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Effect of tillage methods and nitrogen management practices on soil mineral nitrogen and grain protein, and yield of wheat (*Triticum aestivum*) in rice (*Oryza sativa*)-wheat system

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Wheat (*Triticum aestivum* L.) is the second most vital cereal crop globally. After rice (*Oryza sativa* L.) it is India's second most valuable cereal crop. The rice-wheat cropping system (RWCS) is vital for global food safety as it supplies a significant portion of the grain consumed worldwide. In rice-wheat systems, wheat planting is often delayed due to a short turnaround time between crops. As a result, rice-wheat systems based on conservation agriculture (CA) are becoming increasingly popular, especially among farmers in the north-western plains of the Indo-Gangetic Plains (IGP). Conservation tillage practices helps to improve soil nutrients and increase crop yields (Han *et al*. 2020). To tackle the challenges of delayed planting, high cultivation costs, and weed problems in traditional tillage, zero tillage (ZT) has emerged as a resource management approach with the potential to sustain wheat production and increase profitability (Shater *et al*. 2020). Incorporating crop residues into the soil or leaving them on the surface can positively affect the soil's physical, chemical, and biological properties. Tillage practices significantly affect nitrogen (N) losses; when N fertilizer application is not aligned with crop requirements, it leads to greater N losses and lower nitrogen use efficiency (NUE) (Barlog *et al*. 2022). Real-time N management can improve NUE by minimizing the rapid loss of applied N through volatilization and denitrification. A leaf colour chart (LCC) provides a simple, low-cost alternative to a chlorophyll meter, allowing farmers to quickly and accurately assess the crop's N status based on leaf colour (Singh *et al*. 2020). LCC has been successfully used to guide N fertilizer application in crops like rice, wheat, and maize, helping farmers better match N applications with crop needs to enhance nitrogen efficiency. Despite all the advantages of LCC-guided N management in wheat farmers still face difficulties in its widespread adoption, particularly when using ZT and other crop establishment methods (CEM). Hence, a systematic study was planned to evaluate the impact of precision N management under various CEM in wheat.

The experiment was conducted during winter (*rabi*) season of 2020–21 at the ICAR-Indian Agricultural Research Institute, New Delhi (28°38'23"N, 77°09'27"E, and 228.61 m amsl). Soil samples were collected to estimate mineral nitrogen content 7 days after the first and third irrigation and nitrogen application. The experiment was planned using a split-plot design (SPD), with 4 crop establishment methods (CEM) in the main plots, viz. Conventional tillage (CT); Sale seed bed-conventional tillage (SSB-CT); Zero tillage without residue (ZT-R); and Zero tillage with residue applied at 3 t/ha (ZT+R). The sub-plots included 4 nitrogen management options (NMO), viz. No nitrogen application (0 kg N: 60 kg P_2O_5: 60 kg K_2O/ha); Recommended nitrogen application (120 kg N: 60 kg P_2O_5: 60 kg K_2O/ha with 100% P and K as basal and N applied as 33% at basal, 33% at 20–25 days after sowing (DAS), and 33% at 45–50 DAS); Modified nitrogen scheduling (120 kg N: 60 kg P_2O_5: 60 kg K_2O/ha with 100% P and K as basal, no basal N, and three split N applications at 20–5 DAS, 40–45 DAS, and 60–65 DAS); and LCC-guided nitrogen application (120 kg N: 60 kg P_2O_5: 60 kg K_2O/ha with all P and K as basal, no basal N, and split N application based on LCC (≤4.0) at 40 kg N from 20–65 DAS). The gross plot area was 21.6 m^2 and the net plot area 16.32 m^2. Planting was carried on 25 November 2020 by drilling seeds in rows at row spacing of 20 cm × 10 cm. Wheat variety HD-2967 was used as a test crop.

Protein content was calculated as:

$$\text{Protein content} = \text{Nitrogen content of the grain} \times 5.8$$

Protein yield was calculated as:

$$\text{Protein yield} = \text{Protein content in grain} \times \text{Grain yield/ha}$$

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Soil mineral nitrogen: Soil mineral-N content showed significant difference ($P<0.05$) under different CEM and NMO. Under different CEM at 1st sampling (Fig. 1), CT recorded higher mineral-N content at 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm soil depth having 45.7, 42.9, 41.1 and 37.8 mg/kg, respectively and mineral-N content decreases with depth. At 0–15 cm and 15–30 cm depth, CT mineral-N content is significantly higher over other CEM and at 30–45 cm depth CT mineral-N content similar with SSB-CT and at par with other CEM and at 45–60 cm depth CT mineral-N content higher over ZT+R but at par with SSB-CT and ZT. This may be due higher mineralization rate in CT treatments over ZT treatments leads to higher mineral-N and immobilization of N in ZT and ZT+R due to occurrence of stubble and residues leads to lower valve (Xie *et al.* 2022). At 3rd sampling (Fig. 2), ZT+R recorded higher mineral-N content at 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm soil depth having 49.1, 48.1, 43.4 and 43.5 mg/kg, respectively. At 0–15, 30–45 and 45–60 cm depth ZT+R mineral-N content is significantly greater than the SSB-CT, CT but comparable with ZT and at 15–30 cm depth higher over CT but at par with SSB-CT and ZT. This may due to release of immobilized N and higher mineralization rate in ZT treatments which leads to higher mineral N (Liu *et al.* 2021). Conversely higher losses of nitrogen through volatilization and leaching which leads lower mineral-N in conventional tillage which was reduced under the presence of stubbles and residue under zero tillage (Rani *et al.* 2017).

Under different NMO at 1st sampling (Fig. 1), RDN recorded higher mineral-N content at 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm soil depth having 43.9, 41.1, 42.9 and 35.0 mg/kg, respectively and mineral-N content decreases with depth. At 0–15cm depth RDN mineral-N content showed significant difference ($P<0.05$) higher than the No-N, LCC but comparable with Modified N scheduling and at 15–30 cm depth RDN mineral-N content is showed significant variation ($P<0.05$) higher than the No-N, similar with Modified N scheduling but comparable with LCC-guided N application and at 30–45cm depth RDN mineral-N content significantly higher over with other NMO and at 30–45cm depth mineral-N content is not significant. This may be as the basal application of nitrogen to RDN treatments results in higher initial mineral-N. At 3rd sampling (Fig. 2), LCC-guided N application recorded higher mineral-N content at 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm soil depth, with 53.6, 49.9, 47.1 and 44.7 mg/kg, respectively and its content decreases with depth. At 0–15cm, 15–30 cm, 30–45 cm, and 45–60 cm depth LCC-guided N application mineral-N content showed significant variation ($P<0.05$) higher than the No-N, RDN but comparable with Modified N scheduling. Reducing N input improves NUE by minimizing losses from leaching, volatilization, and runoff. High N application rates especially those exceeding plant requirements often results in greater loss. This is common with fixed-time N applications at standard recommended rates (Baral *et al.* 2021). In contrast, LCC-guided N applications which involve prolonged N application at later crop stages reduce these losses due to better synchrony with crop demand and lower N doses thereby minimizing losses from volatilization and immobilization (Kumar *et al.* 2021).

Protein content, yield and grain yield: The study examined wheat quality by analysing grain protein content, finding no significant ($P<0.05$) influence from CEM. The ZT+R method had the highest protein content (12.6%), outperforming ZT, SSB-CT, and CT. However, protein yield showed significant variation ($P<0.05$) influenced by CEM, with ZT+R yielding the highest (638.2 kg/ha) and CT the lowest. Grain protein content showed significant variation ($P<0.05$) influenced by nitrogen management options (NMO). The LCC-guided N application method had the highest protein content (12.9%), comparable to Modified N scheduling but significantly higher than RDN and No-N practices. Protein yield followed a similar trend, with the LCC-guided N application achieving the maximum yield (698.1 kg/ha) and the No-N method the minimum. Higher protein content and yield under ZT+R and ZT methods are

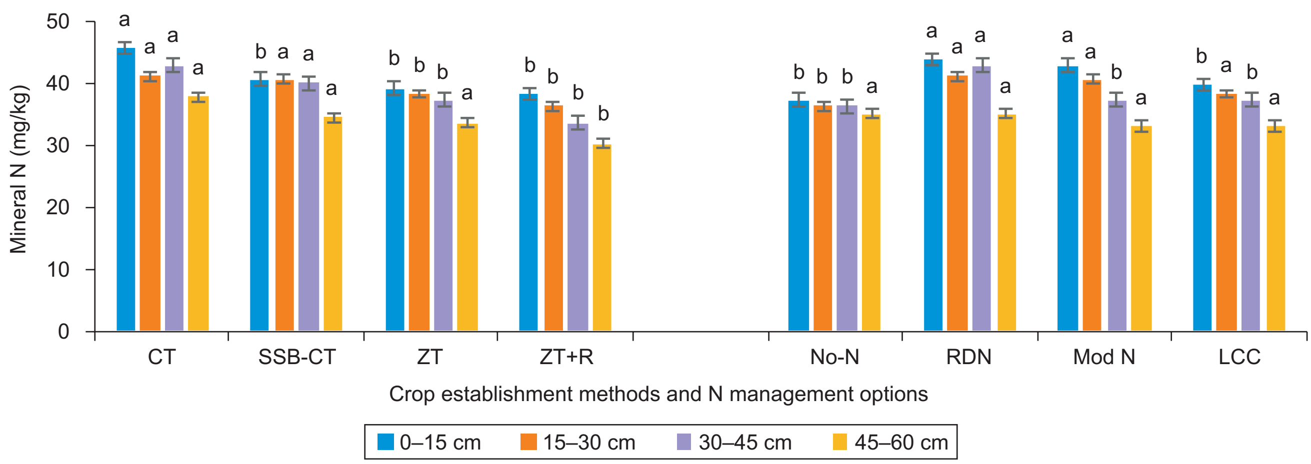

Fig. 1 Effect of tillage methods and nitrogen management options on mineral nitrogen content at 7 days after 1st irrigation and nitrogen application in wheat.

CT, Conventional tillage; SSB, Stale seed bed; ZT, Zero tillage; R, Residue; No-N, nitrogen; RDN, Recommended nitrogen application; Mod N, Modified nitrogen scheduling; LCC, Leaf colour chart guided N application.

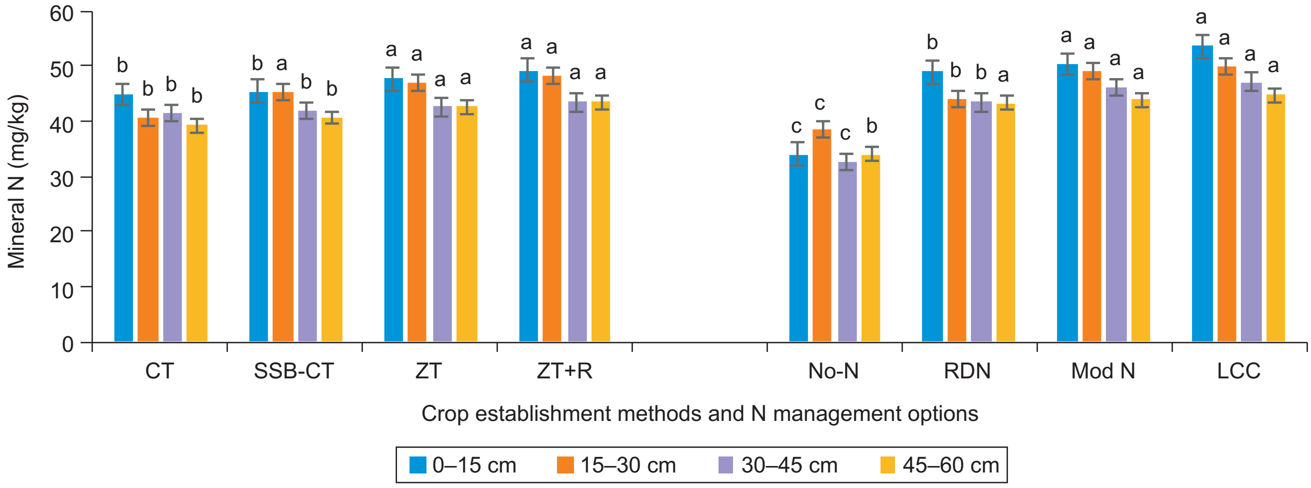

Fig. 2 Effect of tillage methods and nitrogen management options on mineral nitrogen content at 7 days after 3rd irrigation and nitrogen application in wheat.
CT, Conventional tillage; SSB, Stale seed bed; ZT, Zero tillage; R, Residue; No-N, No nitrogen; RDN, Recommended nitrogen application; Mod N, Modified nitrogen scheduling; LCC, Leaf colour chart guided N application.

due to increased N uptake and its conversion into protein (Bhardwaj *et al*. 2021). The highest protein yield observed under LCC-guided N application, while the lowest was with the No-N method. Precise and increased split N applications during growth stages likely improve wheat grain quality. Site specific nutrient management (SSNM) methods also boost protein content and yield through enhanced N uptake and transformation (Sharma *et al*. 2017). The grain yield of wheat showed significant difference (P<0.05) by the different crop establishment methods (CEM) (Table 1). The highest grain yield was achieved with the ZT+R method, which produced 4.99 t/ha. This yield was statistically similar to that of the ZT method but was significantly greater than the yields from the SSB-CT and CT methods. The ZT+R method resulted in a 14.2% higher yield compared to the CT method, a 10.9% increase over the SSB-CT method, and a 5.5% improvement over the ZT method. Effective crop residue management, as seen in the ZT+R method, can enhance nutrient cycling and boost crop yields (Upadhyay *et al*. 2024). The wheat grain yield showed significant variation (P<0.05) varied by various NMO (Table 1). The higher yield obtained under LCC-guided N application method of nitrogen management (5.39 t/ha) which was significantly more than the RDN, No-N but remained statistically comparable with Modified N scheduling practice. LCC-guided N application account for field-to-field and temporal variation in N supply to plants, and so show promise for efficient fertiliser N usage in rice, maize, and wheat crops, resulting in higher yield than blanket recommendations (Singh *et al.* 2014). The increased yield in SSNM may be related to better photosynthate translocation from source to sink, enhanced growth characteristics, and increased inorganic fertiliser application (Neha and Chandrashekar 2018).

Table 1 Effect of crop establishment methods and nitrogen management options on protein content, yield and wheat grain yield

Treatment	Protein (%)	Protein yield (kg/ha)	Grain yield (t/ha)
Crop establishment methods			
CT	11.0	488.3	4.37
SSB-CT	12.1	553.8	4.50
ZT	12.4	595.3	4.73
ZT+R	12.6	638.2	4.99
SEm ±	0.8	14.59	0.11
LSD (P≤0.05)	NS	51.47	0.38
Nitrogen management options			
No-N	10.1	331.2	3.27
RDN	12.3	575.9	4.67
Mod N	12.7	670.5	5.26
LCC	12.9	698.1	5.39
SEm ±	0.07	14.48	0.12
LSD (P≤0.05)	0.20	42.53	0.35

CT, Conventional tillage; SSB, Stale seed bed; ZT, Zero tillage; R, Residue; No-N, nitrogen; RDN, Recommended nitrogen application; Mod N, Modified nitrogen scheduling; LCC, Leaf colour chart guided N application.

SUMMARY

The field experiment was carried out during winter (*rabi*) season of 2020–21 at ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of tillage methods and nitrogen management practices on soil mineral nitrogen and grain protein and yield of wheat in rice-wheat system. The experiment was laid out in a split plot design (SPD), where the main plots included 4 different crop establishment methods, and the sub-plots tested 4 nitrogen management strategies that were replicated thrice. The results showed that, residue retention in zero tillage recorded significantly (P<0.05) higher soil mineral nitrogen,

protein content in grain (12.6%) and grain yield (4.99 t/ha) over other treatments. Similar results also recorded under different nitrogen management practices, where leaf colour chart (LCC)-guided N application has significantly (P<0.05) higher soil mineral nitrogen, grain protein content (12.9%) and grain yield (5.39 t/ha) over remaining treatments. The LCC-guided N application in residue retained (3 t/ha) ZT practices can be recommended in wheat under rice-wheat system for higher soil mineral nitrogen availability, improving grain protein content and productivity.

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