Indian Journal of Agricultural Sciences **93** (8): 930–935, August 2023/Article
https://doi.org/10.56093/ijas.v93i8.137614

Long term conservation agriculture impact on soil nitrogen fractions and wheat (*Triticum aestivum*) yield in subtropical Inceptisol

MOHANKUMAR KARADIHALLI THAMMAIAH[1], VINOD K SHARMA[1]*, CHITER M PARIHAR[1], MANDIRA BARMAN[1], ABIR DEY[1] and DEBASHIS CHAKRABORTY[1]

ICAR-Indian Agricultural Research Institute, Pusa, New Delhi 110 012, India

Received: 11 June 2023; Accepted: 14 July 2023

ABSTRACT

The present study was carried out at ICAR-Indian Agricultural Research Institute (IARI), New Delhi over two consecutive years (2020 and 2021) to evaluate the influence of conservation agriculture (CA) and nitrogen management strategies on wheat yield in an intensified maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-mungbean (*Vigna radiata* L.) cropping system. Results indicated that grain and straw yields of wheat in CA plots were higher, reaching 4829 and 7231 kg/ha, respectively. However, these yields were statistically comparable to those obtained from conventionally tilled plots (4502 and 6611 kg/ha, respectively). Significantly higher wheat grain and straw yields were observed in plots receiving nitrogen fertilizer. Interestingly, the harvest index remained unaffected by both tillage practices and nitrogen management strategies. After two seasons of wheat cultivation, CA plots had significantly higher soil nitrogen fractions, including mineral, alkali-permanganate, potentially mineralizable, microbial biomass N and total nitrogen, compared to conventionally tilled plots. Moreover, all nitrogen-receiving treatments demonstrated significantly higher nitrogen fractions at both soil depths (0–5 and 5–15 cm) compared to the control. Notably, plots treated with urea super granules exhibited superior results in enhancing plant-available nitrogen. In conclusion, this study underscores the importance of CA and various nitrogen management strategies for increasing wheat crop yield and promoting plant-available nitrogen fractions in the soil. These findings provide valuable insights for farmers and researchers looking for sustainable and efficient agricultural practices to optimize wheat production and soil health.

Keywords: Conservation agriculture, Green seeker, Urea super granules, Wheat

Wheat (*Triticum aestivum* L.) is the most widely cultivated cereal crop globally and India stands as the second-largest wheat producer (Yadav *et al.* 2023) fulfilling 13% of the world's wheat demand. Wheat production contributes to one-third of the country's total food grain production (Liu *et al.* 2022). Despite substantial advancements in wheat production over the past decades, India struggles with remarkably low wheat productivity (Karadihalli Thammaiah *et al.* 2022). And also the intensive cultivation practices followed in wheat production have led to serious concerns regarding soil carbon depletion and essential nutrient loss (Parihar *et al.* 2019, Das *et al.* 2020). In response to these challenges, the concept of conservation agriculture (CA) has emerged to promote global agricultural sustainability while enhancing crop yields and soil health (Jat *et al.* 2012). Nitrogen (N) stands out as one of the most crucial limiting nutrients for cereal production, particularly for wheat (Allart *et al.* 2023). Nitrogen fertilizer application has increased significantly over the past decades and it is projected to reach 180 million tonnes by 2030 (FAO 2011). However, cereal-based cropping systems exhibit low nitrogen use efficiency of nearly 40–60% (Kumar *et al.* 2023). The slower decomposition rate of retained crop residue in CA significantly promotes the microbial growth and results in higher soil microbial biomass nitrogen, available nitrogen and also the mineral nitrogen fractions (Dey *et al.* 2016, Parihar *et al.* 2018, 2020). However, some scientists reported inadequate N availability is often associated with the retention of permanent crop residues (Ohyama and Inubushi 2021), resulting in decreased crop production. Nitrogen mineralization under CA is not just influenced by the tillage practices but is also significantly affected by quality of the crop residues retained, i.e. lower the C/N ratio, higher will be the N mineralization (Butnan and Vityakon 2020). Therefore, several researchers propose the inclusion of nitrogen management as the fourth principle of CA. However, studies investigating nitrogen management under CA are limited. Thus, the present study aims to examine the impact of CA and nitrogen management strategies on

[1]ICAR-Indian Agricultural Research Institute, Pusa, New Delhi. *Corresponding author email: vksharma.iari@gmail.com

the yield of wheat crops and soil nitrogen fractions within a maize-wheat-mungbean cropping system.

MATERIALS AND METHODS

Experimental site and design: The present study was carried out at ICAR-Indian Agricultural Research Institute (IARI), New Delhi over two consecutive years (2020 and 2021) to evaluate the influence of conservation agriculture (CA) and nitrogen management strategies on wheat yield in an intensified maize (*Zea mays* L.)-wheat-mungbean (*Vigna radiata* L.) cropping system. The initial soil properties of the experimental site were sandy loam soil with a *p*H of 7.9 and EC 0.32 dS/m. Organic carbon content was measured at 0.497% and the available nitrogen, phosphorus and potassium levels were recorded at 162.1±4.62, 15.2±0.75 and 169.2±6.06 kg/ha, respectively. The long-term CA experiment consisted of different combinations of tillage, crop establishment and residue management practices within a maize-wheat-mungbean rotation (Table 1). Maize sowing took place during the rainy (*kharif*) season (July–October), followed by wheat cultivation during winter (*rabi*) season (November–April) and mungbean cultivation during the summer season (May–June). A standard dose of 60 kg P_2O_5 + 40 kg K_2O per hectare was evenly applied as a basal dose in each plot. This study comprised eight treatments arranged in a split-plot design. The main plots consisted of two treatments involving tillage and residue management practices: zero tillage with residue retention from the previous maize crop (ZT+R) and conventional tillage with residue incorporation from the previous crop (CT+R). The sub-plots consisted of four nitrogen management treatments: Control (without-N), 100% Recommended dose of nitrogen (RDN) through urea ($N:P_2O_5:K_2O$ @150:60:40), 1/3rd RDN through urea + green seeker (GS)-based application of urea and 50% RDN through urea super granules+GS-based application of urea. Three replications were maintained under all the treatments.

Estimating wheat yield: The wheat crop was harvested manually, leaving two border rows unharvested in both directions and 0.5 m in the longitudinal direction. The harvested wheat grain was collected and then oven-dried at 65–70°C for 48 h. The dried grain was weighed to determine the economic yield. The harvest index was calculated by dividing the economic yield by the biological yield and expressing in percentage.

Table 1 Treatment description

Treatment	Notation used
Main plot-Crop establishment techniques	
Zero tillage flat with residue retention	ZT + R
Conventional tillage with residue incorporation	CT + R
Subplot-Nitrogen management strategies	
Control (without-N application)	Control
Recommended dose of N @150 kg N/ha applied through urea	RDN
1/3rd of RDN through urea + green seeker guided application of split N dose	Urea + GS
50% of RDN as basal dose through urea super granules (USG) + green seeker guided application of split N dose	USG + GS

Collection and processing of soil samples: Soil samples were collected in polythene bags from two depths of 0–5 and 5–15 cm using a tube auger. The collection took place in 2021 after the harvest of the wheat crop from the respective experimental units. The soil samples were then air-dried under shade, crushed to pass through a 2 mm sieve and prepared for subsequent analyses.

Estimation of nitrogen fractions: The nitrogen fractions in the soil were determined using post-harvest soil samples from the wheat crop. The following nitrogen fractions were estimated: i) Alkali permanganate N was determined using the procedure outlined by Subbaiah and Asija (1956). ii) Mineral N, including ammonium N (NH_4^+ -N), was estimated following the procedure described by Keeney and Nelson (1982), while nitrate N (NO_3^- -N) was estimated by distilling the same sample after adding Devarda's alloy (50% Cu, 45% Al, 5% Zn). iii) Potentially mineralizable nitrogen (PMN) was measured using the method described by Waring and Bremner (1964), which involved incubating the soil sample under water-saturated conditions in an airtight test tube. iv) Microbial biomass nitrogen (MBN) was estimated using the fumigation extraction method outlined by Brookes *et al.* (1985). v) Total nitrogen (T) was determined using a CHNS analyzer (Nelson and Sommers 1996).

Statistical analysis: The software SAS 9.3 (SAS Institute, Cary, NC, USA) was used for the analysis of variance (ANOVA) of the data obtained from the split-plot design (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Wheat crop yield

Tillage practices and yield: The grain yield of the wheat crop was found to be statistically similar between the zero tillage with residue retention plots (4829 kg/ha) and the conventionally tilled plots with residue incorporation (4502 kg/ha) (Table 2). However, the zero tilled plots exhibited approximately 7.26% higher grain yield compared to the conventionally tilled plots (4502 kg/ha). The straw yield followed a similar trend to that of grain yield, with ZT+R maintaining 9.38% higher straw yield compared to CT+R, although both treatments were statistically comparable. The biological yield, which accounts for the combined grain and straw yield, also showed no significant difference between conservation agriculture and conventional tillage with residue incorporation. These findings align with the results reported by Gupta and Sidhu (2009), who observed no difference in wheat crop yield between residue-retained zero tillage plots and conventionally tilled residue-incorporated plots. Other researchers have similarly noted that the transition from conventional to conservation agriculture may require a period of age hardening for the cropping system to positively impact crop yield (Pradhan *et al.* 2016). Conversely, studies by Giller *et al.* (2009) and Gilbert (2012) have reported either positive or neutral long-term effects of conservation agriculture on plant yield and its attributes. However, Sapkota *et al.* (2014) found significantly higher wheat grain and overall biomass yield under conservation agriculture compared to conventional tillage practices. This contrasts with our present study, which may be attributed to the incorporation of crop residue in the conventionally tilled plots. The per cent harvest index of the wheat crop was not significantly different between ZT+R and CT+R. Similar results were observed for the harvest index of the maize crop under conservation agriculture practices compared to CT+R (Parihar *et al.* 2018).

Nitrogen management and yield: The nitrogen management options demonstrated a significant difference in grain, straw and total biomass yield of wheat compared to the control (Table 2). Similar to the findings of Mohanty *et al.* (2015) in the context of CA, our study also observed a significant increase in wheat grain yield through the application of recommended nitrogen doses compared to the control treatment (without nitrogen). However, among the plots that received nitrogen dosage, non-statistical significant differences were found in the aforementioned yields. As previously mentioned, it is important to note that cereals based cropping systems require sufficient time to achieve significant differences in grain and straw yield through different nitrogen management strategies.

Soil nitrogen fractions

Ammonium and nitrate nitrogen fractions: Both zero tillage with residue retention (ZT+R) and conventional tillage with residue incorporation (CT+R) treatments exhibited higher nitrate-N content compared to ammonium-N content at the specified depths, indicating rapid conversion of mineralized ammonium-N to nitrate-N. Additionally, CA practices showed significantly higher ammonium and nitrate-N fractions at both depths (Table 3). This finding is consistent with the results reported by Parihar *et al.* (2018), who also observed significantly higher mineral nitrogen fractions (ammonium and nitrate) under ZT+R compared to CT+R. The limited soil disturbance under ZT+R might have contributed to the enrichment of mineral nitrogen in the surface soils. All nitrogen management practices (Recommended dose of nitrogen, Urea + green seeker and urea super granules) resulted in significantly higher ammonium content at both tested depths compared to the control. However, there was no significant difference in ammonium content between the different nitrogen management plots at both depths. Similarly, all nitrogen treatments showed significantly higher nitrate-N content compared to the control, with the USG+GS treatment exhibiting significantly higher nitrate-N compared to RDN at both depths. Meanwhile, the Urea+GS treatment had nitrate-N levels similar to both RDN and USG+GS at both depths. The interaction effect of tillage and nitrogen management options turned out to be significant, especially with regard to nitrate nitrogen.

Table 2 Effect of contrasting tillage practices and nitrogen management strategies on yields of wheat (2-year mean data)

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Crop establishment techniques				
ZT+R	4829	7231	12060	40.2
CT+R	4502	6611	11114	40.7
SEm±	83.25	105.32	187.56	0.12
LSD (P=0.05)	NS	NS	NS	NS
Nitrogen management strategies				
Control	3370^b	4639^b	8009^b	42.1
RDN	5106^a	7719^a	12825^a	39.7
Urea+GS	5054^a	7675^a	12729^a	39.7
USG+GS	5133^a	7652^a	12785^a	40.2
SEm±	194.10	224.12	308.20	1.06
LSD (P=0.05)	598.1	690.7	949.7	NS
CET×N	NS	NS	NS	NS

CET, Crop establishment strategies; N, Nitrogen management strategies; NS, Non-significant.

Alkali permanganate nitrogen fraction: Both contrasting tillage practices and nitrogen management options had a significant effect on the alkali permanganate-N content at both depths. The alkali permanganate-N value was higher at the 0–5 cm depth compared to the lower depth for both ZT+R and CT+R treatments. Similar to the mineral-N fraction, the alkali permanganate-N content was significantly higher under ZT+R compared to CT+R at both depths. These results align with the findings of several researchers, who have reported a slower rate of crop residue decomposition under ZT, resulting in improved soil organic carbon and available nitrogen compared to tilled plots (Parihar *et al.* 2020). The retained crop residue acts as a source of organic carbon and nitrogen, enhancing mineralization and making previously unavailable nutrients available in the soil (Tonitto *et al.* 2006). The subplots that received nitrogen fertilizer application exhibited significantly higher alkali permanganate-N content compared to the control at both depths. At the upper surface soil (0–5 cm), the plots receiving USG+GS treatment had significantly higher alkali permanganate-N content (110.69 mg/kg) compared to RDN treatment (103.79 mg/kg), but it was similar to the Urea+GS treatment (107.15 mg/kg). However, at the 5–15 cm depth, all plots receiving nitrogen nutrients showed statistically similar alkali permanganate-N content.

Potentially mineralizable and microbial biomass nitrogen fractions: The potential mineralizable nitrogen (PMN) represents the portion of total nitrogen that becomes available to plants within a reasonable time period. At both soil depths, the effect of ZT+R on enhancing PMN was

Table 3 Effect of contrasting tillage practices and nitrogen management strategies on nitrogen fractions of wheat crop's post-harvest soil

	Nitrogen fractions (mg/kg)					
Treatment	Ammonium-N	Nitrate-N	Alkali-permanganate-N	Potentially mineralizable -N	Microbial biomass-N	Total N
0–5 cm soil depth						
Crop establishment techniques						
ZT+R	19.63[a]	27.25[a]	107.43[a]	48.17[a]	33.29[a]	746.67[a]
CT+R	16.26[b]	21.72[b]	89.79[b]	40.12[b]	28.57[b]	608.33[b]
SEm±	0.21	0.39	1.09	0.56	0.47	15.69
LSD (P=0.05)	1.19	2.37	6.63	3.40	2.89	95.47
Nitrogen management strategies						
Control	11.55[b]	12.37[c]	72.80[c]	26.90[a]	24.34[b]	600[b]
RDN	19.65[a]	27.88[b]	103.79[b]	48.00[b]	32.85[a]	688.33[a]
Urea + GS	20.21[a]	28.25[ab]	107.15[ab]	50.58[a]	32.95[a]	681.67[a]
USG + GS	20.39[a]	29.45[a]	110.69[a]	51.10[a]	33.59[a]	740[a]
SEm±	0.31	0.46	1.31	0.69	0.39	19.58
LSD (P=0.05)	0.96	1.42	4.04	2.12	1.21	60.33
CET @ same N	NS	2.00	NS	3.00	NS	NS
N @ same CET	NS	2.77	NS	4.04	NS	NS
5–15 cm soil depth						
Crop establishment techniques						
ZT+R	17.25[a]	21.89[a]	94.83[a]	42.07[a]	30.53[a]	672.50[a]
CT+R	12.90[b]	17.22[b]	83.25[b]	32.92[b]	25.17[b]	525[b]
SEm±	0.33	0.29	1.10	0.24	0.35	6.21
LSD (P=0.05)	2.05	1.77	6.68	1.46	2.11	84.54
Nitrogen management strategies						
Control	8.71[b]	10.38[c]	64.03[b]	20.25[c]	20.40[b]	525.00[b]
RDN	16.75[a]	21.72[b]	95.20[a]	41.96[b]	30.18[a]	595.00[a]
Urea + GS	17.36[a]	22.84[ab]	96.69[a]	43.42[a]	30.69[a]	606.67[a]
USG + GS	17.50[a]	23.26[a]	100.24[a]	44.36[a]	30.13[a]	648.33[a]
SEm±	0.25	0.32	2.11	0.38	0.38	8.90
LSD (P=0.05)	0.78	0.97	6.49	1.17	1.16	61.45
CET @ same N	NS	1.38	NS	1.66	NS	NS
N @ same CET	NS	2.02	NS	1.95	NS	NS

CET, Crop establishment techniques; N, Nitrogen management strategies; NS, Non-significant. Means followed by a similar letter within a depth are not significantly different (at $P < 0.05$) according to least significant difference test.

found to be significant compared to CT+R, with ZT+R showing 20.10 and 27.77% higher PMN at the 0–5 and 5–15 cm soil depths, respectively. This observation is consistent with the findings of Mahal *et al.* (2018), who also reported significantly higher PMN under no-till soil compared to tilled soil. The higher soil organic carbon content under ZT+R likely contributed to the higher PMN values compared to CT+R. Among the nitrogen management practices, the highest PMN was recorded under the USG+GS treatment, which was significantly higher than the control and RDN treatments. The Urea+GS treatment showed similar PMN values as the USG+GS treatment and was significantly higher than the control and RDN treatments. On average, plots that received nitrogen fertilizer had significantly greater PMN than plots not receiving nitrogen fertilizer (Mahal *et al.* 2018). Likewise, the values for microbial biomass nitrogen (MBN) values were significantly higher under ZT+R than CT+R, showing 16.52 and 21.30% higher MBN values at the 0–5 and 5–15 cm depths, respectively, compared to CT+R. The slower decomposition of retained crop residue under conservation agriculture significantly enhances the availability of mineralizable substrates, thereby promoting microbial growth and resulting in higher soil MBN (Dey *et al.* 2016). The control treatments had a significantly lower

MBN compared to the nitrogen fertilizer treatments, and the plots receiving nitrogen fertilizer showed statistically similar MBN values at both depths.

Total soil nitrogen content: Total nitrogen at different soil depths was influenced by long-term tillage practices and nitrogen management options. At both 0–5 and 5–15 cm soil depths, ZT+R plots exhibited significantly higher total nitrogen compared to CT+R managed plots. The combined effect of tillage and residue management was found to have a significant impact on total soil nitrogen, with ZT+R showing higher values than conventionally tilled plots (Hou *et al.* 2012). Similarly, total soil nitrogen was significantly higher in plots that received nitrogen fertilizer compared to the control at both depths. It is possible that the duration of the experiment was not long enough to detect significant differences between the different nitrogen management plots in terms of total soil nitrogen content. In conclusion, the present study suggests that conservation agriculture practices require more time to positively influence wheat crop performance. All plots treated with nitrogen fertilizer demonstrated significantly higher wheat grain and straw yields. However, the harvest index was not affected by different contrasting tillage practices nor by nitrogen management options. Nevertheless, tillage practices and nitrogen management options significantly influenced soil nitrogen fractions, with ZT+R plots showing higher values for all nitrogen fractions compared to CT+R plots. Among the different nitrogen management options, the long-term benefits of using USG+GS are likely to be greater.

REFERENCES

Allart K, Al Moussawi A, Kerbey L, Catterou M, Roger D, Mortier D and Tetu T. 2023. Splitting nitrogen fertilization is more important than nitrogen level when mixed wheat varieties are cultivated in a conservation agriculture system. *Agronomy* **13**(5): 1295.

Brookes P C, Landman A, Pruden G and Jenkinson D S. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biology and Biochemistry* **17**(6): 837–42.

Butnan S and Vityakon P. 2020. The interactive effects of soil disturbance and residue quality on soil nitrogen mineralisation in a tropical sandy soil. *Soil Research* **58**(3): 277–88.

Das T K, Nath C P, Das S, Biswas S, Bhattacharyya R, Sudhishri S and Chaudhari S K. 2020. Conservation agriculture in rice-mustard cropping system for five years: Impacts on crop productivity, profitability, water-use efficiency, and soil properties. *Field Crops Research* **250**: 107781.

Dey A, Dwivedi B S, Bhattacharyya R, Datta S P, Meena M C, Das T K and Singh V K. 2016. Conservation agriculture in a rice-wheat cropping system on an alluvial soil of north-western Indo-Gangetic plains: Effect on soil carbon and nitrogen pools. *Journal of the Indian Society of Soil Science* **64**(3): 246–54.

FAO. 2011. Food and Agriculture Organization of The United Nations. Current world fertilizer trends and outlook to 2015. Rome, Italy. Available from: ftp://ftp.fao.org/ag/agp/docs/cwfto15.pdf.

Gilbert N. 2012. Dirt poor: The key to tackling hunger in Africa is enriching its soil. The big debate is about how to do it. *Nature* **483**: 525–27.

Giller K E, Witter E, Corbeels M and Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* **114**: 23–34.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. John Wiley and Sons, New York, US.

Gupta R K and Sidhu H S. 2009. Nitrogen and residue management effects on agronomic productivity and nitrogen use efficiency in rice-wheat system in Indian Punjab. *Nutrient Cycling in Agroecosystems* **84**: 141–54.

Hou R, Ouyang Z, Li Y, Tyler D D, Li F and Wilson G V. 2012. Effects of tillage and residue management on soil organic carbon and total nitrogen in the North China Plain. *Soil Science Society of America Journal* **76**(1): 230–40.

Jat M L, Malik R K, Saharawat Y S, Gupta R, Bhag M and Raj Paroda. 2012. *(In) Proceedings of Regional Dialogue on Conservation Agriculture in South Asia*, p. 32. APAARI, CIMMYT, ICAR, New Delhi, India.

Karadihalli Thammaiah M, Pandey R N, Purakayastha T J, Chobhe K A, Vashisth A, Chandra, S, Pawar A B and Trivedi A. 2022. Impact of low molecular weight organic acids on soil phosphorus release and availability to wheat. *Communications in Soil Science and Plant Analysis* **53**(18): 2497–508.

Keeney D R and Nelson D W. 1982. Nitrogen-inorganic forms. *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties* **9**: 643–98.

Kumar K, Parihar C M, Nayak H S, Godara S, Avinash G, Patra K, Sena D R, Reddy K S, Das T K, Jat S L, Ghatala M K, Singh U and Sharawat Y S. 2023. Enhancing maize yield in a conservation agriculture-based maize (*Zea mays*)-wheat (*Triticum aestivum*) system through efficient nitrogen management. *The Indian Journal of Agricultural Sciences* **93**(4): 420–24.

Liu Y, Wang S, Wang X, Chen B, Chen J, Wang J and Zhu K. 2022. Exploring the superiority of solar-induced chlorophyll fluorescence data in predicting wheat yield using machine learning and deep learning methods. *Computers and Electronics in Agriculture* **192**: 106612.

Mahal N K, Castellano M J and Miguez F E. 2018. Conservation agriculture practices increase potentially mineralizable nitrogen: A meta-analysis. *Soil Science Society of America Journal* **82**(5): 1270–278.

Mohanty S K, Singh A K, Jat S L, Parihar C M, Pooniya V, Sharma S and Singh B. 2015. Precision nitrogen-management practices influences growth and yield of wheat (*Triticum aestivum*) under conservation agriculture. *Indian Journal of Agronomy* **60**(4): 617–21.

Nelson D W and Sommers L E. 1996. Total carbon, organic carbon, and organic matter. *Methods of Soil Analysis: Part 3 Chemical Methods* **5**: 961–1010.

Ohyama T and Inubushi K. 2021. *Nitrogen in Agriculture: Physiological, Agricultural and Ecological Aspects*. BoD–Books on Demand.

Parihar C M, Parihar M D, Sapkota T B, Nanwal R K, Singh A K, Jat S L and Jat M L. 2018. Long-term impact of conservation agriculture and diversified maize rotations on carbon pools and stocks, mineral nitrogen fractions and nitrous oxide fluxes in Inceptisol of India. *Science of the Total Environment* **640**: 1382–92.

Parihar C M, Singh A K, Jat S L, Dey A, Nayak H S, Mandal B N and Yadav O P. 2020. Soil quality and carbon sequestration under conservation agriculture with balanced nutrition in an intensive cereal-based system. *Soil and Tillage Research* **202**: 104653.

Parihar C M, Singh A K, Jat S L, Ghosh A, Dey A, Nayak H S and Jat M L. 2019. Dependence of temperature sensitivity of soil organic carbon decomposition on nutrient management options under conservation agriculture in a sub-tropical Inceptisol. *Soil and Tillage Research* **190**: 50–60.

Pradhan A, Idol T and Roul P K. 2016. Conservation agriculture practices in rainfed uplands of India improve maize-based system productivity and profitability. *Frontiers in Plant Science* **7**: 1008.

Sapkota T B, Majumdar K, Jat M L, Kumar A, Bishnoi D K, McDonald A J and Pampolino M. 2014. Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research* **155**: 233–44.

Subbaiah B V and Asija C L. 1956. A rapid procedure for the determination of available nitrogen in soil. *Current Science* **25**: 259–60.

Tonitto C, David M B and Drinkwater L E. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture, Ecosystems and Environment* **112**: 58–72.

Waring S A and Bremner J M. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. *Nature* **201**(4922): 951–52.

Yadav P K, Sikarwar R S, Verma B, Tiwari S and Shrivastava D K. 2023. Genetic divergence for grain yield and its components in bread wheat (*Triticum aestivum* L.): Experimental investigation. *International Journal of Environment and Climate Change* **13**(5): 340–48.