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Effect of biochar and nano urea on growth and yield of soybean

TS Bagade, SK Ghodke, DD Khedkar, NJ Danawale, MS Mane and VS Patil

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Abstract
A Field experiment entitled, "Effect of biochar and nanourea on growth and yield of soybean." was conducted during the year 2024-2025 at the Research Farm of Interfaculty Department of Irrigation water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahilyanagar, Maharashtra, India with an objective of effect of biochar and nanourea application on growth, yield and economics of soybean. The experiment was carried out in randomized block design with thirteen treatment replicated three times and experiment comprises of T_1 - absolute control, T_2 - RDF + FYM, T_3 - RDF + Biochar, T_4 - RDF + Nanourea, T_5 - RDF + Biochar + FYM, T_6 - RDF + Biochar + Nanourea, T_7 - RDF + Biochar + Rhizobium, T_8 - RDF + Biochar + FYM + Nanourea, T_9 - RDF + Biochar + FYM + Nanourea + Rhizobium, T_{10} - 75 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{11} - 50 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{12} - 25 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{13} - 0 % RDN + Biochar + FYM + Nanourea + Rhizobium. The Seed treatment of rhizobium and application of Nanourea @ 50 kg ha^{-1} at the time of sowing along with application of biochar @ 5 t ha^{-1} + FYM @ 12 t ha^{-1} into soil before 15 days of sowing. Soybean crop was planted by hand dibbling at 45 cm × 5 cm spacing. The irrigation was done as per climatological parameter. The result indicated that all the growth and yield contributing character were recorded higher and significantly superior in RDF + Biochar + FYM + Nanourea + Rhizobium. Significantly higher yield of soybean (36.04 q ha^{-1}) was recorded in RDF + Biochar + FYM + Nanourea + Rhizobium and it was par with 75 % RDN + Biochar + FYM + Nanourea + Rhizobium (34.01 q ha^{-1}), RDF + Biochar + FYM + Nanourea (33.80 q ha^{-1}) and 50 % RDN + Biochar + FYM + Nanourea + Rhizobium (33.56 q ha^{-1}). The same trend was observed in terms of economics. It is concluded that, soil application of 50 per cent recommended dose of nitrogen, 100 per cent phosphorus and potassium (25:75:45 N:P_2O_5:K_2O kg ha^{-1}) + Nanourea @ 50 kg ha^{-1} + Seed treatment of rhizobium @ 25 kg^{-1} of seed at the time of sowing along with application of biochar @ 5 t ha^{-1} + FYM @ 12 t ha^{-1} into the soil before 15 days of sowing recorded significantly higher grain and straw yield of soybean for soil maintenance and economically beneficial.

Keywords: Soybean, Biochar, Nano Urea, Rhizobium, FYM

TS Bagade
Interfaculty Department of Irrigation Water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

SK Ghodke
Assistant Professor of Soil Science. Interfaculty Department of Irrigation Water Management, MPKV, Rahuri, Maharashtra, India

DD Khedkar
Associate Professor of Irrigation and Drainage Engineering, Interfaculty Department of Irrigation Water Management, MPKV Rahuri, Maharashtra, India

NJ Danawale
Professor, Department of Agronomy, Chief Scientist (Seed) PGI, MPKV, Rahuri, Maharashtra, India

MS Mane
Associate Dean, College of Agriculture Pune, MPKV, Rahuri, Maharashtra, India

VS Patil
Head Interfaculty Department of Irrigation Water Management, MPKV, Rahuri, Maharashtra, India

Corresponding Author:
TS Bagade
Interfaculty Department of Irrigation water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

Introduction
Soybean (*Glycine max L. Merril*.) is a key crop globally, known for its role in food and oil production. It is a rich source of vegetable protein, which is essential for daily nutrition. This type of protein is not only beneficial for health but also more affordable compared to animal-based protein sources. Soybeans offer a variety of important nutrients, providing a significant per centage of the daily value (DV) in a 100-gram serving (raw). They are especially high in protein and also contain notable amounts of vitamin K, magnesium, zinc and potassium. The composition of soybeans includes 9 % water, 30 % carbohydrates, 20 % fat and 36 % protein. Originally from central China, soybeans have been cultivated since around 7000 BCE. This ancient crop has been a fundamental part of the diets and medicinal practices of China, Japan and Korea for thousands of years. Biochar is a carbon-rich material produced through pyrolysis—the high-temperature heating of biomass (such as crop residues, wood, or manure) in an oxygen-limited environment. Its quantity and quality vary significantly depending on the type of feedstock used, particularly the specific crop residues processed. Biochar can be derived from diverse feedstocks including wood, agricultural residues, and manures (Singh *et al*., 2010b; Wang *et al*., 2011) [14, 17].

Compared to its source biomass, biochar exhibits higher carbon content, lower nitrogen, greater surface area, and enhanced cation exchange capacity (Singh *et al*., 2010b [14]. Yield varies significantly by feedstock type and pyrolysis temperature: agricultural and waste-derived biochars (e.g., rice husk: 39-59 %, poultry manure: 47-68 %, waste sludge: 43-54 %) typically show higher yields than woody materials (e.g., Japanese cedar: 22-41%, sugarcane bagasse: 19-28 %) due to their elevated ash content (Kameyama *et al*. 2017[8]; Windeatt *et al*., 2014[19]). Increasing pyrolysis temperature reduces yield and volatile matter while increasing ash content. It also decreases nitrogen, hydrogen, and oxygen concentrations of carbon (Kameyama *et al*. 2017[8]). Biochar is typically alkaline, with its pH rising as pyrolysis temperature increases; low-temperature biochar, however, can be acidic. Feedstock type also significantly influences pH (Kameyama *et al*., 2017[8]). Cation Exchange Capacity (CEC) reflects a soil's ability to retain essential nutrients. Biochar's negatively charged surfaces attract cations via electrostatic forces. CEC decreases at higher pyrolysis temperatures due to the loss of oxygen-containing functional groups (Suliman *et al*., 2016[16]) and varies with feedstock (Kameyama *et al*., 2017[8]).Electrical Conductivity (EC) measures soluble ions in solution. Biochar's EC depends primarily on feedstock rather than pyrolysis temperature, with manure-derived biochar exhibiting the highest values (Joseph *et al*., 2010[7]).

Nano urea is more effective in nutrient absorption due to reduced losses. It improves input use efficiency, boosts productivity and helps mitigate environmental concerns. Compared to conventional urea prills, nano urea has a much smaller particle size of about 20-50 nm, providing a surface area that is 10,000 times larger than a 1 mm urea prill and containing 55,000 nitrogen particles in place of just one. This increased availability to crops leads to more than 80 % better nutrient absorption, significantly improving nutrient use efficiency. When applied as a foliar fertilizer, nano urea can enhance crop productivity by up to 8 %, with additional benefits like improved soil, air and water quality, along with greater profitability for farmers. As considering effect of alone biochar and enhanced or enriched biochar this investigation will be conducted on "Effect of biochar and nanourea on growth and yield of soybean" during Kharif 2024 at Interfaculty Department of Irrigation Water Management, PGI, M.P.K.V., Rahuri, with an objective of effect of biochar and nanourea application on growth, yield and economics of soybean

Material and methods

The research experiment entitled, "Effect of biochar and nanourea on growth and yield of soybean." was carried out at Post Graduate Institute at farm of Interfaculty Department of Irrigation Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahilyanagar, Maharashtra, India during *Kharif* 2024-25 with an object effect of biochar and nanourea application on growth, yield and economics of soybean. The experiment was carried out in randomized block design with thirteen treatment replicated three times and experiment comprises of T_1 - absolute control, T_2 - RDF + FYM, T_3 - RDF + Biochar, T_4 - RDF + Nanourea, T_5 - RDF + Biochar + FYM, T_6 - RDF + Biochar + Nanourea, T_7 - RDF + Biochar + Rhizobium, T_8 - RDF + Biochar + FYM + Nanourea, T_9 - RDF + Biochar + FYM + Nanourea + Rhizobium, T_{10} - 75 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{11} - 50 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{12} - 25 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_{13} - 0 % RDN + Biochar + FYM + Nanourea + Rhizobium. Treatments plots were prepared after ploughing and harrowing the experimental field was divided in thirty nine-unit plots with plot size 4.0 m x 2.25 m as per the plan of layout of the experimental plot. The recommended dose of fertilizer for soybean 50:75:45 $N:P_2O_5:K_2O$ Kg ha^{-1} and seed treatment of rhizobium @ 25 g^{-1} of seed and application of Nanourea @ 50 kg ha^{-1} at the time of sowing along with application of biochar @ 5 t ha^{-1} + FYM @ 12 t ha^{-1} into soil before 15 days of sowing. Soybean crop was planted by hand dibbling at 45 cm × 5 cm spacing with variety of Phule Durva (KDS 992). The irrigation was done as per climatological parameter and plots were harvested at full maturity (107 DAS) by second week of October. Uniform plant population was maintained by thining at 15 days after sowing. Statically significance of the treatments effects on growth, yield and economics were tested by analysis of variance (ANOVA) using Microsoft excel ™.

Biochar Production

Pyrolysis is a process that thermally decomposes biomass by heating it at elevated temperature under control inert conditions (i.e very little O_2 or under an inert gas atmosphere such as N_2). The stalks of pigeonpea plant were fed to the pyrolysis reactor in oxygen limiting condition here temperature goes up to 450^0C. This process occurs in three stages, first where the moisture content of the biomass was reduced to <10 per cent at the temperature of 180^0C, Second where the biochar production starts with the breakdown of hemicellulose and cellulose at the temperature range 180-360 ^{0}C and last stage where lignin breaks down at the temperature of 450 ^{0}C. In slow pyrolysis the final yield of the converted biochar goes upto 25-35 per cent which was more in comparison to the fast pyrolysis. After conversion of dry pigeon pea stalk to biochar which was converted into powder form with hammering of wooden material.

Table 1: Initial chemical properties of soil

Sr. No.	Parametres	Composition	Method used	Reference(s)
1.	pH (1:2.5)	7.98	Potentiometer	Jackson (1973) [6]
2.	EC (dSm^{-1})	0.16	Conductometer	Jackson (1973) [6]
3.	Organic carbon (%)	0.46		
4.	Available N (kg ha^{-1})	172.88	Alkaline permanganate	Subbiah and Asija (1956) [15]
5.	Available P (kg ha^{-1})	17.84	0.5 M $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965) [18]
6.	Available K (kg ha^{-1})	483.57	*N* N NH_4OAc	Hanway and Heidal (1967) [5]

Table 2: Characterization of Biochar

Particulars	Ph (1:10)	EC (dSm^{-1})	Moisture (%)	Total carbon (%)	Total nitrogen (%)	C:N Ratio
Biochar (Pigeonpea stalks)	9.17	0.53	26.7	49.70	0.24	207.08

Table 3: Effect of biochar and nanourea on growth parameters of soybean at harvest

Tr. No.	Treatments	Plant height $plant^{-1}$ (cm)	Number of branches $plant^{-1}$	Number of leaves $plant^{-1}$
T_1	Absolute Control	71.75	15.20	98.40
T_2	RDF + FYM	84.79	18.07	104.20
T_3	RDF + Biochar	79.39	17.00	103.00
T_4	RDF + Nanourea	82.17	17.47	103.20
T_5	RDF + Biochar + FYM	86.60	18.27	104.93
T_6	RDF + Biochar + Nanourea	83.61	17.93	103.73
T_7	RDF + Biochar + Rhizobium	82.43	17.87	103.47
T_8	RDF + Biochar + FYM + Nanourea	88.77	18.80	106.47
T_9	RDF + Biochar + FYM + Nanourea + Rhizobium	94.46	21.20	111.27
T_{10}	75% RDN + Biochar + FYM + Nanourea + Rhizobium	91.40	19.00	109.40
T_{11}	50% RDN + Biochar + FYM + Nanourea + Rhizobium	88.70	18.47	106.13
T_{12}	25% RDN + Biochar + FYM + Nanourea + Rhizobium	75.35	16.53	101.60
T_{13}	0 % RDN + Biochar + FYM + Nanourea + Rhizobium	73.75	16.47	100.27
	S.Em. ±	2.53	1.00	2.31
	CD at 5 %	7.91	2.97	6.88

Table 2: Effect of biochar and nanourea on yield and yield contributing parameters of soybean at harvest.

Tr. No.	Treatments	Average Numbers of pods $plant^{-1}$	Average Weight of pods $plant^{-1}$	Average Weight of grains per $plant^{-1}$ (g)	Weight of 100 grains (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
T_1	Absolute Control	98.27	59.77	26.85	13.91	18.15	24.26
T_2	RDF + FYM	127.07	72.99	35.05	18.00	29.63	47.41
T_3	RDF + Biochar	107.73	64.30	30.77	15.80	25.63	42.85
T_4	RDF + Nanourea	114.73	68.08	32.38	17.00	23.74	43.07
T_5	RDF + Biochar + FYM	129.27	75.52	36.17	18.64	32.15	48.15
T_6	RDF + Biochar + Nanourea	122.20	72.54	33.86	17.94	28.67	46.71
T_7	RDF + Biochar + Rhizobium	119.13	70.68	33.29	17.45	27.12	44.78
T_8	RDF + Biochar + FYM + Nanourea	131.53	77.83	36.63	19.19	33.80	50.91
T_9	RDF + Biochar + FYM + Nanourea + Rhizobium	135.13	80.18	38.21	19.74	36.04	54.63
T_{10}	75% RDN + Biochar + FYM + Nanourea + Rhizobium	133.13	78.41	37.55	19.32	34.01	53.22
T_{11}	50% RDN + Biochar + FYM + Nanourea + Rhizobium	131.13	76.28	36.41	18.70	33.56	49.89
T_{12}	25% RDN + Biochar + FYM + Nanourea + Rhizobium	105.07	63.93	29.25	15.37	26.26	41.02
T_{13}	0 % RDN + Biochar + FYM + Nanourea + Rhizobium	100.73	62.34	28.21	14.76	27.37	39.83
	S.Em. ±	1.43	1.41	0.69	0.37	1.07	1.69
	CD at 5 %	4.45	4.38	2.01	1.07	3.24	4.96

Table 3: Effect of biochar and nanourea on economics of soybean

Tr. No.	Treatments	Cost of Cultivation (Rs.ha^{-1})	Gross monetary returns (Rs.ha^{-1})	Net monetary Returns (Rs.ha^{-1})	B:C ratio
T_1	Absolute Control	62707	110715	48008	1.77
T_2	RDF + FYM	82351	180743	98392	2.19
T_3	RDF + Biochar	80351	156343	75992	1.95
T_4	RDF + Nanourea	71351	144814	73463	2.03
T_5	RDF + Biochar + FYM	92351	196115	103764	2.12
T_6	RDF + Biochar + Nanourea	81351	174887	93536	2.15
T_7	RDF + Biochar + Rhizobium	80576	165432	84856	2.05
T_8	RDF + Biochar + FYM + Nanourea	93351	206180	112829	2.21
T_9	RDF + Biochar + FYM + Nanourea + Rhizobium	93576	219844	126268	2.35
T_{10}	75% RDN + Biochar + FYM + Nanourea + Rhizobium	93413	207461	114048	2.22
T_{11}	50% RDN + Biochar + FYM + Nanourea + Rhizobium	93250	204716	111466	2.20
T_{12}	25% RDN + Biochar + FYM + Nanourea + Rhizobium	93087	160186	67099	1.72
T_{13}	0 % RDN + Biochar + FYM + Nanourea + Rhizobium	92925	166957	74032	1.80
	S.Em. ±	-	6097	6097	-
	CD at 5 %	-	18367	18367	-

Results and Discussion

Effect of biochar and nanourea application on growth parameters.

The data on growth parameters of soybean are presented in Table 1 and revealed that, the treatment T_9 comprising RDF + Biochar + FYM + Nanourea + Rhizobium was recorded significantly higher plant height, number of branches and number of leaves (94.46 cm, 21.20 branches and 111.27 leaves, respectively) at harvest. However, it was found at par with treatment T_{10} comprising 75 % RDN + Biochar + FYM + Nanourea + Rhizobium, treatment T_8 contained RDF + Biochar + FYM + Nanourea, T_{11} receiving 50 % RDN + Biochar + FYM + Nanourea + Rhizobium and T_5 RDF + Biochar + FYM. This might be due to combined effect of bichar, nanourea and FYM. Similar results have also been previously reported in the published literature (Wisnubroto *et al.* (2016) [20], Mahil and Kumar (2019)[10], Mollick *et al.* (2018) [11], and Cong M *et al.,* (2023) [3].

Effect of biochar and nanourea on yield and yield contributing parameters of soybean.

The data regarding yield and yield contributing parameters of soybean are presented in Table 2. The treatment T_9 receiving RDF + Biochar + FYM + Nanourea + Rhizobium was recorded the significantly higher (135.13 pods plant^{-1}, 80.18 g pod weight plant^{-1}, 38.21 g grain weight plant^{-1} and 19.74 g hundred-grain weight). Similarly, the grain and straw yield of soybean were recorded significantly higher in the treatment T_9 receiving RDF + Biochar + FYM + Nanourea + Rhizobium (36.04 q ha^{-1} and 54.63 q ha^{-1}, respectively). However, it was at par with treatment T_{10} comprising 75 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_8 comprising RDF + Biochar + FYM + Nanourea and T_{11} comprising 50 % RDN + Biochar + FYM + Nanourea + Rhizobium. This increase in grain yield and straw yield might be due to combined effect of biochar, nanourea and FYM application. The minimum grain and straw yield (18.15 q ha^{-1} and 24.26 q ha^{-1}, respectively) was observed in treatment T_1 comprising (Absolute Control). Similar results have also been previously reported in the published literature (Eazhilkrishna *et al.* (2017) [4], Almaroai *et al.* (2020) [1].

Effect of biochar and nanourea on economics of soybean

The data on economics of soybean are presented in Table 3. Significantly higher gross monetary returns and net monetary returns were recorded in treatment T_9 receiving RDF + Biochar + FYM + Nano urea + Rhizobium (Rs. 219844 ha^{-1} and Rs. 126268 ha^{-1}, respectively). However, it was at par with treatment T_{10} comprising 75 % RDN + Biochar + FYM + Nanourea + Rhizobium, T_8 comprising RDF + Biochar + FYM + Nanourea and T_{11} comprising 50 % RDN + Biochar + FYM + Nanourea + Rhizobium. The higher benefit cost ratio was recorded in treatment T_9 comprising RDF + Biochar + FYM + Nano urea + Rhizobium (2.35) followed by T_{10}, T_8 and T_{11}.). Similar results have also been previously reported in the published literature Nsamba *et al*. (2015) [12], Chaddha (2019) [2], Kannoj *et al*. (2022) [9] and Rajput *et al*. (2022) [13].

Conclusion

On the basis of one year research experiments, it is concluded that soil application of 50 per cent recommended dose of nitrogen, 100 per cent phosphorus and potassium (25:75:45 N:P_2O_5:K_2O kg ha^{-1}) + Nanourea @ 50 kg ha^{-1} + Seed treatment of rhizobium @ 25 g^{-1} of seed at the time of sowing along with application of biochar @ 5 t ha^{-1} + FYM @ 12 t ha^{-1} into the soil before 15 days of sowing recorded significantly higher grain and straw yield of soybean for soil maintenance and economically beneficial.

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