Original Research Article

Biochar-based slow-release nitrogen fertilizer performance on growth and development of wheat in Indo-Gangetic Plains

ABSTRACT

Excessive fertilizer-use post green revolution led to increased crop yields keeping the soil health at stake with nutrient losses, leaching and poor soil health. The current study aimed to evaluate the slow-release fertilizer i.e., biochar-coated nitrogen (BCN) fertilizer on the crop biomass, tillers and plant height of wheat in the Indo-Gangetic Plains in comparison to neem-coated urea (NCU). The field experiment was conducted during the winter season of 2021-22 at NEB-Crop Research Centre, G. B. Pant University of Agriculture & Technology, Pantnagar, India. The field experiment was designed with 7 fertilizer dosages viz., 100% recommended dose of nitrogen (N) through neem-coated urea (NCU), 125% N–NCU, 125% N–Biochar-coated urea (BCU), 100% N–BCU, 75% N–BCU and 50% N–BCU with 2 sprays of 4% Nano-Urea (NU), and a Control with no nitrogen, replicated thrice under randomized complete block (RCBD) design. Both the BCN and NCU were applied at different nitrogen dosages, with above and below 25% and 50% of the recommended dosage (120:60:40 kg $N:P_2O_5:K_2O$/ha). The study found that split application of 125% N–BCN resulted in 5.81% to 16.6% increase in plant height at the harvest stage compared to other BCN treatments and a 3.46% to 8.15% increase over nitrogen applied through NCU. For tiller production, 125% N–BCN application led to 3.94% to 12.4% more tillers compared to NCU and 6.61% to 23.7% more than other BCN treatments. Crop biomass accumulation was also higher with 125% N–BCN, showing a 1.44% increase over 125% N–NCU and up to 16.7% more than other BCN doses. The BCN fertilizers proved to be more effective than conventional fertilizers, promoting better nutrient uptake and improved growth rates during critical stages. The study concludes that BCN fertilizers are a promising alternative for sustainable wheat cultivation in the Indo-Gangetic Plains, offering better wheat growth, development and reduced environmental impact, making them suitable for broader agricultural applications.

Keywords: Absolute growth rate; Biochar-coated nitrogen; Crop biomass; Crop growth rate; Relative growth rate

1. INTRODUCTION

The agricultural sector in India, particularly in the Indo-Gangetic Plains (IGP), plays a pivotal role in the nation's food security, supporting a substantial proportion of the population. Wheat is a staple crop in this region, contributing significantly to the country's grain production. However, sustaining high yields in the IGP has become increasingly challenging due to the intensification of agriculture and the reliance on conventional fertilizers, particularly nitrogen (N) fertilizers [1,23]. Wheat cultivation is a cornerstone of Indian agriculture and an important staple food crop, occupying an area of 31.4 million hectares (Mha) with a production of 110.1 million tonnes (Mt) with a productivity of 3.52 t/ha, contributing to the food security of increasing population [1]. Traditionally, wheat production in India relies heavily on the use of conventional nitrogen fertilizers like urea to boost yields. While these fertilizers have driven productivity gains, they also pose several challenges, including nutrient leaching, volatilization, and soil degradation. The overuse and inefficient application of conventional fertilizers have led to declining soil health, reduced nitrogen use efficiency (NUE), and increased environmental pollution through greenhouse gas emissions and water contamination [2,3]. These issues underscore the urgent need for more sustainable practices such as, biochar-based fertilizers, which offer a promising solution by improving nutrient retention and release, enhancing NUE, and restoring soil fertility. Incorporating biochar with slow-release fertilizers can help mitigate the negative impacts of conventional fertilization, promoting sustainable wheat cultivation in India.

The excessive and indiscriminate use of conventional N fertilizers, including conventional bare urea, neem-coated urea, synthetic and complex fertilizers (12:32:16, 19:19:19) etc., have led to several agronomic and environmental issues post green revolution, including nutrient leaching, soil acidification, and the emission of greenhouse gases (GHGs) [2, 21], all of which have long-term implications for soil health and agricultural sustainability. One of the primary concerns associated with conventional nitrogen fertilizers, such as urea, is their rapid release and subsequent leaching losses, which not only reduce the efficiency of nitrogen use but also lead to significant environmental pollution [4]. In the IGPs, where intensive wheat cultivation is prevalent, these challenges are exacerbated by the region's specific climatic and soil conditions, characterized by frequent irrigation, high temperatures, and variable rainfall patterns. These factors contribute to the rapid transformation and loss of nitrogen from the soil-plant system, necessitating frequent and high-rate fertilizer applications to maintain crop productivity. Consequently, there is an urgent need for innovative fertilizer management practices that can enhance nitrogen use efficiency (NUE) while mitigating environmental impacts.

Biochar, a carbon-rich product obtained from the pyrolysis of organic biomass, has emerged as a promising soil amendment due to its ability to improve soil properties and enhance nutrient retention [5]. When used as a carrier for slow-release fertilizers, biochar can potentially mitigate the issues associated with conventional fertilizers by controlling the release of nutrients and improving their availability to plants over an extended period. The porous structure, high surface area, and cation exchange capacity of biochar make it an ideal medium for nutrient retention, reducing leaching losses and increasing the efficiency of fertilizer use. Moreover, the integration of biochar with slow-release nitrogen fertilizers could provide a dual benefit of enhancing crop growth while contributing to soil carbon sequestration, thus aligning with the goals of sustainable agriculture.

The concept of slow-release nitrogen fertilizers (SRNFs) involves the gradual release of nitrogen to match the nutrient uptake patterns of crops, thereby minimizing losses through leaching and volatilization [6,7]. SRNFs have been widely studied and applied in various cropping systems, but their effectiveness is often limited by the environmental conditions and management practices specific to different regions. In the IGPs, the performance of SRNFs could be significantly influenced by the region's unique agro-climatic conditions, necessitating region-specific research to optimize their use [8]. The BCU is better than neem-coated urea in enhancing wheat growth and yield through its improvement of nitrogen use efficiency not only because of its slow, steady release of nitrogen but also by significantly enhancing the health of the soil itself through the porous structure and high cation exchange capacity of biochar, greatly improving nutrient retention, beneficial microbial activity, and structure. Compared to the NCU-treated wheat, comparative studies revealed a higher increment in plant height, tiller production, and biomass accumulation with BCU application. BCU thus possesses superior effectiveness in sustaining crop growth and has further added advantages of increasing partial factor productivity (PFP) and partial nutrient balance (PNB) over that of NCU and conventional urea fertilizers. Maximum PFP, 43.8 kg grain/kg N supplied, and PNB were noted with the application of 130 kg N/ha as BCU [22];

hence, it is more effective for wheat growth and yield improvement along with sustainable agriculture. The combination of biochar and SRNFs presents a novel approach to enhancing nitrogen use efficiency in wheat cultivation, with the potential to improve crop yields, reduce environmental impacts, and promote sustainable agricultural practices in the IGP.

Several studies have demonstrated the benefits of biochar in improving soil fertility, water retention, and microbial activity, all of which contribute to enhanced crop growth. However, the application of biochar as a component of SRNFs in the context of wheat cultivation in the Indo-Gangetic Plains remains underexplored. Understanding the interaction between biochar based slow-release nitrogen fertilizers, and the specific soil and climatic conditions of the IGP is crucial for developing effective fertilizer management strategies in wheat. This research aims to address this gap by evaluating the performance of biochar-based slow-release nitrogen fertilizers on the growth and development of wheat in the Indo-Gangetic Plains. The objectives of this study are (i) to evaluate the effects of biochar-based SRNFs on wheat growth viz., plant height, crop biomass, crop growth rate (CGR), relative growth rate (RGR), and absolute growth rate (AGR). By addressing these objectives, the study seeks to provide insights into the potential of biochar-based SRNFs as a sustainable fertilizer management practice for wheat cultivation in the IGPs.

2. MATERIAL AND METHODS

2.1. Experimental Site

The field experiment to evaluate the effect of biochar-based slow-release fertilizers on growth and development of wheat was conducted at NEB-Crop Research Centre, G. B. Pant University of Agriculture & Technology, Pantnagar, India, during the winter season of 2021-22. The experiment was laid out in randomized complete block design with 7 treatments replicated thrice, as follows: 100% recommended dose of nitrogen (RDN) through neem-coated urea (NCU), 125% RDN–NCU, 100% RDN–Biochar-coated urea (BCU), 100% RDN–BCU, 75% RDN–BCU and 50% RDN–BCU with 2 sprays of 4% Nano-Urea (NU) and a control with no nitrogen. Both the fertilizers were applied at different nitrogen dosages, where the actual recommended dosage of wheat crop was 120:60:40 kg of $N:P_2O_5:K_2O$/ha. The fertilizer doses were broadcasted in split-doses of 25% each in basal, early tillering, active tillering and pre-flowering stage. Only the dosage of nitrogen was altered, while keeping the nutrient dose of phosphorus and potassium constant across the treatments. The nano-urea was applied only with 50% RDN–BCU to evaluate the performance of lower dose of BCU when supplemented with nano-urea (IFFCO) at 30 and 60 days after sowing. The wheat variety HD-2967 was used for sowing with a seed rate of 80 kg/ha through manual line sowing at a spacing of 20cm after ploughing twice and one harrowing.

The biochar-coated urea was compared with neem-coated urea in terms of wheat growth and development. The synthesis of biochar-coated urea was based on the work conducted by Singh et al. [7]. The performance of these different treatments on the wheat growth and development was studies during the experimental season. The experimental soil was categorized as sandy-clay loam, with medium organic carbon content (7.3 mg/kg), low in nitrogen 184.2 kg/ha, with a pH of 6.9 before start of the experiment. During the experimental period the maximum and minimum temperatures were 41.3 ºC and 2.4 ºC, respectively with an annual rainfall of 1338 mm.

Table 1. Physical and chemical properties of experimental soil

Soil texture	Soil pH	Electrical conductivity	Bulk density	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)

		(dS/m)	(g/cm^3)			
Sandy clay loam	6.9	0.24	1.37	184.2	23.4	243.7

2.2. Growth Parameters

The wheat plant samples were collected from a meter row length at 30-day interval till harvest from sowing in lines at 20 cm row spacing, and were subjected to oven-drying at 60 ± 5 ºC for 48 hours until the moisture was removed. The samples were weighed and the output was converted to per hectare basis. On the other hand, the plant height was also measured at 30 days interval, alongside with tillers per hectare. The growth analysis of wheat was measured using the following formulae:

Crop growth rate (CGR, g/m^2/day) $= \frac{w - \mathrm{w}_1}{\mathrm{t}_2 - \mathrm{t}_1} \mathrm{x} \frac{1}{\text{land area}}$

Relative growth rate (RGR, g/m^2/day) $= \frac{\log_e \mathrm{w}_2 - \log_e \mathrm{w}_1}{\mathrm{t}_2 - \mathrm{t}_1}$

Absolute growth rate (CGR, g/m^2/day) $= \frac{\mathrm{h}_2 - \mathrm{h}_1}{\mathrm{t}_2 - \mathrm{t}_1}$

here, w_1 and w_2 are whole plant dry weight at t_1 and t_2 are time interval (30 days). h_2 and h_1 are plant height at t_1 and t_2 are time interval (30 days).

2.3. Statistical analysis

The statistical analysis of data was carried out using 'one-way ANOVA' in SPSS Statistics software (27, IBM, USA) and MS Excel. The means comparison was performed by standard error mean values. the graphs were drawn through Microsoft Excel (version 2309, Microsoft Corporation, USA) software.

3. RESULTS AND DISCUSSION

3.1. Plant Height

The plant height of wheat was influenced by various doses of nitrogen fertilizers at all the stages of crop growth where data were recorded. Significant increase in plant height was observed from 30 DAS, where split-application of 125% N–BCN resulted in taller plants compared to 50% N–BCN+NS, but was similar to rest of the fertilizer doses (Table 1). On the other hand, at 60 and 90 DAS the taller plants were recorded under all fertilizer doses of NCU and BCU except 75% and 50% N—BCU+NS and control without nitrogen. Similarly, the taller plants at harvest stage were found with 125% N–BCU, which was 5.81% to 16.6% increase over other BCN treatments, and 3.46%–8.15% more over nitrogen applied through NCU. The increase in plant height of wheat is due to better nutrient supplementation at the critical crop stages through delayed and continuous release, which is an inherent property of a slow-release fertilizer [9]. On the other hand, although the plant height increased with increased dose of nitrogen through NCU, the nutrient translocation throughout the plant either during early or later stages was comparatively poor over biochar-coated slow-release fertilizers [10,11].

Table 2. Effect of BSRNFs on plant height of wheat at various stages of crop growth

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
100% N–NCU	18.7	39.9	90.1	99.4
125% N–NCU	19.9	41.7	92.9	103.9
125% N–BCN	20.7	42.9	95.1	107.5
100% N–BCN	19.1	40.8	91.4	101.6
75% N–BCN	18.2	39.9	89.0	97.7
50% N–BCN+NS	16.9	37.5	84.9	92.2
N control	12.2	26.4	38.6	59.6
SEm±	0.8	1.7	3.4	3.9
CD (p=0.05)	2.3	5.1	10.1	11.5

N-Nitrogen, NCU-Neem-Coated Urea, BCN-Biochar-Coated Nitrogen, NS-Nano-urea Sprays

3.2. Tillers

The tillers of wheat were significantly influenced by various doses of nitrogen fertilizers, indicating the effect of fertilizer sources from the early stages of the crop growth and development. More number of tillers were recorded with split application of 125% N–BCN over any other dosage of nitrogen application at all the stages of crop growth (Table 2). At 30 DAS, the 125% N–BCN recorded significantly higher tiller count compared to 100% N–NCU, 75% N–BCN, and 50% N–BCN+NS application, but was at par with 125% N–NCU and 100% N–BCN. Similarly at 60 and 90 DAS, split application of 125%, 100% N–BCN and 100% 100% N–NCU reported almost similar number of tillers, but were statistically at par with each other. The increase in tiller count under 125% N–BCN was 3.94–12.4% and 6.61–23.7% more with nitrogen application through NCU and BCU, respectively. The tiller count towards harvest was also found superior with 125% N–BCN application to wheat, but only 12.1% and 38.2% more tillers were reported over 100% N–NCU, and 50% N–BCN+NS application. This is evident that application of BCN fertilizers for wheat can significantly influence the nutrient releasee dynamics, through slow and efficient nutrient-release according to the crop needs [12, 13]. On the other hand, supplementing foliar nitrogen through nano-urea did not influence the tillers of wheat. Application of slow-release fertilizers can improve the biomass production since early stages and positively affect the source-sink relationship by establishing better soil-plant-nutrient relationship [14].

Table 3. Effect of BSRNFs on tillers (no./m^2) of wheat at various stages of crop growth

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
100% N–NCU	263.6	461.5	443.1	351.8
125% N–NCU	289.4	493.2	479.3	386.4
125% N–BCN	298.3	532.7	498.2	397.4
100% N–BCN	274.9	487.6	467.3	377.2
75% N–BCN	231.6	449.2	431.7	344.1
50% N–BCN+NS	217.2	402.7	386.8	287.6

N control	168.7	298.3	263.4	214.5
SEm±	11.4	19.5	18.2	14.4
CD (p=0.05)	33.6	57.4	53.6	42.6

N-Nitrogen, NCU-Neem-Coated Urea, BCN-Biochar-Coated Nitrogen, NS-Nano-urea Sprays

3.3. Crop Biomass

Application of various doses of nitrogen fertilizers, significantly influenced the crop biomass accumulation at different stages of crop growth. The increase in biomass was higher with 125% N–BCN indicating the effect of fertilizer sources from the early stages of the crop growth and development (Table 3). During 30 DAS, the biomass production under 125% N–BCN and NCU was almost similar, but were significantly higher than 50% N–BCN+NS and nitrogen control treatments. Also, at 60 and 90 DAS the crop biomass production was higher with 125% N–BCN and 125% N–NCU treatments. Application of 100% N–BCN resulted in -5.36% less biomass production compared to 125% N–BCN, but was 4.76 and 11.5% more than 75% N–BCN and 50% N–BCN+NS, respectively at 60 DAS. Similarly, the crop biomass at 90 DAS with 100% N–BCN was significantly higher than 50% N–BCN+NS and N control, but 6.24% and 11.5% higher than 75% N–BCN and 50% N–BCN+NS, respectively. Also, a 4.94% more biomass was accumulated with application of 100% N–BCN compared to 100% N–NCU. On the other hand, 125% N–BCN reported only 1.44% increase over 125% N–NCU, which is lower with increased fertilizer dose application. Even with 25% increased nitrogen dose to wheat over 100% N–BCN, the cop biomass accumulated was statistically similar with actual recommended dose. The difference in crop biomass with 100% N–BCN application was 6.72% and 10.5% more over 75% and 50% N–BCN+NS application. But the increased nitrogen dose 125% N–BCN reported 11.3% more crop biomass over 100% N–BCN, also 5.18% and 16.7% more compared to 125% N–NCU and 100% N–NCU, respectively. A considerable increase in the crop biomass with the application of BCN fertilizers is resultant of slow nutrient release and better nutrient uptake and helped in growth and development of wheat [15,16]. The crop nutrient demand for biomass accumulation during tillering and active vegetative stages was effectively met by the biochar coated nitrogen fertilizers, with extended nutrient release and very less nutrient losses [17]. But the nitrogen applied through neem-coated urea can restrict the nutrient losses to some extent compared to BCN fertilizers, there by resulting in lesser crop biomass accumulation.

Table 4. Effect of BSRNFs on crop biomass (g/m^2) of wheat at various stages of crop growth

Treatment	**30 DAS**	**60 DAS**	**90 DAS**	**At Harvest**
100% N–NCU	18.8	216.9	950.7	1036.6
125% N–NCU	20.2	226.8	983.5	1149.8
125% N–BCN	21.3	235.0	997.7	1209.4
100% N–BCN	19.7	222.4	972.2	1085.9
75% N–BCN	18.5	212.3	939.1	1017.5
50% N–BCN+NS	18.0	199.4	894.6	982.6
N control	7.8	133.6	423.4	477.7
SEm±	0.8	9.0	27.2	42.6

CD (p=0.05)	2.4	26.6	80.6	126.8

N-Nitrogen, NCU-Neem-Coated Urea, BCN-Biochar-Coated Nitrogen, NS-Nano-urea Sprays

3.4. Wheat Growth Analysis

The crop growth rate, relative growth rate, and absolute growth rate of wheat were derived based on the crop biomass accumulation and plant height, respectively, at 30 days interval. The rate of increase in crop biomass was significantly higher with application of 125 and 100% N–BCN, and 125 and 100% N–NCU application from 61-90 DAS and 91-harvest of wheat. The variations in the crop growth rate were depicted in the Figure 1. Where the considerable variations the CGR were better visible from 61 DAS to harvest of the crop, indicating the role of slow nutrient release from the BCU fertilizer as compared to quick-release neem coated urea. On the other hand, the relative growth rate of wheat was also significantly influenced by the fertilizer source and the dosage applied. The biomass production over existing crop biomass was comparatively higher with 125% N–BCN and 100% N–BCN application followed by 125 and 100% N–NCU application to the wheat. The positive correlation of the wheat crop biomass, CGR and RGR at 90 DAS was depicted in the Figure 3. The CGR and RGR showed significant positive correlation with crop biomass accumulation at 90 DAS with different dosages of NCU an BCN application to the wheat. With a unit increase in crop biomass (g/m^2) the CGR positively increased by 0.019 g/m2/day, and RGR increased by 0.028 mg/g/day, indicating a better biomass-growth relations with the fertilizer dosages applied. On the other hand, the absolute growth presented in Figure 2, highlighting the wheat absolute growth at different stages, where the AGR at the initial crop growth stages remained almost similar across the treatments, but was found to be influenced at lateral stages. The visible variations in the wheat AGR were found from 61-90 DAS and 91 DAS-harvest of the crop. The AGR indirectly addressed the increase in plant height for every passing day from sowing to harvest of the wheat, indicated that variations from different doses of BCN and NCU fertilizers is evident due to their significant properties including slow and sustained nutrient release [18,19].

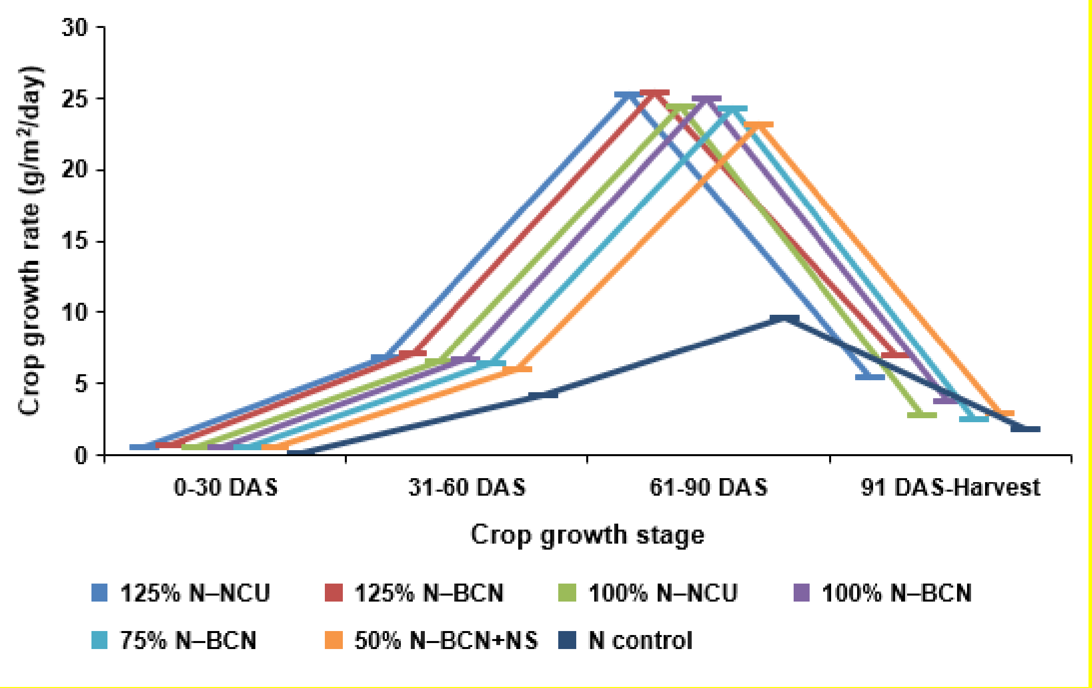

Figure 1. Effect of BSRNFs on crop growth rate (g/m^2/day) of wheat at various stages of crop growth

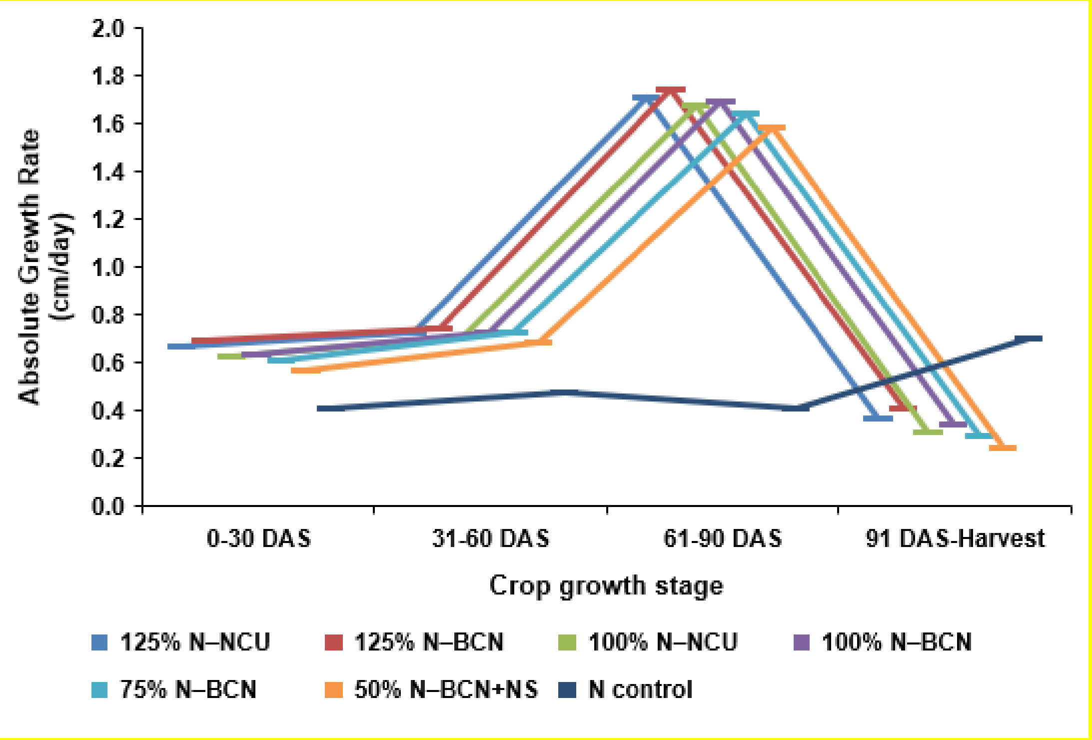

Figure 2. Effect of BSRNFs on absolute growth rate (cm/day) of wheat at various stages of crop growth

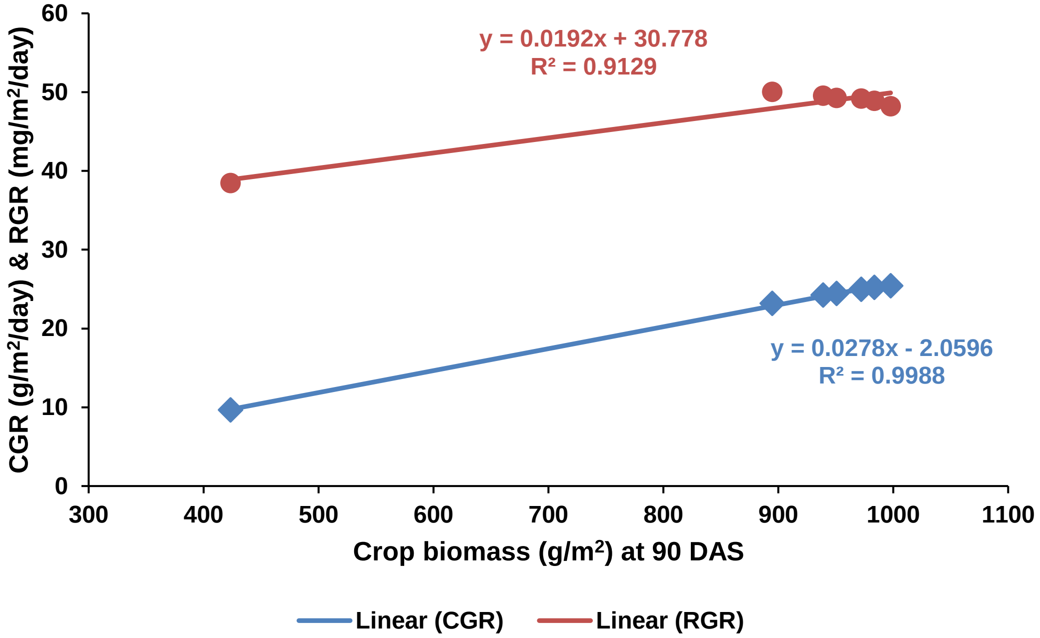

Figure 3. Relationship between crop biomass, crop growth rate and relative growth rate of wheat at 90 DAS

4. CONCLUSION

In conclusion the split-application of 100 and 125%N through BCN consistently led to taller plants, more crop biomass accumulation and better growth rate at various stages of growth, outperforming lower doses and conventional neem-coated urea (NCU). The slow and continuous nutrient release from BCN fertilizers resulted in superior plant height, tiller count, and biomass accumulation, demonstrating their effectiveness in enhancing wheat growth. The split application of 125% N–BCN resulted in 5.81% to 16.6% increase in plant height at the harvest stage compared to other BCN treatments and a 3.46% to 8.15% increase over nitrogen applied through NCU. For tiller production, 125% N–BCN application led to 3.94% to 12.4% more tillers compared to NCU and 6.61% to 23.7% more than other BCN treatments. Crop biomass accumulation was also higher with 125% N–BCN, showing a 1.44% increase over 125% N–NCU and up to 16.7% more than other BCN doses. The findings highlight the potential of BCN fertilizers to optimize nutrient use to improve crop growth, and sustain higher yields by minimizing nutrient losses. The study also showed that while higher nitrogen doses through NCU improved growth metrics, they were still outperformed by BCN due to the ability to sustain nutrient availability over time. These results underscore the benefits of BCN in promoting more sustainable and efficient wheat production systems, with cutting on fertilizer usage and reducing the nutrient losses in the Indo-Gangetic Plains. Further research is needed to explore the long-term effects and economic viability of BCN fertilizers under varying agricultural conditions.

Disclaimer (Artificial intelligence)

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