Indian Journal of Agricultural Sciences **91** (8): 1194–8, August 2021/Article
https://doi.org/10.56093/ijas.v91i8.115874

Nitrogen availability under conventional and conservation tillage in semiarid Inceptisol

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Received: 13 January 2021; Accepted: 01 February 2021

ABSTRACT

The present experiment was conducted to study the spatio-temporal variation of available nitrogen fraction in cotton (*Gossypium hirsutum* L.) in conservation agricultural based long term experiment (since 2010) during 2019–20. The treatment comprises two distinct practices, i.e. conventional tillage (CT) and zero tillage (ZT). Under ZT, permanent narrow bed without (PNB) and with residue of previous crops (PNB+R); permanent broad bed without (PBB) and with residues (PBB+R); flat bed (FB) and FB with residues (FB+R). Soil samples were collected (0-15 and 15-30 cm) at pre-flowering, flowering, boll formation and harvest stages. Adoption of CA practices increased the NH_4-N, NO_3-N and mineral-N fractions of nitrogen at different crop growth stages. Highest NH_4-N, NO_3-N and mineral-N were recorded at flowering and boll formation stage respectively. The effect of crop residue retention and crop establishment methods on available N fractions was prominent up to 15 cm soil depth. Crop residue retained plots recorded significantly higher N fraction compared to respective without residue and CT plots. Residue retained plots of FB, PBB, PNB recorded 50, 25 and 36% higher NO_3-N concentration as compared to respective without residues plots at pre-flowering stage. At flowering stage, maximum NH_4-N was recorded in PBB+R (17.9 mg/kg) and FB+R plots (17.5 mg/kg), which was approximately 68 and 16% higher over CT and PNB+R plots. The results revealed that zero tillage together with PBB+R could be a viable option over conventional practice for maintaining nitrogen availability to plants under cotton-wheat (*Triticum aestivum* L.) cropping system in semiarid climate.

Keywords: Conservation agriculture, Cotton-Wheat, Mineral nitrogen, Nitrogen availability, Soil depth

Cotton (*Gossypium nirsutum* L.)-wheat (*Triticum aestivum* L.), a long established crop production system of North Western plains of India and Pakistan, has unique place in economy of Indian sub-continent. Cotton popularly known as "*White Gold*", a cash crop whereas wheat provides necessary food security, however the productivity of cotton declined in two decades during late nineties (Mayee *et al.* 2008). So, the sustainability is a major issue due to adverse effect of conventional tillage (Abrol and Sunita 2006). Therefore, in recent years shifting toward conservation agriculture (CA) was recorded worldwide. Conservation agriculture reduces the risk of soil erosion and maintains nutrient cycling *via* residue retention, minimum soil disturbance and crop diversification. Besides this, agriculture rely on nitrogen (N) availability and it is most deficient in Indian conditions, therefore its management is crucial for sustainable production and productivity.

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Adopting CA practices may temporarily reduce N availability to plants initially through immobilization, however, it improves in long-run by increasing soil N retention and labile N pool in soil (Yadav *et al*. 2021). Tillage effects on N transformations had been mainly studied through net mineralization rates, as they are useful index of N availability for plant uptake. However, net N availability results from mineralization (ammonification and nitrification) and immobilization and it does not mirror the total amount of N cycling between organic matter and soil inorganic N. Both the processes are influenced by environmental conditions, tillage practice, crop establishment methods, rhizosphere secretion, and type of crop residue added etc. In humid climate, differences in gross N transformation rates in surface soil for no-till and conservation till compared to conventional till have been observed (Hu *et al.* 2013, Sharma *et al.* 2016). Under CA, availability of nitrogen fraction during growth stages of cotton is limited. Since N availability in soil is dynamic in nature because of complex N cycling, pattern of spatio-temporal fluctuation during crop growth stages. Therefore, present study was undertaken to assess the impact of crop residue retention and crop establishment method of long-term CA on NH_4-N, NO_3-N and mineral-N at physiological stages of cotton and their relationship with crop yields in semi-arid tropical agroecosystem.

MATERIAL AND METHODS

Study site and treatment details: The experiment on CA based cotton-wheat system was initiated during 2010 at ICAR- Indian Agricultural Research Institute, New Delhi (28°35 ′N latitude, 77°12 ′E longitude, 228 m amsl). The texture of soil was sandy clay loam having EC 0.64 dS/m, *p*H 7.7 (1:2.5 soil : water) oxidizable soil organic carbon 0.52%, total soil N 832 mg/kg, 0.5M $NaHCO_3$ extractable P 10 mg/kg, and 1 N NH_4OAc extractable K 112 mg/kg. The field experiment was arranged in randomized block design (RBD) with five treatments. The treatment combination includes conventional tillage with flat-bed without residue (CT), zero tilled permanent narrow-bed without residue (PNB) and with residue (PNB+R), zero tilled permanent broad-bed without residue (PBB) and with residue (PBB+R). The two additional treatments, i.e. zero tilled flat-bed without residue (ZT) and with residue (ZT+R) were added during 2011–12. For PNB+R and PBB+R plots, average quantity of approximately 2.6 Mg/ha wheat residue was retained. However, 20 and 40% of the cotton and wheat residue were maintained in the subsequent years, respectively. Residues of cotton involved leaves and tender twigs together with boll husks. Cotton cv. MRC 2017 was sown in the month of May and harvested in November. Cotton crop received 150 kg N/ha, 60 kg P_2O_5/ha, and 40 kg K_2O/ha through urea, DAP and muriate of potash. The application of full dose of P and K and half dose of N was made at the time of sowing and the rest of the N was given in two split dose. The first split dose of N was applied on 21 days after sowing (DAS) while the second split dose was applied on 92 DAS.

Soil sampling and analysis: Soil samples were collected from cotton crop under cotton-wheat system. Sampling was carried at two different soil depths, *i.e.* 0-15 and 15-30 cm at 80, 95, 125 and 164 days after sowing, which correspond to pre-flowering, flowering, boll formation and harvesting stages of crop. Composite soil samples (15 random samples from each plot further thoroughly mixed to make one) in triplicate were collected using tube auger. In case of PNB plots, 10 samples were collected from beds and 5 samples from furrow areas from each plot, further thoroughly mixed to make one. Whereas, in PBB plots, 12 samples were collected from beds and 3 samples from furrow areas from each plot, further thoroughly mixed to make one. Thereafter, soil was placed in open air-dry condition and simultaneously sieved (2 mm mesh size) and homogenized. The gravimetric moisture content of soil was immediately determined. The initial characteristic of soil, i.e. pH, electrical conductivity, soil texture, Walkley and Black carbon (soil organic carbon), total nitrogen, available phosphorus, available potassium was estimated using standard protocols. The ammonium and nitrate nitrogen were extracted from soil as per method suggested by Keeney and Nelson (1982), further ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) were estimated through flow injector analysis (FIAstar 5000-FOSS) assembly. Mineral nitrogen was calculated by adding NH_4-N and NO_3-N.

Statistical analysis: The statistical analyses of the data were carried out by procedures suggested by Gomez and Gomez (1984) for randomized block design (RBD) of the experiment. For calculation of Analysis of variance (ANOVA) and Tukey's Honest significant different test (Tukey HSD), Microsoft office 2016, SAS - 9.3 software was used. Significance referred to in the results is $P< 0.05$.

RESULTS AND DISCUSSION

Ammonium nitrogen: Continued crop residues retention increased the NH_4-N concentration in soil irrespective of crop growth stages at upper depth of soil (0-15 cm). However, no significant effect of crop establishment methods and crop residues retention on NH_4-N in soil was recorded in 15-30 cm depth. In 0-15 cm of soil depth, highest NH_4-N was observed at flowering stage (14.5 mg/kg), and it was 17, 123 and 133% higher than boll formation, harvesting and pre-flowering stages of cotton respectively. Ammonium nitrogen flux in soil at flowering stage was related to the higher rate of ammonification process resulted from application of urea fertilizer, as second split dose of N was applied 5 days before soil sampling at flowering stage. Secondly, some amount of NH_4-N may also contribute from decomposition and further ammonification from crop residues. Among crop establishment methods, PBB+R plots recorded higher NH_4-N throughout crop growth stages. At flowering stage, maximum NH_4-N was recorded in PBB+R plots (17.9 mg/kg), which was 68 and 16% higher over CT and PNB+R plots respectively, whereas FB+R plots recorded similar NH_4-N concentration. Most importantly, among residues retained plots PBB+R recorded higher NH_4-N concentration than other plots except FB+R at flowering stage. Crop residues retention had profound effect on NH_4-N concentration in soil throughout crop growth stages; PBB+R, PNB+R and FB+R plots recorded 35, 30 and 20% higher than respective without residues retained plots at flowering stage. In CA practices, comparatively less soil disturbance in combination with residue retention induced ammonification process, resulting in increased concentration of NH_4-N in CA plots compared to CT plots. As like residues retention, crop establishment methods also influenced availability of NH_4-N concentration in soil, although the impact was not noticeable in all crop establishment methods as compared to CT plots. At harvesting stage of crop, the concentration of NH_4-N in soil was not impacted with the CA practices except PBB+R plots (Table 1). The average concentration of NH_4-N during crop growth period was similar in case of all crop establishment methods with residues retained plots (Table 1). In 15-30 cm of soil depth, there was absolute decrease in NH_4-N concentration as compared to 0-15 cm, and decrement was 58, 78, 53 and 48% at pre-flowering, flowering, boll formation and harvest stage of crop, respectively (Table 1).

Table 1 Ammonium nitrogen (mg/kg soil) content in soil at different physiological growth stage of cotton

Treatment	Pre-flowering	Flowering	Boll formation	Harvest	Mean	Pre-flowering	Flowering	Boll formation	Harvest	Mean
	0-15 cm					15-30 cm				
CT	5.13^{D}	10.7^{E}	11.2^{D}	5.5^{B}	8.1^{C}	2.26	3.04	5.67	2.85	3.45^{BC}
PNB	4.95^{D}	12.0^{DE}	11.6^{CD}	6.1^{B}	8.7^{BC}	2.14	2.85	5.46	2.94	3.35^{C}
PNB+R	7.14^{C}	15.5^{B}	12.6^{B}	6.2^{B}	10.4^{ABC}	2.87	3.41	5.92	3.25	3.86^{ABC}
PBB	4.60^{D}	13.3^{CD}	11.8^{BCD}	6.4^{AB}	9.0^{BC}	2.25	3.35	6.11	3.23	3.74^{ABC}
PBB+R	9.80^{A}	17.9^{A}	15.1^{A}	7.4^{A}	12.6^{A}	3.10	3.58	6.19	3.23	4.03^{AB}
FB	5.49^{D}	14.6^{BC}	12.5^{BC}	5.8^{B}	9.6^{BC}	2.73	2.96	5.55	3.47	3.68^{ABC}
FB+R	8.46^{B}	17.5^{A}	12.1^{BCD}	6.0^{B}	11.0^{AB}	3.55	3.38	6.08	3.62	4.16^{A}
Mean	6.51	14.5	12.4	6.2	9.9	2.70	3.23	5.85	3.23	3.75
Tukey's HSD ($P \leq 0.05$)	1.19	1.51	0.94	1.21	NA	1.18	1.30	1.83	0.84	NA

CT: Conventional tillage; PNB: Planting on permanent narrow beds with zero tillage (ZT); PNB+R: PNB with residue retention; PBB: Planting on permanent broad beds with ZT; PBB+R: PBB with residue retention; FB: Planting on flat bed with ZT; FB+R: FB with residue retention. NA: not applicable. Means followed by same letters within a column are not significantly different at $P<0.05$ according to Tukey's HSD test.

Lower concentration of NH_4-N in 15-30 cm of soil depth might be due to slower decomposition of roots of the previous crop. At lower depth of soil generally less oxidative micro-climate that restricts the proliferation of soil micro-organism involved in decomposition and ammonification process.

Nitrate nitrogen: As like NH_4-N, nitrate nitrogen (NO_3-N) of soil under different treatments was affected by crop residue retention as well as crop establishment methods (Table 2). In 0-15 cm soil depth, highest NO_3-N was found under FB+R (28.9 mg/kg soil) plots at pre-flowering stage and statistically similar with other residues retained plots. It was 48, 46, and 25% higher over FB, PNB, PBB plots, respectively. Higher NO_3-N in residues retained plots might be due to oxidation of NH_4-N, as nitrifiers may get substrate from residues for their proliferation as well as nitrification process. Liu *et al.* (2008) also reported total mineralization rate was higher in residue retained ZT plots, which provides substrate (NH_4-N) for nitrification activity. Similarly, at flowering and harvesting stages no significant difference in NO_3-N was recorded among residues retained plots, whereas at boll formation stage, PBB+R and FB+R outcomes statistically superior over PNB+R (Table 2). Residue retained plots at pre-flowering stage was superior over respective without residues retained plots. Residue retained plots recorded 50, 25 and 36%, higher NO_3-N concentration in FB+R, PBB+R and PNB+R plots as compared to respective without residue

Table 2 Nitrate nitrogen (mg/kg soil) content in soil at different physiological growth stage of cotton

Treatment	Pre-flowering	Flowering	Boll formation	Harvest	Mean	Pre-flowering	Flowering	Boll formation	Harvest	Mean
	0-15 cm					15-30 cm				
CT	17.5^{C}	16.3^{D}	23.4^{D}	11.3^{D}	17.1^{D}	6.56	6.62	8.90	5.20	6.82^{ABC}
PNB	19.7^{BC}	19.4^{CD}	31.3^{BC}	14.1^{CD}	21.1^{BCD}	6.98	6.92	7.88	5.10	6.72^{ABC}
PNB+R	26.8^{A}	23.8^{ABC}	36.4^{B}	19.3^{AB}	26.6^{AB}	5.39	7.60	8.18	5.24	6.60^{BC}
PBB	22.9^{B}	21.1^{BCD}	31.4^{BC}	17.2^{BC}	23.1^{BC}	8.27	7.71	9.78	6.65	8.10^{A}
PBB+R	28.6^{A}	29.0^{A}	46.6^{A}	21.8^{A}	31.5^{A}	6.70	9.13	9.73	6.43	8.00^{AB}
FB	19.3^{BC}	18.5^{CD}	26.8^{CD}	15.3^{C}	20.0^{CD}	6.05	6.31	7.83	5.13	6.33^{C}
FB+R	28.9^{A}	25.5^{AB}	44.6^{A}	20.2^{AB}	29.8^{A}	7.08	7.94	10.12	4.90	7.51^{ABC}
Mean	23.4	21.9	34.4	17.0	27.2	6.72	7.46	8.92	5.52	7.15
Tukey's HSD ($P \leq 0.05$)	3.88	5.76	7.88	3.26	NA	2.47	2.87	3.04	3.21	NA

CT: Conventional tillage; PNB: Planting on permanent narrow beds with zero tillage (ZT); PNB+R: PNB with residue retention; PBB: Planting on permanent broad beds with ZT; PBB+R: PBB with residue retention; FB: Planting on flat bed with ZT; FB+R: FB with residue retention. Means followed by same letters within a column are not significantly different at $p < 0.05$ according to Tukey's HSD test.

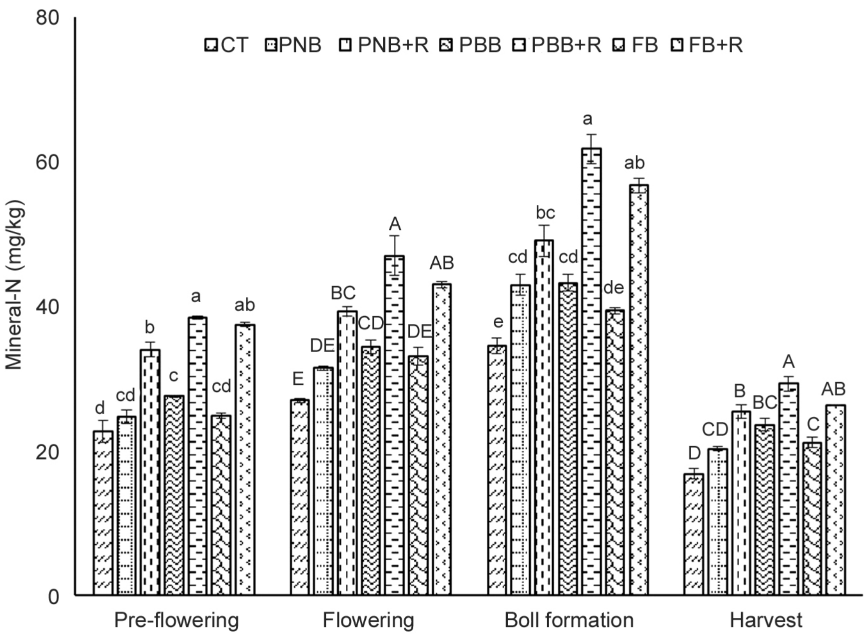

Fig 1 Mineral nitrogen (mg/kg soil) concentration in 0-15 cm depth of soil at different growth stage of cotton under conservation agriculture.

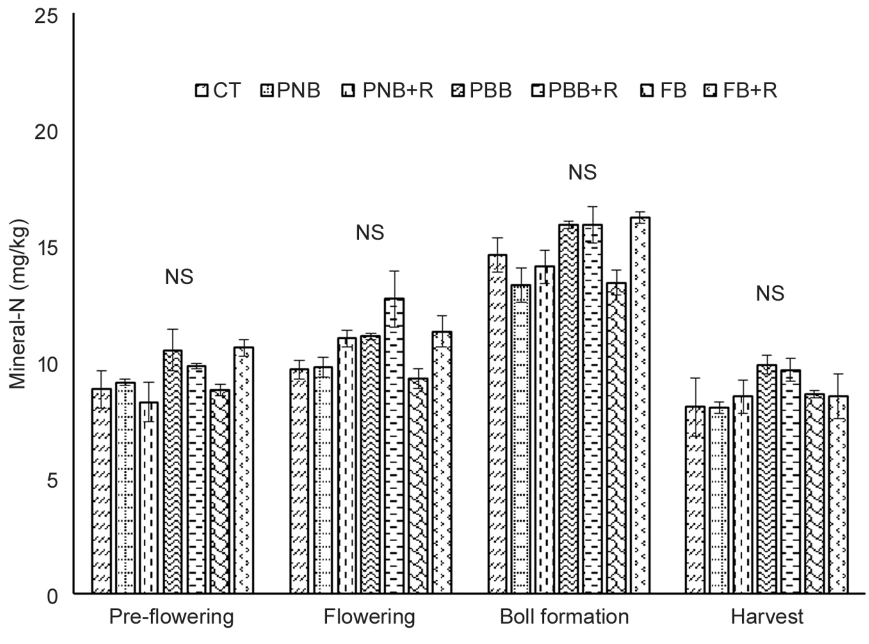

Fig 2 Mineral nitrogen (mg/kg soil) concentration in 15-30 cm depth of soil at different growth stage of cotton under conservation agriculture. CT: Conventional tillage; PNB: Planting on permanent narrow beds with zero tillage (ZT); PNB+R: PNB with residue retention; PBB: Planting on permanent broad beds with ZT; PBB+R: PBB with residue retention; FB: Planting on flat bed with ZT; FB+R: FB with residue retention. Bar indicates standard error. Same letters within a stage are not significantly different at P<0.05 according to Tukey's HSD test.

retained plots at pre-flowering stage. Mean NO_3-N was also significantly higher in residue retained plots as compared to their respective without residue retained plots (except PNB+R) and CT plots. It was noticed that, when crop moving towards harvesting or maturity stage, the NO_3-N concentration in soil was less affected by crop residue retention although crop establishment methods recorded significant effect till harvesting of crops. Among various crop growth stages, highest NO_3-N was recorded at boll formation stage in PBB+R (46.6 mg/kg) and FB+R (44.6 mg/kg soil) plots. The mean NO_3-N concentration was 47 and 57% higher at boll formation as compared to pre-flowering and flowering stage of crop respectively. However, the concentration of NO_3-N in soil decreased by 50% at harvest stage over boll formation stage. Wider C: N ratio (80-100:1) of wheat residue, favored immobilization (Singh *et al*. 2014) of nitrogen into soil microorganism and other pools at the initial crop growth stage, but it favored mineralization at the later stage, and further nitrification process that increased NO_3-N concentration at ball forming stage. Secondly, less substrate availability and NO_3-N uptake by crop favored low NO_3-N concentration at harvesting stage of crop. As like NH_4-N, the concentration of NO_3-N also decreased in 15-30 cm of soil depth as compared to 0-15 cm but no significant difference among the treatments was observed at different stages of crop. However, absolute reduction in NO_3-N was 71, 66, 74 and 68 % at pre-flowering, flowering, boll formation and harvesting stage of crop growth, respectively in 15-30 cm as compared to 0-15 cm of soil depth t. The available N fractions, i.e. NH_4-N, NO_3-N was highly affected due to tillage system and depths, which would suggest that it could be highly dependent on the labile fractions of N, as reported by Sharifi *et al*. (2008).

Mineral nitrogen: Treatments, PBB+R and FB+R recorded highest mineral-N as compared to rest of the treatments throughout growing period of cotton in 0-15 cm soil depth (Fig 1). As like NH_4-N and NO_3-N, residues retained plots consistently recorded higher mineral-N over respective without residue retained plots and CT plots. Only zero tillage with different crop establishment methods not able to release more amount of mineral-N in up to 30 cm of soil depth. At pre-flowering stage mineral-N was highest (38.4 N mg/kg) under FB+R which was 70, 56, 55, 40 and 13% higher over conventional tillage, PNB, FB, PBB and

PNB+R, respectively (Fig 1). Among different crop stages, highest mineral-N was recorded at boll formation stage, which was 28, 56 and 100% higher over flowering, pre-flowering and harvesting stages of crop, respectively. At boll formation stage, residues retained PNB, PBB and FB plots recorded 14, 43 and 44% higher mineral-N over their respective without residue retained zero tilled plots. Similar effect of crop residues retention was also noticed at other studied crop growth stages, in 0-15 cm soil depth (Fig 1). In 15-30 cm soil depth, declining trend in mineral-N was noticed at all crop establishment methods and crop growth stages as compared to 0-15 cm soil depth. As like NH_4-N and NO_3-N, no significant difference in mineral nitrogen among the treatments at various crop growth stage was observed in 15-30 cm of soil depth (Fig 2). This would indicate that long-term conservation agriculture system under semiarid condition may affect soil organic matter as well as organic fraction of N most at 0-15 cm as compared to 15-30 cm soil depth. Moreover, non-significant effect of crop residue and crop establishment method at lower depth may not be due to an increase in labile organic N fractions, lower depth greater protection of these fractions because of less microbial activity (Yadav *et al*. 2021). However, the average concentration of mineral-N was impacted with crop residue retention and different crop establishment methods at lower depth maximum mineral-N were recorded in PBB+R and FB+R treatments.

From the results it may be concluded that N availability, viz. concentration of NH_4-N, NO_3-N and mineral-N were controlled by tillage practices, crop establishment methods and physiological stages of cotton and their interactions. The zero tillage along with PBB+R could be potential alternative to conventional tillage practice for maintaining NH_4-N and NO_3-N in soil under cotton-wheat cropping system in semi-arid climates. For further research, it would be essential to understand the factors affecting the release of available N and their potential supplying power during growing season of different cropping system under different climatic conditions.

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