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Soil Mineral and Nitrate Nitrogen, Plant N Uptake, N Use Efficiencies and Yield as Influenced by Tillage and Nitrogen Management under Wheat Crop in Sub-Tropical Eastern India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PM and AKS managed the analyses of the study. Authors RD and SR managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Accumulation of mineral nitrogen (min-N) in soil profile (0-90 cm) was significantly ($p<0.05$) higher in conventional tillage (CT) than zero tillage (ZT) treatment plots both at 42 days after sowing (DAS) and 84 DAS of wheat, the increase over ZT being 58% and 44% respectively; but at the harvest stage an opposite trend was noted. Min-N accumulation in soil also varied significantly ($p<0.05$) amongst N application rates with its highest value at N150 followed by subsequent reductions with decreasing N levels at all stages of wheat growth, except at harvest where N0 level had the highest accumulation (341.06 kg ha-1) which is ascribed to poor growth and very low plant N uptake. Significant effect of tillage was found on grain yield, dry matter yield and higher plant N uptake recorded under ZT plots over CT. Of the N application levels, N150 produced the highest grain yield and it was significantly ($p<0.05$) higher than all other N treatments. ZT showed highest nitrogen use efficiencies [agronomic efficiency (AE), physiological efficiency (PE) and apparent recovery of

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nitrogen (ARN)] as compared to CT, whereas maximum values of AE (36.28) and PE (29.59) was observed at N120 and these were significantly higher than all other N treatments. As anticipated, highest ARN value was seen at N60 followed by its decrease with increasing levels of N application. Relative proportion of residual inorganic nitrogen (mineral vs. nitrate) in soil profile when compared at the harvest of wheat, a very high proportion of mineral (NH4+ + NO3-) as compared to nitrate nitrogen was evident under both the tillage treatments and more so in ZT than CT plots irrespective of N levels, indicating thereby the predominance NH4+ form of nitrogen in all the layers up to 90 cm soil profile which may be explained by lower nitrification rate due to high water storage in the soil profile during the entire wheat growing season. From the results, it is inferred that plots under ZT combined with N application @150 kg ha-1 proved superior to all other treatment combinations in respect of crop yield, nitrogen use efficiencies, plant N uptake and water storage in soil profile.

Keywords: Tillage; mineral nitrogen; nitrate nitrogen; Agronomic Efficiency (AE); Physiological Efficiency (PE); Apparent Recovery of Nitrogen (ARN).

1. INTRODUCTION

Agricultural practices such as intensive tillage and excessive nitrogen (N) fertilization, can increase N leaching in groundwater, which is a major environmental concern [1]. Tillage accelerates mineralization of crop residue and soil organic N [2,3] and increases accumulation of nitrate-nitrogen (NO_3–N) in the soil profile [4,1]. NO_3-N is highly mobile in soil and can easily leach down the soil profile [5]. Tillage becomes one of the major agricultural activity affecting the transport of NO_3-N to groundwater as it affects soil water properties of the surface as well as subsurface soil. It disturbs the network of macropores thus potentially reducing preferential flow. Timing and rates of N-fertilizer applications can affect both the availability of N for crop growth and the amount of NO_3-N remaining in the soil profile [6]. It is known that the best management practices (BMPs) for fertilizers can decrease NO_3 -N leaching losses from fertilized fields while sustaining crop yield. Numerous studies have demonstrated that no-tillage is useful to decrease agriculture production costs, improve soil structure, increase organic carbon sequestration, reduce soil erosion [7,8] and maintain or increase crop yields [9,10]. Conservation tillage practices, no-tillage (NT) has been adopted worldwide due to its advantages in conserving water and soil, reducing input costs, increasing soil organic carbon and improving crop productivity [11,12,13].

The amount and distribution of inorganic N, primarily NO_3-N, remaining in the soil profile at the end of the growing season (residual N) is greatly affected by fertilizer management and the soil moisture regime as well. Application rates of N is greater than those needed for optimum crop yields can cause an accumulation of large amounts of NO_3-N in the soil profile and, in some cases, movement beyond the root zone [14,15,16]. There are number of factors that can affect the build-up and movement of residual NO_3-N in soil. Among these, fertilizer and irrigation practices are the most important to consider in order to decrease leaching losses and improve economic yield and environmental sustainability.

Wheat (*Triticum aestivum* L.) is the first important and strategic cereal crop for the majority of world's populations. It is the most important staple food of about two billion people (36% of the world population). Worldwide, wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally [17]. It exceeds in acreage and production every other grain crop (including rice, maize, etc.) and is therefore, the most important cereal grain crop of the world, which is cultivated over a wide range of climatic conditions. Nitrogen deficiency is the most widespread nutritional problem in irrigated wheat production. Crop management practices to improve nitrogen-use efficiency have been reviewed by many authors [18,19]. Nitrogen fertilizers (applied as nitrate, NO^{3-}, or ammonium, NH_4^+) improve the amount of grain produced per acre, but nitrogen runoff and volatilization pollute the water and the air. The major grain crops (such as rice and wheat) use only about 40% of the applied fertilizer and the rest is lost to the air, water, and soil microbes. Therefore, improved soil and crop management practices that optimize soil mineral N content and crop N uptake are needed to reduce NO_3–N accumulation in the soil profile and the potential for N leaching [20,2].

Thus, the present investigation was carried out with the objectives to monitor the individual and combined effects of tillage and nitrogen rates on yield of wheat crop, crop N recovery and NO_3-N and min-N distribution in soil profile.

2. MATERIALS AND METHODS

2.1 Site Description

The present study was conducted in research farm of Pundibari campus of the University, Cooch Behar, West Bengal, India for two (2) consecutive wheat growing seasons in 2015-16 and 2016-17. The experimental site is located at 26°23'N, 89°23'E; 41 m above msl (mean sea level), and represents the area under *terai* agro-ecological region belongs to Entisol soil order. The climate of the region is sub-tropical and per humid in nature with moderate temperature in summer, cold in winter and monsoonal rainfall. The area receives a mean annual rainfall of 3124.85 mm, about 80% of which occurs between June and October. The mean maximum and minimum air temperature are recorded as 29.74°C and 18.85°C respectively (average of 16 years: 2001-2016). Annual rainfall and air temperature recorded during study period (Figs.1 and 2) showed minor differences as compared to corresponding long-term data.

2.2 Soil Characteristics

Soils of the study area are formed from alluvial sediments under the influence of high rainfall resulting into huge loss of base forming cations like Ca^{2+} Mg^{2+} through percolating water. Soils in general, are characterized as coarse textured and acidic in reaction. According to soil fertility classification followed in West Bengal, soils are moderately to less fertile with medium to high in total N and total organic carbon, high in total P and medium to low in potassium [21]. The dominant soil texture is a sandy loam and it belongs to Aquic Ustifluvents [22]. The soil physicochemical properties of the present study field showed in Table 1.

2.3 Crop Management Practices

Wheat (var. HD 2967) was sown in ZT and CT plots in both the years in the last week of November and harvested in last week of April. In zero tillage treatment, glyphosate was applied @ 2.0 kg a.i. ha^{-1} seven days before sowing. Wheat was sown using zero till seed cum fertilizer drill with seed rate of 105-110 kg ha^{-1} and fertilizer (N: P: K) @ 120:60:60 Kg/ha. Fifty percent of total N and total amount of phosphorus and potassium at the time of sowing. Complex fertilizer; NPK: 10:26:26 was used as the source of N, P and K at the time of sowing through zero till machine and to compensate the required amount of nitrogen, the difference was supplemented with urea. Two top dressings with urea each @ ¼ the of total after 20-21 and 40-41 days of sowing followed by irrigation. Application of 2, 4-D @ 0.50 kg a.i. ha^{-1} after 32-35 days of sowing to destroy weeds. Boron was applied as borax (20% boron) @ 1g $litre^{-1}$ after 35 and 55 days of sowing. At 80% maturity plants were harvested manually from each treatment plots.

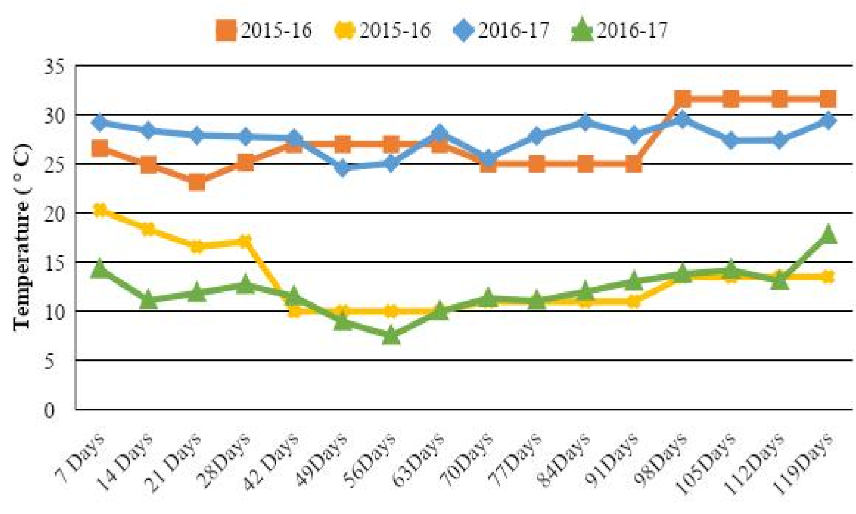

Fig. 1. Maximum and minimum temperature during crop growth period

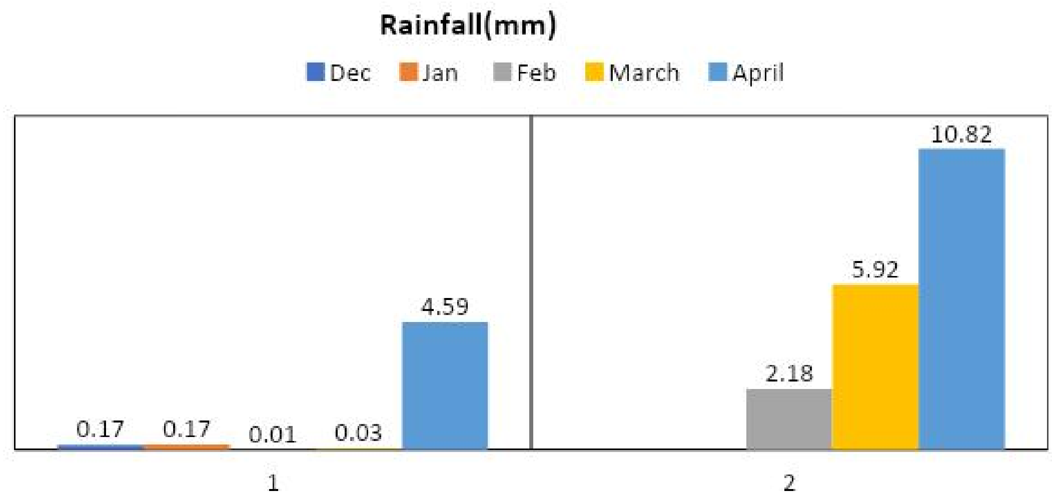

Fig. 2. Monthly rainfall during crop growth period

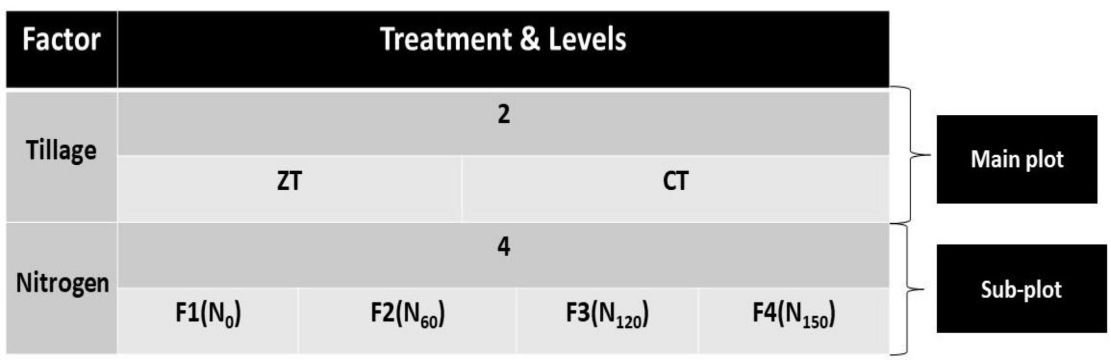

Fig. 3. Treatment details

Note: ZT: zero-tillage; CT: conventional tillage; F: fertilizer; N: nitrogen

Wherein CT treatment, three passes by tractor fitted with cultivator, two passes of power tiller and two passes by rotavator for final land preparation. Seeds were sown at 20 x 10 cm spacing by zero tillage machines without fertilizer. Basal dose of fertilizer applied during final land preparation. All other management practices including the level of nitrogen fertilizer application followed in ZT plots were adopted in case of CT plots for both experiments. Irrigation water applied in all treatment plots three times each of the rates of 127 mm at 21, 42 and 84 DAS.

2.4 Sampling and Analysis

A composite sub-samples of study soils collected from individual treatment plot for each experiment at four depths [0-15, 15-30, 30-60 and 60-90 cm] before sowing, at 42 and 84 DAS and also immediately after the harvest of wheat crop during 2016-17. Sub-sample drawn from five cores for each depth from individual treatment plot were pooled together to form one composite soil sample. After removing all stubbles, residues, root biomass and extraneous substances, composite soil samples for individual treatment plots were homogenized with repeated times till the final weight of 500g was obtained. Samples then air-dried at room temperature, ground in wooden mortar, sieved through 2mm sieve and preserved with care in air-tight polythene containers until the analysis was done. For bulk density (BD) at specified depth, soil cores from three well distributed spots in each treatment plots were collected in all cases using core sampler and tube auger. Plant samples from two consecutive rows each of 0.5 m length in the middle portion of individual treatment plot were collected at 42 and 84 DAS for estimation

Table 1. Physico-chemical properties of the experimental field at the start of the experiment

Soil depth (cm)	pH	Organic C (g kg^{-1})	NO_3N (µg g^{-1})	MIN-N (µg g^{-1})	TOTAL N (µg g^{-1})	BD (g cm^{-1})	Field capacity (v/v)	Texture Sand% Silt% Clay%
0-15	6.13	6.5	4.59	41.35	713.12	1.37	0.47	62.25 26.55 11.2
15-30	6.45	5.1	4.18	37.28	367.5	1.39	0.41	66.55 22.35 11
30-60	6.93	3.9	3.97	37.2	258.35	1.41	0.39	60.35 29.4 10.25
60-90	7.16	2.9	3.27	32.27	245.24	1.39	0.41	62.25 26.7 11.05

of biomass yield. At maturity of wheat crop in both the years, plant samples were harvested at the ground level from three locations each of 1 m^2 area in individual treatment plots, separated into grain and straw after threshing and yields were recorded. After thorough mixing, grain and straw samples each of about 100 g by weight were first washed with tap water repeatedly followed by washing with the distilled water and 0.1 N HCl and finally with the distilled water. After air drying, the samples were oven dried at 60°C until constant weight was obtained. The oven dried samples were ground using Willey Mill grinder and stored properly in plastic container until analysis was done. Grain yield was expressed as 12% moisture level while straw yield at maturity as well as biomass yield at growth stages was expressed on oven dry basis.

Saturated soil paste was prepared and characterized for pHs and ECe following the methods described by [23]. Soil organic carbon was measured by potassium dichromate method suggested by [24]. For total N in soil method of Bremner and Mulvaney [25] was adopted. Soil texture was determined following the Bouyoucos hydrometer method given by Robinson [26]. Soil bulk density was determined by the core method as described by Grossman et.al [27]. Mineral Nitrogen (NH_4^++NO_3^-) was determined by extracting air dried soil with 2 M KCL (1:10) followed by distillation with MgO powder along with Devardo's alloy following method of Keeney and Bremner [28]. Rapid colorimetric determination of nitrate in soil and plant tissue by nitration of salicylic acid, following method of Cataldo et al. [29]. Plant samples were digested using wet oxidation method described by Moore and Chapman [30]. Total N concentration was determined using the Kjeldahl distillation and titration method [25].

2.5 Computations

2.5.1 Reserve NO_3-N (kg N ha^{-1}) [Method: 31]

Reserve NO_3–N = $T_i \times BD_i \times [NO_3]_i \times 0.1$

Where,

T_i is the thickness of soil layer in cm; BD_i is the bulk density in g/cm^3; $[NO_3]_I$ is the soil NO_3–N concentration in mg/ kg,. 0.1 is the conversion factor.

2.5.2 Agronomic Efficiency (AE) [Method: 32]

AE = $(GY_i\text{-}GY_0)/N_i$

Where,

GY_i = grain yield at N_i level of N fertilizer (i=0, 60,120,150 kg/ha); GY_0=grain yield at N_0 level of N fertilizer.

2.5.3 Physiological Efficiency (PE) [Method: 32]

PE = $(GY_i\text{-}GY_0)/\ (NUP_i\text{-}NUP_0)$.

Where,

NUP_i= plant N uptake (grain + straw) at N_i level of Nitrogen; NUP_0= plant N uptake (grain + straw) at N_0 level of Nitrogen.

2.5.4 Crop N recovery (%)/Apparent Recovery of Nitrogen (ARN) [Method: 33]

Crop N recovery (%) = [(Nf -Nc)/F] × 100

Where,

Nf = N uptake from fertilized plot (kg ha^{-1}), Nc = N uptake from control (kg ha^{-1}) and F = total amount of N applied (kg ha^{-1}).

2.5.5 Nutrient uptake

The uptake of N by grain or straw was calculated using the grain or straw dry matter yield and concentrations of N.

2.6 Data Analysis

Obtained data was statistically analysed using Analysis of Variance (ANOVA) technique following randomized complete block design with split plot arrangement [34]. Significance was determined for all the analyses at 0.05 probability level.

3. RESULTS AND DISCUSSION

3.1 Status and Distribution of Min-N in Soil Depth at Different Growth Stages

At 42 DAS, the mean min-N was significantly higher (80.67 mg kg^{-1}) in conventionally-tilled plots (CT) than in zero-tilled (ZT) plot at 0-15 cm depth (Fig. 4a & b). Similar higher amount of min-N recorded in CT at all subsequent layers (15-30, 30-60 and 60-90 cm). There was a clear trend of gradual decrease in min-N with soil depths irrespective of tillage methods. And it is similar with the findings of [35], who reported that mineralization intensity and, hence, available nitrogen is found less in no-tillage system than in plowed tillage system leading to higher nitrogen fertilization requirement in no-till system. Min-N concentration in CT plot ranged from 80.67 to 57.17 mg kg^{-1} and in ZT plots it varied between 47.51 and 33.87 mg/kg. CT system raises the temperature of uncovered soil along with disruption of aggregates, which exposes organic matter to rapid decomposition and, thus, increases mineralization [35]. CT systems mineralized more nitrogen at the soil surface due to soil disturbance [4,36]. Among the N application rates, N_3 level (150 kg ha^{-1}) resulted the highest mean min-N at all soil depths studied ranging from 84.28 to 51.53 mg/kg and it was significantly ($p<0.05$) higher than the rest treatments in each of soil depth. Distribution of min-N in response to N application rate did not follow an uniform pattern in accordance with soil depth. Except at highest application level, no sharp difference in min-N status was observed beyond 30 cm soil depth, more specifically a meagre difference in min-N status was visible between 30-60 and 60-90 cm for all levels of applied N as compared to zero level of applied nitrogen. Interaction effect of tillage and nitrogen application rates on status of min-N at 42 DAS (Table 2) varied significantly among the depths, except at 60-90 cm depth; wherein 60 kg of nitrogen under CT treatment provided numerically higher min-N than any level of applied nitrogen under ZT treatment.

Likewise, at 42 DAS, soils under CT treatment at 84 DAS recorded significantly higher min-N over ZT plots at each of the soil depth (Fig. 5a & b). Further, at 84 DAS, soil min-N maintain almost uniform concentration at all soil depths either in ZT or CT plots. The possible reason of relatively higher level of min-N in deeper layers may be due to the movement of fertilizer nitrogen through irrigation water as these soils are porous with low clay content; and also depends on the rate of fertilizer applied. R.R. Weil et al [37] also reported that N-mineralization rate under the different tillage system were affected by the rate of N fertilization. N-mineralization rates were higher under no tillage than under minimum or conventional tillage at the two lower N rate (34 and 67 Kg N ha^{-1}), and higher under minimum and no tillage than under conventional tillage at the high N rate (101 kg ha^{-1}). 150 kg N ha^{-1} (N_3 level) provided the maximum min-N at all soil depths and it was significantly ($p<0.05$) higher than all other N levels in soil layers except in 30-60 and 60-90 cm. Interestingly, min-N concentration in soil at 60 kg N applied (N_1) was significantly lower than zero N level in 0-15 and 15-30 cm soil depth followed by a minor increase over N_0 level in subsequent depths. Which may be explained by relatively higher removal of N by the plants to satisfy its requirement for maintaining higher biomass yield at N_1 level of N. It is further to state that between N_2 and N_3 level of applied N practically showed no difference in min-N beyond 30 cm soil depth, indicating thereby the mobility of excess of NH_4 –N through the soil layers. Interaction effect of tillage and nitrogen was found significant at all soil depths (Table 2). The highest values of min-N was recorded due to the combined influence of CT and either N_2 or N_3 across the soil depths. This finding was in agreement with Rani et al. [38] who reported that the dynamics of mineral nitrogen in soil were in CT treatment combination with higher level of nitrogen. Pronounced interactive effect of nitrogen with CT as compared to ZT and nitrogen is ascribed to the greater movement of min-N through layers in soil profile because of less penetration resistance and more intimate contact with soil colloidal particles.

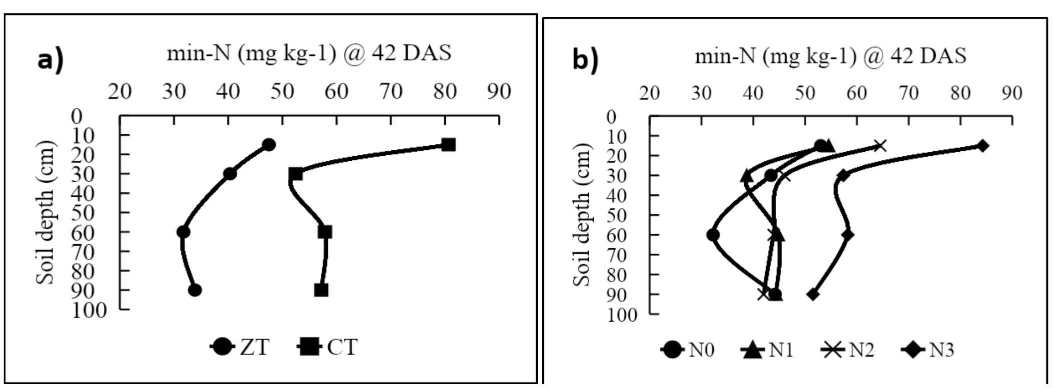

Fig. 4. Effects of tillage (a) and nitrogen (b) application rates on min-N status in different soil depths at 42 DAS of wheat crop

Table 2. Interaction effects of tillage and nitrogen on the status and distribution of min –N (mg kg^{-1}) in different soil depths at 42 DAS & 84 DAS of wheat crop

Tillage×Nitrogen										
42 DAS										
Depth(cm)	**ZTN0**	**ZTN60**	**ZTN120**	**ZTN150**	**CTN0**	**CTN60**	**CTN120**	**CTN150**	**LSD**	**SEM(±0.5)**
0-15	33.42g	36.11f	51.11e	69.39d	72.59c	72.98c	77.93b	99.18a	0.978	0.32
15-30	32.93f	39.96d	29.57g	58.88b	53.9c	37.49e	62.43a	55.89c	1.159	0.38
30-60	15.84c	34.25bc	22.03bc	107.15a	48.64b	55.4b	65.78b	61.58b	41.11	13.55
60-90	29.16d	29.06d	25.22e	52.05b	59.24a	59.7a	58.75a	51c	0.837	0.27
84 DAS										
0-15	52.5e	49e	78.75d	106.75c	106.75c	75.25d	124.25b	150.5a	7.75	2.55
15-30	47.25e	40.25e	84d	96.25c	87.5d	85.75d	120.75b	129.5a	7.22	2.38
30-60	61.25b	63b	91ab	111.45a	80.5ab	98ab	106.75ab	113.75a	46.92	15.47
60-90	49d	63d	91c	85.75c	91c	112b	122.5a	124.25a	5.84	1.92

 # Values in a column followed by same letters are not significantly different at p<0.05 as per DMRT

Table 3. Interaction effects of tillage and nitrogen on status and distribution of NO_3-N (mg kg^{-1}) in different soil depths at 42DAS & 84 DAS of wheat crop

Tillage×Nitrogen										
42 DAS										
Depth(cm)	**ZTN0**	**ZTN60**	**ZTN120**	**ZTN150**	**CTN0**	**CTN60**	**CTN120**	**CTN150**	**LSD**	**SEM(±0.5)**
0-15	4.2e	0.73h	19.2b	11.33c	3.07f	2.07g	9.73d	42.21a	0.958	0.316
15-30	2.067cd	0.267f	2.934c	2.467c	0.467	6.334a	3.801b	1.4de	0.7082	0.233
30-60	0.933c	2.4a	1.6b	0.6c	0.533c	1.534b	2.2a	0.667c	0.473	0.1559
60-90	1.667b	3a	2.867a	1.067b	0.6d	0.867	3.467a	0.4d	0.6962	0.2295
84 DAS										
0-15	0.6e	2.6c	2.53c	10.2b	0.47e	1.53d	2.67c	36.54a	0.419	0.296
15-30	0.867bc	1.534ab	0.933abc	2.267a	0.533bc	1.867a	1.467ab	1.2ab	0.5323	0.1755
30-60	0.733bc	1.133b	1.6b	0.2d	0.2d	1.067b	0.667bc	2.667a	0.6171	0.2034
60-90	1.13b	1.07b	1b	0.33b	0.13b	1b	1.8b	7.07a	3.688	1.216

 # Values in a column followed by same letters are not significantly different at p<0.05 as per DMRT

3.2 Status and Distribution of NO_3-N in Soil Depth at Different Growth Stages

Higher level of average NO_3-N was maintained in soil under CT treatment as compared to ZT plot at four soil depths, although difference between two treatments in respect of NO_3-N concentration were significant in 0-15 and 15-30 cm soil depth (Fig. 6). Higher NO_3-N concentrations up to 30 cm soil depth commensurate with higher biomass yield under CT compared to ZT can be explained by the higher rate of oxidation of NH_4-N into NO_3 form because of low soil water in CT plot along with less penetration resistance in CT resulting into rapid vertical movement through soil layers. Nitrate nitrogen content was higher in the topsoil of 60 cm under CT as compared to NT [39]. Higher infiltration rates are recorded in ZT than CT [40,41,42]. Soil water leachates contain higher nitrate concentrations in CT than in no-tillage production system [43,44]. Accumulation of significantly higher NO_3-N level in ZT over CT plots noticed in 60-90 cm layer in present study.

It is most likely due to accumulation of plant available N fraction that was not utilized by the plants as evidenced from lower biomass yield at the corresponding growth stage under ZT treatment plot. NO_3-N in the leachate was relative lower under CT as compared to NT. This may be related to reduced crop uptake of NO_3 due to undeveloped crop roots in subsurface under NT conditions [45]. Of the N fertilizer rates, the highest NO_3-N was obtained at N_3 level (150 kg/ha) at 0-15 cm depth which was considerably higher than all other levels of N fertilizer application especially the N_1 (60 kg ha^{-1}) which can be explained by the oxidation of high amount of fertilizer N application. Very low leaching losses of NO_3-N when applied at below 150 kg N ha^{-1} [46]. In the subsequent soil depth, no strict relationship between nitrogen and tillage was observed (Table 3). However, presence of higher NO3-N content in the sub surface (>30 cm) at higher nitrogen levels may lead to its loss through leaching as it may not be utilized by the crop [32]. Lopez-Bellido et al. [39] reported that nitrate nitrogen content was higher for upper 60 cm of soil for CT as compared to NT.

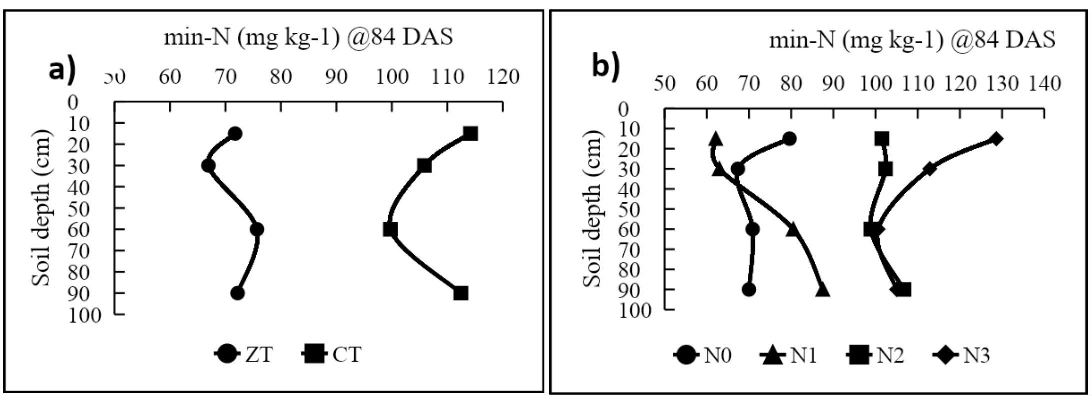

Fig. 5. Effects of tillage and nitrogen application rates on min-N status in different soil depths at 84 DAS of wheat crop

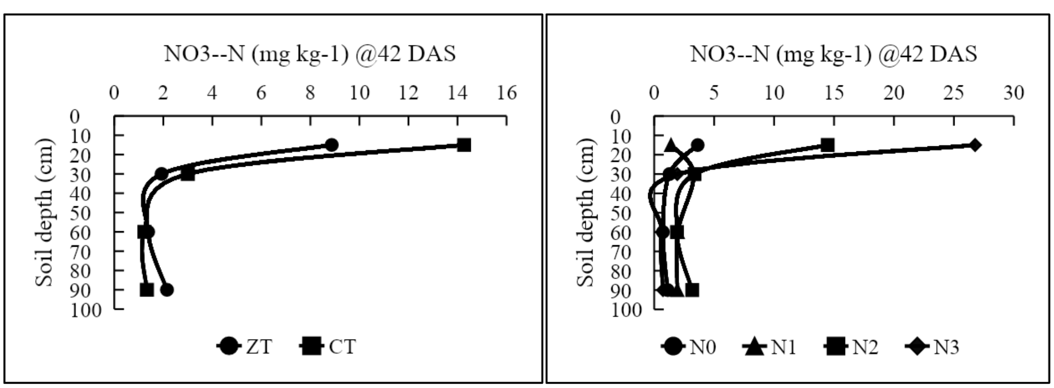

Fig. 6. Concentration and distribution of NO_3-N in soil depths at 42 DAS of wheat crop

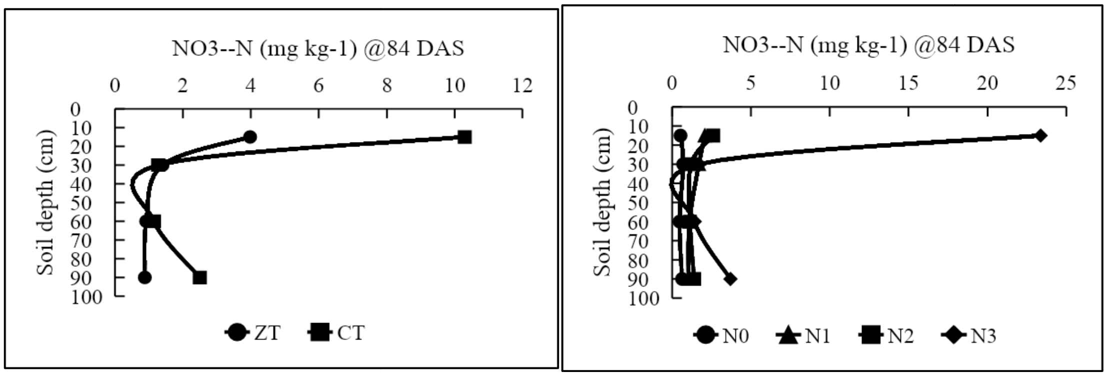

Fig. 7. Concentration and distribution of NO_3-N in soil depths at 84 DAS of wheat crop

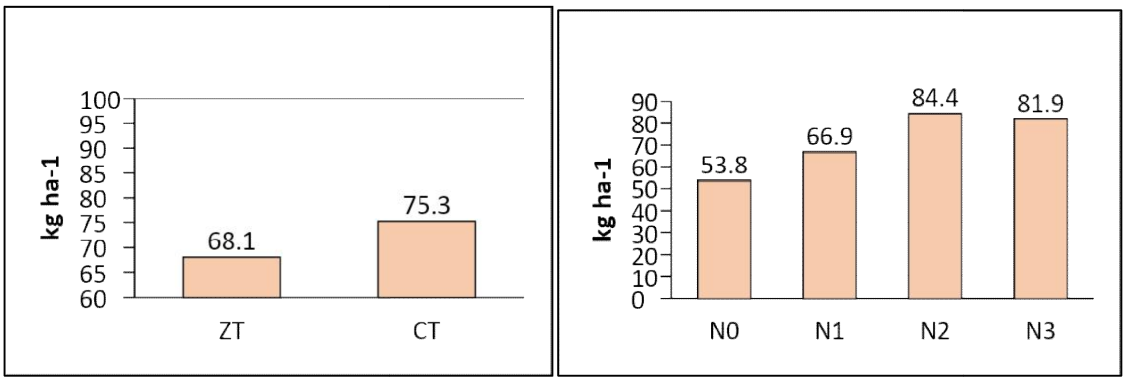

Fig. 8. Effect of tillage and nitrogen levels on biomass yield of 42 DAS wheat crop

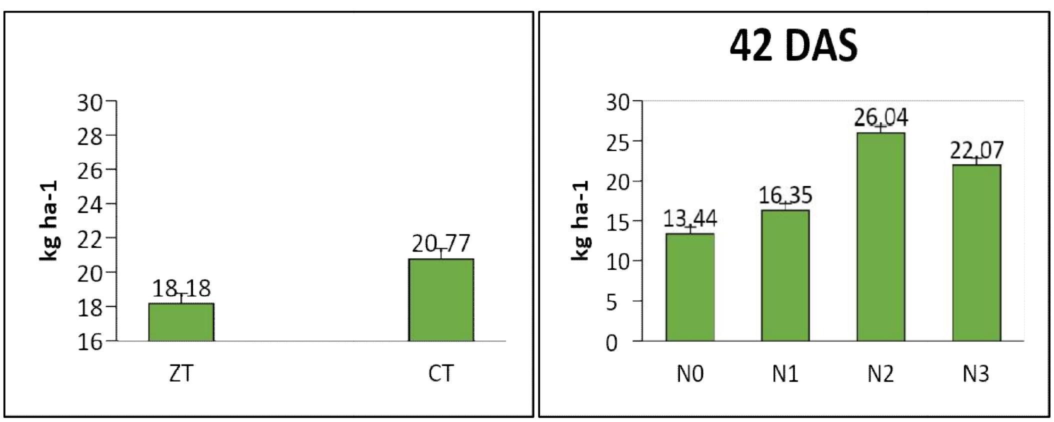

Fig. 9. Effect of tillage and nitrogen levels on N uptake by 42 DAS wheat crop

Mean effect of tillage and nitrogen fertilizer rates on status and distribution of soil NO_3-N estimated at 84 DAS of wheat (Fig. 7) followed almost similar pattern to that at 42 DAS stage. The only difference was with mean effect of nitrogen application rate at N_2 level (120 kg ha^{-1}) wherein the NO_3-N concentration was exceedingly low (2.60 mg kg^{-1}) as compared to that obtained at 42 DAS by the corresponding level of nitrogen fertilizer. This can be interpreted by the higher relative increase of biomass yield and N uptake at N_2 level than N_3 when in comparison between two growth stages. Although, the interaction effect of tillage and nitrogen was found significant at all soil depths but its effect was mostly confined within 0-15 cm depth (Table 3). N mineralisation and N leaching increase with increasing intensity of soil tillage [47]. Reduced tillage has therefore been suggested as a potential measure to mitigate N leaching losses.

3.3 Biomass Yield and N Uptake of Wheat Plant at Different Growth Stages at 42 DAS and 84 DAS

Significantly ($p<0.05$) higher biomass yield (75.3 kg ha^{-1}) and N uptake (20.77 kg ha^{-1}) recorded in CT followed by ZT plot (Fig. 8 and Fig. 9) at 42 DAS. Across all N levels, highest biomass yield and N uptake were recorded at N_2 (120 kg ha^{-1}) level followed by N_3 and these two were statistically at per with each other. Significant interaction between tillage and nitrogen with respect to biomass yield (Table 4) was obtained by the treatment combination of CTN_3 (97.5 kg ha^{-1}) which was significantly higher than all other treatment combinations, the lowest being at ZTN_0. In case of N uptake, the highest value (30.66 kg ha^{-1}) was attend by ZTN_2 and it was statistically at per with that obtained by CTN_3 treatment combination (29.67 kg/ha). Relatively higher amount of N was absorbed by plants in ZT than CT plot because of which is likely due to the maintenance of higher soil water at the vicinity active root system of the plants facilitating higher rate of N utilization.

At 84 DAS, the biomass yield and N uptake (Figs. 10 and 11) in response to tillage and N levels followed almost a similar pattern with that of at 42 DAS; the only differences were with the magnitudes. The highest average biomass of 651.6 kg $ha^{-1}$was obtained in CT in reference to the average of 370.9 kg ha^{-1} in ZT plot. Similarly, among the N levels, highest mean biomass of 564.4 kg/ha was obtained at N_2 as against the lowest 449.4 kg ha^{-1}at N_0 level. In contrast with 42 DAS, N uptake appeared to be the highest at the treatment combination of CTN_2 (80.10 kg ha^{-1}), which was significantly higher than any other treatment combination.

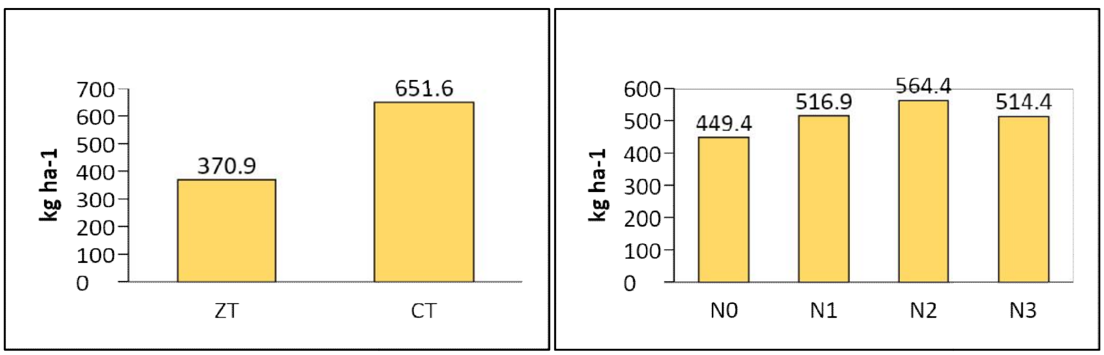

Fig. 10. Effect of tillage and nitrogen levels on biomass yield of 84 DAS of wheat crop

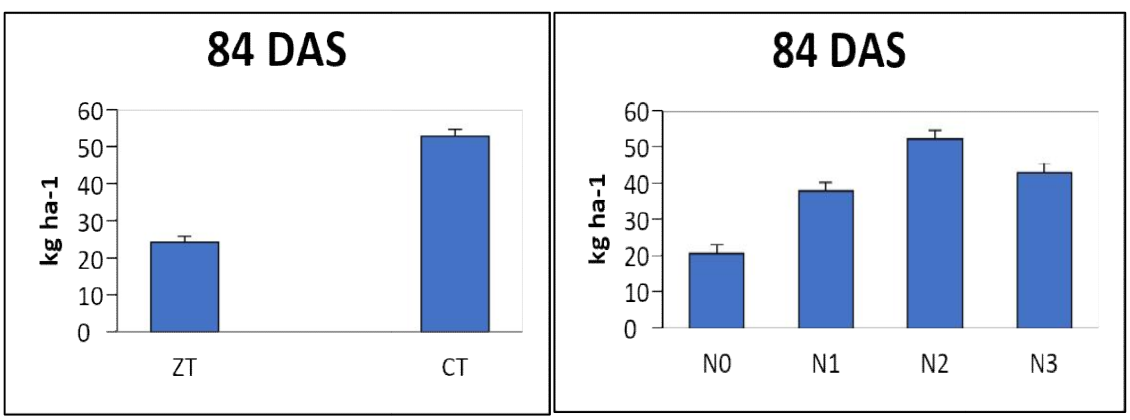

Fig. 11. Effect of tillage and nitrogen levels on N uptake by 84 DAS of wheat crop

Table 4. Interaction effect of tillage and nitrogen levels on biomass yield and N uptake by 42DAS and 84 DAS of wheat crop

		42DAS		84 DAS	
		Biomass yield (kg ha^{-1})	**N-uptake (kg ha^{-1})**	**Biomass yield (kg ha^{-1})**	**N-uptake (kg ha^{-1})**
Treatments					
Tillage (T)	ZT	68.13b	18.18b	370.94b	24.18b
	CT	75.31a	20.77a	651.56a	52.94a
	SEM(±0.5)	**1.52**	**0.85**	**9.33**	**2.39**
	LSD	**4.6**	**1.82**	**28.31**	**5.13**
Nitrogen (N)	N_0	53.75c	13.44d	449.38c	20.70d
	N60	66.88b	16.35c	516.88b	37.96c
	N120	84.38a	26.04a	564.38a	52.44a
	N150	81.88a	22.08b	514.38b	43.15b
	SEM(±0.5)	**2.15**	**1.2**	**13.2**	**3.38**
	LSD	**6.51**	**2.58**	**40.04**	**7.25**
Interaction effect					
T x N	ZTN0	51.25d	10.40d	375.00d	17.64c
	CTN0	56.25d	16.48c	523.75c	23.75c
	ZTN60	70.00c	17.18c	387.50d	25.04c
	CTN60	63.75c	15.51c	646.25b	50.87b
	ZTN120	85.00b	30.67a	418.75d	24.78c
	CT N120	83.75b	21.41b	710.00a	80.09a
	ZTN150	66.25c	14.48c	302.50e	29.24c
	CTN150	97.50a	29.67a	726.25a	57.06b
	SEM(±0.5)	**3.04**	**1.7**	**18.67**	**4.78**
	LSD	**9.21**	**3.65**	**56.62**	**10.25**

*# Values in a column followed by same letters are not significantly different at p<0.05 as per DMRT; The lower case letters are used for comparing main plot and subplot effects, respectively; * Significant at p<0.05. Here a>b>c>d>e*

Table 5. Effects of tillage (T) methods and N application rates on grain yield (GY), above ground dry matter (DM) and total N uptake (TN uptake) by wheat crop

Treatments		GY (Mg ha^{-1})	DM (Mg ha^{-1})	TN (Kg ha^{-1})
Tillage (T)	ZT	3.398a	10.7a	141.33a
	CT	3.033b	9.28b	128.89b
	SEM(±0.5)	0.074	0.256	2.797
	LSD	0.224	0.778	8.485
Nitrogen (N)	N_0	1.680d	5.38c	55.85d
	N_1	2.915c	9.69b	125.9c
	N_2	3.763b	11.94a	152.28b
	N_3	4.503a	12.95a	206.42a
	SEM(±0.5)	0.104	0.363	3.956
	LSD	0.317	1.1	12
Interaction effect				
T x N	ZTN0	1.647d	5.53d	59.43e
	CTN0	1.713d	5.23d	52.27e
	ZTN1	3.447b	11.72ab	149.37c
	CTN1	2.383c	7.66c	102.44d
	ZTN2	3.847b	12.23a	139.94cd
	CT N2	3.680b	11.65ab	164.62c
	ZTN3	4.650a	13.3a	216.59a
	CTN3	4.357a	12.6a	196.24b
	SEM(±0.5)	0.148	0.513	5.595
	LSD	0.448	1.555	16.97

Table 6. Effects of tillage and N application on N use efficiencies (AE PE and ARN) in wheat crop

Mean effect		AE	PE	ARN
Tillage	ZT	17.10a	32.01a	0.42a
	CT	8.15a	18.18a	0.33a
	SEM	**1.77**	**2.99**	**0.04**
	LSD	**10.76**	**18.21**	**0.26**
	N60	24.56a	43.34a	0.55a
N rate	N120	18.15b	27.76b	0.66a
	N150	7.79c	29.29b	0.30b
	SEM	**1.48**	**3.75**	**0.05**
	LSD	**4.56**	**11.54**	**0.16**
Interaction effect				
	ZTN60	35.35a	57.49a	0.62a
	CTN60	13.77b	29.19ab	0.47ab
	ZTN120	24.18b	32.72ab	0.78a
	CTN120	12.11bc	22.81ab	0.53a
	ZTN150	8.88c	37.84a	0.27b
	CTN150	6.70c	20.73ab	0.32ab
	SEM	**2.53**	**5.48**	**0.08**
	LSD	**11.51**	**21.79**	**0.3**

3.4 Crop Yield and Total N Uptake at the Final Harvest of Wheat Crop

A significant difference in average grain yield between ZT (3.39 Mg ha^{-1}) and CT (3.03 Mg ha^{-1}); also a dry matter yield between two tillage treatments was recorded (Table 5). Higher dry matter yield of 10.7 Mg ha^{-1}recorded in ZT over CT (9.28 Mg ha^{-1}). The positive effect of ZT on grain yield was in agreement with several studies [41,48]. Explanations of the yield increase under the NT system in wheat production include the enhancement of the soil's water-holding capacity [49]. In this context, the probable reason for the yield compensation in this study was to some extent the soil water conservation. Results further indicated that ZT plots favour higher shoot growth than CT. An increase in mean grain yield with increasing levels of N fertilizer application was noted, N_3 (4.50 Mg ha^{-1}) and N_2 (3.76 Mg ha^{-1}) was visible. Dry matter yield followed the similar pattern to that of grain yield in response to N fertilizer. The interaction effect of tillage and nitrogen application rates (Table 5) was found significant both in cases of grain yield and dry matter yield, highest yield parameters being with the combined influence of zero tillage and 150 kg ha^{-1} level of N (ZTN_3). Increase in fertilizer application, the nitrogen uptake throughout the growth season significantly increased the grain and straw yields [50,51].

Total N uptake by wheat plant (Table 5) showed no significant difference in response to tillage methods, although numerically higher amount of total N was absorbed by the plant (115.7 kg ha^{-1}) in ZT than that in CT (111.67 kg ha^{-1}). Similar results also reported by Rani et al. [38] that the interaction effect of tillage, residue and nitrogen management was not significant on nitrogen uptake by wheat grain and straw. The highest mean amount of total N (152.93 kg ha^{-1}) was absorbed by wheat plant at N_3 level (150 kg ha^{-1}) followed by N_2 (120 kg ha^{-1}) and N_1(60 kg ha^{-1}), which varied significantly with one another and also figured to be considerably higher as compared to zero level of nitrogen application. Interaction effect of tillage and nitrogen on total N uptake varied among the treatment combinations. The maximum total N uptake by wheat plant was observed at ZTN_3 combination followed by CTN_3 but these were statistically at per with each other. These findings reveal that N_3 level of nitrogen either in ZT or CT created favourable soil environment that promoted higher level of nitrogen absorption by the plants and it is related to Rani et al. [38] who reported that nitrogen uptake by wheat grain and straw increased significantly with increase in the nitrogen levels.

3.5 Agronomic Efficiency (AE) Physiological Efficiency (PE) and Apparent Recovery of Nitrogen (ARN)

AE and PE were significantly higher in ZT than CT treatment (Table 6). Both N use efficiency (NUE) parameters were found to be highest at the lower level of nitrogen (60kg ha^{-1}) followed by a gradually decrease with increasing N levels. Both NUEs by wheat decreased with increase in nitrogen levels. Sieling et al. [52] also showed that mineral fertilizer NUE for winter wheat decreased with increasing N levels. The ARN of wheat were significantly higher in 60 kg N ha^{-1} than that of 120 kg N ha^{-1} [38]. This observation was quite pertinent since increasing the level of N application, there was a gradual decrease in relative yield and as well as N uptake values. This is mainly attributed to the losses of nitrogen at higher level of N application and also due to the fact that yield of wheat didn't increase in the same proportion as that of nitrogen application. Similar results have been reported by many workers [53,54]. From the data on interaction effect, it seems that combined influence of ZT and 60 kg N ha^{-1} (ZTN_1) gave rise the highest AE as well as PE values which was significantly higher than all other treatment combinations.

4. CONCLUSION

This study tested the sustainability of conservation agriculture (CA) techniques to overcome problems related to intensive agriculture for sustainable wheat production in the *terai* region of West Bengal state. Both the tillage system had a significant impact on the grain yield. However, this impact was influenced by weather conditions, especially the amount of rainfall and distribution during the growing season. The N fertilizer rate also showed a significant effect on grain yield, status and distribution of min-N and nitrate nitrogen throughout the growing period. ZT technique could be a valuable alternative to CT in the areas of *terai* region. There was little bit significant difference between ZT and CT with respect to Min-N and NO_3^--N content at all the depths. With the increase in nitrogen fertilizer dose, in most of the cases the Min-N and NO_3^--N content increased with increasing soil depths. Therefore, the farmers are advised to apply minimum amount of nitrogen to avoid nitrogen losses. Also, the effect of tillage and nitrogen was a significant on grain and biomass yield of wheat, nitrogen uptake, ARN and NUE of wheat. Thus, the farmers can successfully adopt no-tillage with 150kg/ha of nitrogen and can save time, labour and energy. Nitrogen uptake and nitrogen concentration in plant increased with increase in nitrogen levels but NUE and ARN decreased with the increase in N levels. Hence, there is a trade-off between yield and nitrogen use efficiency with respect to nitrogen dose which needs to be optimized. Conclusively, our results suggested that the plots under ZT combined with N application @150 kg ha^{-1} proved as most appropriate treatment combination in respect of crop yield, nitrogen use efficiencies, plant N uptake and water storage in soil profile.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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