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Integrated effect of fertilizers and biochar on performance of groundnut

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ABSTRACT

A field investigation was carried out during late *kharif*, 2024 at the Agricultural College Farm, Bapatla to study the influence of biochar and fertilizers on groundnut (TAG 24 variety) cultivated in sandy loam soils. The experiment consisted of eight treatments involving combinations of the recommended dose of fertilizers (30: 40: 50 kg N: P_2O_5: K_2O ha^{-1}) and gypsum was applied commonly for all treatments except control, with cotton stalk biochar applied at 2 and 4 t ha^{-1}. The study was designed using a Randomized Block Design (RBD) with three replications. Results showed that the combined application of 100% RDF + biochar @ 4 t ha^{-1} (T_6) lead to the highest values for dry matter production, yield components, and nutrient uptake. Though nutrient content (N, P, and K) in plant tissues were statistically non-significant, their uptake values were notably higher in integrated treatments. Improvement in crop performance was linked to biochar's superior water holding capacity (128.6 %), organic carbon (79.2%), and porosity (33.87%). Overall, integrated nutrient management using biochar and fertilizers enhanced groundnut yield and soil health, providing a promising approach for sustainable cultivation in light-textured soils.

Keywords: *Biochar, Groundnut, Integrated nutrient management, Nutrient uptake, Soil properties and yield*

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crop cultivated in India, especially in semi-arid and arid regions. It serves as a major source of edible oil, protein, and fodder, contributing significantly to both nutritional security and rural livelihoods. However, its productivity is often constrained by the poor fertility status of soils, especially in sandy loam soils like those found in coastal Andhra Pradesh. These soils typically have low water holding capacity, organic matter, and nutrient retention capacity, making groundnut cultivation both input-sensitive and environmentally vulnerable.

Continuous and unbalanced use of chemical fertilizers has further degraded the physical and chemical health of these soils, leading to declining crop responses and inefficiencies in nutrient use. In this context, integrated nutrient management strategies that combine organic amendments with inorganic fertilizers are gaining prominence for their ability to improve soil health and crop yield.

Biochar has emerged as a promising soil amendment in recent years. It is a carbon-rich, porous material produced through fast pyrolysis with the thermal decomposition of organic biomass under limited oxygen supply. The characteristics of biochar depend greatly on the type of feedstock and pyrolysis conditions used. In the present study, cotton stalks were used to produce biochar due to their local availability. The resulting cotton stalk biochar was alkaline in nature (pH 8.6), had high organic carbon content (79.2%), and exhibited excellent water retention (128.6%) and cation exchange properties making it highly suitable for ameliorating degraded sandy soils.

When applied to soil, biochar can influence a wide range of soil properties. Its porous structure helps to improve soil aeration, reduce bulk density, and enhance moisture retention. The surface functional groups on biochar particles contribute to higher cation exchange capacity (CEC), enabling better nutrient retention and reduced leaching losses. Moreover, biochar has a long residence time in soil and is relatively resistant to microbial decomposition, contributing to long-term improvements in soil organic carbon pools and stability.

Several studies have indicated that the synergistic application of biochar with chemical fertilizers can further enhance nutrient uptake and crop yields by improving nutrient use efficiency. However, the magnitude of these effects depends on soil texture, climate, biochar characteristics, and crop type. For instance, in sandy loam soils, the addition of biochar can help compensate for the inherently low nutrient-holding capacity, particularly when used in combination with nitrogen, phosphorus and potassium fertilizers, which are most prone to leaching.

The present field investigation was conducted to assess the integrated effect of fertilizers and cotton stalk biochar on the performance of groundnut (TAG 24 variety) grown in sandy loam soils under late kharif conditions. The study aimed to evaluate the changes in soil physical and chemical properties, yield attributes, and nutrient uptake under various combinations of fertilizer and biochar, to identify the most effective treatment for improving groundnut productivity sustainably.

MATERIALS AND METHODS

A field experiment entitled "Integrated effect of fertilizers and biochar on performance of groundnut" was conducted during the late *kharif* season of 2024 at the Agricultural College Farm, Bapatla, to evaluate the impact of biochar and fertilizer integration on groundnut productivity and soil health. The experimental site falls under the Krishna Godavari agro-climatic zone and is characterized by sandy loam soil (77.0% sand, 6.7% silt, 16.3% clay), slightly acidic (pH 6.93), non-saline (EC 0.35 dS m^{-1}), with low oxidisable (labile) organic carbon (0.35%), organic carbon (0.69%), and cation exchange capacity (14.0 cmol (P^{+}) kg^{-1}). The test crop used was groundnut (TAG 24 variety), and the experiment was laid out in a Randomized Block Design (RBD) with eight treatments replicated three times.

The treatments were: T_1 - Control (no fertilizer or biochar), T_2 - 100% RDF (30: 40: 50 kg N: P_2O_5: K_2O ha^{-1}), T_3 - Biochar @ 2 t ha^{-1}, T_4 - Biochar @ 4 t ha^{-1}, T_5 - 100% RDF + Biochar @ 2 t ha^{-1}, T_6 - 100% RDF + Biochar @ 4 t ha^{-1}, T_7 - 75% RDF + Biochar @ 2 t ha^{-1}, T_8 - 75% RDF + Biochar @ 4 t ha^{-1}. Cotton stalk biochar was produced via slow pyrolysis at 350–400°C under limited oxygen and was applied to the soil one week before sowing. The biochar had the following properties: bulk density- 0.41 g cm^{-3}, pore space- 33.87%, pH- 8.6, EC- 0.78 dS m^{-1}, organic carbon- 79.2%, nitrogen- 0.29%, phosphorus- 0.27%, potassium-1.1%, water holding capacity- 128.6 % and conversion efficiency- 38.5%. Nutrients were supplied through urea (N), single super phosphate (P), and muriate of potash (K), applied according to the treatment schedule.

Soil samples were collected before sowing and after harvest to analyze physical parameters such as bulk density, particle density, porosity, and water holding capacity, and chemical parameters including pH, EC, CEC, oxidisable (labile) organic carbon, and organic carbon. Crop observations at harvest included haulm yield, pod yield, kernel yield, shelling percentage, 100 kernel weight, and nutrient uptake (N, P, K) in both haulm + shell and kernel. The data were analyzed using analysis of variance (ANOVA), and treatment means were compared at the 5% level of significance. Standard statistical methods were employed to compute the Critical Difference (CD), Standard Error of Mean (SEM), and Coefficient of Variation (CV%), ensuring scientific reliability.

RESULTS AND DISCUSSION

Soil physical properties

Bulk density

The data pertaining to the bulk density of soil at harvest is presented in table 1 The findings indicate that the application of integrated effect of fertilizers and biochar didn't show any significate effect on bulk density of the soil.

Soil bulk density generally decreased from before sowing to harvest. The highest bulk density of 1.57 Mg m^{-3} was observed in T_1 (Control), while the lowest bulk density of 1.46 Mg m^{-3} was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}) at harvest indicating an integrated effect of fertilizer and biochar combinations on soil bulk density. The observed trend of decreasing bulk density with biochar application may be attributed to the lower density of biochar and its potential to improve soil aggregation. However, the lack of statistical significance in this study suggests that other factors, such as soil texture, biochar characteristics, and environmental conditions, may influence the effectiveness of biochar in altering soil bulk density.

In the present investigation, the combined application of fertilizers and biochar did not showed a

Table: 1. Integrated effect of fertilizers and biochar on physical properties in soil

Treatments	Bulk density ($Mg\ m^{-3}$)	Particle density ($Mg\ m^{-3}$)	Porosity (%)	WHC (%)
T_1 - Control	1.57	2.48	36.7	35.8
T_2 - 100% RDF (30-40-50)	1.55	2.49	37.7	36.8
T_3 - Biochar @ 2t ha^{-1}	1.5	2.54	41.3	39.6
T_4 - Biochar @ 4t ha^{-1}	1.49	2.55	41.4	40.4
T_5 - 100% RDF + Biochar @ 2t ha^{-1}	1.49	2.51	40.7	40.9
T_6 - 100% RDF + Biochar @ 4t ha^{-1}	1.46	2.58	43.2	43.9
T_7 - 75% RDF + Biochar @ 2t ha^{-1}	1.5	2.54	42.5	40.7
T_8 - 75% RDF + Biochar @ 4t ha^{-1}	1.48	2.55	42	42.4
SEm ±	0.05	0.08	2.85	1.5
CD @0.05	NS	NS	NS	5.3
CV%	5.19	5.3	12.2	6.5

significant influence on soil bulk density. This result is consistent with the findings of Hartati *et al.* (2025), who reported non-significant changes in the bulk density of Spodosols and Ultisols when biochar was applied along with liquid fertilizers. Although biochar is known to reduce bulk density ranging between 3-31% as noted by Blancocanqui (2017) such effects are not always consistent and depend on factors like soil texture, biochar type, rate of application, and the duration of the study. The absence of a significant effect in the current study may thus be attributed to similar controlling factors.

Particle density

The data obtained on the integrated effect of fertilizers and biochar on soil particle density is presented in table 1 The highest particle density of 2.58 Mg m^{-3} was observed in T_6 (100% RDF + biochar @ 4 t ha^{-1}), while the lowest particle density of 2.48 Mg m^{-3} was recorded in T_1 (100% RDF) at harvest.

The particle density of soil at harvest was not significantly different among the treatments, indicating a non-significant integrated effect of fertilizer and biochar combinations on soil particle density. The observed stability in particle density with the integrated application of fertilizers and biochar may be attributed to the inherent characteristics of the soil and the properties of the biochar used. In sandy loam soils, the addition of biochar and fertilizers did not lead to significant changes in particle density, possibly due to the already low bulk densities of these soils and the relatively short duration of the study.

In the current study, the incorporation of biochar along with fertilizers did not bring about any significant changes in particle density. This finding is consistent with the observations of Alghamdi *et al.* (2020), who reported that the use of finely ground biochar (particle size <1 mm) had no notable impact on the particle density of sandy loam soils. Similarly, Glab *et al.* (2016) also observed non-significant effects on particle density following biochar application. These findings suggest that particle density, being primarily governed by the mineral composition of soil particles, is relatively unaffected by biochar amendments, particularly when applied at moderate rates or with finer particle sizes.

Porosity

According to the results, the integrated application of fertilizers and biochar exhibited variations in soil porosity presented in table 1 The highest porosity of 43.2% was observed in T_6 (100% RDF + biochar @ 4 t ha^{-1}), while the lowest porosity of 36.7% was recorded in T_1 (Control). Despite these variations, the differences among treatments were not statistically significant, indicating that the combined application of fertilizers and biochar did not significantly influence soil porosity. In sandy loam soils, the addition of biochar and fertilizers did not lead to significant changes in porosity, possibly due to the relatively short duration of the study.

In the present study, the combined application of biochar and fertilizers did not result in a significant alteration in soil porosity. This outcome is in line with the findings of Liu *et al.* (2012), who observed non significant effect on the porosity of sandy loam soils following the application of biochar and fertilizers. Likewise, Hardie *et al.* (2014) reported that the incorporation of biochar into soil did not bring about noticeable changes in porosity. These results imply that the influence of biochar on soil porosity may be limited, particularly in lighter-textured soils or when applied in combination with inorganic fertilizers.

Water holding capacity

The data presented in table 1 indicate that the integrated application of fertilizers and biochar significantly enhanced the soil water holding capacity from sowing to harvest. The highest WHC value of 43.9% was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), is with 22.7% higher over the control (T_1 - 35.8%). Treatments T_8 (42.4%), T_7 (40.7%), and T_5 (40.9%) also recorded substantial improvements over control. These treatments were also superior to T_2 (100% RDF) 36.8%, indicating the beneficial role of biochar in improving soil water retention when applied in combination with fertilizers. The improved WHC can be attributed to the porous nature of biochar, which enhances the overall soil structure and its ability to retain moisture.

Since biochar is more porous in nature and has high specific surface area, on addition to soil it generally increases porosity and water holding capacity of soils (Verheijen *et al*., 2010). Herath *et al*. (2013) also noticed increase of WHC with addition of biochar because it increases in soil microporosity in sandy soils and also due to high absorptive nature of biochar to water.

Physico chemical properties

Soil reaction (pH)

The results presented in table 2 showed that although the differences were not statistically significant, there was a modest increase in soil pH with higher rates of biochar application. At harvest, the highest pH values of 7.14 in T_6 (100% RDF + biochar @ 4 t ha^{-1}) and 7.12 in T_8 (75% RDF + biochar @ 4 t ha^{-1}) were superior than T_1 (Control) and T_2 (100% RDF), which had the lowest pH of 6.87. Due to alkaline nature of biochar, up on its addition to soil caused increase in soil pH.

The application of biochar, either alone or in combination with fertilizers, did not result in a significant change in soil pH. This is consistent with the findings of Wang *et al.* (2021), who reported no significant alteration in pH after applying phosphorus rich biochar to sandy soils during a short-term (3-week) incubation. Similarly, Basirijahromi *et al.* (2020) observed only a non-significant numerical increase in pH following the addition of hardwood biochar to flooded sandy soils. These results suggest that the effect of biochar on soil pH may depend on factors such as soil texture, moisture conditions, type of biochar, and duration of incubation, and that short term responses may not always reflect significant changes.

Electrical conductivity (EC)

The data in the Table 2 revealed that the combined application of fertilizers and biochar resulted in a minor, non-significant reduction in soil electrical conductivity. At harvest, the highest EC value of 0.35 dS m^{-1} was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), likely due to enhanced leaching of salts with irrigation water under biochar-amended conditions. In contrast, the lowest EC values occurred 0.28 dS

Table: 2. Integrated effect of fertilizers and biochar on pH, EC and CEC in soil

Treatments	pH	EC (d Sm^{-1})	CEC (cmol (P$^+$) kg^{-1})
T_1 - Control	6.87	0.28	14.30
T_2 - 100% RDF (30-40-50)	6.93	0.29	14.50
T_3 - Biochar @ 2t ha^{-1}	7.05	0.29	14.90
T_4 - Biochar @ 4t ha^{-1}	7.10	0.30	15.10
T_5 - 100% RDF + Biochar @ 2t ha^{-1}	7.09	0.31	17.20
T_6 - 100% RDF + Biochar @ 4t ha^{-1}	7.14	0.35	18.60
T_7 - 75% RDF + Biochar @ 2t ha^{-1}	7.11	0.32	16.20
T_8 - 75% RDF + Biochar @ 4t ha^{-1}	7.12	0.33	17.80
SEm ±	0.20	0.02	0.87
CD @0.05	NS	NS	2.64

m^{-1} in T_1 (Control) and 0.29 dS m^{-1} in T_2 (100% RDF), indicating less effective salt dissipation.

A non-significant increase in electrical conductivity (EC) was observed with the application of biochar. This slight rise in EC may be attributed to the presence of ash residues in the biochar, which are often rich in carbonates of alkali and alkaline earth metals, as reported by Nigussie *et al.* (2012).

Cation exchange capacity (CEC)

The data presented in table 2 indicated a significant increase in soil cation exchange capacity (CEC) at higher application rates of biochar in combination with fertilizers. The highest CEC value of 18.6 cmol (p^+) kg^{-1} was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), followed by T_8 (75% RDF + biochar @ 4 t ha^{-1}) with 17.8 cmol (pz) kg^{-1}, both measured at the harvest stage. These values were significantly superior over T_1 and T_2 and increased 33.3 and 27.1% over T_1 and 25.7% and 20.3% over T_2 treatments. Overall, soil CEC showed a gradual increase toward the harvest stage of the groundnut crop, indicating the positive and cumulative influence of biochar when integrated with fertilizers on the soil nutrient holding capacity.

Significant increase in CEC with addition of biochar was also supported by Masulili *et al*., 2010, which revealed the presence of high carboxylic and phenolic functional groups in biochar results in high surface negative charge which caused greater ability to exchange cations. Biochar has a greater ability than other soil organic materials to adsorb cations due to its high surface area, high negative charge and high charge density (Elangovan *et al*., 2014).

Oxidisable (labile) organic carbon (%)

The data in table 3 showed that the application of biochar along with fertilizers significantly improved the oxidisable organic carbon content of the soil. Treatments with biochar at both 2t ha^{-1} and 4 t ha^{-1} (T_5, T_6, T_7, and T_8) recorded higher organic carbon levels compared to non-biochar treatments (T_1 and T_2). This indicates the positive role of biochar in enhancing soil organic matter due to its stable carbon structure and slow decomposition rate.

At harvest, the highest organic carbon content (0.52%) was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), followed closely by T_8 (0.50%). These values reflect a 62.5% and 56.2% increase over the control (T_1- 0.32%), and were also significantly higher than T_2 (100% RDF -0.37%), with an increase of 40.5% and 35.1%, respectively. Even lower rates of biochar (T_5 and T_7) showed improvement, up to a lesser extent.

The overall increasing trend in organic carbon from sowing to harvest suggests that biochar, especially at higher rates, can effectively improve soil carbon content when applied along with fertilizers. This combined approach can support better soil health and long-term sustainability.

Due to high organic carbon content of biochar, up on its application to the soil, it releases carbon into the soil system and also due to the mineralization of organic matter adsorbed by the biochar particles the

Table: 3. Integrated effect of fertilizers and biochar on oxidisable (labile) and organic carbon in soil

Treatments	Oxidisable organic carbon (%)	Organic carbon (%)
T_1 - Control	0.31	0.72
T_2 - 100% RDF (30-40-50)	0.33	0.74
T_3 - Biochar @ 2t ha^{-1}	0.38	0.82
T_4 - Biochar @ 4t ha^{-1}	0.4	0.83
T_5 - 100% RDF + Biochar @ 2t ha^{-1}	0.46	0.89
T_6 - 100% RDF + Biochar @ 4t ha^{-1}	0.52	0.95
T_7 - 75% RDF + Biochar @ 2t ha^{-1}	0.45	0.87
T_8 - 75% RDF + Biochar @ 4t ha^{-1}	0.5	0.92
SEm ±	0.03	0.04
CD @0.05	0.08	0.12
CV%	10.7	8.38

organic carbon content in the soil gets increased. Elangovan *et al*., 2014 reported that biochar itself is a matrix of organic complex and its application to soil system increases soil organic carbon. Abrishemkesh *et al*., (2015) observed a significant increase in organic carbon in biochar amended soils.

Organic carbon (OC)

The organic carbon (OC) content of soil was significantly influenced by the application of biochar in combination with fertilizers, as shown in table 4. The highest OC value of 0.95% was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), followed by T_8 (75% RDF + biochar @ 4 t ha^{-1}) with 0.92%, and T_5 (100% RDF + biochar @ 2 t ha^{-1}) with 0.89%. These treatments were markedly superior to T_1 (Control - 0.72%) and T_2 (100% RDF - 0.74%).

An increase of 31.9% of OC was observed in T_6 treatment when compared to T_1. Even the treatments with lower biochar rates (T_3 and T_4) exhibited increased OC values (0.82% and 0.83%), indicating a positive response of organic carbon to biochar addition. These results confirm that biochar application improves the OC status of soil, likely due to its stable carbon content and its contribution to long-term organic matter buildup.

Overall, the increase in OC with biochar treatments supports its potential to enhance soil carbon stocks and contribute to improved soil quality and fertility when integrated with fertilizer management.

The significant increase in OC was also supported by Qadeer *et al*., 2014 as the addition of biochar to soil considerably increases the organic pool of the soil. Biochar being rich source of carbon, up on its addition to the soil enhances the carbon accumulation and sequestration which increases the OC of the soil system (Trupiano *et al*., 2017).

Haulm yield

The data in table 4 shows a clear enhancement in groundnut haulm yield with integrated nutrient management practices. The highest haulm yield (2.06 t ha^{-1}) was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), which was statistically on par with T_5 (1.98 t ha^{-1}), T_8 (1.93 t ha^{-1}) and T_7 (1.91 t ha^{-1}). In contrast, the lowest yield (1.46 t ha^{-1}) was observed in T_1 (Control), and T_2 (100% RDF alone) recorded only 1.78 t ha^{-1}, both being significantly inferior to T_6.

When compared to the control, T_6 showed a 41.1% increase in haulm yield, and even over T_2, the increase was 15.7%, highlighting the synergistic effect of biochar and RDF in promoting vegetative biomass. This improvement could be due to better nutrient availability, enhanced soil structure, and increased microbial activity associated with biochar application, which likely contributed to improved root growth and nutrient uptake, thus boosting haulm production.

4.5.2 Pod yield

The data in table 4 clearly indicates that integrated nutrient management involving biochar and RDF had a significant positive effect on groundnut pod yield. The highest yield (4.03 t ha^{-1}) was recorded in T_6 (100% RDF + biochar @ 4 t ha^{-1}), which was statistically on par with T_5 (3.92 t ha^{-1}), T_8 (3.77 t ha^{-1}) and T_7 (3.61 t ha^{-1}). In contrast, the lowest yield (2.88 t ha^{-1}) was observed in T_1 (Control), while T_2 (100% RDF alone) recorded a yield of 3.56 t ha^{-1}, both significantly lower than T_6.

When compared to the control, T_6 recorded a 39.9% increase in pod yield, and over T_2, the increase was 13.2%, suggesting a strong synergistic effect of combining biochar with inorganic fertilizers. This improvement can be attributed to enhanced nutrient retention, improved soil structure, and increased microbial activity due to biochar addition, which collectively promoted better crop growth and productivity under T_6.

The enhanced availability of soil-bound nutrients through chelation and their uptake by the plants was the cause of the rise in pod and haulm yield following the addition of biochar. The enhanced ability of the biochar-treated soils to retain water and nutrients may be the cause of the increase in peanut output (Agegnehu *et al.,* 2015).

4.5.3 Kernel yield

The kernel yield data presented in table 4 showed a marked improvement under integrated treatments involving biochar and fertilizers. The highest kernel yield (2.99 t ha^{-1}) was obtained in T_6 (100% RDF + biochar @ 4 t ha^{-1}), which was statistically on par with T_5 (2.85 t ha^{-1}), T_8 (2.82 t ha^{-1}), and T_7 (2.61 t ha^{-1}). The lowest yield (1.98 t ha^{-1}) was recorded in T_1 (Control), while T_2 (100% RDF) yielded 2.54 t ha^{-1}.

Table:4. Integrated effect of fertilizers and biochar on yield parameters of groundnut

Treatments	Haulm yield (t/ha)	Pod yield (t/ha)	Kernal yield (t/ha)	Shelling (%)	100 kernal weight (g)
T_1 - Control	1.46	2.88	1.98	68.7	36.8
T_2 - 100% RDF (30-40-50)	1.78	3.56	2.54	71.3	43.2
T_3 - Biochar @ 2t ha^{-1}	1.74	3.39	2.42	71.4	40.7
T_4 - Biochar @ 4t ha^{-1}	1.76	3.42	2.47	72.2	41.4
T_5 - 100% RDF + Biochar @ 2t ha^{-1}	1.98	3.92	2.85	72.7	44.2
T_6 - 100% RDF + Biochar @ 4t ha^{-1}	2.06	4.03	2.99	74.2	44.6
T_7 - 75% RDF + Biochar @ 2t ha^{-1}	1.91	3.61	2.61	72.3	43.2
T_8 - 75% RDF + Biochar @ 4t ha^{-1}	1.93	3.77	2.82	74.8	43.4
SEm ±	0.09	0.15	0.14	2.71	1.53
CD @0.05	0.27	0.45	0.43	NS	NS
CV%	8.56	7.13	9.39	6.50	6.27

An increase of 51% of kernel yield was observed in T_6 treatment when compared to control (T_1), clearly indicating that the combined application of biochar and inorganic fertilizers had a synergistic effect on yield improvement. This may be attributed to enhanced nutrient uptake efficiency, better root development, and improved microbial activity stimulated by the porous structure and organic carbon content of biochar. These findings were consistent with earlier reports, where a biochar dose of 10 t ha^{-1} along with NPK significantly enhanced rice grain yield from 4.32 t ha^{-1} (Control) to 6.79 t ha^{-1} (Zaitun *et al.,* 2011), suggesting similar mechanism.

4.5.4 Shelling percentage

The data on shelling percentage of groundnut present in table 4 which indicated that there was no significant difference in shelling percentage with the application of biochar and fertilizers. However slight increase could be noticed at higher application rates of biochar. Highest shelling percentage of 74.2% was observed in T_6 (100% RDF + biochar @ 4 t ha^{-1}). Lowest shelling percentage of 68.7% was noticed in T_1(control).

100 kernel weight (gm)

The data on 100 kernel weight of groundnut present in table 4.9 which revealed that that highest 100 kernel weight of 44.6 g was noticed in T_6 (100% RDF + biochar @ 4 t ha^{-1}) and lowest 100 kernel weight of 36.8 g in T_1(Control). The treatments were not significantly differed in 100 kernel weight.

CONCLUSION

The results of the study clearly demonstrate that the combination of fertilizers with cotton stalk biochar significantly improved soil water retention, nutrient holding capacity, and groundnut productivity over individual applications. While biochar or fertilizers alone provided moderate benefits, their integrated use particularly in T_6 (100% RDF + biochar @ 4 t ha^{-1}) resulted in superior performance across soil physical and chemical properties, organic carbon build up, and yield parameters. This synergistic effect can be attributed to the ability of biochar to improve soil structure and enhance nutrient use efficiency of applied fertilizers. Therefore, the integrated application of biochar with inorganic fertilizers emerges as a sustainable and effective strategy for improving soil health and maximizing groundnut yield under sandy loam conditions.

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