

Soil chemical properties and nitrogen-use efficiency as affected by different sources and nitrogen application schedules under zero-tillage wheat (*Triticum aestivum* L.) in Haryana

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ABSTRACT

Low nutrient use efficiency ($\leq 40\%$) and environmental pollution due to improper fertilizer management and heavy tillage are the biggest problems in current world agriculture. Thus, for the solution of these challenges, a two-year field experiment was carried out during *Rabi* season of (2022-23 and 2023-24) in Chaudhary Charan Singh Haryana Agricultural University, Hisar (India) to study the effect of different sources and nitrogen application times on soil chemical properties and nutrient use efficiency. Five different N doses in the main plots and four different N application times in the sub plots have been laid out in the split plot design for the analysis of data. The result of data revealed that application of 100% nitrogen through urea significantly resulted higher available nutrients in soil and higher nutrient use efficiency followed by the application of 75% recommended nitrogen through urea and 25% through nano urea in both respective years. On the other hand, application of nitrogen in three equal split doses (1/3 as basal + 1/3 after 1st irrigation + 1/3 after 2nd irrigation) recorded significantly higher nutrient use efficiency and being at par with application of N (1/3 as basal +1/3 before 1st irrigation +1/3 before 2nd irrigation), while soil available NPK and OC did not show any significant difference among different N application schedules during both consecutive years.

Key words: Wheat, urea, nano-urea, NUE and zero tillage

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most extensively grown cereal crop in the world and is used as a staple food by nearly 2.5 billion people in the world. Among major cereals, wheat ranks first in area (220.7 m ha) and production (785 m t) at the global level during 2022–23, and it is the staple food of nearly 35 percent of the world population (USDA, 2022). In India area, production and average productivity of wheat was 31.23 m ha, 112.92 m t and 36.24 q ha⁻¹, during 2023–24, respectively (Anonymous, 2024). Whereas, in

Haryana, wheat is growing over an area of 3.75 m ha with a production of 12.45 m t and productivity of 44.22 q ha⁻¹ during 2020–21 (ICAR-IIWBR, 2023–24). To keep pace with the annual population growth rate of India, *i.e.*, 0.97%, and to meet the future wheat demand of India by 2050, *i.e.*, 140 million tonnes, the productivity from present level of 3.3 t ha⁻¹ to 4.7 t ha⁻¹ and production of wheat by 46% have to be increased (Sarkar *et al.*, 2023).

Various factors may be responsible for stagnating wheat yields in North-West India such as late sowing, inappropriate crop establishment, inadequate and imbalance nutrient management and degrading soil health. Nitrogen management is the most important factor responsible factor for low productivity of wheat (Sarkar *et al.*, 2023). Under conditions of intensive agriculture systems,

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the traditional wheat cultivation requires high inputs of N fertilizers which is related to the risk of N losses (Skolnikova *et al.*, 2022). Urea is one of the superlative nitrogen rich fertilizers which is easily converted into ammonia in the soil, but less than half of it is available to the plants, while, the rest of the urea gets lost in the soil and air by leaching, de-nitrification and volatilization, thereby resulting in low N use efficiency and causes environmental pollution (Yang *et al.*, 2015). In the majority of soils, urea's nitrogen usage efficiency is normally low, ranging from 20 to 50 (Upadhyay *et al.*, 2023). Whereas, nano urea is a modified form of traditional fertilizers based on nanotechnology, addresses challenges in traditional agriculture due to population growth, soil nutrient depletion, limited land resources, and climate change (Singh *et al.*, 2023). A recent review on nano-urea confirmed their high solubility, stability, effectiveness, time-controlled release, targeted activity, low ecotoxicity, consistency, simple delivery and safe and disposal methods (Kumar *et al.*, 2023). Thus, the combined application of conventional fertilizers and nano fertilizers increased the available amount of N, K, Zn and Cu in soil when tested at the harvest of the crop (Khardia *et al.*, 2022). Improper nitrogen application time during the crop growing period is one of the most limiting factor for wheat production. Whereas, excessive investment and improper application methods of N fertilizer by farmers in production further exacerbate N loss, which not only reduces N use efficiency (NUE), but also causes serious resource waste and environmental pollution (Ma *et al.*, 2024). However, adoption of appropriate N fertilizer management practices is reported to increase N recovery up to 70–80% (Belete *et al.*, 2018). To improve NUE and reduce the risk of reactive N loss, the traditional fertilization strategy in wheat production is to apply N fertilizer in 3–4 times to alleviate the accumulation of nitrate in the soil and promote the absorption and utilization of N by plants (Hao *et al.*, 2023). The current understanding is that a 2-split application of N fertilizer is suited to the slightly heavier soils of eastern Haryana where the rice–wheat system dominates and that 3-way split should apply in the west and south-west regions that have lighter soils and where rice is not grown (Bhardwaj *et al.*, 2010). In

addition, to reduce the soil disturbance (due to conventional tillage), cost of cultivation and environmental pollution in wheat cultivation, zero tillage system is a good option to overcome these challenges (Jat *et al.*, 2018). Zero till seeding of wheat also allows band application of basal fertilizer which ensure placement of phosphatic fertilizers right in the seed zone and also allows a saving of 25% in the seed rate to obtain sufficient plant stand as compared to traditional broadcasting. Therefore, to address the challenges of diminishing soil fertility and for increasing NUE through combined application of urea and nano urea, the current experiment on exploring optimum application rate and time of N fertilizer during the crop growing period coupled with conservation agriculture (zero-tillage) can play a greater role in improving NUE, crop production and soil properties along with improving environmental quality, ecological sustainability, and economic viability.

MATERIALS AND METHODS

The field experiments were laid out during Rabi season of 2022-23 and 2023-24 at Research Farm of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. Twenty treatments, comprising five doses of nitrogen (50% RDN through Urea + 50% RDN through Nano Urea; 62.5% RDN through Urea + 37.5% RDN through Nano Urea; 75% RDN through Urea + 25% RDN through Nano Urea; 100% RDN through Urea and Control) and four different N application times (1/2 as basal application + 1/2 after 1st irrigation; 1/2 after 1st irrigation + 1/2 after 2nd irrigation; 1/3 as basal + 1/3 after 1st irrigation + 1/3 after 2nd irrigation; 1/3 as basal + 1/3 before 1st irrigation + 1/3 before 2nd irrigation) worked out during respective years in three replications. The soil of the experiment was sandy loam having 8.2 and 7.8 pH, 0.3 dSm⁻¹ EC and 0.4 % OC with 164.5 and 168.0 kg ha⁻¹ available N, 13.2 and 12.5 kg ha⁻¹ available P and 255.2 and 247.4 kg ha⁻¹ available K status. Sowing of WH-1105 variety of wheat with a seed rate of 100 kg ha⁻¹ was done on 21st of November, 2022-23 and 2023-24 using zero till machine at 20 cm row to row spacing. The crop was fertilized with RDF

(150:60:60 kg/ha N, P_2O_5 and K_2O) and the source of nutrient used included Neem coated Urea (46 % N), SSP (16 % P_2O_5), MOP (60% K_2O) and Nano Urea (4% N). Recommended dose of fertilizers viz., entire quantity of phosphorus and potassium were applied at the time of sowing, while, RDN through Urea was applied in two and three equal splits i.e., as basal, before and after first and second irrigation, as per treatment and RDN through Nano Urea has been applied at 46 DAS by manual compressed air sprayer as per treatment during both the years of experimentation. The soil samples were collected from 0-15 cm soil profile at the initial and at the end of experimentation during both crop seasons. The soil samples after air dried ground and passed through 2 mm mesh sieve were analyzed for available N, P, K and OC.

NUE expressed in term of Agronomic efficiency and partial factor productivity of Nitrogen

1. Estimation of Agronomic efficiency of nitrogen was computed based on the relative crop performance in fertilized plots as compared to plots without N fertilization (Fageria and Baligar, 2008). Agronomic efficiency of N expressed as kg grain/kg N applied and it was calculated using the following formula;

$$AE = \frac{YN - Y_0}{FN}$$

Where, AE is Agronomic efficiency, YN and Y_0 are the grain yield with and without N applied, respectively and FN is the amount of nitrogen fertilizer applied.

2. Partial factor productivity (PFP) of the applied nitrogen is calculated by dividing grain yield from a treatment ($kg\ ha^{-1}$) to the amount of nitrogen ($kg\ ha^{-1}$) applied and expressed as kg grain/kg N applied ($PFP = N\ output/N\ input$). Other agronomic practices viz., irrigation, weeding, hoeing and plant protection measures have been supplied at appropriate times during the crop period. The data on various soil chemical parameters and nutrient use efficiency were carried out as per different procedures and statistically analyzed with the help of OPSTAT developed by Sheoran *et al.*, (1998).

RESULTS AND DISCUSSION

Effect of nitrogen sources and its application times on soil chemical properties The data related

to soil chemical properties i.e., organic carbon, available nitrogen, available phosphorus and available potassium as influenced by source and time of nitrogen application presented in Table 1.

Organic carbon in soil (%)

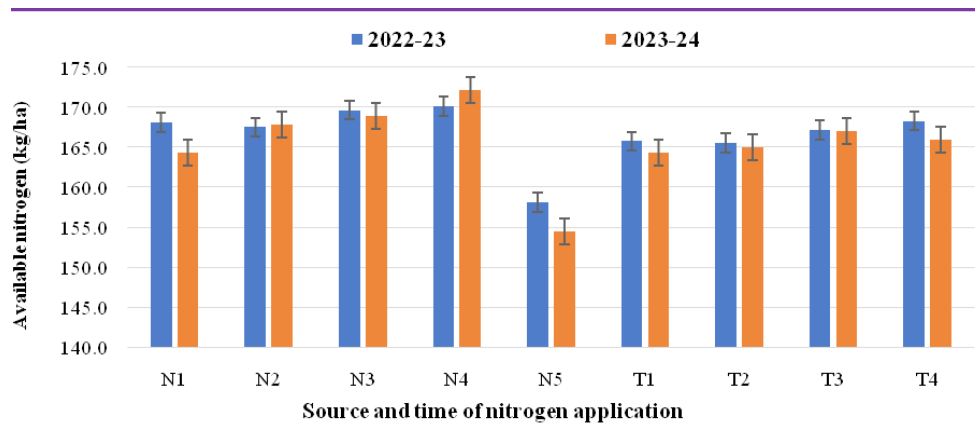
Organic carbon is an indication of organic carbon fraction of soil, formed due to microbial decomposition of organic residue. The perusal of data related to organic carbon in soil after termination of study during both of the years (2022-23 and 2023-24) has been given in Table 1. Organic carbon did not significantly affect by different sources of nitrogen, however, it varied between 0.38-0.41% during first year and 0.36-0.39% during second year after harvest of crop. It might be due to application of RDF through chemical fertilizer without adding any organic materials, resulting in decline of soil organic carbon. Among the different nitrogen application times, organic carbon in soil was not influenced significantly after harvest of wheat in both the years of investigation. It was ranged from 0.39% to 0.40% and 0.36% to 0.38% during both years, respectively. Kumar *et al.*, (2023) have been reported similar results and found non-significantly effect of nitrogen application times on organic carbon of soil.

Available nitrogen (kg/ha)

Data on available N status in soil after termination during both the years of study (2022-23 and 2023-24) is mentioned in Table 1 and Figure 1. Available N in soil was significantly influenced by nitrogen sources. Highest available N in soil was accumulated with 100% of recommended dose of nitrogen through Urea than control, which was statistically at par with rest of the treatments after harvest of wheat during first year of study. Whereas, during second year, it remained at par with application of 75% RDN through Urea + 25% RDN through Nano Urea and being superior than application of 62.5% RDN through Urea + 37.5% RDN through Nano Urea. The treatment in which 50% RDN applied through Urea + 50% RDN through Nano Urea showed lower available nitrogen content in soil which was due to inadequate supply of nitrogen through Nano Urea as compare to requirement of wheat crop and also might be due to the higher uptake of nitrogen in

Table 1. Effect of different sources and times of nitrogen application on organic carbon and available nitrogen in soil under zero-tillage wheat

Treatments	Soil chemical properties			
	Organic carbon (%)		Available N(kg/ha)	
	2022-23	2023-24	2022-23	2023-24
<i>Sources of Nitrogen</i>				
N ₁ : 50 % RDN through Urea + 50% RDN through Nano Urea	0.39	0.37	168.08	164.30
N ₂ : 62.5 % RDN through Urea + 37.5% RDN through Nano Urea	0.39	0.39	167.50	167.78
N ₃ : 75 % RDN through Urea + 25% RDN through Nano Urea	0.41	0.37	169.63	168.97
N ₄ : 100% RDN through Urea	0.39	0.37	170.13	172.18
N ₅ : Control	0.38	0.36	158.08	154.46
SEm ±	0.01	0.01	1.39	1.85
CD (P = 0.05)	NS	NS	3.21	4.26
<i>Times of Nitrogen Application</i>				
T ₁ : 1/2 as basal application + 1/2 after 1 st irrigation	0.40	0.38	165.75	164.27
T ₂ : 1/2 after 1 st irrigation + 1/2 after 2 nd irrigation	0.39	0.37	165.55	164.98
T ₃ : 1/3 as basal + 1/3 after 1 st irrigation + 1/3 after 2 nd irrigation	0.39	0.36	167.15	166.95
T ₄ : 1/3 as basal +1/3 before 1 st irrigation + 1/3 before 2 nd irrigation	0.40	0.38	168.29	165.95
SEm ±	0.01	0.01	1.48	1.22
CD (P = 0.05)	NS	NS	NS	NS

**Fig. 1.** Effect of different sources and times of nitrogen application on available nitrogen of zero- tillage wheat during 2022-23 and 2023-24

treatments where spray of Nano Urea has been done. Similar result also reported by Upadhyay *et al.*, (2023) and Kumar *et al.*, (2019) who observed that application of 50% recommended N doses with spraying of nano-urea registered significantly lower mineral N compared with recommended 100% NPK application. Time of nitrogen application had non-significant effect on available N status in soil in both the years, it was ranged between 165.8 to 168.3 kg/ha and 164.3 to 167.0 kg/ha after harvest of crop during both of the years, respectively. This result is in conformity with the finding of Kumar *et al.*, (2023) who found non-significant effect of nitrogen application times

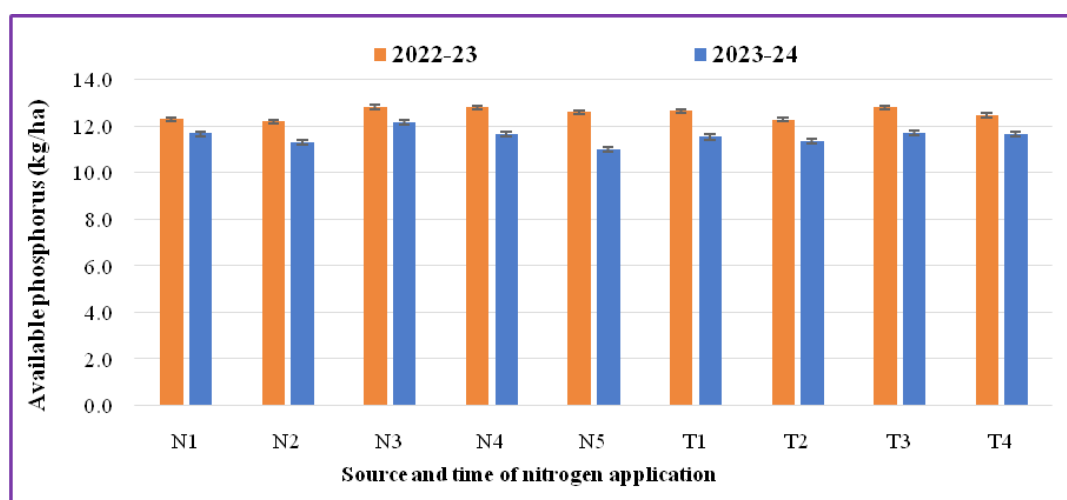
on available nitrogen in soil.

Available phosphorus (kg/ha)

The data pertaining to available phosphorus in soil is presented in Table 2 and Figure 2. Available P in soil was not influenced significantly when different sources of nitrogen was tested, but numerically higher available P was recorded with application of 75 % RDN through Urea + 25% RDN through Nano Urea. As a result of mismatch, the available phosphorus content in soil showed significant decline after the termination of both years of experimentation. The decline in soil available P might be due to fewer activities of soil mi-

Table 2. Effect of different sources and times of nitrogen application available phosphorus and available potassium in soil under zero-tillage wheat

Treatments	Available P(kg/ha)		Available K(kg /ha)	
	2022-23	2023-24	2022-23	2023-24
<i>Sources of Nitrogen</i>				
N ₁ : 50 % RDN through Urea + 50% RDN through Nano Urea	12.28	11.66	250.17	244.07
N ₂ : 62.5 % RDN through Urea + 37.5% RDN through Nano Urea	12.18	11.28	250.25	243.45
N ₃ : 75 % RDN through Urea + 25% RDN through Nano Urea	12.81	12.16	252.83	242.33
N ₄ : 100% RDN through Urea	12.79	11.64	249.75	242.95
N ₅ : Control	12.57	11.00	249.33	241.53
SEm ±	0.44	0.32	2.18	2.18
CD (P = 0.05)	NS	NS	NS	NS
<i>Times of Nitrogen Application</i>				
T ₁ : 1/2 as basal application + 1/2 after 1 st irrigation	12.62	11.51	249.53	241.93
T ₂ : 1/2 after 1 st irrigation + 1/2 after 2 nd irrigation	12.26	11.33	250.13	242.53
T ₃ : 1/3 as basal + 1/3 after 1 st irrigation + 1/3 after 2 nd irrigation	12.77	11.70	251.53	243.93
T ₄ : 1/3 as basal +1/3 before 1 st irrigation +1/3 before 2 nd irrigation	12.45	11.65	250.67	243.07
SEm ±	0.31	0.25	2.17	2.17
CD (P = 0.05)	NS	NS	NS	NS

**Fig. 2.** Effect of different source and time of nitrogen application on available phosphorus of zero-tillage wheat during 2022-23 and 2023-24

croorganisms due to lack of organic manures and crop residues. These results are supported by the finding of Chai *et al.*, (2015); Buzea *et al.*, (2007) and Solanki *et al.*, (2008). A perusal of data revealed that available P in soil was not influenced significantly by different split application of N after harvest of wheat during both the years of investigation. Highest available P was recorded with application of N in three split doses *viz.*, 1/3 as basal, 1/3 after 1st irrigation and 1/3 after 2nd irrigation. Kumar *et al.*, (2023) have been reported similar results and found non-significant effect of

different split application of N on available P in soil.

Available potassium (kg/ha)

Available potassium in soil did not showed any significant difference between different sources of nitrogen (Table 3 and Fig. 3). It ranged from 249.3 kg/ha to 252.8 kg/ha in the first year of study and 241.5 kg/ha to 244.1 kg/ha in the second year of study after termination of the experiment. The decline in available potassium after both growing season as compared to the initial

value could be attributed to the differences between the potassium uptake in different treatments and due to unavailability of organic sources of K in soil. Also, the potassium equilibrium in soil, which enables the soil to maintain available potassium content in soil despite differences in uptake, also resulted in non-significant differences among different treatments. Similar result also reported by Chai *et al.*, (2015). Data further indicated that time of nitrogen application had no significant effect on soil available K in both years, it ranged from 249.5 to 251.5 kg/ha and 241.9 to 243.9

kg/ha after the growing season of both the years of experimentation, respectively. Kumar *et al.*, (2023) found similar results and reported that available K in soil was not affected by different nitrogen application times.

Effect of nitrogen sources and its application times on nutrient use efficiency

Nutrient use efficiency (NUE) of nitrogen is an indicator of nitrogen productivity in wheat. The NUE of nitrogen in wheat under different sources of N treatments discussed in terms of

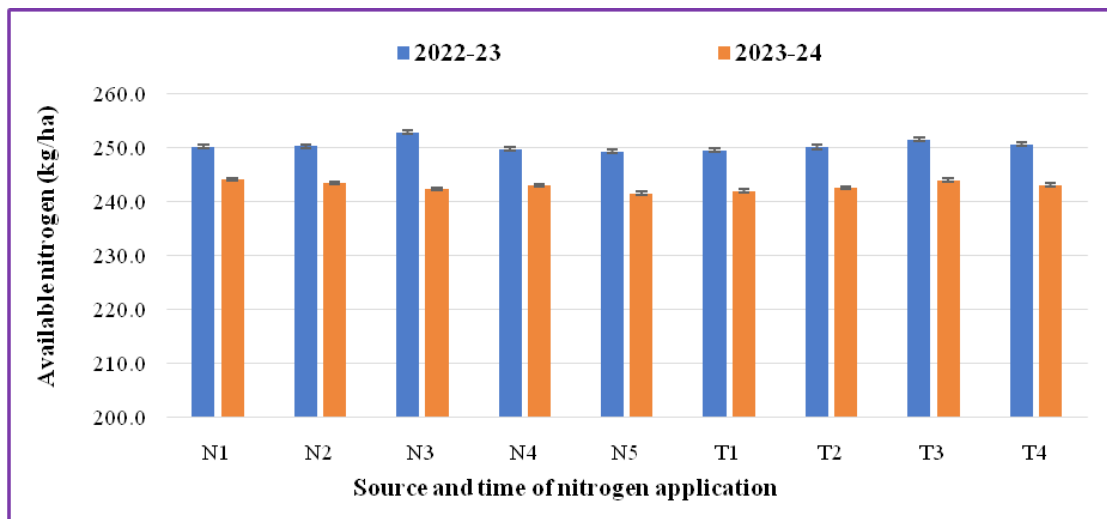


Fig. 3. Effect of different source and time of nitrogen application on available potassium of zero-tillage wheat during 2022-23 and 2023-24

Table 3. Effect of different sources and times of nitrogen application on nitrogen use efficiency in zero-tillage wheat

Treatments	Nitrogen use efficiency (NUE)			
	PFP (kg grain/kg N applied)		AE ($Y_f - Y_c$ /RDN)	
	2022-23	2023-24	2022-23	2023-24
<i>Sources of Nitrogen</i>				
N ₁ : 50 % RDN through Urea + 50% RDN through Nano Urea	27.18	27.84	2.60	2.95
N ₂ : 62.5 % RDN through Urea + 37.5% RDN through Nano Urea	28.62	29.29	4.04	4.89
N ₃ : 75 % RDN through Urea + 25% RDN through Nano Urea	29.55	30.22	5.03	5.62
N ₄ : 100% RDN through Urea	30.65	31.31	6.07	6.70
N ₅ : Control	—	—	—	—
SEm ±	0.92	0.87	0.59	0.52
CD (P = 0.05)	2.12	2.03	1.36	1.19
<i>Times of Nitrogen Application</i>				
T ₁ : 1/2 as basal application + 1/2 after 1 st irrigation	27.11	27.77	2.53	3.33
T ₂ : 1/2 after 1 st irrigation + 1/2 after 2 nd irrigation	27.94	28.61	3.23	3.89
T ₃ : 1/3 as basal + 1/3 after 1 st irrigation + 1/3 after 2 nd irrigation	29.53	30.19	5.26	5.68
T ₄ : 1/3 as basal +1/3 before 1 st irrigation +1/3 before 2 nd irrigation	28.19	28.86	3.61	4.21
SEm ±	0.77	0.75	0.37	0.40
CD (P = 0.05)	1.58	1.52	0.76	0.82

partial factor productivity (PFP) and agronomic efficiency (AE).

Partial factor productivity (kg/kg)

The data regarding this parameter of nutrient use efficiency indicated that partial factor productivity of N significantly influenced by sources of nitrogen (Table 3). Application of 100% RDN through Urea recorded significantly higher PFP as compared to all the rest of treatments during both the year of study, respectively. Among different times of N application, significantly higher N use efficiency (29.53 kg grain/kg N applied during first year and 30.19 kg grain/kg N applied during second year) was recorded with three split doses of Urea *viz.*, 1/3 as basal, 1/3 after 1st irrigation and 1/3 after 2nd irrigation which was significantly superior than rest of treatments where nitrogen was applied in two split doses. The partial factor productivity of N in wheat was declined gradually with successive increase in dose of nitrogen through Nano Urea with supplementation of urea fertilizer in decreased dose. Belete *et al.*, (2018) also reported that split application of nitrogen ($\frac{1}{4}$ at sowing, $\frac{1}{2}$ at tillering and $\frac{1}{4}$ at booting) produced the highest nitrogen use efficiency traits. These findings are in agreement with the result of Coventry *et al.*, (2011) and Kumar *et al.*, (2023).

Agronomic efficiency (kg/ha)

Agronomic efficiency significantly influenced by sources of nitrogen during both the years (Table 3). Among the treatments, application of 100% RDN through urea recorded significantly higher agronomic efficiency which was significantly at par with application of 75% RDN through Urea + 25% RDN through Nano Urea in both the years. Ayed *et al.*, (2016) reported that the increase of nitrogen dose increased NUE in each site. These

results are in accordance with the work of Upadhyay *et al.*, (2023), Kumar *et al.*, (2023) and Sharma *et al.*, (2014). Data further revealed that time of N application significantly affected AE in wheat as well. Three split doses of nitrogen *viz.*, 1/3 as basal, 1/3 after 1st irrigation and 1/3 after 2nd irrigation responded significantly higher N use efficiency during both the years of investigation. Mesfin *et al.*, (2021) also observed that agronomic nitrogen efficiency was higher in split application and this indicates efficient use of nutrient by plants when applied in split application than applied at once. Similar result also reported by Usman *et al.*, (2014), Haile *et al.*, (2012), Rahman *et al.*, (2011) and Prasad (2007).

CONCLUSION

Results of this evaluation explained that available nitrogen in soil after both growing seasons increased with increase in application of recommended dose of nitrogen through Urea (100% RDN through urea) and being at par with application of 75% RDN through Urea + 25% RDN through Nano Urea whereas, available phosphorus and potassium in soil declined after both growing seasons as compared to initial value. The decline could be attributed to the differences between the phosphorus and potassium uptake in different treatments and due to unavailable organic sources of P and K in soil. NUE of nitrogen recorded significantly higher value with the application of 100% RDN through urea which closely followed the treatment, application of 75% RDN through Urea + 25% RDN through Nano Urea during both the years of study. Among the treatments of N application time, three equal split doses *viz.*, 1/3 as basal + 1/3 after 1st irrigation + 1/3 after 2nd irrigation was superior with respect to NUE than N application in two equal split doses during both consecutive years.

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