Research Article

Nitrogen Use Impact on Nitrogen Use Efficiency and Lint Yield in Zero Tillage Cotton

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Abstract | Residues retention in zero tillage (ZT) system is a highly resourceful mean of managing nitrogenous fertilizers and optimizing the nitrogen (N) use efficiencies, lint yield and fiber quality in wheat-cotton system. Therefore, a field experiment was conducted during 2014, 2015 and 2016 at Cotton Research Station, Dera Ismail Khan, Pakistan to explore N management practices for ZT cotton grown into standing wheat straw. The trial was conducted in a randomized complete block (RCB) design with three replications. Results showed that cotton lint yield and fiber quality was good during 2016 than that in 2014 and 2015. Ammonia volatilization loss from urea broadcast over the residue covered surface, followed by irrigation, was low (<2 kg ha^{-1}) regardless of time of urea application. N treatments significantly affected the N uptake, N use efficiencies, lint yield and fiber quality traits. Drilling of 24 kg N ha^{-1} as DAP into soil at cotton seeding followed by three top-dressing of 42 kg N ha^{-1} each just prior to first, second and third irrigations significantly enhanced seed cotton yield, quality, N uptake and N efficiencies compared to conventional practices. In conclusion, drilling of 24 kg N ha^{-1} as DAP into the soil at cotton sowing followed by three top-dressing of 42 kg N ha^{-1} each just prior to first, second and third irrigations is a better applied N management strategy for ZT cotton that enhanced cotton yield, quality and N efficiency in wheat-cotton system.

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Introduction

Growing of upland cotton after wheat crop is an important cropping system in Pakistan and area under the system is 7.1 million hectares (Govt. of Pakistan, 2016; PCCC, 2016; FAO, 2004). Wheat straw is used as animal fodder and household fuel. Removal/burning of wheat residues is a common practice in Pakistan causing severe air-pollution and huge losses of organic carbon-C, crop nutrients and soil biota (Zhang et al., 2012). As a result, cotton lint yield in wheat-cotton system has become stagnant or declined. The decreasing soil fertility, mainly soil organic matter (SOM) is one of the key factors responsible for this decline (Usman et al., 2013a). Hence there is a stress on accumulation of soil organic matter and

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to improve it in soil, crop residues are normally advocated. Removal of wheat residue negatively affects soil eco-system along with organic manure sources (Singh et al., 2002). Residues on the surface of soil act as a mulch that protect the soil from structural degradation and has positive effect on soil productivity, storage space, and supply of moisture and nutrients (Khan et al., 2014; Wang, 2006). Residues retention may affect soil fertility, soil physicochemical properties and cotton productivity (Endale et al., 2002). Nutrients in crop residues and soil amendments are more available to crops if they are retained into the soil rather than removed/burnt. Keeping in view importance of residues retention/ incorporation into soil one should adopt appropriate tillage method. One of the environmentally acceptable alternative methods of residue disposal is residue incorporation with conventional tillage (CT; including disc plow, tiller, rotavator, and leveling operations), which can increase soil organic matter, improve physical and biological conditions of the soil, and prevent soil degradation (Blaise and Ravindran, 2003; Read et al., 2006; Mert et al., 2006). However, CT that involves numerous plowings and disturbs the entire soil surface (Endale et al., 2002) for incorporation of wheat residues is neither feasible nor economical in case of wheat-cotton system. Because the time between harvesting of wheat and sowing of cotton is short for land preparation and decomposition of incorporated rice residues, which may delay sowing of cotton beyond favorable sowing time. CT enhances mineralization of soil N and loss of N through leaching and denitrification (Kienzler, 2010). Both surface residue retention and zero tillage-ZT probably encourage main changes in nitrogen dynamics and N management in comparison to conventional tillage with straw removal (Scheer et al., 2008). ZT may decrease nitrogen mineralization by reducing decomposition of SOM, mainly in the primary 2–3 years of its adoption; wheat residues cover can affect N dynamics from volatilization and immobilization (Raun and Johnson, 1999; Blaise et al., 2005). Zero tillage with straw retention (ZTsr) enhances soil organic-matter and total soil N and therefore encourages main shifts in N management (Nehra et al., 2005). Research indicated that ZT plus straw cover had greater aggregate size and stability and OC in soil than CT (Bauer and Roof 2004). Usman et al. (2013 a, b) reported depressed cotton yield and NUE of conservation tillage (ZT) if practiced in short terms (1-2 yrs) compared with CT. Higher seed cotton yield achieved with ZT plus residue retention may be due to positive effect of the practice on moisture accessibility for crops (Nehra et al., 2005), hastening of organic matter decomposition and higher nutrient availability. The conventional nitrogen application practice in Pakistan for cotton cultivated into tilled soil without wheat residues is to apply a total of 150 kg N ha^{-1} as urea, 60 kg P ha^{-1} as triple super phosphate and 30 kg K ha^{-1}as potassium sulphate. All the phosphorous was applied at sowing, while N was applied in three split doses, 50 kg at sowing, 50 kg at 1st irrigation, and 50 kg at 3rd irrigation (Khan et al., 2014). The objective of the experimental trial was to determine the optimum time and partitioning of nitrogen (urea) application to zero tillage (ZT) cotton grown into standing wheat residues. The hypotheses was that delaying application of N until the active fraction of residue-C has decomposed will reduce N immobilization, and that irrigation applied immediately after broadcasting of fertilizer N will reduce NH3 volatilization. More specifically the purpose of the present research was to determine the optimum time and method of urea application for maximizing cotton lint yield and nitrogen use efficiency (NUE) of irrigated ZT cotton dibbled into wheat straw/residues.

Materials and Methods

Site

Field experiments were conducted at Cotton Research Station (CRS), Dera Ismail Khan, Pakistan (31º49´ N, 70°55´, 166 m a.s.l.) for three years (2014-2017). The soil of the experimental site is hyperthermic and Typic Torrifluvents (Soil Survey Staff, 2009). It is moderately saline; less fertile than the typical cotton belt in Punjab, Pakistan, having relatively high silt and clay content; and needs irrigation for crop production.

Soil analysis

Soil samples were collected from 0 to 30 cm depth before sowing and analyzed for physicochemical characteristics. The experimental soil was a silty clay (150 g kg^{-1} sand, 450 g kg^{-1} silt, 400 g kg^{-1} clay) with 6.6 g kg^{-1} SOM, 0.3 g kg^{-1} total soil nitrogen (TSN), available phosphate and potassium contents of 7.7 and 191 mg g^{-1} soil, respectively.

Experimental procedure

The experiment contains fourteen splits of N urea (total 126 kg N ha^{-1} in all treatments) applied at cotton dibbling/seeding, before the 1st, 2nd and 3rd irrigations (Table 1). At cotton seeding, different levels of nitrogen (36, 81 and 126 kg N ha^{-1}) were either broadcast on the surface of residues prior to pre-sowing irrigation (7 days before cotton dibbling) or after the pre-sowing irrigation and just before sowing. Post-sowing applications of N-urea were top dressed directly before the first (28 DAS), second irrigation (63 DAS) and third irrigation (98 DAS) as per the treatment. All thirteen treatments also received 24 kg N ha^{-1}as DAP with the seed, thus the total N addition was 150 kg N $ha^{-1}$for all treatments (Table 1). Nitrogen control treatment was also included. All the treatments without control received a basal dose of DAP (30 kg P ha^{-1}) with the seed, and MOP (25 kg K ha^{-1}). The experiment had a randomized complete block design with split plot combined over years. A net plot size was 3m×10m. Wheat was the previous crop at the study site in all the years. Wheat (cv. Hashim-8, a standard variety of the region) was sown in the 2nd wk of December under irrigated conditions during the years of study. Wheat crop was fertilized with 120 kg N, 60 kg P and 30 kg K ha^{-1}. After wheat harvest, field was irrigated. When field came in proper moisture condition, cotton was direct-seeded into wheat residue. Cotton (cv. CIM-600, a standard Bt variety of cotton for the region) was sown at 75 cm inter-row and 22.5 cm intra-row spacing with dibbling method on May 5, 2014, May 7, 2015, and May 8, 2016, respectively. Weeds were controlled with herbicide application (Haloxyfop (108 g a.i. ha^{-1}) + Lactofen 24 EC (168 g a.i. ha^{-1}). The crops were harvested in the last week of November.

Field and laboratory measurements and data collection

Collection of volatilized ammonia in each treatment was collected in chambers (one per plot) during the 1st ten days following each application of nitrogen in 2014 cotton season. The chambers contained plastic pots (30-cm internal diam-eter × 45-cm height) which were pressed 2 to 3 cm into the soil. A traditional dish of 100 ml and 10cm internal diameter, including 2 percent Boric Acid (20 mm) was placed on a 10cm high wooden tripod inside each chamber to absorb volatilized Ammonia (Jones, 2006; Engel et al. 2011). After every 2, 4, 6 and 10 day of N-urea application, the boric acid were collected and replaced with fresh BA traps after about 30 minutes. The traps were collected in the morning and directly taken to the laboratory, where they were titrated with dilute H SO to determine the concentration of ammonium-N. The ammonia volatilization rate was calculated by taking into account the amount of ammonia N collected in the dish, the cross sectional area of the plastic pot, and the interval for sample collection.

Table 1: *Details of treatments.*

Treatments	Amount (kg ha^{-1}) and method of N fertilizer applied					
	Sowing[A]	1st irrigation[B]	2nd irrigation[C]	3rd irrigation[D]	Total	Treatment abbreviations
T1	0	0	0	0	0	Control
T2	24D+36B	90TD1	0	0	150	36B+90 TD1
T3	24D+36B	45TD1	45TD2	0	150	36B+45TD1+45TD2
T4	24D+36B	30TD1	30TD2	30TD3	150	36B+30TD1+30TD2+30TD3
T5	24D+81B	0	45TD2	0	150	81B+45TD2
T6	24D+81B	0	0	45TD3	150	81B+45TD3
T7	24D+126B	0	0	0	150	126B
T8	24D	42TD1	42TD2	42TD3	150	42TD1+42TD2+42TD3
T9	24D+36B-PSI	90TD1	0	0	150	36B-PSI+90 TD1
T10	24D+36B-PSI	45TD1	45 TD2	0	150	36B-PSI+45TD1+45TD2
T11	24D+36B-PSI	30TD1	30 TD2	30TD3	150	36B-PSI+30TD1+30TD2+30TD3
T12	24D+81B-PSI	0	45TD2	0	150	81B-PSI+45TD2
T13	24D+81B-PSI	0	0	45TD3	150	81B-PSI+45TD3
T14	24D+126B-PSI	0	0	0	150	126B-PSI

[A] 24D = diammonium phosphate drilled with the seed at 24 kg N ha^{-1} in T2–T14, 36B = urea broadcast before sowing at 36 kg N ha^{-1} etc., 36B-PSI = urea broadcast before the pre-sowing irrigation at 36 kg N ha^{-1} etc.
[B] 30TD1 = urea top dressed prior to first irrigation at 36 kg N ha^{-1} etc.
[C] 30TD2 = urea top dressed prior to second irrigation at 36 kg N ha^{-1} etc.
[D] 30TD3 = urea top dressed prior to third irrigation at 36 kg N ha^{-1} etc.

Chlorophyll measurement

Chlorophyll concentration was obtained using Minolta SPAD-502 chlorophyll meter. Readings were taken at 80 days after sowing (DAS) in 2014. Five plants were selected randomly from each plot. Readings were measured of the uppermost fully expanded leaf of each plant and average values were determined.

Yield and yield attributes

Data on bolls per plant, five plants were taken randomly from each plot and mature bolls were counted then averaged. Fifty mature bolls were picked and weight per boll (gram seed cotton/boll) was calculated. From each treatment seed cotton was handpicked, pooled over the picks and ginned to determine total cotton lint yield.

Total N uptake and Nitrogen use efficiencies

Data on lint yield, total N uptake (kg ha^{-1}), N agronomic efficiency, NAE (kg kg^{-1}), N physiological efficiency, NPE (kg kg^{-1}), and N recovery efficiency, NRE (%) were recorded. Lint yield was recorded in kg ha^{-1} for each treatment, using the two central rows of each subplot. Five representative plants from each plot were sampled for determining N concentration in each treatment. The plant samples were finely ground to pass a 1-mm sieve. Plant components such as leaves, burs, stalks, lint and seeds were chemically analyzed for nitrogen content by use of the Kjeldahl method (Bremner and Mulvaney 1982). The N concentration of plant components was determined separately. For the calculation of N uptake, the N concentration (%) was multiplied by the respective dry weight of the plant component and then summed to determine total N uptake. The N efficiency indices were calculated as follows:

$NAE = \text{lint yield } F - \text{lint yield } C / \text{Amount of N applied}$

(Lint yield F is the lint yield of N-fertilized plots and lint yield C is the lint yield of control plots (Novoa and Loomis, 1981):

$NPE = \text{lint yield } F - \text{lint yield } C / TNU\_F - TNU\_C$

[(TNU_F is the total N uptake of N-fertilized and TNU_C is the total N uptake of control plots (Isfan, 1990)]

$NRE\ (\%) = TNU\_F - TNU\_C / \text{Amount of N applied}$ *(Dilz, 1988)*

Quality characteristics

For fiber length, representative samples of cotton lint were taken from each plot and mean length was obtained by using high volume instrument (HVI) system in laboratory. Similarly, micronaire (which indicates fiber fineness), and fiber strength all were determined in laboratory through HVI system in Central Cotton Research Institute, Multan, Pakistan.

Statistical Analysis

Trials data were analyzed as a split plot design by with years as the main plots and N treatments as sub-plots combined over years according to Statistix 8.1 version. Means were further separated and compared using LSD test at 0.05 level of probability

Results

Weather

Rainfall was comparatively low and unequally distributed during the three growing seasons 2014-2017. Total rain-fall was 163 mm in 2014, 197 mm in 2015 and 242 mm in 2016. Mean maximum and minimum air temperature in 2014 (34 and 21°C), 2015 (33 and 20°C) and 2016 (33 and 17°C) Figure 1.

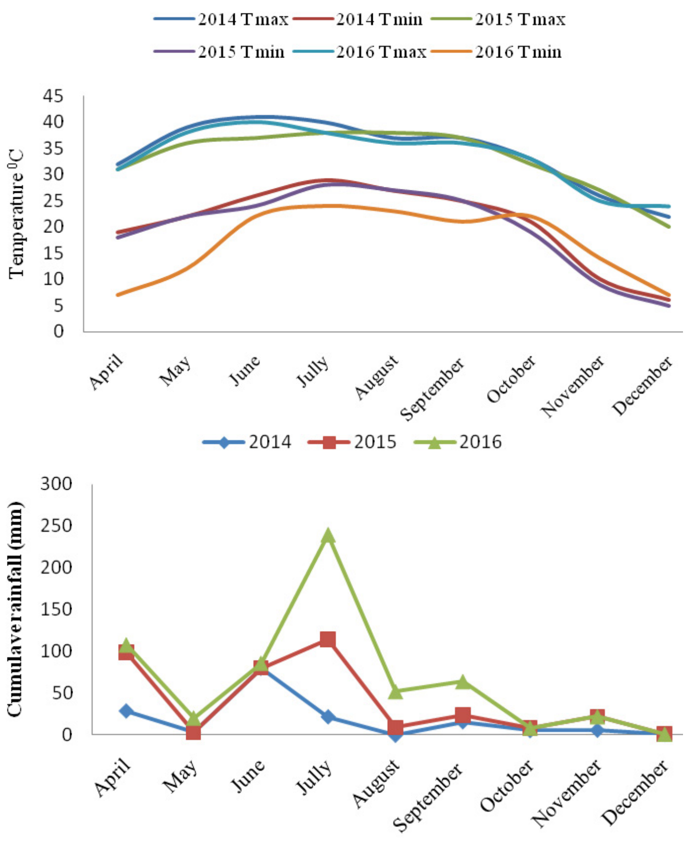

Figure 1: *Weather data*

Table 2: *Effect of amount, method and time of application of N fertilizer on bolls, boll weight, lint yield and Chlorophyll of cotton sown into wheat residue*

Treatments No	Treatments	Bolls /plant	Boll weight (g)	Lint yield (kg/ha)	Chlorophyll reading
	A. Year				
	2014	25.27 c	2.71 b	961.5 c	-
	2015	26.57 b	2.72 b	1094.0 b	-
	2016	29.07 a	2.83 a	1159.4 a	-
	LSD (0.05)	0.94	0.02	31.53	
	B. *Treatment				
T1	Control	17.23 i	2.1344 f	489.3 i	37.30 j
T2	36B+90 TD1	20.07 h	2.7644 de	1021.0 g	43.50 gh
T3	36B+45TD1+45TD2	28.77 c	2.7911 cd	1138.8 c	44.43 cd
T4	36B+30TD1+30TD2+30TD3	32.30 a	2.8511 b	1236.6 b	45.67 b
T5	81B+45TD2	30.93 b	2.7978 c	1121.0 cd	43.27 h
T6	81B+45TD3	27.33 d	2.7911 cd	1110.6 cd	43.73 fg
T7	126B	25.77 f	2.7444 e	918.7 h	42.60 i
T8	42TD1+42TD2+42TD3	32.17 a	2.8878 a	1343.8 a	47.57 a
T9	36B-PSI+90 TD1	27.47 d	2.7711 cde	1058.0 f	44.23 de
T10	36B-PSI+45TD1+45TD2	27.33 d	2.7811 cd	1103.2 de	43.90 ef
T11	36B-PSI+30TD1+30T-D2+30TD3	31.37 b	2.8744 ab	1262.6 b	45.77 b
T12	81B-PSI+45TD2	25.40 f	2.7611 de	1059.4 f	44.67 c
T13	81B-PSI+45TD3	24.80 g	2.7744 cde	1062.4 f	43.77 fg
T14	126B-PSI	26.63 e	2.7744 cde	1077.7 ef	43.54 fgh
	LSD (0.05)	0.49	0.032	30.60	2.06
	LSD (0.05) year × treatment	ns	Ns	Ns	ns

Note: Any two means in their respective group sharing no common letter(s) are significant (p<0.05)

Ammonia volatilization and Chlorophyll content

Total nitrogen loss during ammonia volatilization in all treatments was less than 2 kg N per hectare. (Data not given). Chlorophyll content was significantly affected by N treatments. Chlorophyll reading in 2014 ranged from 37.30 in control treatment to 47.57 in T8 (Table 2).

Yield attributes and yield

There were no significant year by treatment interactions for boll number, boll weight, lint yield and chlorophyll reading. Therefore, pooled data for the three years are presented and discussed (Table 2). Lint yield was significantly higher in the third year (2016) than in the first and second years. There was a highly significant effect of fertilizer treatment on boll number, boll weight, and lint yield. Drilling of 24 kg N ha^{-1}as DAP into the soil at seeding followed by three top-dressings of 42 kg N ha^{-1} each just prior to first, second and third irrigations (T8) produced significantly highest number of boll per plant, lint yield and chlorophyll reading among all other combinations.

Total N uptake and N use efficiencies

N uptake was significantly affected by year, N treatments and their interaction (Table 3). Total N uptake was significantly lower in 2015 than other years. Total nitrogen uptake was optimum in T8 plots. Highest NAE, NPE, and NRE recorded with urea application delayed until the first, second and third irrigations (T8).

Fiber quality

Data averaged over the years on fibre quality parameters such as fiber length, strength and micronaire are presented in Table 4. Year had no effect on fiber properties except fiber length. Fibre length was higher in 2016 than in 2014 and 2015. N treatment (T8) resulted in significantly lower micronaire value (higher fiber fineness). Higher fiber length and strength were recorded in treatments with N (urea) application delayed until the first, second and third

Table 3: *Effect of amount, method and time of application of N fertilizer on N uptake and N use efficiency of cotton sown into wheat residue*

Treatments No	Treatments	Total N uptake (kg ha^{-1})	N agronomic efficiency (kg kg^{-1})	N physiological efficiency (kg kg^{-1})	Nitrogen recovery efficiency (%)
	A. Year				
	2014	87.52 a	3.85	10.31	34.59
	2015	67.93 b	3.891	10.60	33.95
	2016	90.36 a	3.92	10.20	35.57
	LSD (0.05)	3.47	Ns	Ns	Ns
	B. *Treatment				
T1	Control	29.89 g	0.00 i	0.00 f	0.00 g
T2	36B+90 TD1	81.00 f	3.54 g	10.41 cd	34.07 f
T3	36B+45TD1+45TD2	85.22 d	4.32 c	11.78 b	36.89 d
T4	36B+30TD1+30TD2+30TD3	88.56 c	4.98 b	12.78 a	39.11 c
T5	81B+45TD2	83.00 e	4.21 cd	11.94 b	35.41 e
T6	81B+45TD3	81.00 f	4.16 cd	12.10 b	34.07 f
T7	126B	80.11 f	2.867 h	8.57 e	33.48 f
T8	42TD1+42TD2+42TD3	99.67 a	5.69 a	12.23 ab	46.52 a
T9	36B-PSI+90 TD1	88.00 c	3.80 f	9.76 d	38.74 c
T10	36B-PSI+45TD1+45TD2	89.00 c	4.09 de	10.46 c	39.41 c
T11	36B-PSI+30TD1+30TD2+30TD3	92.22 b	5.16 b	12.38 ab	41.56 b
T12	81B-PSI+45TD2	85.89 d	3.80 f	10.189 cd	37.333 d
T13	81B-PSI+45TD3	79.11 f	3.81 f	11.733 b	32.815 f
T14	126B-PSI	84.44 de	3.92 ef	10.83 c	36.44 de
	LSD (0.05)	1.92	0.20	0.67	1.27
	LSD (0.05) year × treatment	3.32	Ns	Ns	2.20

Note: Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

irrigations (T8) and applied prior to the pre-sowing irrigation plus delayed until the first, second and third irrigations (T11).

Discussion

The direct dibbling of ZT cotton in standing wheat residues is still in experimental phase in north-western Pakistan. The technology will take time to be adopted on a large scale. However, cotton growers take interest in the technology due to the lowest cost of cultivation (Blais and Ravindran, 2003; Boquet et al., 2004). The observed significant increase in cotton lint yield in ZT is mainly a result of specific yield determining components such as higher number of bolls per plant and boll weight over the three years (Usman et al., 2013). The lower lint yield in 2014 might be due to lower solar radiation during the boll formation period. Photosynthesis can make an important contribution to boll formation period and yield (Pettigrew and Jones, 2001). The higher cotton yields was probably due to the reason that the nutrients in crop residues and soil could be improved through the adjustment of abundant microorganisms after straw residue returning to the field (Sayre and Hobbs, 2004; Govaerts et al., 2005; Wang et al., 2007). In the first growing season, the microorganisms might have consumed more N and C nutrients to meet their own growth requirement (Bessam and Mrabet, 2003). Thus, the lower bolls per plant, boll weight, and finally lesser lint yield have been reported. However, in the third growing season, the decomposed straws release nutrients to accelerate the process of initiation of yield and yield components resulting in final increase of cotton lint yield (Pettigrew and Jones, 2001; Kennedy and Hutchinson, 2001). Nitrogen is a limiting factor and its effective management can optimize cotton yield, quality, and N efficiency. There are several chances of N losses which affect both in yield and environmental pollution. Split application of N is one such option to avoid losses and to enhance N use efficiency (NUE) and cotton yield. There are numerous probabilities of

Table 4: *Effect of amount, method and time of application of N fertilizer on fibre characteristics of cotton sown into wheat residue*

Treatments No	Treatments	Fiber length (mm)	Fiber strength (g tex^{-1})	Micronaire
	A. Year			
	2014	28.63 b	27.54	4.20 a
	2015	28.54 b	27.76	4.52 a
	2016	28.75 a	27.91	3.64 b
	LSD (0.05)	0.12	Ns	0.34
	B. *Treatment			
T1	Control	28.17 i	27.21 g	4.52 a
T2	36B+90 TD1	28.53 gh	27.60 f	4.42 b
T3	36B+45TD1+45TD2	28.70 cde	27.79 cd	3.92 h
T4	36B+30TD1+30TD2+30TD3	28.80 abc	27.90 b	3.76 ij
T5	81B+45TD2	28.67 def	27.77 d	4.06 g
T6	81B+45TD3	28.57 fgh	27.72 d	4.0222 g
T7	126B	28.47 h	27.63 ef	4.32 cd
T8	42TD1+42TD2+42TD3	28.90 a	27.89 b	3.69 j
T9	36B-PSI+90 TD1	28.33 gh	27.63 ef	4.26 de
T10	36B-PSI+45TD1+45TD2	28.67 def	27.79 cd	4.1556 f
T11	36B-PSI+30TD1+30TD2+30TD3	28.87 ab	27.99 a	3.79 i
T12	81B-PSI+45TD2	28.67 def	27.79 cd	4.36 bc
T13	81B-PSI+45TD3	28.63 efg	27.71 de	4.26 de
T14	126B-PSI	28.77 bcd	27.87 bc	4.22 ef
	LSD (0.05)	0.12	0.08	0.08
	LSD (0.05) year × treatment	Ns	ns	ns

Note: Any two means in their respective group sharing no common letter(s) are significant ($p<0.05$)

N losses which influence both cotton production and ecological pollution. Splitting of N is one such option to avoid losses and to increase N efficiency and cotton lint yield and quality. Nitrogen split application of 150 kg N ha^{-1} had a significant effect on cotton yield and yield components over the 3 yr as a whole. The highest cotton yield was obtained when total N (150 kg N ha^{-1}) was applied as four equal splits (T8), i.e., at sowing, 1st irrigation, 2nd irrigation, and 3rd irrigation or drilling of 24 kg N ha^{-1}as DAP into the soil at seeding followed by three top-dressings of 42 kg N ha^{-1}each just prior to first, second and third irrigations. While there was no effect delaying the application on ammonia loss, applying a smaller amount of fertilizer N at sowing and delaying its application to coincide with the third irrigation may have reduced N immobilization and denitrification due to mineralization of most of the readily mineralizable C fractions of the residues, thereby increasing cotton yield. Leaving the urea on the surface of the soil as in T7 exposes it to increased risks of volatilization and immobilization (Engel et al., 2011). These processes might be happened in other treatments due to less urea broadcast at sowing. However, cotton yield was not affected due to the potential nitrogen loss in these treatments because most of the total N applied is distributed after sowing. Our results revealed that ZT cotton plus straw retained in combination with T8 (24D+42TD1+42TD2+42TD3) significantly increased cotton lint yield, quality, N uptake, and NUE. ZT with straw retained and application of N in fourteen uniform splits might have caused effective utilization of resources that led to the higher cotton yield (Wang, 2006). The better performance of ZT cotton in standing wheat straw in combination with T8 is usually attributed to the synergistic effects of organic and inorganic fertilizers, which improve the efficiency of each other (Boquet at al., 2004). Similarly, higher NUE could be obtained with the integration of ZT in standing wheat straw and splitting of N fertilizer (Habtegebrial et al., 2007). Hence, on the basis of more cotton lint yield and N efficiency indices, the results suggested that ZT cotton in standing wheat straw in combination with better N splitting may be an appropriate alternative to the CT system.

Conclusions

Our data indicated that ZT in standing wheat straw with 150 kg N ha^{-1} applied in four equal splits (T8) had the highest cotton lint yield, quality characteristics, N uptake, and NUE. ZT plus split application of N fertilizer has the potential to promote cotton yield on sustainable basis with no environmental hitch. There was no indication of N limitations in the ZT cotton compared to the other tillage methods, indicating that there was no need to increase N rate when using ZT system. Long term application of the technology may result in soil fertility and productivity at reduced cost of production.

Author's Contribution

Niamat Ullah Khan: Conducted the research, collected data, did statistical analysis and wrote the manuscript.
Farkhanda Khan: Supervised the research and provided technical support.
Qadir Ullah: Helped in revieing the manuscript.
Muhammad Kashan: Helped to make avialable the resources for research.
Abdur Rauf: Helped in prepration of methodology and data collection.

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