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Impact of modified biochar on crop yield under water stress condition

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Abstract
An investigation entitled, ''Effect of N And K Loaded Nanobiochar Fertilizers on Maize (*Zea mays*) Yield Under Rainfed Conditions'' was conducted at Advanced Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, during the year 2022 and 2023. The soil of the experiment was sandy loam in texture, slightly acidic in pH (6.6), low in organic carbon (0.32%), available nitrogen (161 kg habvik1411@gmail.coma^{-1}) and potassium (87.4 kg ha^{-1}) but medium in available phosphorus (14.5 kg ha^{-1}). Field experiment was laid out in randomized block design with three replications, comprising of twelve treatments. There was no significant difference among the various treatments with respect to pH, EC, bulk density, porosity and penetration resistance. The application of N and K-loaded nanobiochar fertilizers notably boosted both grain and stover yields in 2022 and 2023. Regarding grain yield, T_4 recorded the highest yield in 2022 at 38.53 q ha^{-1}, while T_{12} produced a slightly lower but comparable yield of 37.06 q ha^{-1}. In 2023, T_{12} achieved the highest grain yield of 43.04 q ha^{-1}, outpacing other treatments. The study concluded that nitrogen and potassium loaded nanobiochar application improved the soil properties, crop growth and yield of maize as compared to sole application of recommended dose of fertilizers.

Keywords: Nanobiochar, fertilizer, yield, organic carbon, acidic

1. Introduction
Maize (*Zea mays*) is one of the most important cereal crops globally, playing a crucial role in food security, particularly in developing regions. However, under rainfed conditions, maize productivity is often limited due to insufficient and irregular rainfall, coupled with nutrient deficiencies and poor soil health. Fertilizer application is a key agricultural practice to improve crop yields, but the traditional use of chemical fertilizers often leads to environmental concerns, such as soil degradation, nutrient leaching, and greenhouse gas emissions. In recent years, there has been growing interest in alternative, more sustainable fertilization strategies that can mitigate these environmental impacts while enhancing crop performance. Nanobiochar, a novel fertilizer made by loading nutrients such as nitrogen (N) and potassium (K) onto biochar nanoparticles, has emerged as a promising solution to improve soil fertility and plant growth. The unique properties of nanobiochar, such as its high surface area, porosity, and enhanced nutrient retention capacity, enable it to improve soil structure, water retention, and nutrient availability. Moreover, the slow-release nature of nanobiochar ensures that nutrients are delivered to plants in a controlled manner, which is especially beneficial in rainfed agricultural systems where water availability is often uncertain. The application of N and K-loaded nanobiochar fertilizers has shown potential in improving soil properties, promoting nutrient cycling, and ultimately enhancing crop yield. However, limited research has focused on evaluating the effectiveness of these fertilizers specifically for maize cultivation under rainfed conditions, which are characterized by water scarcity and nutrient loss. Therefore, this study aims to assess the impact of N and K-loaded nanobiochar fertilizers on maize yield under rainfed conditions. By investigating the effects of these innovative fertilizers on soil fertility and plant growth, this research seeks to provide insights into sustainable fertilization practices that can enhance maize productivity and contribute to food security in drought-prone regions.

Despite the growing body of research on biochar's benefits, limited studies have focused on the specific impact of N and K-loaded nanobiochar fertilizers on crop performance, particularly under rainfed conditions. Rainfed agriculture, which accounts for a significant portion of global maize production, is inherently more vulnerable to water stress, leading to reduced nutrient uptake and crop yields. As such, improving nutrient availability in these systems is essential to boost maize productivity. The present study seeks to bridge this gap in knowledge by exploring the impact of N and K-loaded nanobiochar fertilizers on maize yield in rainfed areas. By evaluating the effectiveness of this innovative fertilizer in enhancing soil nutrient availability, water retention, and crop performance, this research aims to provide valuable insights for sustainable agricultural practices that can be adopted in rainfed maize-growing regions worldwide.

Moreover, this research holds significant potential for the development of smart fertilization strategies tailored to the unique challenges faced by farmers in water-scarce regions. By enhancing the understanding of how nanobiochar fertilizers interact with both soil and plants in rainfed conditions, the findings could pave the way for more efficient and environmentally friendly agricultural practices. Such innovations could play a pivotal role in addressing food security challenges, particularly as global climate change threatens the reliability of rainfall patterns and exacerbates the vulnerability of rainfed agriculture.

2. Materials and Methods

2.1 Site characteristics and experimental design

Geographically, the experimental site is situated at 32°39′ N latitude and 74° 53' E longitude at an elevation of 332 metres above mean sea level falling in the sub-tropical foot hill lands of Shiwaliks in Jammu and Kashmir. The meteorological data with respect to rainfall, temperature and relative humidity acquired from the meteorological observatory located near to the experimental site at ACRA, Dhiansar of SKUAST-Jammu, revealed that experimental site, in general is bestowed with hot and dry early summers followed by hot and humid monsoon seasons and cold dry winters. Field experiment was conducted during 2022 and 2023. The experiment was comprised of 12 treatments which were laid out in randomized block design with 3 replications at Research Farm, Advanced Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar, SKUAST-Jammu. The detail of the treatments is given below and the layout is shown in table 1.

Table 1: The detail of the treatments is given below and the layout is shown

S. No.	Treatment details	Symbol
1	Control	T_1
2	100% RDF (NPK)	T_2
3	100% RDF (NPK)+ 2ton B	T_3
4	100% RDF (NPK) + 4ton B	T_4
5	100% NPK + 2 Kg NB	T_5
6	100% NPK+ 6 Kg NB	T_6
7	75% RD N + 2Kg NBN + PK	T_7
8	75% RD N + 6Kg NBN + PK	T_8
9	75% RD K + 1Kg NBK + NP	T_9
10	75% RD K + 3Kg NBK + NP	T_{10}
11	75% RD N + 75% RD K + 2Kg NBN + 1Kg NBK	T_{11}
12	75% RD N + 75% RD K + 6Kg NBN + 3Kg NBK	T_{12}

2.2 Soil and leaf analysis

After land preparation of the experimental field, soil samples from 0-15 cm depth were taken by following two step procedure of random sampling using core sampler (Peterson and Calvin, 1965) [5]. The soil samples were drawn randomly from five different spots in the field before imposition of the experimental treatments. The soil samples obtained from all the spots were mixed to form initial composite sample. The soil samples obtained from all the spots were mixed to form initial composite sample. The composite soil sample so collected was air dried, grinded, and passed through 2 mm sieve and used for analysis of different physico-chemical properties. Furrows were opened manually with the help of liners at a specified row to row distance of 75 cm and plant to plant distance of 20 cm at a depth of 4-5 cm. The seeds were sown in furrows by *kera* method and then seeds were covered with soil. A seed rate of 20 kg ha^{-1} was used for sowing of maize crop. After 10 days of sowing gap filling was done wherever required, to maintain proper plant population. Full dose of P_2O_5, K_2O through DAP, MOP and half of nitrogen was applied through urea as basal. Further, the remaining half amount of nitrogen was applied 30 DAS. Maize crop was fertilized with recommended dose of nutrients *viz.* 60 kg ha^{-1} nitrogen (N), 40 kg ha^{-1} phosphorus (P_2O_5) and 20 kg ha^{-1} potassium (K_2O). The nutrients were supplied in form of urea, diammonium phosphate and murate of potash. While quantity of phosphorus, potassium was applied as basal dose and half quantity of nitrogen was applied to all the treatments as per technical programme. Earthing up and top dressing of urea was done 30 DAS. Crop was harvested manually from net plot when husk cover was completely dried and black coloration was found in grain base (black band). The experimental crop was harvested manually with the aid of sickle when it reached maturity. To eliminate border effects, one row from each side of the plot, from the proximal and distal ends of each row of the individual plot were harvested and collected separately. The crop plants from the net plot were harvested and decobed. The remaining plants were tied into individual bundles. The net harvest was stored in its designated plot and allowed to dry in the sun for three to four days. After drying the bundle weight was calculated by using a weighing balance. A maize sheller was used to thresh the harvested maize crop from each plot separately. Treatment wise grain yield was recorded by taking weight of grains by using electronic balance whereas stover yield of each plot was taken with the help of spring balance at the time of harvesting. Plant height of randomly tagged five plants of maize crop in all the plots was measured using meter scale. The plant height was taken from the ground surface to the tip of upper most fully opened leaf at 30, 60, 90 DAS and at harvest. The cob length from tagged plants in each plot was figure out by measuring the length from base to tip of the cob with the help of a measuring tape. The mean cob length per plant was calculated by averaging the observations collected from each treatment and was expressed in centimeters (cm). The mean cob weight from a sample of five cobs was recorded after shade dried and were expressed in grams (g). To measure cob girth, wrap a flexible measuring tape around the thickest part of the cob and record the circumference in centimeters or millimeters. Repeat the measurement on multiple cobs and calculate the average for accuracy. Plant samples were taken at the time of harvesting for estimation of nitrogen, phosphorus, potassium, and zinc concentration. The grains of maize were also taken for uptake studies from each plot. The samples were oven dried, then finely ground with electric grinder and analysed for nitrogen, phosphorus, and potassium. Nitrogen, phosphorus, and potassium uptake by grains and stover samples were calculated by multiplying per cent nutrient content with their respective dry matter accumulation.

2.3 Statistical analysis

The data presented in thesis are the mean values. All the observations are statistically analysed by using analysis of variance. The results were tested for the treatments mean by applying F-test of significance based on null hypothesis (Cochran and Cox, 1957) [1]. Wherever necessary, standard errors along with critical difference at 5 per cent of significance were computed for discriminating the treatment effects for chance effects.

3. Results and Discussion

3.1 Soil moisture

The data demonstrates a significant increase in soil moisture content due to the application of biochar, nanobiochar (NB), and nitrogen (N) and potassium (K) loaded nanobiochar (NBN and NBK) across different growth stages of maize (30 and 90 days after sowing, DAS). At 30 DAS, treatments T_4 (100% NPK + 4 ton biochar) and T_{12} (75% RD N + 75% RD K + 6 kg NBN + 3 kg NBK + P) recorded the highest soil moisture content (17.7 cm and 18.49 cm, respectively) in 2022 and 2023, significantly outperforming the 100% recommended dose of fertilizers (RDF) (14.8 cm and 13.93 cm). Similarly, at 90 DAS, T_4 and T_{12} maintained the highest soil moisture content (7.6% and 8.78%, respectively), while the control (T_1) recorded the lowest moisture content (5.3% and 5.7%) in both years. These results highlight the effectiveness of biochar and nanobiochar in improving soil water retention and availability. This improvement can be attributed to the high surface area and porous structure of nanobiochar, which allows it to absorb and retain substantial amounts of water. Supporting this, Omran *et al*. (2023) [4] found that nanobiochar increased soil moisture content by 5% to 8% at a depth of 0-5 cm compared to the control. Similar findings regarding the impact of nanobiochar on soil moisture capacity have also been documented by Yang *et al*. (2020) [10] and Zhou *et al*. (2018) [11].

3.2 Effect of N and K Loaded Nanobiochar Fertilizers on Growth parameters, yield and yield attributes

Nitrogen loaded nanobiochar play a significant role in enhancing the height of rice plants. This study supported by the findings of Ibrahim *et al*. (2023) [2], who reported a 6.88% increase in plant height with the application of 0.75% nanobiochar. Additionally, a significant correlation exists between 1000-grain weight, yield parameters and different nanobiochar contents, as noted by Yang *et al*. (2020) [10]. The application of both basal and foliar forms of nanobiochar has been shown to substantially improve growth traits in carrots, with a linear increase in shoot and root growth recorded in response to increasing concentrations (Khaliq *et al*., 2023) [3]. Similar results were observed by Saxena *et al*. (2014) [8], who found a linear increase in shoot length of wheat plants with increasing water soluble carbon nanoparticles. Previous studies indicate the beneficial effects of nanobiochar on plant growth compared to inorganic fertilizers, as it releases nutrients slowly in the soil, thus fulfilling the nutritional needs for optimal growth (Ramanayaka *et al*., 2020) [6]. The application of nanobiochar in agriculture is associated with advantages such as enhanced nutrient retention and a gradual release of nutrients (Sheokand *et al*., 2023) [9], contributing to improved soil fertility and crop productivity (Sarma *et al*., 2024) [7]. Nitrogen loaded nanobiochar play a significant role in enhancing the height of rice plants. This study supported by the findings of Ibrahim *et al*. (2023) [2], who reported a 6.88% increase in plant height with the application of 0.75% nanobiochar. Additionally, a significant correlation exists between 1000-grain weight, yield parameters and different nanobiochar contents, as noted by Yang *et al*. (2020) [10]. The application of both basal and foliar forms of nanobiochar has been shown to substantially improve growth traits in carrots, with a linear increase in shoot and root growth recorded in response to increasing concentrations (Khaliq *et al*., 2023) [3]. Similar results were observed by Saxena *et al*. (2014) [8], who found a linear increase in shoot length of wheat plants with increasing water soluble carbon nanoparticles. Previous studies indicate the beneficial effects of nanobiochar on plant growth compared to inorganic fertilizers, as it releases nutrients slowly in the soil, thus fulfilling the nutritional needs for optimal growth (Ramanayaka *et al*., 2020) [6]. The application of nanobiochar in agriculture is associated with advantages such as enhanced nutrient retention and a gradual release of nutrients (Sheokand *et al*., 2023) [9], contributing to improved soil fertility and crop productivity.

4. Conclusions

The application of N and K-loaded nanobiochar fertilizers has shown significant potential in enhancing maize yield under rainfed conditions. By providing a slow-release mechanism for essential nutrients, nanobiochar fertilizers mitigate the challenges posed by nutrient leaching, a common concern in rainfed agricultural systems, ultimately promoting sustained nutrient availability throughout the growing season. The improvements in maize yield observed in response to N and K-loaded nanobiochar fertilizers highlight their effectiveness in optimizing plant growth and productivity, particularly in areas with limited access to irrigation. This innovative approach presents a sustainable alternative to conventional fertilization methods, offering both economic and environmental benefits by reducing the need for frequent fertilizer applications and minimizing nutrient runoff. Given the growing challenges posed by climate change and water scarcity, the findings from this study underscore the importance of adopting such novel technologies to ensure food security and promote sustainable agricultural practices in rainfed regions. Future research should focus on further refining nanobiochar formulations and exploring their long-term effects on soil health, nutrient dynamics, and crop yields, with the aim of enhancing the resilience of rainfed farming systems globally.

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