.

The DMY obtained in this study was lower than values reported by Jimoh et al. (2019), likely due to differences in manure type, application rates, climatic conditions, and soil properties. However, the yields fall within the range reported for Megathyrsus maximus under tropical conditions (Akinola, 2018; Mounirou

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et al., 2023), indicating practical agronomic relevance.

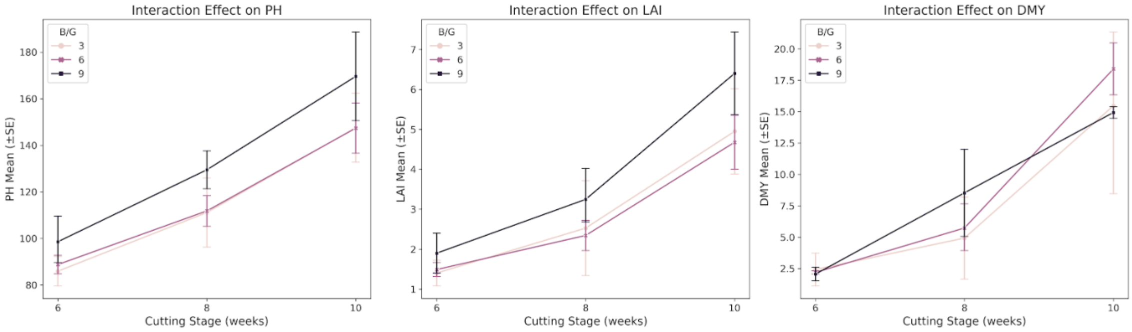

Figure 1. Multi-panel interaction effect of Biochar-Goat manure (B/G) levels and Cutting Stage on core growth and productivity metrics: (a) Plant Height (PH), (b) Leaf Area Index (LAI), and (c) Dry Matter Yield (DMY). Error bars represent the Standard Error (±SE) of the mean (n=3). While numerical trends are apparent, no significant interaction ($P > 0.05$) was observed for any parameter.

The interaction between biochar–goat manure application rate and cutting stage had no significant ($P > 0.05$) effect on dry matter yield, plant height, or leaf area index (Figure 1; Table 3). This indicates that the response of *Panicum maximum* to cutting stage was consistent across all amendment levels. The largely parallel trends observed across treatments suggest that biomass accumulation was primarily governed by plant developmental stage rather than differential responses to amendment rates. This implies that nutrient availability from the biochar–manure mixture did not vary sufficiently across growth stages to modify yield patterns within the duration of the study, and may also reflect variability in biochar properties due to the absence of physicochemical characterization.

Conflict of interest

No conflict of interest declared by the authors.

Conclusion

Cutting stage was the primary determinant of growth and dry matter yield of *Panicum maximum* under Sudan Savannah conditions, while increasing biochar–goat manure application beyond moderate levels did not significantly improve biomass yield within a single growing cycle. The absence of a significant interaction between amendment rate and cutting stage indicates that biomass accumulation was largely governed by plant maturity rather than differential nutrient response. Although higher amendment rates produced numerical increases in some vegetative traits, these did not translate into significant yield advantages. In contrast, delaying harvest to 10 weeks after planting (WAP) maximized canopy development and dry matter yield. Therefore, optimizing cutting stage—specifically harvesting at 10 WAP—offers a more effective strategy for improving forage productivity than increasing amendment rates under the conditions of this study.

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