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Nanobiochar Production, Evaluation, and Impact on the Effectiveness of Fertilizers and the Productivity of Maize Crop on Sandy Soil

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ABSTRACT
Agriculture nanotechnology is an interesting method for improving soil fertility and increasing agricultural production. Thus, the goal of this study was to create and characterize nanobiochar (NBC), as well as assess its impact on sandy soil qualities and their implications for maize yield components along with nutritional status. In addition, a field experiment in sandy soil at the Ismailia Agriculture Research Station farm in Ismailia Governorate, Egypt, during two successive summer seasons of 2021–2022, was conducted. The maize plant was cultivated to evaluate the efficiency of applied nanobiochar (NBC) at varied rates (0, NBC_1, NBC_2, and NBC_3), which equal (0.0, 0.2, 0.4, and 0.6%), respectively, in conjunction with (60 and/or 80%) of the recommended full dose of both nitrogen (N_1 and N_2) and potassium (K_1 and K_2), respectively. This experiment's static design is a split-split design with three repetitions. The study analyzed nanobiochar (NBC) using TEM images and FTIR, revealing its specific size (12.1 nm). It revealed surface functional groups like aromatic C=C, epoxy C-O, alkoxy C-O, hydroxy-OH, H-bonding, N-H, aliphatic C-H, and Si-O groups. Elemental analyses revealed a C element content of 48.49%, H (2.748%), N (4.096%), S (0%), and O (44.69%), respectively. Also, the surface area of NBC was determined and recorded at 1315.4 m^2 g^{-1}. Regarding the findings of the field study, applying all treatments (NBC, N, and K) at all dosages increased soil attributes such as pH, electric conductivity, organic matter, and nutrient availability in maize soil over both cultivated seasons when compared to the control treatment. In general, the average values of administered nanobiochar, N, and K dosages show that the high rate of application has an effect on soil parameters. Furthermore, maize yield for both research seasons shows that NBC_3 coupled with N_2 and K_2 treatment resulted in the highest yield component (straw and grains). In both maize crop seasons, a similar trend was seen in the total nitrogen and potassium content of straw and grain. Finally, the study discovered that using nanobiochar as soil conditioners with different nitrogen and potassium fertilizer rates increased soil chemical characteristics and fertility in sandy soil, leading to increased crop components and macronutrient content.

Keywords: Nanobiochar create, TEM, FTIR, Soil chemical properties, Maize yield

1. Introduction
Agriculture has been greatly influenced by climate change and technological challenges, which has led to the usage of soil additions like biochar to boost crop output and enhance the efficiency with which chemical fertilizers are utilized. Sugarcane bagasse (SCB), a plentiful agricultural and industrial waste, is a fibrous residue left over after the sugar extraction process. Typically, a tone of sugarcane produces 280 kg of bagasse and 5.4 x 108 dry tons of sugarcane that are processed to produce sugar juice annually (Cardona *et al*., 2010). Therefore, in addition to using this trash to produce fuel, chemicals, papers, newspapers, etc., it must also be used to transform into goods with additional value. Thus, it may be applied to the process of making biochar. A material called biochar is created when biomass is thermochemical converted in an environment with little oxygen. Because of its physicochemical characteristics, it affects the environment in both beneficial and harmful ways. Biochar

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is regarded as a beneficial and active ingredient for long-term soil development plans (Ahmad *et al*., 2016). It is a carbonaceous, solid, refractory substance that is made by pyrolyzing waste biomass. The production and properties of the compound are greatly influenced by the feedstock's composition and the pyrolysis conditions (Pandey *et al*., 2020). Biochar is produced by pyrolyzing feedstock at temperatures between 350 and 600°C under oxygen-limited conditions (Sohi *et al*., 2010). The carbonization temperature plays a crucial role in the structure of biochar products, since the two primary factors that determine the properties of biochar are the kind of feedstock and the pyrolysis condition. Chen *et al*. (2019a) observed that biochar is considered a support material for enhancing soil properties and immobilizing enzymes in which a fraction of the biomass is converted into gaseous, liquid, and solid compounds because of its low cost, porosity, presence of surface functional groups, and modest surface area. According to Tein (2016), biochar is a concrete mass of carbon that is stable (Pandey *et al*., 2020). Due to its high surface activity, BC modifies the mobility and bioavailability of the chemicals by substantially contributing to the overall sorption of organic compounds in supplemented soil (Lian and Xing, 2017). According to Xia *et al*. (2020), the application rate, pyrolysis temperature, biochar feedstock, soil type, initial nutrient levels, and N&K fertilizer application rate all had an impact on the contradictory results. An interesting new approach to improving soil fertility and raising crop yields in agriculture is the use of nanotechnology. Biochar can become nanobiochar, which is widely used in the cycling of soil, plants, and the atmosphere. Owing to its tiny particle size and great specific surface area, nanocarbon may be combined with soil microelements and nutrients to create high-efficiency fertilizers with ease (Roy and Megill, 2000; Vacher *et al*., 2003; Mesarič *et al*., 2013; Guo *et al*., 2013). Nanobiochar enhances soil quality, making it more suitable for development plant growth. According to Chen *et al*. (2017), nanobiochar with a size less than 100 nm has more mobility in water and soil environments than microbiochar derived from grinding or crushing biochars. Unlike bulk biochar, which may store nutrients and immobilize hazardous compounds, nanobiochar as a transporter may enable natural solutes and pollutants to circulate. Furthermore, Zhou *et al*. (2018) claimed that nanobiochar might prevent nutrient loss from rainfall-induced erosion on loess slopes with varying plant wrap up and completed that nanobiochar had a substantial effect on soil moisture. Wang *et al*. (2016) discovered that fertilizer containing nanobiochar may boost crop yield by 10% to 20% while lowering fertilizer requirements by 30% to 50%.

Conversely, maize (*Zea mays*, L.) is an extremely valuable crop for feeding people along with animals. Of all the cereal crops, it comes in third. Increasing maize production in Egypt is crucial to filling the gap between supply and demand (Sayed, 2016). Furthermore, maize has greater potential than other cereals and can absorb a substantial amount of nutrients from the soil at various stages of development. Nitrogen, phosphorus, and potassium are the most important nutrients for enhanced yield and quantity, and they essentially control a plant's capacity to reproduce (Chaudhry *et al*., 2003).

Thus, the goals of this study were to: (i) create nanobiochar from bagasse using an easy-to-use and affordable technique for use in agriculture. (ii) to assess the qualities of the nanobiochar that was synthesized. (iii) to clarify how nanobiochar amends and enhances certain chemical characteristics of sandy soil, which reflect on maize crop productivity.

2. Materials and Methods

In this work, nanobiochar was synthesized using a hydrothermal reactor and characterized using several methods. This might be a useful technique for learning more about how nanobiochar behaves in different environmental conditions in plants and soil.

2.1. Synthesis of nanobiochar

This procedure has two steps: -

A-Biochar preparation

Biochar was created by washing sugarcane bagasse numerous times with tap water, air-drying it, and then cutting it into little pieces. Following that, the material was crushed and sieved through a 60-mesh sieve, then exposed to pyrolysis at 350 °C for 3 hours.

B-Nano-biochar synthesis

1. In a hydrothermal reactor (Fig.1), place 1 g of uniformed, 60-mesh screen-size biochar.

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2. Add 15 mL of concentrated HNO_3 and 45 mL of concentrated H_2SO_4 to each gram of powdered biochar. Allow the reaction to proceed at room temperature in the fume hoods for 2 hours.
3. Pour the mixture into a beaker with 1000 mL of deionized water after transferring it from the hydrothermal reactor. Stir with a glass rod for one minute, then set the beaker aside for ten minutes.
4. Remove the particles and pass the suspension through a 0.22-M membrane vacuum filter.
5. Place the filter membrane (coated with charcoal nanodots) in a dry oven at 65°C for 48 hours **(Guo *et al.*, 2020).**

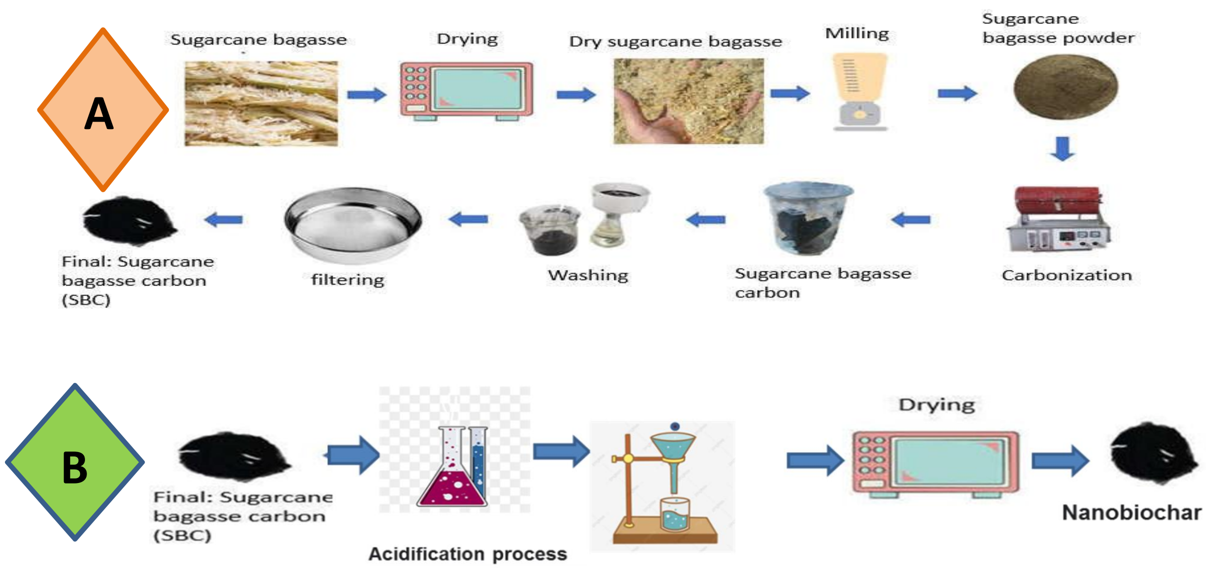

Fig. 1: Preparation of biochar and nonobiohar from bagasse

2.2. Nano-biochar characterization

1. The structure of nanobiochar's surface was examined by the use of Transmission Electron Microscopy (TEM).
2. The Fourier-transform infrared spectra analyzer (Backman-IR 250 double beam grading spectrophotometer) was used to measure the structures of the nanobiochar. The scanning range was 400–4000 cm^{-1}. At the Micro Analytical Centre, Cairo University, the dried powder was prepared for infrared spectra using the KBr pellet technique described by Stankovich *et al.* (2007).
3. The elemental makeup of nano-biochar was analyzed by an antomatic analyzer CHNS (Varioel 111 elementer) at the Microanalytical Centre, Cairo University. Oxygen was determined by deducting the aggregate sum of carbon%, nitrogen%, hydrogen%, and sulfur% from 100 (Zhao *et al.,* 2015).
4. The BET surface area analyzer (Autosorb AS-1MP, Quanta Chrome, USA) at Cairo University's Micro Analytical Centre was used to determine the specific surface area of biochar.

2.3. Field experiment

A field experiment cultivated with maize (*Zay maize* Triple Hybrid Variety 321) in sandy soil below an irrigation system with sprinklers was carried out at the Agriculture Research Centre experimental station in the Ismailia region of the Ismailia Governorate, Egypt, over two consecutive summer seasons in 2021 and 2022. The farm of the institute is situated at latitude 30° 35 41.9" N and longitude 32° 16 45.8". The purpose of this study was to see how different rates of nanobiochar (0.0, 0.2, 0.4, and 0.6%) in composites varying the rates of nitrogen and potassium fertilizers (60 and 80%) of typical dosages affected soil chemical properties, maize yield productivity, and nutrient uptake. The soil under investigation was examined using the techniques outlined by Cottenie *et al.* (1982). Table 1 displays a few of the soils used in the experiment locations' physical and chemical properties. The features of employing nanobiochar are also displayed in Table 2.

Table 1: Some of the experimental soil's chemical and physical characteristics

Properties	Values	Properties	Values
Particle size distribution %		**Chemical properties**	
Coarse sand	50.4	$CaCO_3$ %	**1.40**
Fine sand	40.4	pH (soil: water suspension 1:2.5)	**7.73**
Silt	30.2	EC dSm^{-1} (1:5 soil: water extract)	**0.37**
Clay	6.00	Organic matter %	**0.32**
Texture class	Sandy		
Soluble cations and anions (meq L^{-1})			
Ca^{++}	0.94	CO_3^{-}	--
Mg^{++}	0.89	HCO_3	1.42
Na^{+}	1.45	Cl^{-}	1.02
K^{+}	0.45	SO_4^{--}	1.29
Available nutrients (mg Kg^{-1})			
N	40.0		
P	15.0		
K	67.0		

Table 2: Some of the chemical features of nanobiochar that were employed in the experiment.

Characteristics	Values
pH (1:2.5 soil : water suspension)	7.92
EC dS m^{-1} (1:5)	2.97
Surface area (m^2g^{-1})	1354
CEC (cmole kg^{-1})	79.03
P%	1.4
K%	1.9

Experimental design

The split-split plot design was used to establish up the experiment with each treatment reproduced three times. The main plots were four nanobiochar rates (0, 0.2, 0.4, and 0.6%). The sub main plots show two nitrogen fertilizer rates (60 and 80% of the required dosage). The sub-sub main plots represent two potassium fertilizer rates (60 and 80% of the demanded dosage).

Fertilizers application

Prior to cultivation, fertilizer treatments were administered to maize crops, including superphosphate (15% P_2O_5) at a rate of 200 kg fed. $^{-1}$. In order to provide potassium, potassium sulphate (48% K_2O) was administered at two different rates: 60% and 80% of the suggested dosages (50 kg fed^{-1}. Each was split into two equal dosages, the first of which was administered at seeding and the second of which was added 30 days later. After 15, 30, 45, and 60 days following planting, nitrogen treatments (60 and 80% of the necessary dosage) were also administered in the form of ammonium nitrate (33.5% N) at 400 kg fed^{-1}, split into four equal doses.

Soil analysis

At the end of the growing season, soil samples were obtained from each plot of soil and analysed for several soil chemical properties, as stated by Cottenie *et al*. (1982) as follows:

1. The electrical conductivity (EC) dSm^{-1} in soil water extract is 1:5.

2. The pH of the soil was tested in 1:2.5 soil water suspension.
3. Organic matter percentage (OM%)
4. Nitrogen forms (available nitrogen, NH_4, and NO_3).
5. Potassium forms (soluble, exchangeable, and available) were determined.

Plant sample

Plants have been collected at harvest time in order to assess the grain and straw yield components of the maize crop. According to Page *et al*. (1982), plant materials were weighed, oven dried at 70 °C to a consistent dry weight, then crushed and digested using a mixture of H_2SO_4 and H_2O_2. After that, the digested samples were assessed for nutrients (N and K) using the Cottenie *et al*. (1982) technique, and the total amount of nutrients in the plant's grain and straw was calculated.

Statistical analysis

The acquired data underwent statistical analysis of variance using a computer software CoStat Software (2004).

3. Results and Discussion

3.1. Nanobiochar structural properties.

Biochar is made from polycyclic aromatic hydrocarbons, which have six carbon atoms bound in a ring. Biochar is resistant to biological and chemical changes due to the existence of such an aromatic structure (Farshad *et al*. 2015). Biochar contains additional elements besides carbon, such as hydrogen and oxygen. Certain minerals, such sulphur, phosphorus, and nitrogen, could be present depending on the raw material that was used to make the biochar. This carbon compound has a variety of functional groups, including hydroxyl, ketone, ester, aldehyde, amino, nitro, and carboxyl. The size of the pores in nanobiochar is split into three categories: (1) macrospores with a diameter more than 50 nm. (2) Mesoporous with a diameter of 2 to 50 nm. (3) Microspores having a diameter of less than 2 nm.

3.2. Identification of nanobiochars

3.2.1. Transmission electron microscopy (TEM)

The TEM pictures (Fig. 2) demonstrated the production of biochar nanoparticles, as shown in Fig. 1. The linked holes on the surface of nanobiochar are visible by TEM image analysis. The size of the NBC varied from 4.94 to 12.1 nm. Their ideal size may be confirmed by using high-resolution electron microscopy to determine their shape, size, and composition. According to Guo *et al*. (2020), biochar nanoparticles were generated as evidenced by TEM pictures, and biochar nanodots, which ranged in size from 2 to 10 nm, were revealed by TEM measurement. Furthermore, the pure pyrolyzed biochar exhibited a broad variety of sizes and a range of 1.6% to 2.6% for the proportion of nanoparticles. Moreover, the surface area of NBC was 1315.4 m^2 $gm.^{-1}$ it's due to the heat treatment of biochar at 350 ° C which left many pores to increase its surface area. According to Abed Hussein *et al*. (2022), nano biochar has a specific surface area of more than 1500 m^2 gm^{-1} at 400°. The parameters of the thermal breakdown process and the kind of biomass directly affect the attributes of nanobiochar, such as elemental composition, porosity %, particle or pore size, and the presence of degradable hydrocarbons. Pratap *et al*. (2021) found that reducing biochar to nanosize improves its properties such as high surface area, high porosity, increased surface functional groups and surface active sites, which leads to increased adsorption of pollutants, enhanced nutrient retention and thus increased crop yield.

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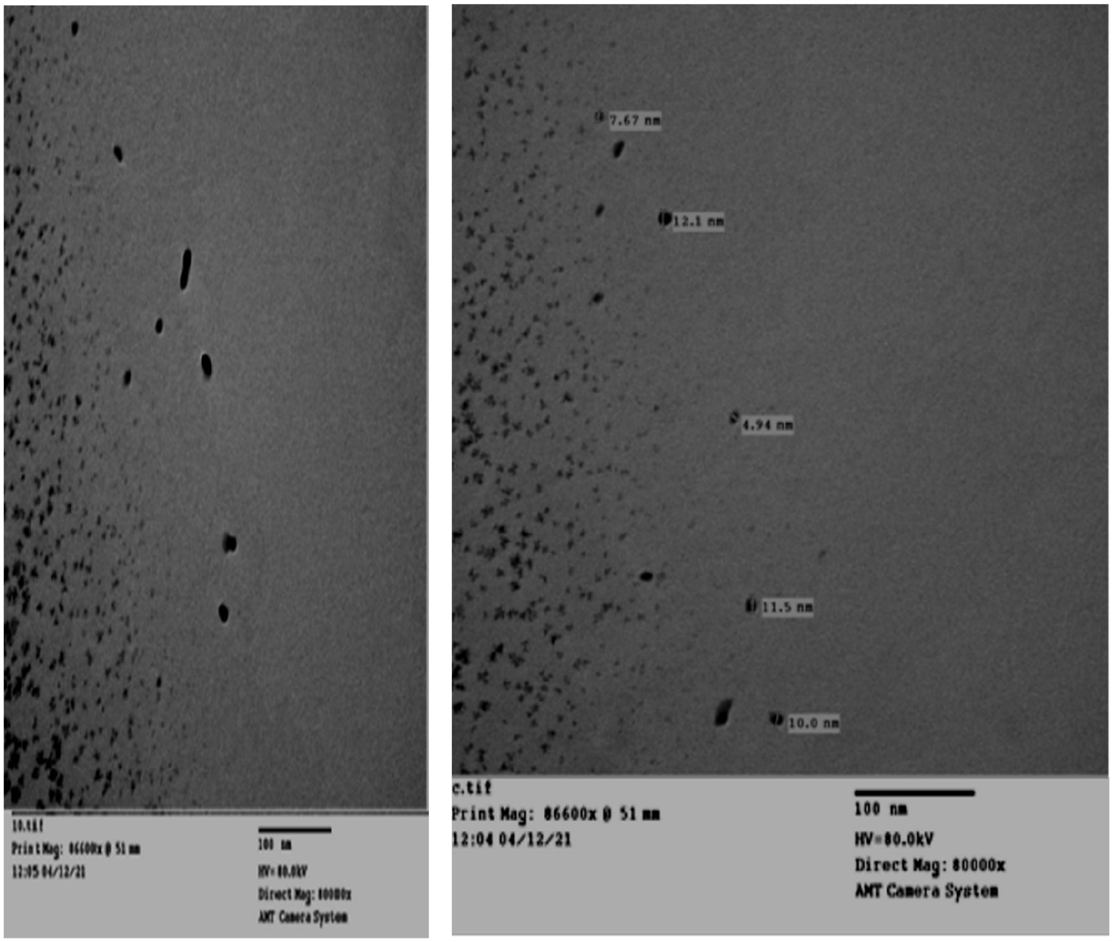


Fig. 2: TEM pictures of nanobiocahr derived from sugarcane bagasse pyrolysis

3.2.2. Fourier-transform infrared spectra analyzer (FTIR)

The materials' structure and functional groups were studied using FTIR spectrum analysis, as indicated in Table 3. FTIR spectra were obtained with a resolution of 1 cm^{-1} in the 400–4000 cm1 range. The carboxyl C=O (1716 cm^{-1}), aromatic C=C (1618 cm^{-1}), epoxy C-O (1228 cm^{-1}), alkoxy C-O (1107 cm^{-1}), hydroxyl-OH (3433 cm^{-1}), and Si-O (579 cm^{-1}) groups all displayed evident adsorption bands in the NBC. The presentation of functional groups containing oxygen, such as C=O and C-O (Fig.3).

When compared to biochar, nanobiochar contains more strong peaks and more functional groups, with numerous newly developing peaks such as primary alcohol stretching and aliphatic chains. Agriculture-based biochar containing COOH and other CO functional groups provides sorption sites in the environment for heavy metals, dyes, and other contaminants. The FTIR spectrum was obtained in the manner described in the literature (Song *et al*., 2019). Furthermore, Ayman *et al*. (2020) discovered that the examination of biochar shows that it has a lot of functional groups, including carbonyl and silicon groups, hydroxyl (OH), ketone (C=O), carboxyl (COOH), siloxane (Si-O-Si), and silanol (Si-O, Si-H). The broadband intensity in the bagasse-produced biochar ranges from 3670 to 2750 cm^{-1}, with a highest peak at 3400 cm^{-1}. The stretching vibration of OH groups is represented by this peak. Moreover, the carboxyl, carbonyl, and ketone groups were seen between 3000 and 1500 cm^{-1}. Furthermore, the silicon groups surfaced in the 1200–300 cm^{-1} range. These findings suggest that the biochar generated at temperatures lower than 500°C contains a significant amount of active groups (Zolfi Bavariani *et al*., 2019). According to Sadia *et al*. (2023), biochar and nanobiochar spectra show alkane C–H stretching at (3000–2840 cm^{-1}), secondary N–H bend at 1650–1550 cm^{-1}, methyl C–H asymmetric stretching at 1440–1400 cm^{-1}, primary alcohol C–O stretching at 1085–1050 cm^{-1}, trisubstituted alkene C=C bending at 840–790 cm^{-1}, and at 795 cm^{-1} C–H bending. At 1000–625 cm^{-1}, one aromatic ring substitute. Additionally, two peaks between 980 and 1100 cm^{-1} and between 650 and 800 cm^{-1} are visible in the FTIR spectra study. The existence of Si–O–Si bonds with stretching vibrations and curvature is indicated by these peaks.

Table 3: FTIR spectra of the generated nanobiochar's chemical composition and functional group types

Peaks (cm^{-1})	Assignment
3433	Frequency of H-bonding of O-H, N–H Stretching (trace).
2919	Aliphatic C-H stretching.
1716	Olefin and aromatic C=C, C=O stretching of COOH, ketones (trace), quinine and amide.
1618	Aromatic C=C, strong H-bond C=O conjugated ketones.
1540	Amide and/or aromatic C=C.
1344	OH deformation and C=O stretching of phenolic OH, C–H deformation of CH_2 and CH_3 groups, COO- anti-symmetric stretching.
1228	C–O Stretching and OH deformation of COOH, C–O stretching of aryl ethers.
1107	Aliphatic CH_2, OH or C–O groups.
579	Aromatic ethers, possibly polysaccharides and Si-O of silicates.
452	Para-di-substituted aromatic ring bend.

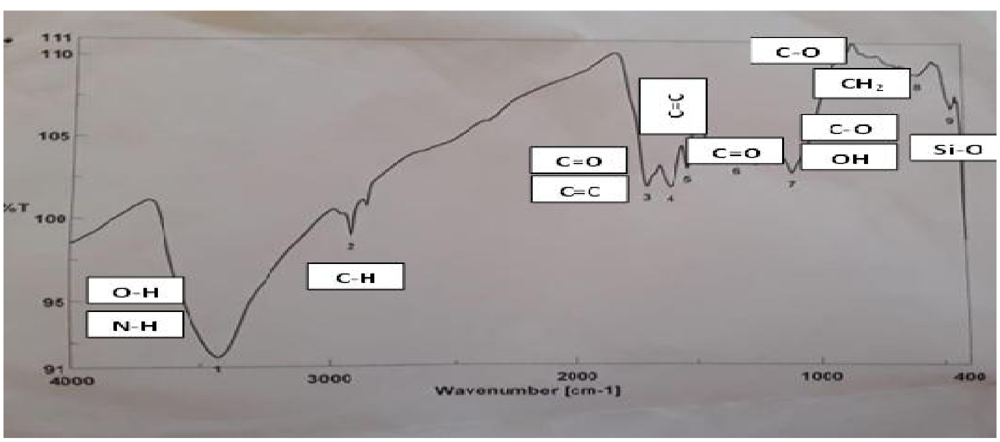


Fig. 3: FTIR spectra of the chemical composition of the generated nanobiochar, along with the functional group types.

3.2.3. The elemental analyses of nanobiochar (EM).

Table 4 displays the element composition of nanobiochar (EM). Based on theoretical calculations, we can deduce that the C element content in NBC was around 48.49% and the N element content was 4.096, which aligns with the experimental findings of the elemental analysis. Furthermore, in the NBC, H (2.748%) and S (0%) were noted. In the meantime, the O element content in the NBC was around 44.67%, according to the EA data.

Table 4: The elemental analyses result of NBC.

Elements	C%	N%	H%	S%
NBC	48.49	4.096	2.748	0

3.3. Field experiment.

3.3.1. Effects of nanobiochar application on some soil chemical properties

Data in Table (5) showed the changes of some soil chemical properties (pH, EC and OM) as affected by the studied treatments. The addition of NBC causes changes in pH, electrical conductivity (EC) and organic matter (OM %).

A. Soil reaction

Table 5 shows that soil pH was modestly elevated as a result of varying NBC application rates when compared with control; this tendency was consistent over both seasons. The mean value of pH under different NBC rates was, in general, increased as the NBC rate increased; NBC_3 recorded the highest pH value as compared to other rates. A similar tendency was seen for mean pH values as modified by varying rates of nitrogen or potassium; high rates were associated with higher pH values than low rates. Furthermore, mean values of NBC, N and K in the second season had the highest pH levels when compared to the first season.

Table 5: Some chemical parameters of the studied soil's response following maize crop harvesting in two subsequent seasons, as altered by varying rates of NBC, nitrogen, and potassium fertilizer applied.

Treatments			First season			Second season		
Nanobiochar rates (%)	**Nitrogen rates**	**Potassium rates**	**pH 1:2.**	**EC dSm^{-1}**	**OM %**	**pH 1:2.5**	**EC dSm^{-1}**	**OM %**
Control			7.68	0.85k	0.55k	7.82e	0.62i	0.58l
NBC_1 0.2%	**N_1**	**K_1 (60%)**	7.77	1.12h	0.64i	8.21a	1.16f	1.00k
	60%	**K_2 (80%)**	7.73	1.08i	0.61j	7.77g	1.12e	1.04j
	Mean		7.75	1.13	0.63	7.87	1.14	1.02
	N_2	**K_1 (60%)**	7.86	1.17g	0.66i	7.97c	1.08h	1.09g
	80%	**K_2 (80%)**	7.81	1.06j	0.89d	7.92d	1.24e	1.17h
	Mean		7.84	1.06	0.78	7.92	1.16	1.13
NBC_2 0.4%	**N_1**	**K_1 (60%)**	7.95	1.37a	0.73h	7.99c	1.35c	1.01i
	60%	**K_2 (80%)**	7.79	1.16e	0.86e	7.90f	1.17f	1.32c
	Mean		7.87	1.23	0.80	7.94	1.26	1.17
	N_2	**K_1 (60%)**	7.86	1.30d	0.75g	7.97c	1.12e	1.27f
	80%	**K_2 (80%)**	7.65	1.18f	1.06b	7.76g	1.25e	1.30c
	Mean		7.75	1.18	0.91	7.76	1.18	1.28
NBC_3 0.6%	**N_1**	**K_1 (60%)**	7.84	1.32c	0.84f	7.96c	1.37b	1.22d
	60%	**K_2 (80%)**	7.61	1.34b	0.91c	8.06b	1.15f	1.23e
	Mean		7.72	1.24	0.90	7.98	1.26	1.23
	N_2	**K_1 (60%)**	7.78	1.13h	0.90c	7.90f	1.30d	1.46b
	80%	**K_2 (80%)**	7.72	1.31d	1.21a	7.84e	1.51a	1.53a
	Mean		7.75	1.31	1.21	7.93	1.33	1.50
Mean of Nano-biochar		**(0.2%)**	7.79	1.11	0.70	7.89	1.15	1.08
		(0.4%)	7.81	1.21	0.85	7.88	1.22	1.22
		(0.6%)	7.74	1.26	0.96	7.93	1.33	1.36
Mean of Nitrogen rates		**(60%)**	7.78	1.14	0.75	7.89	1.12	1.03
		(80%)	7.87	1.20	0.91	8.10	1.17	1.06
Mean of Potassium rates		**(60%)**	7.72	1.15	0.72	7.92	1.25	1.22
		(80%)	7.79	1.17	0.94	7.94	1.31	1.34

The interaction between tested treatments Table 5 observed that the pH values were increased from 7.68 to 7.95 in first season but in the second season increased from 7.82 to 8.21. These interactions between all treatments in the soil led to an increase in pH values, which ranged from 0.27 to 0.39 units for both seasons. Additionally, the first season's greatest pH value was recorded for NBC_2 combined with N_1 and K_1, whereas the second season's values were higher for NBC_1 N_1K_1 treatment. The dissolution of alkaline substances may be responsible for the pH rise. Gezahegn *et al*. (2019) reported a similar outcome and noted that the addition of biochar raises the pH of the soil because metal cations compete with H^+ ions for cation exchange surface sites. The biochar's magnesium, calcium, sodium, and potassium oxides, carbonates, and hydroxides hydrolyze to produce hydroxide ions, which raise the soil's pH. Consequently, applying nonbiochar to the soil might alter its pH over time. Similarly, depending on a variety of conditions, such as the kind of waste used to make the nanobiochar, NBC may raise the pH of the soil (Kundu *et al*., 2020; Mohammad *et al*., 2021). The results of Van Zwieten *et al*. (2010) and Chan *et al*. (2007), who demonstrated a rise in soil pH following the application of nanbiochar, are also consistent with the data collected. As the pyrolysis temperature increases, Van Zwieten *et al*. (2009) found that the pH of the biochar increases in two parallel ways: (1) the concentration of basic elements (alkali metals and alkaline earth metals) inherited from the feedstock increases, and (2) the concentration of acidic surface functional groups decreases. These results are in line with other studies (Ronsse *et al*., 2013) that showed a decrease in acidic functional groups with greater pyrolysis temperatures and an increase in components essential to plant nutrition.

B. Electric conductivity

Table 5 shows the dissolved salt content (electrical conductivity) determined at the end of the experiment in both seasons of maize-cultivated soil. All treatments applied resulted in a considerable rise in EC values overall when compared to the control. In comparison to the control, the average EC values were greater with higher rates of NBC, N, and K application over both research seasons. According to research by Wang *et al*. (2016) and Laird *et al*. (2010), the electric conductivity in soil rose progressively as the amount of nanobiochar grew. This may be because of the high CEC of the soil and the abundance of negatively charged functional groups on the surface, which allows biochar to retain nutritional cations like NH_4^+, K^+, Ca^{+2}, and Mg^{+2}. Furthermore, in comparison to the first season, the same therapies rose in the second. According to Nigussie and Kissi (2011), another explanation for the strong and positive correlation between EC and exchangeable bases during biochar reduction is the presence of ash, which has a high concentration of basic cations. Additionally, Table 5 demonstrates that the $NBC_2N_1K_1$ and $NBC_3N_2K_2$ treatments had the greatest EC values in the first and second seasons, respectively, when the NBC, N, and K treatments were combined. obtained data that was in concordance with Ulyett (2014) and Hua *et al*. (2014).

C. Organic matter

Table 5 shows the soil organic matter following maize harvesting in both cultivated seasons. The results show that the administered NBC, N, and K treatments significantly increased organic matter (OM) relative to the control during two seasons. The mean values of NBC, N, and K show that OM content was greater when high rates of all tested treatments were used in two seasons. These results are in line with those of Utomo (2010) and Sukartono *et al*. (2011), who found that adding more biochar to the soil resulted in a significant increase in carbon and organic carbon content compared to control. According to the findings, adding nanobiochar to the soil greatly improves the organic carbon content (Kianfar, 2020; Majdi *et al*., 2021). Furthermore, biochar may absorb soil organic matter, increasing soil organic carbon content along with CEC and preserving soil organic carbon, according to research by Honarvar *et al*. (2021). As a result, the soil's organic carbon does not break down and instead grows more organic matter over time.

As a result, the soil's organic carbon does not break down and instead grows more organic matter over time. Furthermore, in two seasons, the treatments of NBC_3 mixed with N_2 at K_2 resulted in considerably higher OM content. This treatment achieved high OM% levels of 1.21 and 1.53% in maize soil for two seasons, respectively. The outcomes that were achieved match those observed by Lu *et al*. (2014b) and Liu *et al*. (2016). When 0.8% nanobiochar is given to the soil, the amount of organic carbon rises by approximately 41% after 210 days. Nanobiochar is thought to improve the stability of soil organic carbon while decreasing mineralization (Syah *et al*., 2021; Dmitry *et al*., 2021). Organic carbon stability in soil can be enhanced in three ways: (1) aggregation of organic carbon; (2) fusion of organic carbon with clay and silt particles (silt or fine-grained soil); and (3) soil biochemical stabilization through the creation of degradable SOC compounds. Abed Hussein *et al*. (2022) recently found that nanobiochar micrometric porosity enhances soil moisture-holding capacity and increases soil moisture-holding capacity and increasing moisture means reducing the decomposition of SOC.

D. The effect of nanobiochar combined with nitrogen and potassium at varying rates of N and K formed in soil

Table 6 provides data in the current NBC based on the availability of N and K as well as their forms in the soil following the harvest of maize crops in both farmed seasons. According to the findings, the administration of the medicines resulted in an increase in both N and K forms when compared to the control therapy. As the applied rate on NBC increased, the mean values of the potassium and nitrogen forms gradually rose. As the application rate rose, so did the total available nitrogen, ammonium, and nitrate. The directions for soluble, exchangeable, and available potassium are the same. As stated by Albiter *et al*. (2010), the presence of nanobiochar in a consistent crop lowers the rate of nitrogen delivery to the deep soil.

Table 6: Response of nitrogen and potassium forms after harvested at two seasons as affected by applied different rates of nanobiochar and nitrogen and potassium fertilizer.

Treatments			First season					
			Nitrogen forms			Potassium forms		
Nanobiochar rates (%)	Nitrogen rates (%)	Potassium rates (%)	Avail. N	NH4+	NO3-	Ka	Ks	Ke
	Control		86.90j	65.03L	21.91d	42.00e	19.63h	11.47f
NBC1 0.2%	N1 60%	K1 (60%)	112.20i	96.03k	16.21f	56.50d	25.35e	31.15e
		K2 (80%)	123.20h	104.50j	18.70e	61.50c	26.65e	34.85e
	Mean		117.68	100.25	17.43	59.00	26.00	33.00
	N2 80%	K1 (60%)	131.01g	111.81f	19.23e	64.35c	27.95e	36.40e
		K2 (80%)	141.01d	122.71b	21.11d	81.90b	29.25d	52.65c
	Mean		136.01	117.25	20.15	73.13	28.60	44.53
NBC2 0.4%	N1 60%	K1 (60%)	131.11g	99.03k	21.31d	62.10c	21.45g	42.47d
		K2 (80%)	137.01f	107.01i	23.04c	62.88c	27.30e	41.43d
	Mean		134.06	103.00	22.14	62.49	24.38	41.95
	N2 80%	K1 (60%)	137.01f	112.81e	24.21c	68.67c	30.53c	41.37d
		K2 (80%)	154.61b	123.03b	30.61a	96.97b	30.70c	64.47b
	Mean		145.82	117.92c	27.40	82.82	30.62	52.92
NBC3 0.6%	N1 60%	K1 (60%)	132.31g	109.53h	21.71d	73.62c	20.80g	52.82c
		K2 (80%)	139.91e	114.54d	23.43c	89.70b	24.70f	66.30b
	Mean		136.07	112.00	22.55	81.66	22.75	59.56
	N2 80%	K1 (60%)	147.01c	120.03c	28.03b	92.30b	37.70b	54.60c
		K2 (80%)	158.81a	128.01a	30.34a	111.15	42.90a	68.25a
	Mean		152.88	124.25	29.11	101.73	40.30	61.43
Mean of nanobiochar		(0.2%)	126.85	108.75	18.79	66.06	24.90	38.76
		(0.4%)	139.94	110.46	24.77	72.66	27.50	47.44
		(0.6%)	144.47	118.13	25.83	91.69	31.53	60.49
Mean of nitrogen rates		(60%)	129.27	105.08	20.70	67.72	24.38	44.84
		(80%)	144.90	119.81	25.55	85.89	33.17	52.96
Mean of potassium rates		(60%)	131.77	108.19	21.76	69.59	27.30	43.13
		(80%)	142.40	116.69	24.49	84.02	30.25	54.66

Table 6: Continued

			Second season					
			Nitrogen forms			Potassium forms		
Nanobiochar rates (%)	**Nitrogen rates (%)**	**Potassium rates (%)**	**Avail. N**	**NH4+**	**NO3-**	**Ka**	**Ks**	**Ke**
	Control		89.84k	67.9lL	22.01	52.31k	24.74h	27.52l
NBC1 0.2%	**N1 60%**	**K1 (60%)**	115.10j	98.90k	16.20	66.80j	30.46f	36.30k
		K2 (80%)	126.11i	107.41	18.71f	71.83i	31.76e	40.00j
		Mean	120.58	103.10	17.48	69.26	31.11	38.15
	N2 80%	**K1 (60%)**	133.91h	114.71f	19.31f	74.63g	33.06d	41.55i
		K2 (80%)	143.93e	125.54c	18.41f	92.2c	34.36d	57.80f
		Mean	138.91	120.10	18.81	83.38	33.71	49.67
NBC2 0.4%	**N1 60%**	**K1 (60%)**	134.31h	102.1i	32.2a	73.2h	27.56g	61.34e
		K2 (80%)	140.21f	110.13	30.14	74.01f	33.41d	73.52b
		Mean	137.28	106.11	31.17	73.62	30.49	67.43
	N2 80%	**K1 (60%)**	140.23f	115.93f	24.34	79.81e	36.64c	63.12d
		K2 (80%)	157.9b	126.13	31.83a	108.13b	36.81c	76.77a
		Mean	149.04	121.03	28.01	93.95	36.73	69.95
NBC3 0.6%	**N1 60%**	**K1 (60%)**	136.31g	113.63e	22.71e	89.43d	27.92g	45.67g
		K2 (80%)	143.81d	118.63	25.21	105.31b	31.82e	40.60i
		Mean	140.06	116.10	23.96	97.30	29.87	43.14
	N2 80%	**K1 (60%)**	151.03c	124.13c	26.93c	107.93b	44.82b	43.15h
		K2 (80%)	162.84a	132.61a	30.23a	126.81a	50.02a	71.29c
		Mean	156.87	128.35	28.52	118.37	47.42	57.22
Mean of nanobiochar		**(0.2%)**	129.75	111.60	18.15	76.32	30.01	34.83
		(0.4%)	143.16	113.57	29.59	83.79	33.61	68.69
		(0.6%)	148.46	122.23	26.24	107.33	38.65	83.79
Mean of Nitrogen rates		**(60%)**	132.64	108.44	24.20	80.06	30.49	49.57
		(80%)	148.27	123.16	25.11	98.23	39.29	58.95
Mean of Potassium rates		**(60%)**	135.14	111.55	23.59	81.93	33.41	48.52
		(80%)	145.77	120.05	25.72	96.36	36.36	60.00

By creating nitrate accumulation in the soil, excessive nitrogen application increases the danger of nitrate leaching (Zhang *et al*., 2010). According to Dempster *et al*. (2012), using biochar increases nitrate adsorption. By banding nanobiochar 5–10 cm below the surface, nitrate leaching may be reduced and nitrogen utilization efficiency increased in fertilized soils. Furthermore, the application of NBC at various rates in combination with nitrogen and potassium reveals that the treatment NBC_3 combined with N_2 and K_2 was, in general, superior for total nitrogen availability and its forms (NH_4^+-N and NO^-_3 –N) in maize soil during both seasons. In the first and second seasons, the maximum significant values of (NH_4^+-N) were 128 and 132.6 mg Kg^{-1} soil, respectively, compared to (NO_3^--N) 31 and 32 mg Kg^{-1} soil. Applying nanobiochar to the soil improved the availability of nitrogen significantly by increasing adsorption sites and nutrient availability. Kameyama *et al*. (2012) discovered that at high pyrolysis temperatures, the biochar had a high pH (8.7-9.8) and reasoned that NO_3^- adsorption was caused by base functional groups rather than physical adsorption because surface area and microspore volumes followed different trends when compared to observed NO_3^- adsorption. Recently, Abed Hussein *et al*. (2022) found that, as a consequence, the fertilizer's effectiveness rises and the plant receives more nutrients throughout the growing season. In accordance to research, biochar can reduce the rate of nitrogen fertilizer (ammonium compounds) leaching by up to 60%. Moreover, the impact diminishes the biochar's surface functional groups that are accountable for NO_3^- and NH_4^+ adsorption, therefore elevating the quantities of these elements in the soil (Zhang *et al*., 2018; Zhou *et al*., 2017). Over time, the N. molecules adsorbed on the surface of the biochar may desorb and become accessible (Taghizadeh-Toosi *et al*., 2012).

The pattern for the potassium forms, on the other hand, was the same for the nitrogen forms: exchangeable (Ke), soluble (Ks), and available (Ka). The treatment NBC_3 in conjunction with N_2 and

K_2 produced the greatest potassium forms (Ka, Ks, and Ke) for maize soil during two seasons, according to the results. This outcome can be explained by the fact that, particularly in organic farming, biochar can be a useful supply of potassium for crop uptake since over 50% of its total potassium content dissolves in water and is bioavailable (Berek *et al*., 2018).

These results correspond with Yang *et al*. (2020), who found that when soil was amended at rates of 0.7% and 1% with nanobiochar, the average accessible potassium level rose by 11.1% and 22.6% relative to the control, respectively. Additionally, nanobiochar can improve soil fertility by making macronutrients like potassium more readily available in the soil (Dong, *et al*., 2016). When adsorption is minimal, available potassium is relatively mobile in the soil (Rens *et al*., 2018). The attachment of nanobiochar to soil particles, which increased the number of microscopic soil pores, hampered the long-term flow of potassium ions. This ensures high potassium ion concentrations in the root layer and extends the residence time of the accessible potassium ions in the nanobiochar layer. This improves the utilization of potassium by spring maize.

To clearly illustrate the situation and state that there is a linear relationship between the rate of nanobiochar and the amount of organic matter in the soil. Fig. 4 illustrates the substantial positive linear connection (R^2 = 0.987 and R^2 = 1) that was discovered for the two seasons' rates of nanobiochar and OM%, respectively. The results of this experiment also showed a similar pattern between the N forms in the soil and the rates of nanobiochar (Fig. 5), with R^2 = 0.929, R^2 = 0.885, and R^2 = 0.855 for N, NH_4^+, and NO_3^-, and R^2 = 0.928, R^2 = 0.985, and R^2 = 0.986 for Ka, Ks, and Ke at the first season, respectively. As well as in the second season, R^2 = 0.940, R^2 = 0.808, R^2 = 0.470 for N, NH_4^+ and NO_3^-, respectively. This demonstrated a good relationship between the examined factors and nanobiochar rates for both seasons.

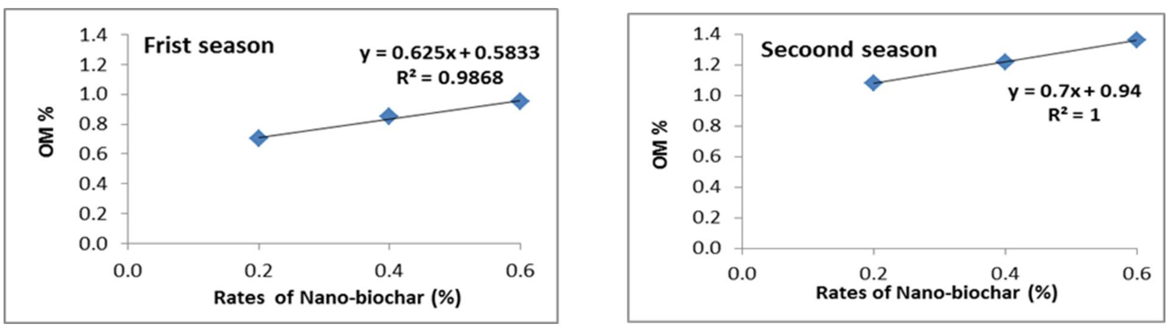


Fig. 4: Relations between organic matter concentration in the studied soil after harvest and different rates of nanobiochar.

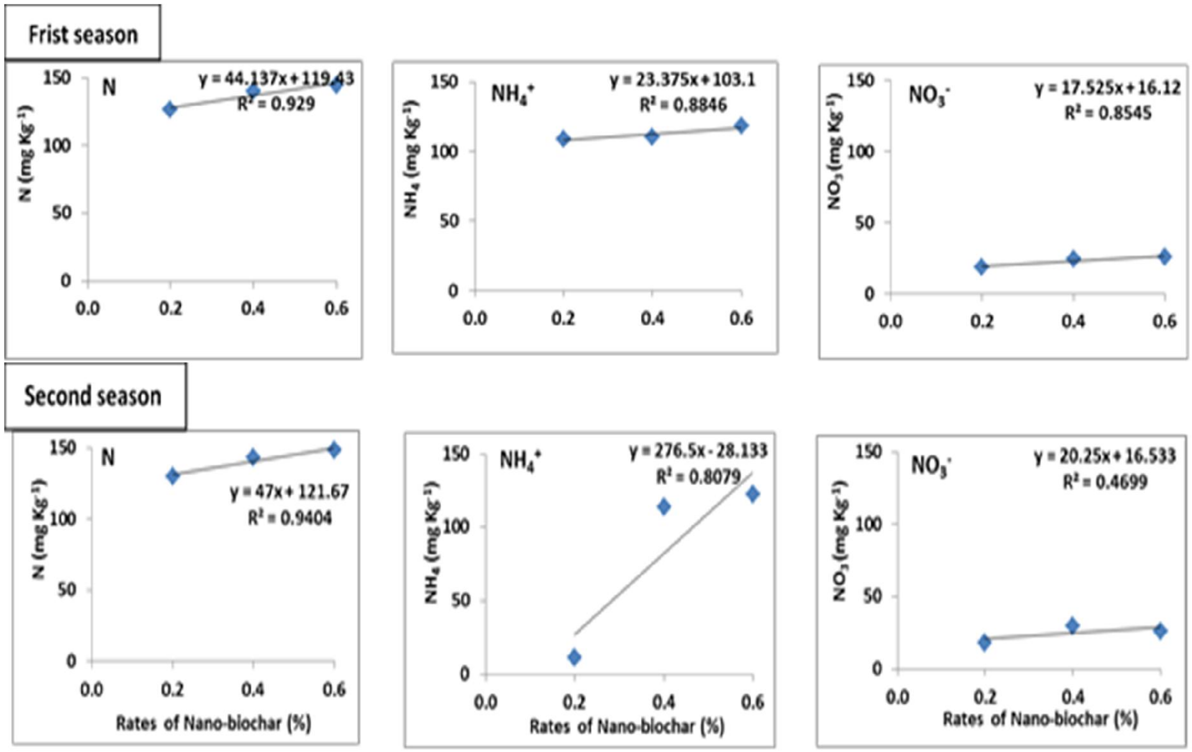


Fig. 5: Relationships between nitrogen forms of the experimental soil after maize harvested at different rates of nanobiochar.

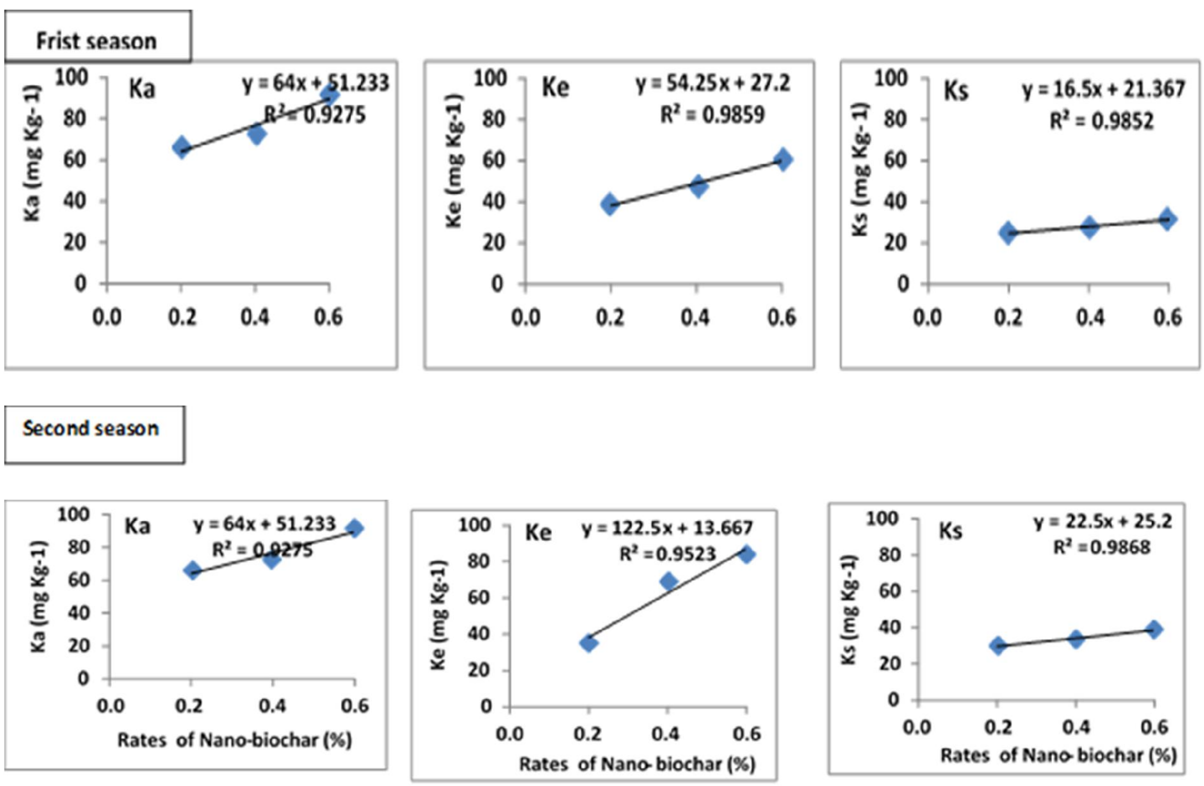


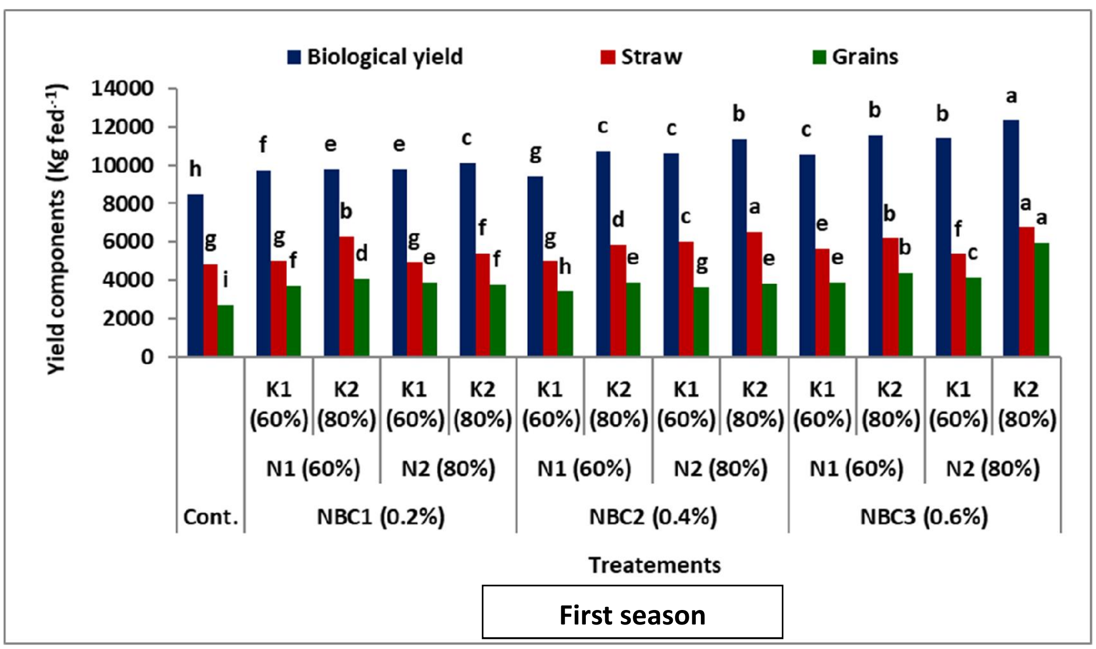
Fig. 6: Relationships between potassium forms of the tested soil after being harvested at different rates of nanobiochar.

2-The effect of nanobiochar combined with different rates of nitrogen and potassium on maize yield components and total macronutrient content

A-Yield components

Fig. 7 illustrates the impact of nanobiochar as a new soil conditioner on the three components of maize output (biological yield, straw, and grain yield) when combined with different rates of nitrogen and potassium application. The outcomes show that, compared to the control treatment, applying various treatments significantly increased the components of maize yield. These findings are consistent with those of Harpole and Biederman (2013), who discovered that nanobiochar functions as a soil conditioner, enhancing soil physical characteristics and nutrient usage efficiency and thereby promoting plant growth. Plant growth and development can be aided by nanoparticles by boosting nutrient intake, improving water uptake efficiency, and increasing photosynthetic activity. Furthermore, the application of biochar increases the availability of soil moisture and nutrients to plants, resulting in increased plant growth and crop production. Because of its physical and chemical qualities, as well as its porous structure, nanobiochar has emerged as a viable choice for soil amendment, an effective enzyme support, and an excellent adsorbent.

Also, over the course of two seasons, the application of NBC_3 in combination with N_2 and K_2 had been superior for the growth of maize yield components (biological yield, grain, and straw yield) in both tested seasons. In the first season of maize plants, the relative percentage of biological yield, straw, and grain was 79.41, 69.24, and 75.93%, respectively, compared to the control. As well as the second season, the percentage was 45.18, 39.91, and 61.3 % for the same yield component, respectively. The obtained findings might be attributed to the presence of nanobiochar, increased specific surface area, micro porosity, and surface hydrophobicity (Qin *et al*., 2012; Zhou *et al*., 2017, 2018; Yang, 2020). Wang *et al*. (2016) discovered that nanobiochar fertilizer may increase crop productivity by 10% to 20% while reducing fertilizer requirements by 30% to 50%. According to research, biochar can reduce the rate of nitrogen fertilizer (ammonium compounds) leaching by up to 60%. In the context of the influence of different rates of nanobiochar application, mean values showed that, in general, the application NBC_3 rate of nanobiochar considerably enhanced maize yield components (biological yield, straw yield, and grain yield). The acquired data might be attributed to the addition of nanobiochar, which improves soil quality, creates a favorable environment for microorganisms, and enhances soil WHC and fertility, hence enhancing soil suitability for plant production and development (Farid *et al*., 2014; Liu *et al*., 2020). A similar pattern was seen with mean maize yield (straw and grains) values as impacted by high rates of both N and K treatments (80% N and 80% K).



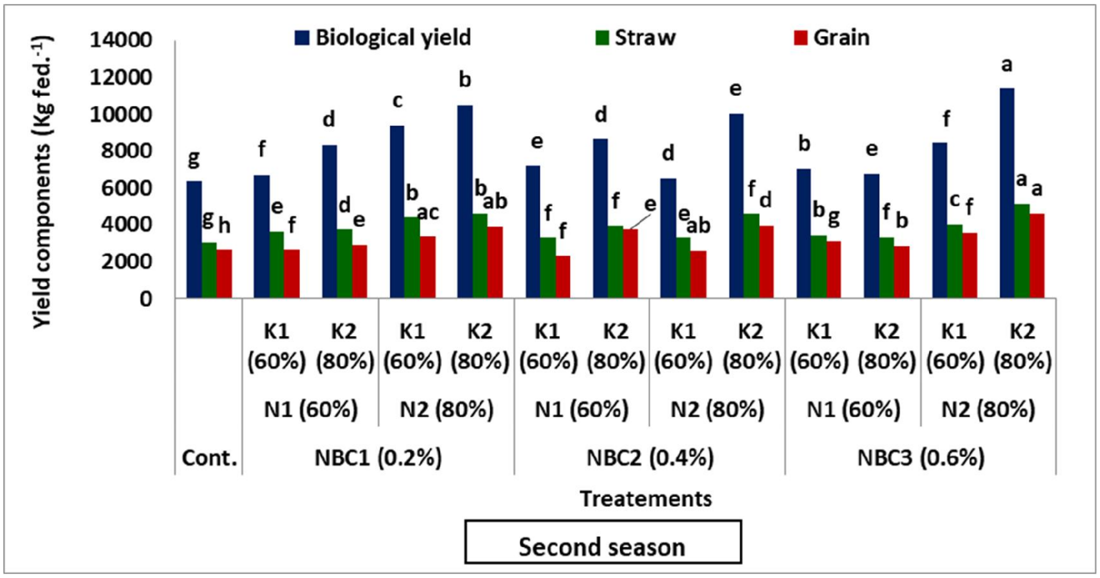


Fig. 7: Responses of maize yield to use different rates of nanobiocahr at various rates of nitrogen and potassium fertilizer.

B. Total content of nitrogen and potassium nutrients in maize crop

The results in Fig. 8 illustrate the application of nanobiocahr rates coupled with varied nitrogen and potassium rates at maize crops (straw and grain) throughout two seasons. The results clearly reveal that when all treatments were applied, all values of macronutrient total content (N and K) in both the straw and grain of the maize plant at two seasons were considerably raised when compared to the control. The maximum value was attained in the first and second seasons by combining NBC_3 with N_2 and K_2. Furthermore, the total content of the maize crop (straw and grain) responded to high rates of applied NBC, N, and K fertilizers; average values were superior in both total nitrogen and potassium total content.

It is worth mention that, the overall macronutrient content followed the same pattern as yield components. Such increases may be due to pore structure of nanobiochar, which likely provides a habitat for soil microorganisms, which in turn may aid in making nutrients available to crops. Also, the availability of N and K increased significantly, as expected, by increasing the rates of N and K fertilizers in the presence of nanobiochar. Such results are confirmed by those of Dhuldhaj *et al*. (2021) who stated that nanobiochar have wide application in agriculture as it improves soil fertility, enhance growth of crops, and also increase the mobilization of nutrients and minerals, and makes availability higher amount of nutrients to the plants. According to Hamidzadeh *et al*. (2023), biochar and nanobiochar have demonstrated their usefulness in agriculture by increasing crop yield and soil fertility. The biochar can be used individually or along with certain nutrients can enhance plant growth in comparison to treatment of chemical fertilizer (Agarwal *et al*., 2022). The application of biochar along with organic and inorganic fertilizer can enhance the content of necessary elements such as total nitrogen and potassium, available nitrogen, potassium, and phosphorus (Liu *et al*., 2022). Biochar also have role in nitrogen cycle and influence soil nitrification, it can reduces inorganic nitrogen and emit N_2O, helps to increase rate of nitrogen fixation, and makes available nitrogen to crops (Ayaz *et al*., 2023).

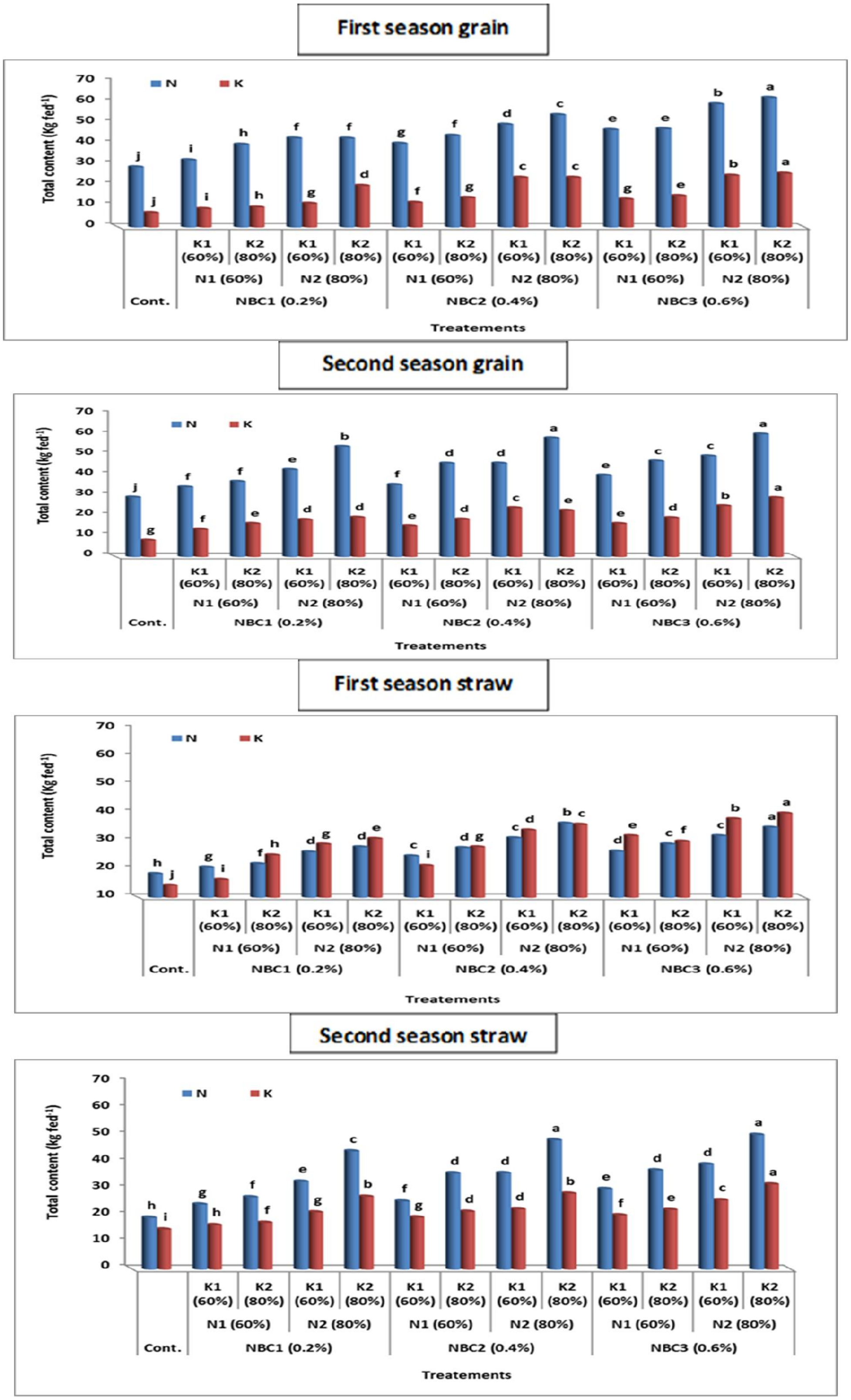


Fig. 8: The effect of nanobiochar coupled with varied nitrogen and potassium rates on the total N and K content of the maize crop at two seasons

The biochar addition in soil enhances the growth of soil ammonia-oxidizing microorganisms, and also it can accelerate rate of nitrification (Yao *et al*., 2022). Rajput *et al*., (2022) who found that application of Nano-biochar can enhance the crop yield around 10-20% and also it can reduce the use of fertilizer by 30-50% .

4. Conclusion and Future Prospects

The study examined the impacts of varying rates of nanobiochar (NBC) application on soil physical and chemical qualities, rated fertilizer consumption, and maize growth characteristics in the field. Nanobiochar is a soil additive that may be used to improve the quality of the soil. Enhancement of soil is one of the many agricultural and environmental benefits of adding nanobiochar to soil. Therefore, adding nanobiochar to the soil is a very promising approach for sustainable agriculture. In this investigation, different concentrations of fertilizer made of potassium and nitrogen were mixed with varying quantities of nanobiochar. In order to examine the effects of different nanobiochar rate treatments on soil and crop yield, maize was planted as a test crop. In conclusion, improved soil chemical properties (i.e., increased soil pH, EC, and organic matter content) as well as increased macronutrient availability (N and K) in sandy soil were obtained by increasing the application rate of nanobiochar from 0.4% to 0.6% with varying rates of nitrogen and potassium fertilizer. This had an impact on both the tested yield components as well as their total macronutrient content under the experimental conditions. Nevertheless, more extensive studies are needed to investigate the long-term stability of nanobiochar before it can be used on a broad basis as a novel soil supplement. By absorbing nutrients from fertilizers, nanobiochar can be a useful source of macro- and micronutrients. So, plant development can be improved by the addition of nanobiochar supplementation.

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