Turk J
Field Crops
2023, 28(2), 147-155
DOI: 10.17557/tjfc.1291613

EVALUATION OF WHEAT WITH DIFFERENT COATED CONTROLLED RELEASE UREA AND APPLICATION TIME IN SEMI-ARID CONDITIONS

Muhammad YOUNIS[1†], Sadam HUSSAIN[2,3†], Ghadeer M. ALBADRANI[3], Khairiah ALWUTAYD[3], Jinjin WANG[2†], Shaista JABEEN[4], Safdar ALI[1], Ilkay YAVAS[5], Saddam HUSSAIN[1,3**]*

[1] University of Agriculture, Department of Agronomy, Faisalabad, 38040, PAKISTAN
[2] Northwest A&F University, College of Agronomy, Yangling, Shaanxi 712100 P. R. CHINA
[3] Princess Nourah bint Abdulrahman University, Department of Biology, Riyadh, SAUDI ARABIA
[4] Northwest A&F University, College of Life Sciences, Yangling, Shaanxi 712100 P. R. CHINA
[5]Aydin Adnan Menderes University, Department of Plant and Animal Production, Aydın, TURKEY
Corresponding authors: iyavas@adu.edu.tr*; sadamhussainuaf@gmail.com*
†These authors contributed equally to this work.

Received: 03.05.2023

ABSTRACT

Optimal nitrogen (N) application rate, source and timing are important to achieve high wheat yield. Overdose of N as basal dose promotes excessive vegetative growth and delays maturity, resulting in low N use efficiency (NUE) and crop yield. The current study was conducted for two years (2018-2019 and 2019-2020) to examine the influence of various N sources viz., common-urea, Zn-coated urea, neem-coated urea, and polymer-coated urea and their application methods (basal- and split-application) on the growth, physiology, yield, and related traits in wheat under semi-arid conditions. Results showed that N sources and application methods significantly affected the growth, physiological and yield-related traits; neem-coated urea applied in splits remained the most effective source for the observed traits, followed by Zn-coated, polymer-coated, and common urea. Compared with common urea, neem-coated urea significantly increased chlorophyll (Chl) and carotenoid contents under basal and split application. Neem-coated urea also recorded higher biological and grain yields than other treatments which were associated with higher values of yield-related traits including the number of productive tillers, number of spikelets, and number of grains per spike. For N application methods, split application significantly improved the plant height, Chl pigments, yield- and yield-related traits compared with the basal application. In conclusion, neem-coated urea application as a split application performed well followed by Zn-coated and polymer-coated urea in improving the growth and overall yield.

Keywords: Basal application, neem-coating, nitrogen, split application, urea, wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) is among the major cereal crops and is consumed worldwide as a stable food and for carb requirements. In Pakistan, which has an agro-based economy, wheat crop contributes about 9.60% and 1.9% to the value addition in agriculture and gross-domestic production, respectively. According to an estimate, about 9052 thousand hectares are under the cultivation of wheat crop from where about 25.750 million tonnes are produced each year (Akhlaq et al., 2022).

Nitrogen (N), the major nutrient input in cereal production, plays an essential role in the growth and developmental processes (Wang et al., 2022; Israilov et al., 2023). This nutrient is also required for various physiological and biochemical events in plants. Nitrogen-sufficient input increases leaves' greenish and stimulates the formation of chlorophyll and photosynthetic activities which in turn increases assimilates production (Gulluoglu et al., 2015; Huang et al., 2022; Rafiq et al., 2023). Wheat N demand is low during the initial stages of stand establishment and increases rapidly during the exponential phase of growth. However, N utilization by crop plants is highly dependent on its source, time of application, crop species, and environmental conditions (Wang et al., 2022; Taskin and Bilgili, 2022). It is commonly recommended that N application into various splits significantly increases crop performance in terms of better growth and high seed yield associated with higher photosynthesis and continuous production of assimilates (Shah et al., 2012; Wang et al., 2022a). Best practices for nutrient management are based on the 4 R's (right form, right place, right timing, and right rate), which provide the highest likelihood for nutrient availability to match plant demand.

Urea is among the major and cheapest sources of N applied throughout the world (Ehsanullah et al., 2012). In the modern agricultural era, the demand and utilization of urea are steadily increasing worldwide. However, severe environmental and economic problems are associated with the application of urea (Khan et al., 2021). Over-dose application of urea cannot continually increase crop yields and leads to cost overruns and significant environmental issues. According to an estimate, only 35% of applied urea is consumed by crop plants (Bilal and Aziz, 2022). Under field conditions, most of the applied N is lost due to nitrification and denitrification, ammonia volatilization, and runoff (Guo et al., 2023). The extreme losses in the forms of NO_3, N_2O, and NH_3 volatilization pollute the soil and the environment; these greenhouse gases are the leading causes of global warming (Guo et al., 2022; Qian et al., 2022). To reduce these losses and improve N use efficiency in crops and agricultural sustainability, there is an urgent need to use a suitable N source with optimum management practices. Slow-release fertilizers provide a sustainable solution to deal with these problems (Ozturk and Yildirim, 2013; Ahmad et al., 2022).

Controlled released fertilizers reduce N losses by the release of nutrients according to the crop demands (Rehana et al., 2022). Different organic-based coating materials including neem- and polymers are also used to produce slow-release fertilizers for reducing N losses through leaching and volatilization and increasing crop N use efficiency (Waqar et al., 2022). As a natural nitrification inhibitor, neem-coated urea slows down the release of N, improves N utilization and reduces associated N losses, ultimately protecting soil and the environment (Al-Ansari and Kareem, 2013). Moreover, polymer-coated urea, as a synthetic nitrification inhibitor, also provides a sustainable solution to reduce N losses and enhance crop N utilization efficiency (Fan and Lia, 2010). Polymer coated urea could synchronize the N release characteristic with the plant demand, which improved the wheat yield and soil health. Meanwhile, the ease application of these controlled released fertilizers reduced the labor cost and increased the nitrogen use efficiency and yield of wheat. However, various crops, soil, and environmental-related factors can influence the efficacy of these controlled released fertilizers (Verburg et al., 2022). There is a lack of information on the application of urea fertilizers coated with organic materials under field conditions, particularly for wheat crop. In this experiment, it was hypothesized that the application of coated fertilizers, as compared with traditional urea, will improve the productivity of wheat crop. Our specific objectives were to (i) evaluate the efficacy of organic-coated controlled-release fertilizers for improving the growth, physiological traits, and productivity of wheat, and (ii) compare the performance of these fertilizers under basal and split applications.

MATERIALS AND METHODS

Experimentation

The current experiment was executed at the Agronomic Research Area, Department of Agronomy, University of Agriculture Faisalabad. The field trial was conducted for two consecutive years during the winter seasons of 2018-19 and 2019-2020. The experimental site had the following properties: Organic matter = 0.68%, Bulk density = 1.43 g cm^{-3}, porosity = 46.48%, pH = 7.8, Nitrogen = 0.046%, Phosphorus = 7.1 ppm, Exchangeable potassium = 120 ppm. The commonly cultivated wheat variety Ujala-2016 was sown through a drill at a seeding rate of 125 kg ha^{-1} during both study years with 22.5 cm distance between the crop rows. Fertilizers were applied at the recommended rate of 120, 90, and 60 kg ha^{-1} for N, phosphorus, and potash, respectively. The treatments were comprised of (i) different N sources viz. common-urea, Zn-coated urea, neem-coated urea, and polymer-coated urea, and (ii) N application methods viz. basal- and split-application. The Zn-coated urea was prepared according to the procedure of (Nazir et al., 2021). For neem-coated urea, the seeds of neem were collected from different trees. Dried seeds were extracted to the oil, and about 1000 mg oil was used to coat one kg of urea. The polymer-coated urea was obtained from the Institute of Soil and Environmental Sciences, UAF. Treatments were arranged in randomized complete block design under split plot arrangement where application methods and N sources were assigned to the main- and sub-plots, respectively. For basal application, the whole of N was applied at the time of sowing while for split application, it was applied at three different stages i.e., 50, 25 and 25% N at sowing, crown root initiation and maximum tillering stage, respectively. Each treatment was replicated thrice. Each experimental unit had a net size of 7.29 m^2 (4 m × 1.8 m) and eight rows of wheat crop. Weather data (Average temperature, Relative Humidity and Rainfall) during experiments were collected from Agricultural Meteorology Cell, Department of Agronomy, University of Agriculture, Faisalabad (Figure 1).

For seedbed preparation, one application of rotavator along with two cultivations with planking was done.

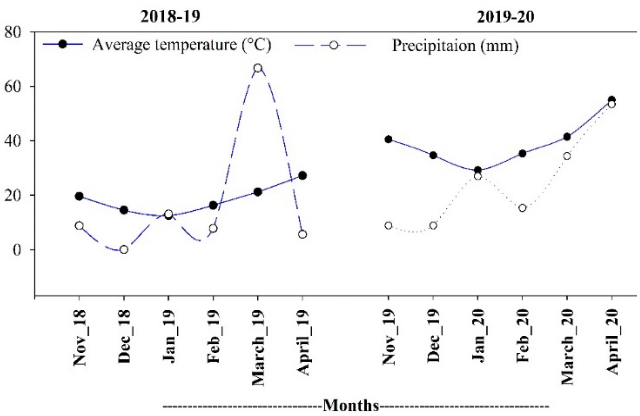

Figure 1. Average temperature (°C) and rainfall (mm) during the cropping season from November 2018 to April 2020.

Data recorded

Crop growth parameters

The first sampling was done after 30 days of sowing where plant samples were taken from each experimental unit and weights of various organs were measured. Later, the next samplings were done with a 15-day interval to measure the growth traits.

For LAI, firstly, 10 g of the subsample of green laminae was taken. Later, the leaf area meter (LI-3100C) was used to measure the value of leaf area, which was further used to calculate the LAI, according to the below equation.

$$LAI = \text{leaf area/land area}$$

The crop growth rate (CGR) was calculated according to the described method by Hunt (1978), using the below equation.

$$CGR = W_2 - W_1 / t_2 - t_1$$

Where, W_1 and W_2 are total dry weights harvested at time t_1 and t_2, respectively.

For measuring plant height, eight plants, from each experimental unit, were selected randomly at the physiological maturity stage, and the plant height from the land surface to the tip of plant was measured and averaged.

Physiological traits

Photosynthetic pigment

Acetone-based digestion method was followed to calculate the pigment contents at the physiological maturity stage. Firstly, fresh leaves samples were extracted in 5 mL of 80% acetone. Next, the filtered solution was centrifuged at 14000*rpm* for 15 min at cold temperature. Later, the supernatant was used to measure the absorbance spectrophotometrically at the wavelengths of 665, 649 and 470 nm for Chl a, Chl b and carotenoids content, respectively. Total Chl was shown as the sum of Chl a and Chl b. The following formulas were used to calculate the actual values:

$$\text{Chlorophyll a} = 11.75A_{665} - 2.350A_{649}$$

$$\text{Chlorophyll b} = 18.61A_{649} - 3.960A_{665}$$

Nitrogen content in leaves and stem

A detailed described method of Ryan et al. (2001) was followed to estimate N content in wheat leaves and straw. For that, oven-dried and ground samples of both organs were used to determine N content by using the Micro-Kjeldhal method, according to the below equation:

Nitrogen (%) = 14.1 x (titrant for sample (mL) - titrant for blank (mL)) x N of acid x d.f. / Weight of sample (g) x 10

Yield and related-traits

The standard procedures were followed to calculate the yield and related traits. In each experimental unit, the number of total tillers was counted. Moreover, a one-meter square area in each experimental unit was harvested for the number of spikes where five spikes were randomly selected, and their average was used. The number of grains per spike was achieved from the same spikes used. An electric weighing balance was used to weigh the 1000 grains. The grain and straw yields were considered as the total biological yield which was determined the weighing the whole plants from a unit area. The half area in each experimental unit was harvested to determine the grain yield and later the average was used. The percentage of grain and biological yield was used as the harvest index.

Statistical analysis

Initially, a three-way interaction was examined to find out the individual and concurrent effects of N sources, application methods, and study years. Years have a non-significant influence on all recorded traits; thus, the mean value was used for further analysis. Therefore, two-way ANOVA analysis was carried out to find the influence of N sources and methods on the growth, physiological and yield-related traits. Tukey's HSD test was used to test the treatments' difference at 5% probability level. Origin-pro software was used for the graphical presentation.

RESULTS

Chlorophyll and carotenoids content

Nitrogen sources and methods significantly affected the Chl and carotenoid contents, however, the interactive influence was non-significant. Among the N sources, neem-coated urea significantly improved the Chl a, b, total Chl, and carotenoid contents under both basal and split application followed by Zn-coated and polymer-coated urea. However, significantly lower values were recorded for the application of common urea under both basal and split application. As compared with the common-urea application, neem-coated urea increased Chl. a, b, total Chl., and carotenoid contents by 382.85, 401.88, 164.25, and 78.57% under basal application while 558.82, 283.62, 939.42, and 94.11% under split application. Between the application methods, split application depicted significantly higher values than the other one (Figure 2).

Leaf area index and crop growth rate

There was a significant difference between LAI and CGR among the N sources and methods. However, the interactive influence of N methods and sources was non-significant. Among the N sources, neem-coated urea depicted significantly higher values of LAI and CGR at various growth stages under both basal and split applications followed by zinc-coated and polymer-coated urea. However, the significantly lower values of these traits at various growth stages were recorded for the application of common urea under both basal and split application (Figure 2). As compared with the common-urea application, neem-coated urea increased LAI by 33.33, 21.87, 18.57 and 21.54% under basal application while 35.2, 14.85, 15.60 and 13.77% under split application at 45, 60, 75 and 90 DAS, respectively. Similarly, neem-coated urea increased CGR by 31.46, 29.73, 35.57 and 16.78% under basal application and 27.61, 28.75, 24.93 and 12.44% under split application at 45-60, 60-75, 75-90 and 90-105 DAS, respectively, as compared to that of common-urea for those minimum values was recorded (Figure 3). Between the application methods, split application depicted significantly higher values than basal application (Figure 3).

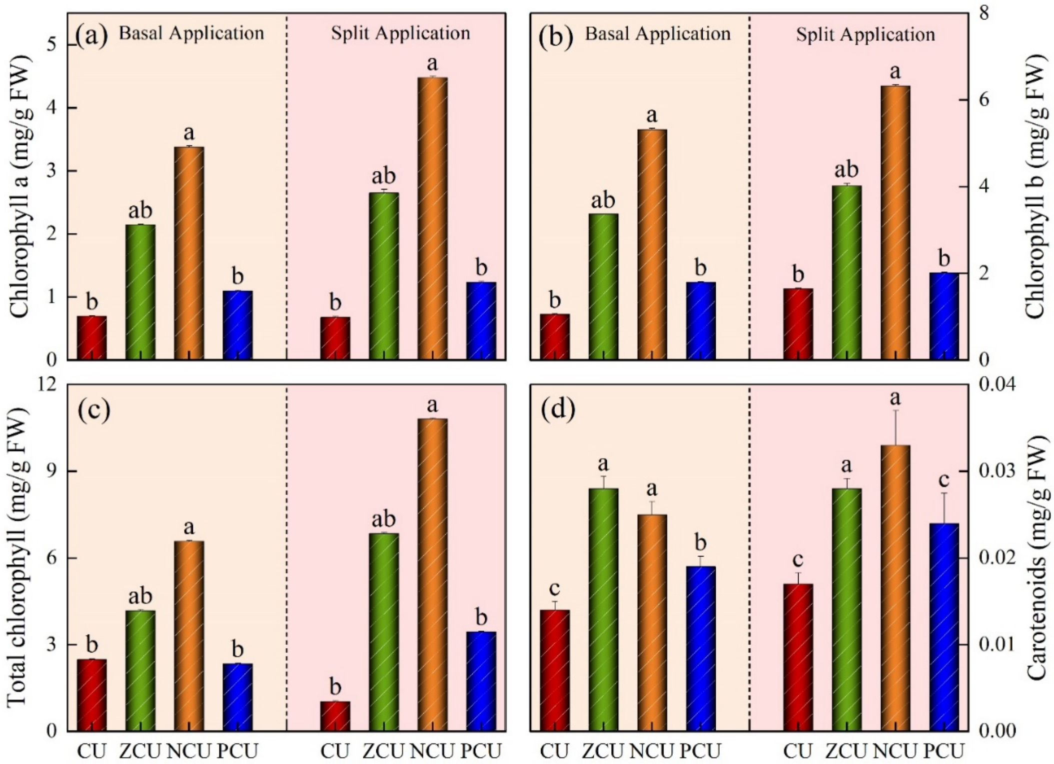

Figure 2. Effect of various nitrogen (N) sources (CU, common urea; ZCU, zinc-coated urea; neem-coated urea (NCU) and polymer-coated urea (PCU)) and application methods (basal and split application) on chlorophyll a (A), chlorophyll b (B), total chlorophyll (C) and carotenoids content (D) in wheat. Different lower-case letters above the bars show significant difference among N sources at each application method.

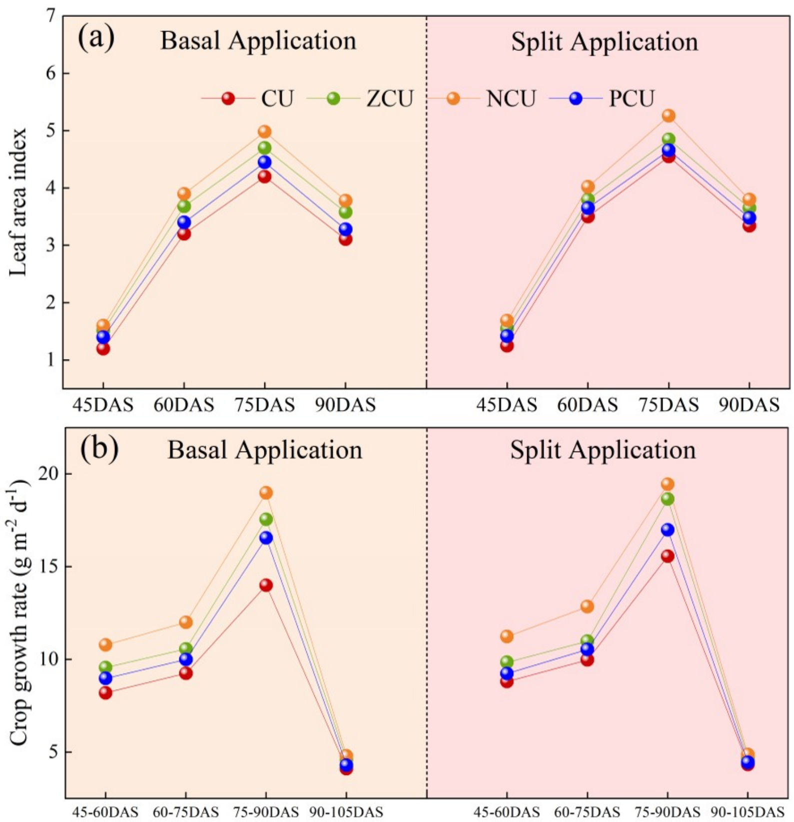

Figure 3. Effect of various nitrogen (N) sources (CU, common urea; ZCU, zinc-coated urea; neem-coated urea (NCU) and polymer-coated urea (PCU)) and their application methods (basal and split application) on leaf area index and crop growth rate of wheat at various stages. At x-axis, various values indicate the days after sowing.

Plant height and yield-related traits

Nitrogen sources and methods significantly affected the plant height, number of productive tillers, number of spikelets, and number of grains per spike however, the interactive influence was non-significant. Among the N sources, neem-coated urea significantly increased plant height, number of productive tillers, number of spikelets, and number of grains per spike followed by zinc-coated and polymer-coated urea. However, the significantly lower values of these traits were recorded for the application of common urea under both basal and split application (Table 1). As compared with the common-urea application, neem-coated urea increased plant height by 12.87% (averaged of both application methods). Similarly, neem-coated urea increased the number of productive tillers, number of spikelets and number of grains per spike by 22.11, 25.41, and 27.65% (average of both methods), respectively, when compared with common-urea. Between the application methods, split application depicted significantly higher values than basal application (Table 1). Split application increased plant height, number of productive tillers, number of spikelets, and number of grains per spike by 5.71, 36.21, 34.85, and 9.80%, respectively, compared with basal application.

Table 1. Agronomic traits of wheat as affected by various N sources and application times.

N sources /Application	Basal	Split	Mean	Basal	Split	Mean
	Plant height (cm)			Number of productive tillers (m^{-2})		
Common Urea	98.93	104.50	101.71 C	441.00	617.00	529.00 B
Zn-coated Urea	106.42	112.58	109.50 B	492.33	685.00	588.67 AB
Neem-coated Urea	110.66	119.00	114.83 A	567.67	725.00	646.33 A
Polymer-coated Urea	104.87	110.50	107.68 B	446.00	623.67	534.83 B
Mean	105.22 B	111.64 A		486.75 B	662.67 A	
F-value (HSD)	N=22.41 (3.52)**; A=286.95 (1.63)*; N×A=0.32^{ns}			N=7.68 (60)*; A=20.29 (168)*; N×A=0.13^{ns}		
	Number of spikes			Number of grains per spike		
Common Urea	451.00	627.00	539.00 C	44.07 e	51.80 d	47.93 C
Zn-coated Urea	512.33	705.00	608.67 B	52.73 cd	57.60 bc	55.17 B
Neem-coated Urea	597.67	755.00	676.33 A	58.17 ab	63.50 a	60.83 A
Polymer-coated Urea	461.00	638.67	549.83 BC	49.07 d	54.73 b-d	51.90 B
Mean	505.50 B	681.42 A		51.01 B	56.91 A	
F-value (HSD)	N=22.41 (60)**; A=286.95 (168)*; N×A=0.32^{ns}			N=24.07 (3.42)*; A=24.09 (5.17)**; N×A=0.32^{ns}		

The means with the different lowercase letters are significantly different to each other. * Indicates p<0.05; ** indicates p<0.01; ***, p<0.001; ns indicates non-significant.

Yield and harvest index

There was a significant difference in yield and harvest index among the N sources and application methods except for harvest index under various N sources. However, the interactive influence of N methods and sources was non-significant. Among the N sources, neem-coated urea depicted significantly higher values of yields under both application methods i.e., basal, and split application followed by zinc-coated and polymer-coated urea. However, the significantly lower values of these traits were recorded for the application of common urea under both basal and split applications (Table 2). As compared with the common-urea application, neem-coated urea increased 1000-grain weight, biological yield, and grain yield by 14.28, 44.45, and 30.17% (average of both application methods), respectively (Table 2). Between the application methods, split application depicted significantly higher values than basal application. Split application increased 1000-grain weight, biological yield, grain yield, and harvest index by 8.08, 36.21, 9.11 and 8.10%, respectively, as compared to the basal application (Table 2).

Nitrogen content in leaves and stem

There was a significant influence of N sources (P<0.01) and application methods (P<0.05) on N content in leaves and stem. However, the interactive effect of both treatments was non-significant (P<0.05) for these traits (Table 3). Among the N sources, neem-coated urea depicted significantly higher values of N contents when compared with other sources. For N content in leaves and stem, N sources were ordered as neem-coated urea > Zn-coated urea > polymer-coated urea > common-urea. Neem-coated urea increased N content in leaves and stem by 76.35 and 61.13%, respectively (average of both methods), as compared with common-urea. Between the application methods, split application depicted significantly higher values of N content in leaves and stem which were 21.59 and 22.51% more than basal application (Table 3).

Table 2. Wheat yield and related components as affected by various N sources and application times.

N sources/ Application	Basal	Split	Mean	Basal	Split	Mean
	1000-grain weight (g)			Biological yield (t ha^{-1})		
Common Urea	39.96	44.71	42.33 D	8.85	10.88	9.87 C
Zn-coated Urea	44.99	47.71	46.35 B	11.17	12.32	11.74 B
Neem-coated Urea	47.42	49.51	48.47 A	12.18	13.97	13.07 A
Polymer-coated Urea	42.29	46.84	44.56 C	10.03	12.85	11.44 B
Mean	43.66 B	47.19 A		486.75 B	662.67 A	
F-value (HSD)	N=25.01 (1.60)**; A=84.98 (1.64)*; N×A=1.62^{ns}			N=18.65 (0.93)**; A=83.54 (0.91)*; N×A=1.28^{ns}		
	Grain yield (t ha^{-1})			Harvest index (%)		
Common Urea	3.02	3.73	3.38 C	34.36	34.48	34.42 A
Zn-coated Urea	3.55	3.83	3.69 B	31.17	31.85	31.51 B
Neem-coated Urea	4.30	4.50	4.40 A	32.33	35.61	33.97 AB
Polymer-coated Urea	3.60	3.73	3.67 B	29.08	36.17	32.62 AB
Mean	3.62 B	3.95 A		31.73 B	34.53 A	
F-value (HSD)	N=25.76 (0.26)**; A=25.44 (0.28)*; N×A=2.26^{ns}			N=2.54 $(2.55)^{ns}$; A=45.48 (1.78)*; N×A=3.68^{ns}		

The means with the different lowercase letters are significantly different to each other. * Indicates p<0.05; ** indicates p<0.01; ***, p<0.001; ns indicates non-significant.

Table 3. Nitrogen accumulation in wheat as affected by various N sources and application times.

N sources/ Application	Basal	Split	Mean	Basal	Split	Mean
	Leaf N accumulation (%)			Stem N accumulation (%)		
Common Urea	2.80	4.55	3.68 D	3.97	5.19	4.58 D
Zn-coated Urea	4.33	5.70	5.02 B	5.65	6.88	6.27 B
Neem-coated Urea	5.90	7.08	6.49 A	6.88	7.88	7.38 A
Polymer-coated Urea	3.80	4.81	4.31 C	4.80	6.15	5.48 C
Mean	4.21 B	5.54 A		5.33 B	6.53 A	
F-value (HSD)	N=47.61 (0.54)**; A=28.47 (1.07)*; N×A=0.81^{ns}			N=131.97 (0.31)**; A=46.58 (0.75)*; N×A=0.50^{ns}		

The means with the different lowercase letters are significantly different to each other. * Indicates p<0.05; ** indicates p<0.01; ***, p<0.001; ns indicates non-significant.

Pearson's correlations

Pearson's correlations showed a significant positive association among most of the studied traits (Figure 4). The values indicate a positive correlation among productive tillers, thousand-grain weight, spikelets/spike, physiological traits, and grain yield. Similarly, a positive association was also observed between chlorophyll and carotenoid contents and grain yield, which is consistent with meaning of these traits (Figure 4).

DISCUSSION

The results of the present study supported our hypothesis that organic coated-urea improves the growth, physiology, and yield of wheat crop. Among the N sources, neem-coated urea significantly improved the growth indices such as plant height, leaf area index, and crop growth rate in wheat than other treatments. The crop growth rate is an important indicator which determines the influence of any treatment. The application of slow-release fertilizers reduces N losses and increases N retention in the soil for a longer period thus improving N availability and uptake which subsequently leads to better growth and biomass production. Similar results were reported by previous studies that slow-release fertilizers significantly improve the growth and development of field crops. For example, in a recent study, Ma et al. (2022) studied that controlled released fertilizers improved the overall performance of wheat crop under field conditions. In another study, Versino et al. (2020) also reported significant improvement in growth indices under the application of slow-release fertilizers. Previously, Fan and Li (2010) also demonstrated that coated-urea potentially improved plant growth when compared with normal urea. Under coated fertilizer application, the nutrient solubilizing microbes could have helped to ensure nutrient availability for longer times and decreased their losses in soil (Shah et al., 2023). Nonetheless, the bioactive compounds present in bioactive coated urea are known to enhance nutrient bioavailability to plants, for better growth and development, through the solubilization of insoluble soil fractions in rhizosphere to ensure continuous supply. On the other hand, the rapid hydrolysis process of common urea might have caused N heavy loss, which resulted in a lower soil available inorganic N concentration compared with coated-fertilizers.

Furthermore, we also reported that coated urea improved the Chl pigments when compared with normal urea application. Nitrogen is an important nutrient for plant growth as it is an essential component of Chl that absorbs light energy for photosynthesis (Earl and Tollenaar, 2007). In line with our results, previous studies also documented the positive influence of coated urea on photosynthetic pigment formation. For example, Scharf et al. (2006) depicted a significant increase in Chl pigment formation in seedlings exposed to coated urea.

Nitrogen sources also influence the N plant and translocation in different plant organs. According to our results, coated urea significantly improved N content in leaves and stems where maximum values were depicted for neem-coated urea. Similar to our results, previous studies also reported the higher uptake and translocation of N under slow-release N sources. For example, Hala et al. (2014) stated that neem-coated urea is much more conducive to improving N uptake by crop plants and reducing N losses. In a recent study, working with maize crops, Ji et al. (2021) demonstrated that slow-released fertilizers improved N uptake and its utilization by crop plants, when compared with normal urea as an N source. Similar was also reported by previous studies by Xiao et al. (2019) who demonstrated higher N uptake and utilization in seedlings when supplemented with controlled-released fertilizers.

In this experiment, we also depicted higher grain and biological yield in seedlings treated with coated urea. As compared with normal urea, higher grain yield was associated with higher values of photosynthetic pigments and yield-related traits under coated-urea application (Figure 2, Table 1). Working with a wheat-maize cropping system, Zheng et al. (2016) depicted significantly higher grain yield under coated-urea application, as compared to that of normal urea. This increase in yield was associated with higher traits-related traits and overall N utilization efficiency (Zheng et al., 2016). Some previous studies also reported the same (Otteson et al., 2007). The wheat grain yield increments were linked with the number of grains per spike and physiological traits, which ultimately enhanced the wheat grain weight (Figure 4), somehow, due to Zn supportive pollination through betterments in photosynthesis, sugar transformation, flowering, and grain formation (Shah et al., 2023). Moreover, responsive yield increments might also have resulted from the higher Zn uptake and recovery along with improved agronomic efficiencies. Previous studies also witnessed the bio-active Zn-coated urea-based enhancement in the morphological, yield, and quality parameters of rice (Nazir et al., 2021; Shah et al., 2023).

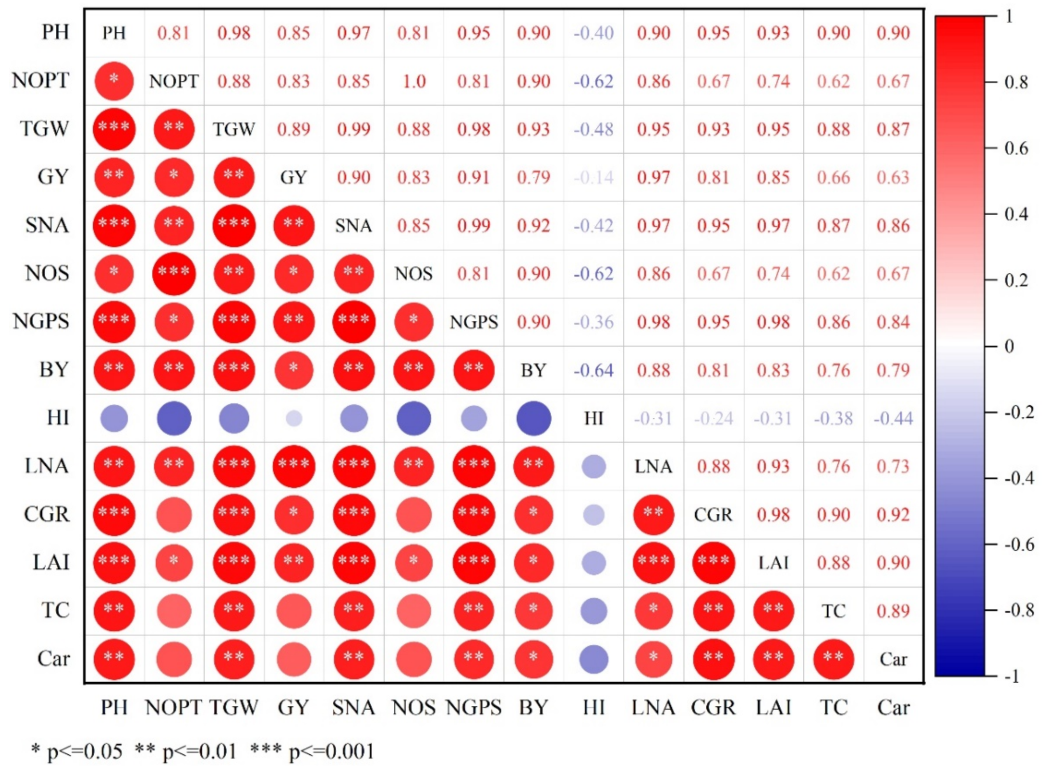

Figure 4. Co Pearson's correlations between the studied traits. PH: plant height, NOPT; number of productive tillers, TGW: thousand grain weight; GY: grain yield, BY: biological yield, HI: harvest index, NOS: number of spikes, NGPS: number of grains per spikes, SNA: shoot nitrogen accumulation, LNA, leaf nitrogen accumulation, CGR: crop growth rate, LAI: leaf area index, TC: total chlorophyll content, Car: carotenoid content.

Among the application methods, the split application was more effective in improving the growth, physiological traits, and yield of wheat as compared with the basal application. Previously published reports reported some positive and negative influences of basal application. Most of the conducted studies documented that slow-release fertilizers application as the basal application provides N too fast, depending upon the crop varieties and fertilizer type; thus, the basal application would not be an effective approach for improving N uptake and its utilization by crop plants (Farmaha and Sims, 2013; Ma et al., 2021). Similarly, some authors also stated that the application of coated urea at once decreased the grain yield of rice and other crops, which was associated with the unavailability of N at lateral growth stages (Mi et al., 2017). Moreover, compared with other crops, winter wheat has a longer growth period (Zhao et al., 2020); hence, basal application of N fertilizer is more prone to improve the growth at the early phase while slow at the reproductive phase, therefore reducing N utilization efficacy and grain yield (Li et al., 2021).

CONCLUSIONS

The present study demonstrated that neem-coated urea when applied in split-application increased the growth, physiological traits, and yield of wheat. The increase in yield under the same treatment was associated with increased values of yield-related traits including the number of productive tillers, number of spikelets, and number of grains per spike. For N application time, split application significantly improved the growth, physiology, and yield of wheat as compared with the basal application. Overall, neem-coated urea with split application is recommended to improve the productivity of wheat.

ACKNOWLEDGMENTS

The authors acknowledge the support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP-HC2022/4), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

LITERATURE CITED

Ahmad, A., Z. Aslam, T. Javed, S. Hussain, A. Raza, R. Shabbir, F. Mora-Poblete, T. Saeed, F. Zulfiqar, M.M. Ali and M. Nawaz. 2022. Screening of wheat (*Triticum aestivum* L.) genotypes for drought tolerance through agronomic and physiological response. Agronomy 12(2): p.287.

Akhlaq, M., S.W. Ali, A. Murtaza, M.A. Javed, A. Ahmad Khan and R.M. Amir. 2022. Impact of initial grain moisture, fumigation, and storage period on physicochemical characteristics of wheat in Pakistan. J. Food Process Preserv. 46(4): p.e16387.

Al-Ansari, E. and M.A.A. Kareem. 2013. Some plant extracts retard nitrification in soil. Act. Agric. Sloven. 103:5-13.

Bilal, H.M. and T. Aziz. 2022. Nitrogen use efficiency in crop production: issues and challenges in South Asia. Nitrogen Assessent.127-148.

Earl, H.J. and M. Tollenaar. 2007. Maize leaf absorbance of photosynthetically active radiation and its estimation using chlorophyll meter. Crop Sci. 37: 436-440.

Ehsanullah, K., G. Jabran, M. Hussain and M. Rafiq. 2012. Effect of nitrogen fertilization and seedling density on fine rice yield in Faisalabad, Pakistan. Pakistan J. Soil Environ. 31: 152-156.

Fan, X.H. and Y.C. Li. 2010. Nitrogen release from slow-release fertilizers as affected by soil type and temperature. Soil Sci. Soc. Am. J. 74:1635.

Farmaha, B.S. and A.L. Sims. 2013. Yield and protein response of wheat cultivars to polymer-coated urea and urea. Agron. J. 105(1):229-236.

Gulluoglu, L., H. Arioglu and H. Bakal. 2015. The effects of different nitrogen doses on tuber yield and some agronomical traits of early potatoes. Turkish J. Field Crop. 20(1):120-124.

Guo, R., R. Qian, F. Han, A. Khaliq, S. Hussain, L. Yang, P. Zhang, X. Chen and X. Ren. 2023. Managing straw and nitrogen fertilizer based on nitrate threshold for balancing nitrogen requirement of maize and nitrate residue. J. Environ. Manage. 329: p.117084.

Guo, R., R. Qian, L. Yang, A. Khaliq, F. Han, S. Hussain, P. Zhang, T. Cai, Z. Jia, X. Chen and X. Ren. 2022. Interactive Effects of Maize Straw-Derived Biochar and N Fertilization on Soil Bulk Density and Porosity, Maize Productivity and Nitrogen Use Efficiency in Arid Areas. J. Soil Sci. Plant Nutr. 1-21.

Hala, Y., O. Jumadi, A. Muis, H. Hartati and K. Inubushi. 2014. Development of urea coated with neem to increase fertilizer efficiency and to reduce greenhouse gas emissions. J. Tek. 65:11-15.

Huang, P., F. Shen, A. Abbas, H. Wang, Y. Du, D. Du, S. Hussain, T. Javed and S. Alamri. 2022. Effects of different nitrogen forms and competitive treatments on the growth and antioxidant system of *Wedelia trilobata* and *Wedelia chinensis* under high nitrogen concentrations. Front. Plant Sci. 13.

Hunt, R. 1978. Plant growth analysis. Edward Arnold, U.K, p. 26-38.

Israilov, I., K. Sheraliev, G. Abdalova, A. Iminov, K. Allanov, A. Karimov and B. Khaitov. 2023. Interactive effects of n fertilization and *Bradirhizobia japanicum* on agronomical traits of soybean in salt-affected soils. Turkish J. Field Crop. 28(1):15-25.

Ji, P.T., X.L. Li, Y.J. Peng, Y.C. Zhang and P.J. Tao. 2021. Effect of polyaspartic acid and different dosages of controlled-release fertilizers on nitrogen uptake, utilization, and yield of maize cultivars. Bioengineered 12(1):527-539.

Khan, N.U., A.A. Khan, M.A. Goheer, I. Shafique, S. Hussain, S. Hussain, T. Javed, M. Naz, R. Shabbir, A. Raza and F. Zulfiqar. 2021. Effect of zero and minimum tillage on cotton productivity and soil characteristics under different nitrogen application rates. Sustainability 13(24): p.13753.

Li, G., R. Gu, K. Xu, B. Guo, Q. Dai, Z. Huo and H. Wei. 2021. Split application of a mixture of controlled-release and common urea for improving quality and agronomic and economic performance in wheat production. Crop Sci. 61(6):4402-4415.

Ma, Q., R. Tao, Y. Ding, X. Zhang, F. Li, M. Zhu, J. Ding, C. Li, W. Guo, X. Zhu and H. Sheng. 2022. Can split application of slow-release fertilizer improve wheat yield, nitrogen efficiency and their stability in different ecological regions? Agronomy 12(2): p.407.

Ma, Q., M. Wang, G. Zheng, Y. Yao, R. Tao, M. Zhu, J. Ding, C. Li, W. Guo and X. Zhu. 2021. Twice-split application of controlled-release nitrogen fertilizer met the nitrogen demand of winter wheat. Field Crops Res. 267: p.108163.

Mi, W., S. Zheng, X. Yang, L. Wu, Y. Liu and J. Chen. 2017. Comparison of yield and nitrogen use efficiency of different types of nitrogen fertilizers for different rice cropping systems under subtropical monsoon climate in China. Eur. J. Agron. 90:78-86.

Nazir, Q., X. Wang, A. Hussain, A. Ditta, A. Aimen, I. Saleem, M. Naveed, T. Aziz, A. Mustafa and N. Panpluem. 2021. Variation in growth, physiology, yield, and quality of wheat under the application of different zinc coated formulations. Appl. Sci. 11(11): p.4797.

Otteson, B.N., M. Merghoum and J.K. Ranson. 2007. Seeding rate and nitrogen management effects on spring wheat yield and yield components. Agron. 7:1-49.

Ozturk, G. and Z. Yildirim. 2013. Effect of bio-activators on the tuber yield and tuber size of potatoes. Turkish Journal of Field Crops 18(1): 82-86.

Qian, R., R. Guo, Y. Liu, M.A. Naseer, S. Hussain, D. Liu, P. Zhang, X. Chen and X. Ren. 2022. Biodegradable film mulching combined with straw incorporation can significantly reduce global warming potential with higher spring maize yield. Agric. Ecosyst. Environ. 340: p.108181.

Rafiq, M., M. Saqib, H. Jawad, T. Javed, S. Hussain, M. Arif, B. Ali, M.S.A. Bazmi, G. Abbas, M. Aziz and M.K. Al-Sadoon. 2023. Improving quantitative and qualitative characteristics of Wheat (*Triticum aestivum* L.) through nitrogen application under semiarid conditions. Phyton. 92(4): 1001:1017

Rehana, M.R., R. Gladis and B. Joseph. 2022. Controlled Release of Nutrients for Soil Productivity-A Review. Curr. J. Appl. Sci. Technol. 41(20):34-46.

Ryan, J., G. Estefan and A. Rashid. 2001. Soil and Plant Analysis Laboratory Manual. 2nd eds. ICARDA, Syria.

Scharf, P.C., S.M. Brouder and R.G. Hoeft. 2006. Chlorophyll meter readings can predict nitrogen need and yield response of corn in the North-Central USA. Agron. J. 98:655-665.

Shah, S.S.H., M. Azhar, F. Nadeem, M.A. Ali, M.N. Khan, I. Ahmad, M.Y. Khurshid, M. Hasnain, Z. Ali and A.A.A.A. Shaheen. 2023. Enhancements in yield, agronomic, and zinc recovery efficiencies of rice-wheat system through bioactive zinc coated urea application in Aridisols. *Plos one* 18(3): p.e0282615.

Shah, Z., M.Z. Shah and A. Rab. 2012. Enhancing efficiency of N fertilizer through nitrapyrin Vs split application on wheat crop. Sarhad J. Agric. 29: 371-378.

Taskin, S.Z. and U. Bilgili. 2022. Effects of different nitrogen sources on turf quality and plants growth of some warm-season turfgrasses. Turkish J. Field Crop. 27(1):167-174.

Verburg, K., P.J. Thorburn, M.P. Vilas, J.S. Biggs, Z. Zhao and G.D. Bonnett. 2022. Why are the benefits of enhanced-efficiency fertilizers inconsistent in the field? Prerequisite conditions identified from simulation analyses. Agron. Sustain. Develop. 42(4):73.

Versino, F., M. Urriza and M.A. García. 2020. Cassava-based biocomposites as fertilizer controlled-release systems for plant growth improvement. Ind. Crops and Prod. 144: p.112062.

Waqar, M., M. Habib-ur-Rahman, M.U. Hasnain, S. Iqbal, A. Ghaffar, R. Iqbal, M.I. Hussain and A.E. Sabagh. 2022. Effect of slow release nitrogenous fertilizers and biochar on growth, physiology, yield, and nitrogen use efficiency of sunflower under arid climate. Environ. Sci. Pollut. Res. 29(35): 52520-52533.

Wang, J., S. Hussain, X. Sun, P. Zhang, T. Javed, E.S. Dessoky, X. Ren and X. Chen. 2022. Effects of nitrogen application rate under straw incorporation on photosynthesis, productivity and nitrogen use efficiency in winter wheat. Front. Plant Sci. 13:862088.

Wang, J., S. Hussain, X. Sun, X. Chen, Z. Ma, Q. Zhang, X. Yu, P. Zhang, X. Ren, M. Saqib and M. Farooq. 2022a. Nitrogen application at a lower rate reduce net field global warming potential and greenhouse gas intensity in winter wheat grown in semi-arid region of the Loess Plateau. Field Crops Res. 280: p.108475.

Xiao, Y., F. Peng, Y. Zhang, J. Wang, Y. Zhuge, S. Zhang and H. Gao. 2019. Effect of bag-controlled release fertilizer on nitrogen loss, greenhouse gas emissions, and nitrogen applied amount in peach production. J. Clean. Prod. 234: 258-274.

Zhao, H.X., P. Zhang, Y.Y. Wang, T.Y. Ning, C.L. Xu and P.U. Wang. 2020. Canopy morphological changes and water use efficiency in winter wheat under different irrigation treatments. J. Integr. Agric. 19(4):1105-1116.

Zheng, W., M. Zhang, Z. Liu, H. Zhou. H. Lu, W. Zhang, Y. Yang, C. Li and B. Chen. 2016 Combining controlled released urea and normal urea to improve nitrogen use efficiency and yield under wheat-maize double cropping system. Field Crops Res. 197:52-62.