Effects of NPK Fertilizer and Rice Husk Biochar Rates on Growth and Yield of Paddy Rice in Western Kenya, Ahero

Anthony A.C. Mendy[1],[2]*, Erick Cheruiyot[2], Samuel Mwonga[2]

[1]Ministry of Agriculture, Livestock and Food Security, Department of Agriculture, Cape Point, Bakau, The Gambia

[2]Department of Crops, Horticulture and Soils, Egerton University, Kenya

*Corresponding Author

Abstract

Rice (*Oryza sativa L.*) is an important food crop worldwide. Continuous cropping, inadequate NPK fertilizer application, and soil amendments reduce yields. This study aimed to determine the effect of NPK fertilizer and biochar on rice growth and yield. The study was conducted at Ahero Paddy Rice Scheme in Kenya between May 2024 and January 2025. The experiment used a split-plot layout in a randomized complete block design (RCBD) with three replications. Main plot treatments included NPK 17-17-17 (0, 100, 200, and 300 kg ha-1), while subplots consisted of Rice husk biochar (0, 5, 10, and 15 t ha^{-1}). Data collected included: Number of tillers, plant height, yield, and yield components. Data were subjected to analysis of variance (ANOVA) using R software version 4.4.1, and means were separated using Fisher's Least Significant Difference at $p<0.05$. NPK fertilizer significantly increased rice tillering by 21.87 percent, 26.71 percent, and 33.15 percent for 100, 200, and 300, respectively, compared to the negative control. NPK increased the grain yield by 30.1 percent, 42.7 percent, and 37.5 percent for 100, 200, and 300 kg ha^{-1}, respectively. Biochar did not significantly affect rice growth and yield. NPK fertilizer affected growth and yield because it releases nutrients quickly into the soil, making them available for plant use. In contrast, biochar tends to adsorb nutrients due to its porous nature, which are usually not readily available for plant use in the short term.

Keywords: Biochar, NPK fertilizer, paddy field, paddy rice, rice husk

Introduction

Rice (Oryza sativa L.) is the second most-consumed food crop after wheat and a staple for more than 3.5 billion people worldwide. West Africa has the largest rice-producing countries in Africa, including Côte d'Ivoire, Nigeria, and Mali. In East Africa, Tanzania leads production, followed by Kenya and Uganda.

Compound (NPK) fertilizer and straight fertilizers like urea are nutrient sources in rice production, used as basal and top dressings, respectively. NPK fertilizers, along with other nutrient sources from soil amendments and minerals, can provide adequate soil nutrients required for plant growth. NPK is a source of nitrogen (N), phosphorus (P), and potassium (K) in relatively large quantities. Deficiencies in these nutrients result in poor plant growth, reduced plant biomass, and lower grain yield. It is estimated that 50 percent to 70 percent of the total N applied is lost to the environment, accounting for 39 percent to 60 percent of global nitrous oxide (N_2O) emissions from the soil (Iboko et al., 2023).

Biochar, a porous carbonaceous material produced through pyrolysis of plant biomass, improves soil structure and pH, helping to neutralize soil acidity and make nutrients available to plants (Faloye et al., 2017). Biochar can be produced from agricultural waste, forestry waste, and other organic waste materials (Xia et al., 2023). Rice husk biochar (RHB) improves soil

properties by enhancing drainage, aeration, and water retention. It also has a high-water storage capacity, making it a carbon sink. Rice husk biochar increases microbial activity and disease suppression, making it an important soil amendment (Conte et al., 2025). Its incorporation into the soil influences soil structure, texture, bulk density, and porosity. The physical structure of the biochar provides a larger surface area on which soil microorganisms, such as mycorrhizae and bacteria, bind important nutritive cations and anions. Biochar has shown positive impacts on soil microbial biomass and activity, which are related to the quantity applied (Abdelhafez & Abbas, 2020; Li et al., 2020).

Rice farmers continuously cultivate the same land with inadequate fertilizer and amendments because of the high cost of fertilizer. Applying organic carbon to soils improves overall soil fertility and, hence, productivity by enhancing soil structure, water and nutrient-holding capacity, leading to increased crop yields. Despite existing research on the benefits of biochar, its specific effects on rice nutrient acquisition, particularly nitrogen and phosphorus, remain largely unexplored. This study investigated the effect of biochar on paddy rice growth and yield.

Material and Methods

Experimental Sites

The study was conducted at the Ahero farmer paddy field (latitude -0.179518S^{o} and longitude 34.974228W^{o}) in Onjiko ward, Nyando Sub-County, Kisumu County (see Figure 1). The Ahero farmer paddy field is at an altitude of 1,219 meters above sea level and has an annual average low temperature of 17^{o} C and an annual average high temperature of 22.8^{o} C. It lies in the lower midland III agro-ecological zones and has average annual rainfall ranging from 900 mm to 2200 mm. The soils are classified as vertisols.

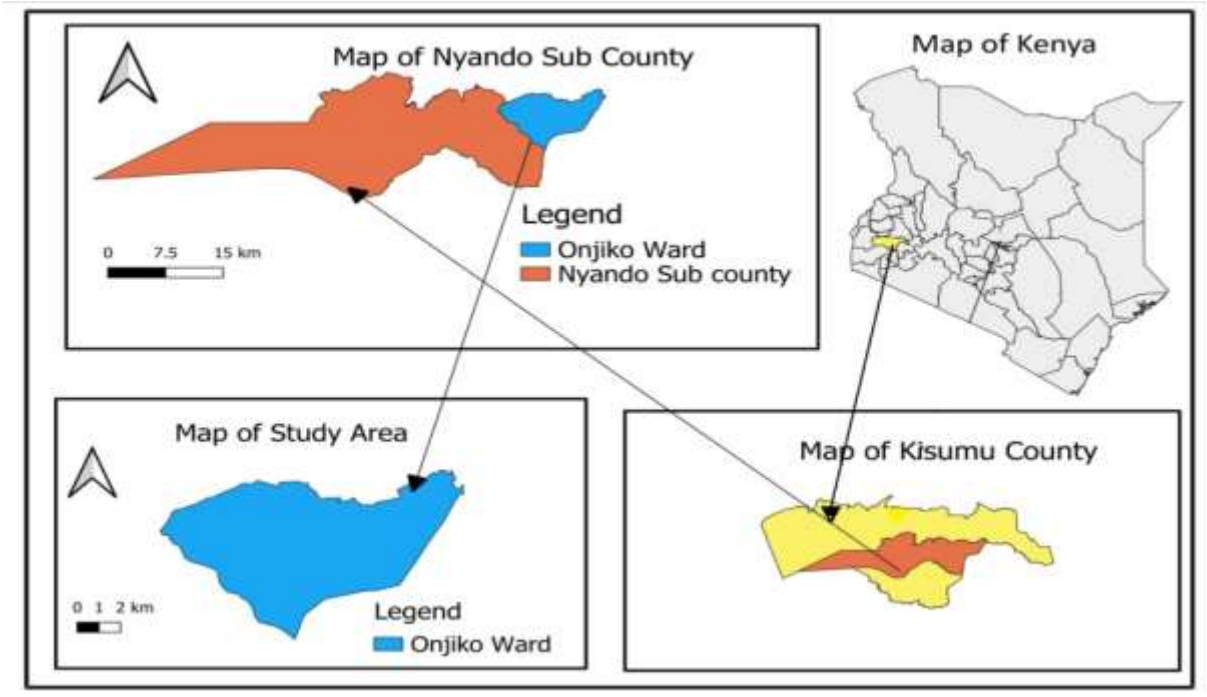


Fig. 1: Map of The Study Area

Research Materials

The test rice variety was IR2793-80-1, which is a commercial variety preferred by farmers in the region. Its attributes include high yields, high tillering, tall stature, and maturity in 120 days. The genotype was tested for response to different rates of commercially obtained inorganic NPK (17:17:17) and rice husk biochar.

Table 1: Fertilizer and Biochar Treatments

Treatment	NPK fertilizer (kg ha $^{-1}$)	Urea (kg ha $^{-1}$)	Biochar (t ha $^{-1}$)	Nutrient application rate (kg ha $^{-1}$)		
				N	P_2O_5	K_2O
F0	0	0	0	0	0	0
F100	100	50	0	40	17	17
F200	200	100	0	80	34	34
F300	300	150	0	120	51	51
B0	0	0	0	0	0	0
B5	0	0	5	0	0	0
B10	0	0	10	0	0	0
B15	0	0	15	0	0	0

NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t ha^{-1}and B15 = 15 t ha^{-1}.

Experimental Design and Treatments

The experiment was laid out as a split-plot Randomized Complete Block Design (RCBD), with NPK fertilizer in the main plots and biochar in the subplots in farmers' fields. The treatments were 0, 100, 200, and 300 kg ha^{-1} of NPK fertilizer obtained from Elgon Kenya Limited, while rice husk biochar was 0, 5, 10, and 15 t ha^{-1} obtained from Safi Organic Limited in Mwea in central Kenya. Each plot measured 3 m x 2 m and was conducted in 2 seasons (May 2024 to September 2024 and September 2024 to January 2025).

Agronomic Practices

The land was ploughed with a mouldboard plough, then puddled manually to obtain a fine tilth. The field was divided into 3 main blocks of dimensions 10 m x 9.5 m, separated by 1 m. Each block was subdivided into 8 plots, each measuring 3 m x 2 m, separated by a 0.5 m wide and 0.3 m high dyke to manage water and minimize cross-contamination of the treatments. Seeds were nursed and transplanted as 2 seedlings per stand after 21 days, without thinning.

The NPK fertilizer rates were broadcast as a basal application 3 days after transplanting the rice seedlings. Topdressing was done with urea (46% N) in split form; 75 percent at 30 days and 25 percent at 60 days after transplanting. Biochar was applied via the strip method as a basal application and incorporated into the soil before transplanting. Plots were irrigated to maintain water levels of 2-3 cm from planting through maturity. Weeding was done twice, at 30 and 60 days after transplanting. There was no pest or disease incidence, so no pesticides were applied during the period.

Data Collection

Growth Data

Data were collected by randomly tagging plants in the inner rows of a plot. Tiller numbers were counted manually at 30 and 60 days after transplanting (DAT). Plant height was measured in cm at 50 percent heading using a ruler from the base of the crop to the collar of the last leaf

sheath. At 50 percent heading, ten flag leaves from eight plants per plot were collected from the designated plants in the inner rows, placed in sample brown paper bags, and taken to the Egerton University soil lab for oven drying at 70°C, then ground to obtain a fine sample for analysis (Dobermann, 2000).

Yield and Yield Components

The yield components taken include: panicle number, panicle length, spikelet number per panicle, biomass weight, 1000-grain weight, grain yield, and panicle-harvest index (PHI). Panicle length was measured manually using a ruler. Spikelet number per panicle and number of grains per spikelet from 8 panicles were counted manually at harvest. The above-ground biomass was harvested from 3 randomly selected hills per plot. Fresh weight was measured before oven-drying at 70 °C for 72 hours, after which dry weight was recorded. A thousand-grain weight (1000) was measured using an electronic balance (Denver Instrument Company). Grain yield was determined from a 1 m^2 quadrat of 15 hills in the four middle rows in a plot, then threshed and air-dried to a constant weight. Panicle Harvest index (PHI) was taken and calculated using the formula:

Panicle harvest index (PHI) =grains /grains + whole panicle ……1

Statistical Analysis and Results

All collected data were analysed using R software version 4.4.1. A general linear model (GLM) was used to conduct analysis of variance (ANOVA). Mean separation was done using Fisher's least significance difference at $p \leq 0.05$.

Effect of NPK Fertilizer and Biochar on Paddy Rice Tiller Number at 60 Days After Transplanting (DAT)

Figure 2 illustrates the tiller number at the maximal tillering stage (60 DAT) across two consecutive seasons. A notable change in tiller number was observed at 60 DAT in both seasons. Application of NPK fertilizer at 100, 200, and 300 kg ha^{-1} increased tiller number by 17.7 percent, 31.91 percent, and 39.74 percent in season 1, and by 40.40 percent, 41.93 percent, and 63.0 percent in season 2, respectively. However, biochar application at 5, 10, and 15 t ha^{-1} reduced tillering by 11.11 percent, 14.28 percent, and 9.53 percent, respectively, compared with no biochar in season 1. The same biochar treatments did not influence tiller number in season 2.

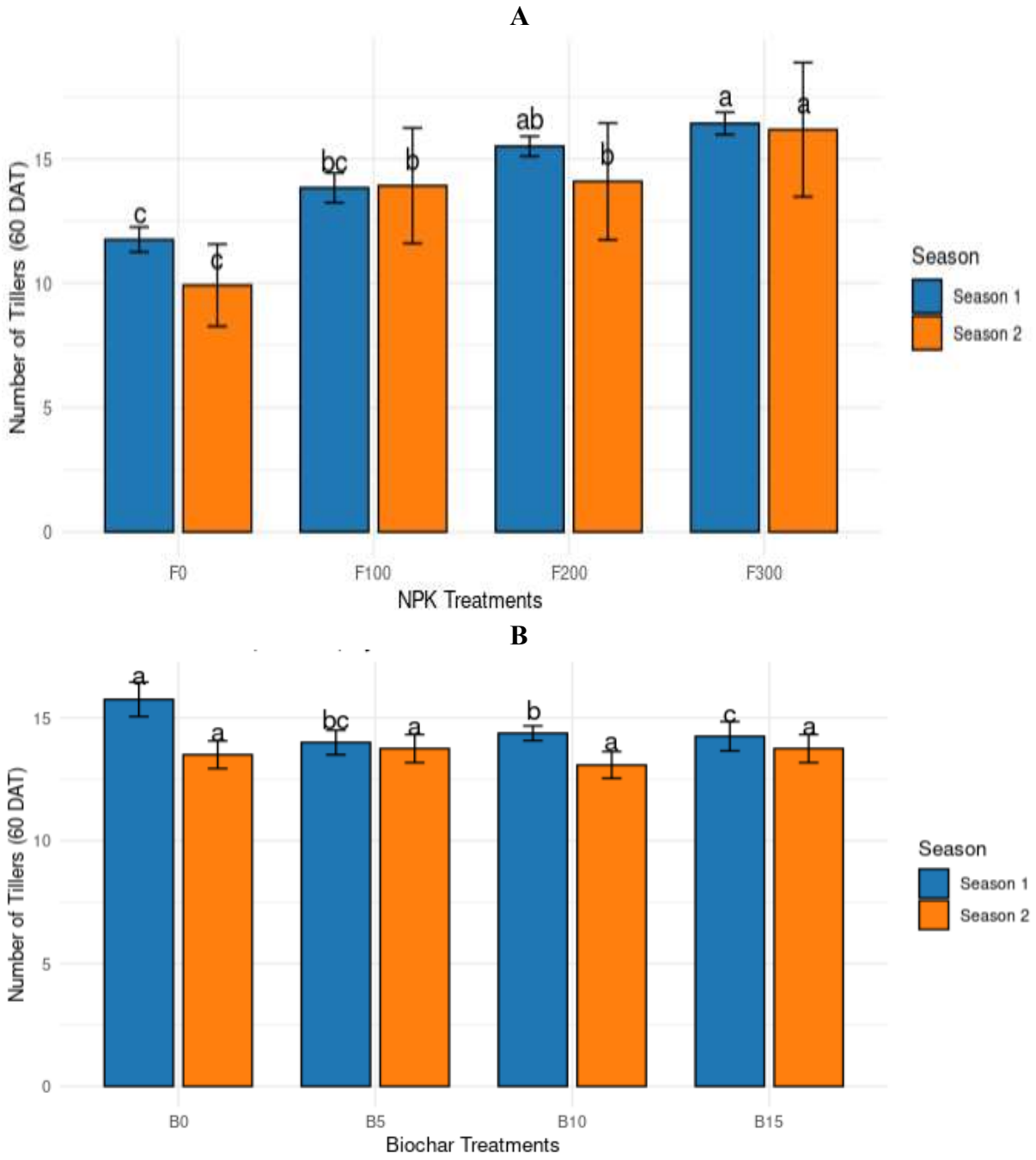


Fig. 2: Effect of NPK and Rice Husk Biochar on Tiller Number at 60 DAT; NPK Treatments (A) and Biochar Treatments (B).

NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t ha^{-1}and B15 = 15 t ha^{-1}.

Effect of NPK Fertilizer and Biochar on Above-Ground Biomass and Plant Height

Table 2 presents the effects of NPK and Biochar application on rice above-ground biomass (AGB) and plant height. Across all levels, NPK fertilizer application did not increase AGB in Season 1. In Season 2, NPK fertilizer treatments at F100, F200, and F300 increased AGB by 54.59 percent, 78.70 percent, and 104.46 percent, respectively. The maximum NPK application rate of 300 kg ha^{-1} resulted in above-ground biomass that doubled that of the control. Biochar application did not significantly influence AGB in either season.

Higher NPK fertilizer application rates of 200 and 300 kg ha^{-1} resulted in significantly taller plants ($p<0.05$) by 5.5 cm and 6.9 cm, respectively, compared with the control in season

1. Similar effects were observed in season 2, with 200 and 300 kg ha^{-1} producing taller plants by 3.05 cm and 4.86 cm, respectively, compared with no NPK fertilizer. Application of a higher rate of biochar at 15 t ha^{-1} produced plants taller than the control by 50.8 percent and 50.9 percent in seasons 1 and 2, respectively, whereas lower rates gave effects similar to the control in both seasons.

Table 2: Effect of NPK and Biochar on Above-Ground Biomass and Plant Height

	Season 1		Season 2	
Treatments	**Above-Ground Biomass (t ha^{-1})**	**Plant Height (cm)**	**Above-Ground Biomass (t ha^{-1})**	**Plant Height (cm)**
NPK rates				
F0	5.91a	56.79b	3.81c	56.38c
F100	6.48a	59.94ab	5.89b	57.89bc
F200	7.90a	62.23a	6.81ab	59.43ab
F300	7.56a	63.73a	7.79a	61.24a
CV	**38.18**	**7.34**	**16.67**	**3.35**
SD	**2.66**	**4.45**	**1.01**	**1.97**
Biochar rates				
B0	6.78a	59.85b	5.85a	57.73b
B5	6.48a	60.75ab	6.03a	58.84ab
B10	7.90a	60.33ab	6.12a	58.58ab
B15	7.56a	61.75a	6.30a	59.78a
CV	**17.34**	**3.11**	**13.77**	**3.10**
LSD	**1.02**	**1.59**	**0.70**	**1.53**

Means followed by the same letter in the same column within the NPK treatments and within the Biochar treatments are not significantly different as per LSD test ($p<0.05$).
NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t ha^{-1}and B15 = 15 t ha^{-1}.

Effect of NPK Fertilizer and Biochar on Yield Components of Paddy Rice

Table 3 presents results for panicle length, number of spikelets, and grains per spikelet. Across NPK fertilizer rates, panicle length showed no significant difference ($p>0.05$) in season 1. However, 200 kg ha^{-1} produced the longest panicles, 0.6 cm longer than 300 kg ha^{-1}, which produced the shortest. By contrast, a higher amount of biochar applied at 15 t ha^{-1} reduced panicle length by 4.66 percent. Biochar application did not affect panicle length in season 2 at any level. Similarly, spikelet number in season 1 followed the same trend as panicle length. All treatments produced a mean of 9 spikelets per panicle.

A similar effect was observed in season 2, where all treatments did not change the spikelet number. Biochar showed no significant effect on spikelet number in either season. Neither NPK nor biochar concentrations significantly influenced grain count per panicle, which averaged at least 12.0 grains in season 1. In season 2, application of NPK fertilizer at 200 kg ha^{-1} increased the number of grains per spikelet by 9.09 percent, while biochar applied at 5 t ha^{-1} increased the number of grains per spikelet by 3.51 percent compared with the no-biochar treatment.

Table 3: Effect of NPK Fertilizer and Biochar on Yield Components of Paddy Rice

Treatments	Season 1			Season 2		
	Panicle length (cm)	Spikelet number	Grains per spikelet	Panicle length (cm)	Spikelet number	Grains per spikelet
NPK Rates						
F0	23.1a	9.0a	12.0a	23.1b	8.8ab	11.0b
F100	23.2a	8.6b	12.4a	23.4ab	9.0a	11.5ab
F200	23.4a	8.9ab	12.0a	23.6a	9.0a	12.0a
F300	23.3a	9.0a	12.0a	23.0b	8.8ab	11.7a
CV	**4.20**	**3.87**	**10.40**	**2.15**	**2.81**	**4.94**
LSD	**0.97**	**0.34**	**1.26**	**0.50**	**0.25**	**0.57**
Biochar Rates						
B0	23.3ab	8.7a	12.3a	23.3a	8.9a	11.4b
B5	23.6a	9.1a	12.3a	23.4a	8.9a	11.8a
B10	23.6a	8.8a	12.2a	23.4a	8.8ab	11.6ab
B15	22.5b	8.9a	11.8a	22.9a	8.9a	11.5ab
CV	**4.32**	**6.44**	**8.26**	**2.94**	**3.25**	**2.79**
LSD	**0.85**	**0.48**	**0.84**	**0.58**	**0.24**	**0.27**

Means followed by the same letter in the same column within the NPK treatments and within the Biochar treatments are not significantly different as per LSD test ($p<0.05$).
NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t $ha^{-1}$and B15 = 15 t ha^{-1}.

Effect of NPK Fertilizer and Biochar on Panicle Harvest Index (PHI)

NPK fertilizer increased PHI at all application levels compared with the control in both seasons. Across all treatments (100, 200, and 300 kg ha^{-1}), NPK fertilizer increased PHI by 21.48 percent, 29.70 percent, and 19.89 percent in season 1, and by 25 percent, 38.2 percent, and 32.65 percent in season 2, respectively (Figure 3). Biochar application at 5 t ha^{-1} (B0) showed a depression in PHI, similar to the control, compared with B10 and B15 in season 1; while in season 2, none of the treatments increased PHI compared with the control (B0).

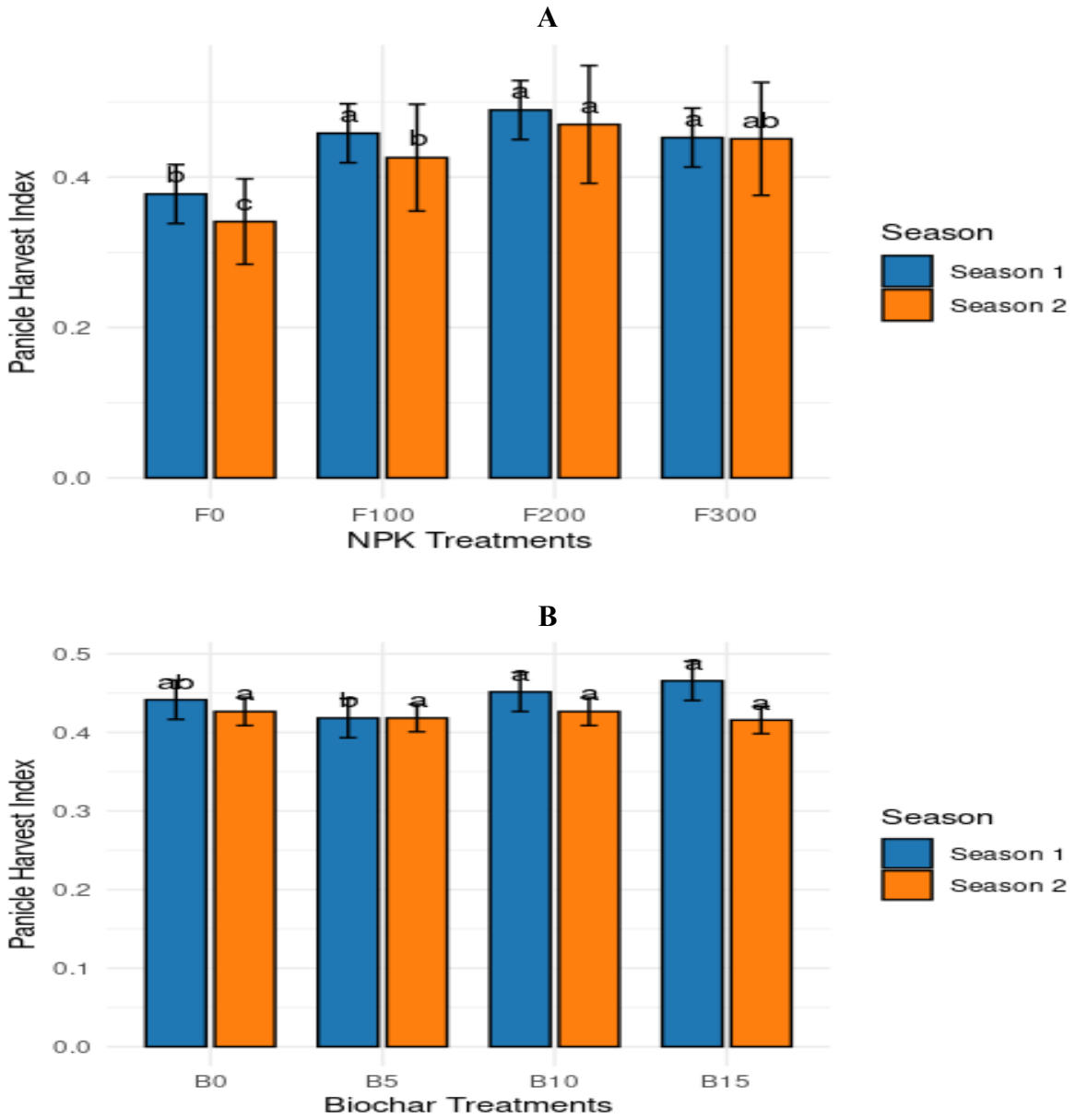


Fig. 3: Effect of NPK (17:17:17) and biochar on Panicle Harvest Index (PHI) NPK Treatments (A) and Biochar Treatments (B).

NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t ha^{-1}and B15 = 15 t ha^{-1}.

Effect of NPK Fertilizer and Biochar on Grain Yield and 1000-Grain Weight

Application of NPK fertilizer enhanced rice yields in both seasons (Table 4). Given that all the rates gave better yields compared to the control, 200 kg ha^{-1} was outstanding, with increases of 57.62 percent and 98.36 percent in season 1 and season 2, respectively. In contrast, biochar showed equivalent impacts to the control across all application rates in season 1. In season 2, biochar application differed from the control, being 1.66 percent lower. NPK application at 300 kg ha^{-1} reduced grain weight by 2.13 percent and 1.65 percent compared to 200 kg ha^{-1}, which gave the highest weight in both seasons (Table 4).

Table 4: Effect of NPK Fertilizer and Biochar on Grain Yield and 1000-Grain Weight

Treatments	Season 1		Season 2	
	Grain Yield (t ha^{-1})	1000 Grain Weight (g)	Grain Yield (t ha^{-1})	1000 Grain Weight (g)
NPK Rates				
F0	3.54c	25.90c	2.45c	25.05b
F100	4.88b	26.53b	3.69b	25.65ab
F200	5.58a	27.21a	4.86a	26.47a
F300	4.87b	26.63b	4.70a	26.04a
CV	**5.32**	**1.78**	**9.18**	**3.59**
LSD	**0.25**	**0.47**	**0.36**	**0.93**
Biochar Rates				
B0	4.78a	26.38c	3.97a	25.54b
B5	4.62a	26.53bc	3.90a	25.94a
B10	4.76a	26.74a	3.96a	25.89a
B15	4.72a	26.62ab	3.88a	25.83a
CV	**3.86**	**0.85**	**9.77**	**1.01**
LSD	**0.15**	**0.19**	**0.32**	**0.22**

Means followed by the same letter in the same column within the NPK treatments and within the Biochar treatments are not significantly different as per LSD test ($p<0.05$).
NPK rates: F0 = 0 kg ha^{-1}, F100 = 100 kg ha^{-1} F200 = 200 kg ha^{-1}, F300 = 300 kg ha^{-1}; For Biochar rates: B0 = 0 t ha^{-1}, B5 = 5 t ha^{-1}, B10 = 10 t ha^{-1}and B15 = 15 t ha^{-1}.

Both seasons yielded more grain weight at 200 kg ha^{-1}, with effects comparable to the somewhat reduced or elevated rates of 100 kg ha^{-1} and 300 kg ha^{-1}, respectively. Biochar application did not affect grain weight in season 1. Grain weight responded differently to biochar application rates compared to the control in season 2, as shown in Table 4. The highest grain weight was observed at 5 t ha^{-1}, which was 0.56 g heavier than the no-biochar treatment in season 2.

Discussion

Effect of NPK Fertilizer and Biochar on Tiller Number at 30 and 60 Days After Transplanting

Several factors influence tiller number, including light, nitrogen availability, and water management. Flooding during season 2, which occurred during active tillering for about 1 week in October 2024, affected tillering, inhibited microbial activity, and reduced nutrient availability to plants, as supported by research conducted by Hindersah et al. (2022). The significance observed at 60 DAT may reflect adequate nutrient use by the plant, especially nitrogen. NPK is a fast-releasing fertilizer that allows quick nutrient uptake from the soil. Biochar can enhance soil physics and biology, which can influence tiller development at 60 DAT (Canatoy et al., 2023).

Although not all tillers develop into panicles, tiller production significantly contributes to panicle numbers and is therefore an important stage in rice production. These results are in line with Budiono et al., (2019) that showed that fertilizer use in rice production significantly increased the number of tillers only 35 days after transplanting, due to transplanting shock and the regeneration ability of the transplanted seedlings.

Effect of NPK Fertilizer and Biochar on Above-Ground Biomass and Plant Height
Application of NPK and biochar did not influence aboveground biomass. However, plant height changed significantly in treatments with the highest NPK and biochar levels. Biochar can effectively improve soil quality and yield in subsequent seasons of planting due to the slow rate of its carbon decomposition(Phares & Akaba, 2022).

According to Ali et al. (2020) the amount of soil amendment has a direct effect on the soil structure, phosphorus availability, and rice growth. This explains biochar's significant influence on plant height at the highest application level. Optimal NPK application promotes the production of taller plants, as reported by Paiman (2021), where the highest application dosage showed a positive correlation with plant height. Nitrogen stimulates meristematic tissues; therefore, increased rice shoot length affects overall plant height.

Effect of NPK Fertilizer and Biochar on Yield Components of Paddy Rice
The yield components of rice were determined by panicle length, number of spikelets, and grains per spikelet. In both seasons, panicle lengths did not differ significantly at any level of NPK application. These results align with Paiman (2021), which showed that NPK application influences overall rice yield but not panicle length.

Biochar increases nutrient solubilization and the deposition of NPK in the top layer of the soil, making these nutrients more available to plants with shallow roots (Oladele et al., 2019). Li et al. (2020) further emphasized this, reporting that biochar increases microbial biomass, though the magnitude of this effect depends on biochar properties. Moreover, organic fertilizers tend to release nutrients slowly into the soil, so panicle length, spikelet numbers, and grains per spikelet did not change in the first season of planting. This explains the positive effect of biochar application on panicle length in this experiment.

Effect of NPK Fertilizer and Biochar on Panicle Harvest Index (PHI)
There was an increase in PHI for the treatments compared with the control (F0). However, different NPK fertilizer rates did not differentially affect PHI, as a similar effect was reported in a study done by Manni and Sharma (2023)where different nitrogen levels exerted a minimal influence on the harvest index. on the harvest index.

This result may be affected by soil type and fertility, as alluvial soils have low nutrient content. These findings were confirmed by Paiman et al. (2021) who, in their study, reported that application of NPK fertilizer at doses exceeding 480 kg ha¯1 is necessary for alluvial soils.

Effect of NPK Fertilizer and Biochar on Grain Yield and 1000 Grain Weight
The results showed that NPK application significantly contributes to overall rice yield. This is attributed to the immediate availability of nutrients to plants from inorganic fertilizers. Organic amendments stabilize soil structure, leading to an increased mean weight diameter and water retention capacity. Additionally, biochar increased soil available phosphorus, supporting root development and growth. This could be attributed to grain yield in the first season (Chen et al., 2021). However, these results contrast with those of several authors, who consider 5 t ha^{-1} of biochar the optimal rate and report higher yields for certain crops such as wheat and maize.

According to Huang et al. (2019), applying fertilizer in the fourth and sixth seasons increased sink size and total rice biomass. It further concluded that the positive effect of biochar on rice yield can only be achieved after subsequent application. This may be due to the decline in rice yields in season two.

Conclusions and Recommendations

NPK fertilizer positively influenced rice growth and yield. However, applying more than 200 kg ha^{-1} NPK improved vegetative growth but reduced grain yield and grain weight. Plain rice husk biochar at the tested levels did not affect rice growth and yield in either season.

It is recommended that farmers should not apply NPK fertilizer beyond 200 kg $ha^{-1,}$ in this study area. Studying the effects of plain rice husk biochar within a single planting season is not sufficient to give a precise result. Further studies are also recommended to assess the long-term effects of biochar and the combined effects of synthetic NPK fertilizer and rice husk biochar on rice plant growth and yield.

References

Abdelhafez, A., & Abbas, M. (2020). *Applications of Biochar for Environmental Safety*. BoD – Books on Demand.

Akter, A., Islam, M. R., Islam, M. R., Islam, M. A., Hasan, S. L., Uddin, S., & Rahman, M. M. (2022). Methods of urea fertilizer application influence growth, yield, and nitrogen use efficiency of transplanted Aman rice. *Water*, *14*(21), Article 21. https://doi.org/10.3390/w14213539

Ali, I., Ullah, S., He, L., Zhao, Q., Iqbal, A., Wei, S., Shah, T., Ali, N., Bo, Y., Adnan, M., Amanullah, & Jiang, L. (2020). Combined application of biochar and nitrogen fertilizer improves rice yield, microbial activity and N-metabolism in a pot experiment. *PeerJ*, *8*, e10311. https://doi.org/10.7717/peerj.10311

Anwari, G., Mandozai, A., & Feng, J. (2019). Effects of biochar amendment on soil problems and improving rice production under salinity conditions. *Advanced Journal of Graduate Research*, *7*(1), 45–63. https://doi.org/10.21467/ajgr.7.1.45-63

Bhattacharyya, S. S., Ros, G. H., Furtak, K., Iqbal, H. M. N., & Parra-Saldívar, R. (2022). Soil carbon sequestration – An interplay between soil microbial community and soil organic matter dynamics. *Science of The Total Environment*, *815*, 152928. https://doi.org/10.1016/j.scitotenv.2022.152928

Budiono, R., Adinurani, P. G., & Soni, P. (2019). Effect of new NPK fertilizer on lowland rice (Oryza sativa L.) growth. *IOP Conference Series: Earth and Environmental Science*, *293*(1), 012034. https://doi.org/10.1088/1755-1315/293/1/012034

Canatoy, R. C., Jeong, S. T., Cho, S. R., Galgo, S. J. C., & Kim, P. J. (2023). Importance of biochar as a key amendment to convert rice paddy into carbon negative. *Science of The Total Environment*, *873*, 162331. https://doi.org/10.1016/j.scitotenv.2023.162331

Chen, M., Zhang, S., Liu, L., Wu, L., & Ding, X. (2021). Combined organic amendments and mineral fertilizer application increase rice yield by improving soil structure, P availability and root growth in saline-alkaline soil. *Soil and Tillage Research*, *212*, 105060. https://doi.org/10.1016/j.still.2021.105060

Conte, P., Librici, C., Nicosia, A., Palmeri, V., Pampalone, V., & Ferro, V. (2025). Wood-Biochar influence on rill erosion processes and hydrological connectivity in amended soils. *Hydrological Processes*, *39*(2), e70093. https://doi.org/10.1002/hyp.70093

Dianga, A.-I., Musila, R. N., Joseph, K. W., Dianga, A.-I., Musila, R. N., & Joseph, K. W. (2021). *Rainfed Rice Farming Production Constrains and Prospects, the Kenyan Situation*. IntechOpen. https://doi.org/10.5772/intechopen.98389

Dobermann, A. (2000). *Rice: Nutrient Disorders & Nutrient Management*. Int. Rice Res. Inst.

Faloye, O. T., Alatise, M. O., Ajayi, A. E., & Ewulo, B. S. (2017). Synergistic effects of biochar and inorganic fertiliser on maize (*zea mays*) yield in an alfisol under drip irrigation. *Soil and Tillage Research*, *174*, 214–220. https://doi.org/10.1016/j.still.2017.07.013

Gu, W., Wang, Y., Feng, Z., Wu, D., Zhang, H., Yuan, H., Sun, Y., Xiu, L., Chen, W., & Zhang, W. (2022). Long-term effects of biochar application with reduced chemical fertilizer on

paddy soil properties and japonica rice production system. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.902752

Haque, A. N. A., Uddin, M. K., Sulaiman, M. F., Amin, A. M., Hossain, M., Solaiman, Z. M., & Mosharrof, M. (2022). Rice growth performance, nutrient use efficiency and changes in soil properties influenced by biochar under alternate wetting and drying irrigation. *Sustainability*, *14*(13), Article 13. https://doi.org/10.3390/su14137977

Hindersah, R., Kalay, A. M., & Talahaturuson, A. (2022). Rice yield grown in different fertilizer combination and planting methods: Case study in Buru Island, Indonesia. *Open Agriculture*, *7*(1), 871–881. https://doi.org/10.1515/opag-2022-0148

Huang, M., Fan, L., Jiang, L., Yang, S., Zou, Y., & Uphoff, N. (2019). Continuous applications of biochar to rice: Effects on grain yield and yield attributes. *Journal of Integrative Agriculture*, *18*(3), 563–570. https://doi.org/10.1016/S2095-3119(18)61993-8

Iboko, M. P., Dossou-Yovo, E. R., Obalum, S. E., Oraegbunam, C. J., Diedhiou, S., Brümmer, C., & Témé, N. (2023). Paddy rice yield and greenhouse gas emissions: Any trade-off due to co-application of biochar and nitrogen fertilizer? A systematic review. *Heliyon*, *9*(11). https://doi.org/10.1016/j.heliyon.2023.e22132

Li, X., Wang, T., Chang, S. X., Jiang, X., & Song, Y. (2020). Biochar increases soil microbial biomass but has variable effects on microbial diversity: A meta-analysis. *Science of The Total Environment*, *749*, 141593. https://doi.org/10.1016/j.scitotenv.2020.141593

Manni, T. B., & Sharma, R. (2023). Assessing the optimal level of NPK fertilizers for enhancing production of spring rice in Kanchanpur, Nepal. *Big Data in Agriculture*, *5*(1), 36–42. https://doi.org/10.26480/bda.01.2023.36.42

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A., & Fasina, A. (2019). Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (Oryza sativa) yield grown on an Alfisol in Southwestern Nigeria. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(3), 295–308. https://doi.org/10.1007/s40093-019-0251-0

Paiman, A., Kusumastuti, C. T., Gunawan, S., & Ardiani, F. (n.d.). *Maximizing the Rice Yield (Oryza Sativa L.) using NPK Fertilizer*. https://doi.org/10.2174/1874331502115010033

Phares, C. A., & Akaba, S. (2022). Co-application of compost or inorganic NPK fertilizer with biochar influences soil quality, grain yield and net income of rice. *Journal of Integrative Agriculture*, *21*(12), 3600–3610. https://doi.org/10.1016/j.jia.2022.07.041

Shrestha, J., Karki, T. B., & Hossain, M. A. (2022). Application of nitrogenous fertilizer in rice production: A review. *Journal of Nepal Agricultural Research Council*, *8*, 16–26. https://doi.org/10.3126/jnarc.v8i.44815

Shrestha, J., Shah, K. K., & Timsina, K. P. (2020). Effects of different fertilizers on growth and productivity of rice (Oryza sativa L.): A review (Journal Paper 1). *International Journal of Global Science Research*. https://doi.org/10.26540/ijgsr.v7.i1.2020.151

Xia, L., Chen, W., Lu, B., Wang, S., Xiao, L., Liu, B., Yang, H., Huang, C. L., Wang, H., Yang, Y., Lin, L., Zhu, X., Chen, W. Q., Yan, X., Zhuang, M., Kung, C.-C., Zhu, Y.-G., & Yang, Y. (2023). Climate mitigation potential of sustainable biochar production in China. *Renewable and Sustainable Energy Reviews*, *175*, 113145. https://doi.org/10.1016/j.rser.2023.113145