Research Article

Response of Wheat to Tillage and Nitrogen Application in a Cotton-Based Cropping System

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Abstract | Wheat (*Triticum aestivum L.*) yield and yield components are influenced by tillage and time of nitrogen application as well as soil type and cropping system. The objective of this study was to evaluate the response of spring wheat seeded in three tillage systems *viz.*, zero (ZT), reduced tillage (RT), and conventional tillage (CT) to split application of N fertilizer [50 kg N at sowing + 100 kg N ha^{-1} at first irrigation (T_1); 50 kg N at first irrigation + 100 kg N ha^{-1} at second irrigation (T_2); 50 kg N at sowing + 50 kg N at first irrigation + 50 kg N ha^{-1} at second irrigation (T_3); and 50 kg N at first + 50 kg N at second + 50 kg N ha^{-1} at third irrigation (T_4)] in cotton (*Gossypium hirsutum L.*) based cropping system. The experiment was conducted on a silty clay soil at Agricultural Research Institute, Ratta Kulachi, Dera Ismail Khan, Pakistan, during 2010–2011. The effects of three tillage systems as main plot factor and four split N fertilizer application timings as subplot factor were studied in a randomized complete block design with split plot application. The results revealed that zero tillage had higher spikes m^{-2}, 1000 grain weight and biological yield compared to other tillage systems. However, N agronomic efficiency, grain yield and net benefit were similar for all three tillage systems. Regarding N application timing, T_3 had highest values for N agronomic efficiency, grain yield and yield components. Results also suggested that application of N in three splits particularly in T_3 is more productive and economical strategy for wheat production following cotton. It is concluded that wheat seeded in zero tillage following cotton did not decrease stand or yield compared to conventional tillage and wheat grain yield and N agronomic efficiency increased with application of 150 kg N ha^{-1} in three equal splits *viz.* at sowing, first irrigation, and second irrigation.

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Introduction

Wheat and cotton grown in sequence impact the amount of nutrients available for subsequent plant growth (Gan et al., 2003). Although cropping system influences crop nutrient availability, it mostly affects N, which is probably most affected by management practices. Nitrogen is extensively deficient in alkaline and calcareous soils of Pakistan (Shah et al., 2010). Nitrogen management plays a key role in crop productivity and N management will be affected by crop species and cropping system (Campbell et al., 1995). Some researchers reported lower wheat yield and N use efficiency (NUE) when grown in zero tillage after exhaustive crops such as cotton compared to continuous conventional tillage wheat (Knowles et al., 1993). The lower NUE in wheat may be attributed to N immobilization due to previous crop residues. Nitrogen application at proper time is important to ensure profitable wheat production (Howard et al., 2002). Many studies have shown that split application of N fertilizer results in higher NUE

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and higher grain yield than under single applications (Khan et al., 2011; López-Bellido et al., 2012). However, current N recommendations developed for conventional tillage system may be insufficient for optimizing wheat production under zero tillage (McConkey et al., 2002) and need reconsideration due to potential effects of crop residues on soil surface on N transformations and crop development (Weisz et al., 2001). Growing wheat in rotation can enhance yield by influencing crops insect pests, diseases, weeds, water and nutrients uptake (Campbell et al., 1990). A sustainable cropping system is essential for agronomic, economic, and environmental safety (Camara et al., 2003). Cotton followed by wheat is one of the common cropping systems prevailing in D. I. Khan, Pakistan.

Growing wheat in sequence with cotton has the potential for increasing farmers' income. However, in cotton–wheat cropping system, late sowing of wheat can be a problem due to delayed harvest of late maturing cotton. This leaves very narrow time for land preparation to sow wheat. However, conventional tillage is waning in wheat production systems (Carr et al., 2003) and zero tillage that reduce the turn-around time for wheat cultivation after cotton have been developed (Sheikh et al., 2003). Zero tillage wheat is useful in terms of timeliness, low cultivation cost, less use of machinery and hence less diesel consumption, and appears to be a good alternative to conventional tillage. However, sowing wheat in zero tillage following cotton requires some specific crop management and may present problems such as late wheat sowing and managing previous crop residues (Staggenborg et al., 2003). Crop residues can adversely affect wheat yield, thereby creating an obstacle to the adoption of zero tillage technology that effectively controls soil erosion (Rasmussen et al., 1997). Zero tillage may reduce wheat germination and stand establishment due to poor seed–soil contact and less uniform seedbed conditions compared with conventional tillage. However, Hunt et al. (1997) reported that wheat grain yield from zero tillage and reduced tillage was similar to conventional tillage. In recent years, cotton production has considerably increased in Southeast Asia, but the effect of zero tillage and reduced tillage wheat in cotton based cropping system has not been adequately investigated (Hunt et al., 1997). A suitable tillage in combination with N fertilizer application time needs to be developed for sustainable crop production without jeopardizing the soil and environmental quality. Few studies have been conducted on the response of wheat to tillage and N application time in cotton based cropping system. Therefore, the objective of this study was to evaluate the impact of different tillage systems and time of N application on wheat grown after cotton.

Material and Methods

The study was carried out at Agricultural Research Institute, Ratta Kulachi, Dera Ismail Khan, Pakistan, during 2010–2011. The experiment was conducted on a field previously occupied by cotton crop. Three tillage systems viz., Zero tillage (ZT), reduced tillage (RT), and conventional tillage (CT) as main plot factor and four split N fertilizer application [50 kg N at sowing + 100 kg N ha^{-1} at first irrigation (T_1), 50 kg N at first irrigation + 100 kg N ha^{-1} at second irrigation (T_2), 50 kg N at sowing + 50 kg N at first irrigation + 50 kg N ha^{-1} at second irrigation (T_3) and 50 kg N at first + 50 kg N at second + 50 kg N ha^{-1} at third irrigation (T_4)] as subplot factor in randomized complete block design with split plot arrangement replicated four times. The subplot size was 3 × 10 m^2. The cultivar used was Hashim-8, a short-cycle, spring wheat of medium height. The cultivar showed good productivity and adaptability, even if grown late in a season. The preceding cotton crop was also supplied with N and P fertilizer at a rate of 120 kg N and 90 kg P ha^{-1}, respectively. Soil available K was adequate. Wheat was sown on December 4, 2010 at a seed rate of 120 kg ha^{-1} with 30 cm wide rows soon after cotton harvest. Zero tillage wheat was sown with zero tillage drill without land preparation. Reduced tillage plots were prepared with tiller followed by rotavator, while conventional tillage plots were prepared with disc plow, tiller, rotavator and after leveling wheat was sown with seed drilling machine. Nitrogen and Phosphorus fertilizers were applied at the rate of 150 kg N and 60 kg P ha^{-1} in the form of Urea and Triple super phosphate, respectively. All of the P fertilizer was applied at sowing while N was applied according to subplots treatments as mentioned earlier. Wheat crop was irrigated 5 times during the growing season. First irrigation was given 20 days after crop emergence, while subsequent irrigations were given at one month intervals. Wheat was harvested in last week of May. Data were recorded on spikes m^{-2}, spike length (cm), grains spike^{-1}, 1000 grain weight (g), biological yield (kg ha^{-1}), grain yield (kg ha^{-1}), harvest index (%), cost of production (Rs. ha^{-1}), nitrogen agronomic efficiency [(grain yield of the N fertilized plot - grain yield of control) / amount of N applied)] and net benefit (Rs. ha^{-1}) (gross income– total cost of production) (Usman et al., 2012). Data were then subjected to statistical analysis of variance appropriate to randomized complete block design with split plot arrangement and least significant difference test was applied for mean comparison using MSTATC software (Steel and Torrie, 1980).

Results and Discussion

Number of Spikes per m^2

Number of spikes per m^2 was significantly affected by tillage and nitrogen timing and splitting (Table 1). There were more spikes m^{-2} in zero tillage (270) and reduced tillage (263) compared to conventional tillage (260). However, Khan et al. (2011) reported lower spikes under zero tillage compared to other tillage systems while studying rainfed wheat. The difference in research findings may be due to variations in soil, moisture, and weather conditions during growing season. The data further revealed that T3 showed the highest number of spikes m^{-2} (314), while control plot produced the lowest spikes m^{-2} (193). The higher spikes in T3 plots may be ascribed to efficient use of N fertilizer and distribution of more resources to crop plants compared to other treatments (Laghari et al., 2010; Youseftabar et al., 2012). Mean values for N timing and splitting displayed highest number of spikes in T3 (314) followed by T4 (297), while the control showed lowest spikes m^{-2} (193). The tillage × N interaction was not significant.

Table 1. *Effect of tillage and nitrogen application timing on spikes m^{-2} in wheat.*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	196	195	188	193 e
T1	242	242	236	240 d
T2	281	278	273	277 c
T3	324	312	306	314 a
T4	305	290	296	297 b
Tillage mean	270 a	263 ab	260 b	

$LSD_{0.05}$ for tillage= 6.614, Nitrogen = 14.53
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Spike Length (cm)

Spike length was significantly affected by N fertilizer timing and splitting, however, both the tillage and tillage × N interaction effects were not significant (Table 2). Mean values for N timing and splitting revealed that longest spikes were recorded in T3, i.e., when 50 kg N fertilizer was applied at sowing, 50 kg at first irrigation, and 50 kg N ha^{-1} at second irrigation. Spikes length recorded in T2 and T4 were statistically similar. The shortest spikes (5.5 cm) were recorded in T0 where no fertilizer was applied. The increase in spike length with T3 may be attributed to better synchronization between N availability and plant demand (Afridi et al., 2010).

Table 2. *Effect of tillage and nitrogen application timing on spike length (cm) in wheat.*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	5.3	5.3	6.0	5.5 d
T1	8.8	7.8	7.5	7.8 c
T2	9.5	8.5	7.8	8.3 b
T3	9.0	9.3	9.0	9.3 a
T4	9.0	8.8	8.5	8.8 b
Tillage mean	8.2	7.9	7.8	

$LSD_{0.05}$ for Nitrogen = 0.4342
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Grains per Spike

Data on grains $spike^{-1}$ was significantly affected by tillage, N, and tillage × nitrogen interaction (Table 3). Mean values for tillage revealed that reduced tillage had higher number of grains $spike^{-1}$ (44.3) compared to zero tillage (42.7) and conventional tillage (42.0). In N fertilizer timing and splitting, T3 had highest number of grains $spike^{-1}$ (51.9) among all other treatments. In tillage × nitrogen interaction, T3 showed highest number of grains $spike^{-1}$ in zero tillage (55.5) followed next by reduced tillage (50.8) and conventional tillage (49.5). The data also revealed that minimum number of grains $spike^{-1}$ (29.3) was recorded in T0 irrespective of the tillage intensity. The increase in grains $spike^{-1}$ with split application, i.e., with T3 may be attributed to prolonged period for nutrients availability to crop growth as reported by some researchers (Mandal et al., 2005; Melaj et al., 2003).

1000-Grain Weight (g)

The 1000-grain weight was significantly affected by tillage, nitrogen and tillage × nitrogen interaction

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(Table 4). Heavier grains were recorded in zero tillage (37.5 g) compared to conventional tillage (34.4 g). Reduced tillage gave statistically an identical grain weight to zero tillage and conventional tillage. Mean values for nitrogen timing and splitting showed highest (41.6 g) and lowest 1000-grain weight (28.0 g) in T3 and T0, respectively. Similarly in interaction effects, T3 showed higher 1000-grain weight under zero tillage compared to reduced tillage and conventional tillage.

Table 3. *Effect of tillage and nitrogen application timing on grains spike^{-1} in wheat.*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	29.3 i	29.3 i	29.3 i	29.3 e
T1	39.5 h	45.5 ef	41.0 gh	42.0 d
T2	43.5 fg	47.5 cde	43.5 fg	44.9 c
T3	55.5 a	50.8 b	49.5 bc	51.9 a
T4	45.8 ef	48.5 bcd	46.5 de	46.9 b
Tillage mean	42.7 b	44.3 a	42.0 b	

$LSD_{0.05}$ for tillage= 1.597, Nitrogen =1.513, Tillage × N=2.620
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

The results reveal that both zero tillage and reduced tillage were superior to CT in producing heavier grains particularly when N fertilizer was either applied with T3 or T4. Analogous results were communicated by Hassan et al. (2010) and Hirzel et al. (2011) who reported that split application of nitrogen significantly enhanced all plant traits except crop emergence.

Biological Yield (kg ha^{-1})

Biological yield was significantly affected by tillage and N timing and splitting (Table 5). The interaction between tillage and N was non-significant. Zero tillage had higher biological yield (14053 kg ha^{-1}) compared to reduced tillage (12958 kg ha^{-1}) and conventional tillage (12753 kg ha^{-1}). Analogous results were communicated by López-Bellido et al. (2012) who reported higher yield for zero tillage compared to other tillage systems. Under zero tillage crop residues decompose slowly, however, in the long run residues may provide a longer, more continuous supply of nutrients than a single fertilizer application. Slowly released N would be less susceptible to gaseous and leaching losses. The organic matter may also be vital to supply energy to the soil microbial biomass and formation of stable soil aggregates (Carefoot and Janzen, 1997). Regarding N timing and splitting, highest biological yield (18177 kg ha^{-1}) was recorded when one third (50 kg N ha^{-1}) of total N fertilizer (150 kg N ha^{-1}) was applied each at sowing, at first irrigation and at second irrigation (T3). The higher biological yield with T3 may be attributed towards optimum time and split application of N fertilizer among all other treatments (Jan et al., 2010). The crop might have higher N uptake and efficient N utilization in case of T3 compared to all other treatments.

Table 4. *Effect of tillage and nitrogen application timing on 1000- grains weight (g).*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	29.3 hi	27.0 j	27.8 ij	28.0 e
T1	36.3 fg	31.3 h	30.0 h	32.5 d
T2	39.0 cde	38.3 def	36.0 g	37.3 c
T3	42.8 a	41.5 ab	40.5 bc	41.6 a
T4	40.3 bcd	40.3 bcd	37.8 efg	39.4 b
Tillage mean	37.5 a	35.7 ab	34.4 b	

$LSD_{0.05}$ for tillage=2.290, Nitrogen =1.253, Tillage × N=2.170
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Table 5. *Effect of tillage and nitrogen application timing on biological yield (kg ha^{-1}).*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	3209	3425	4750	3795e
T1	13818	12193	11867	12626d
T2	16355	14932	13875	15054c
T3	19518	17688	17325	18177a
T4	17364	16551	15950	16622b
Tillage mean	14053a	12958b	12753b	

$LSD_{0.05}$ for tillage= 717.1, Nitrogen = 1128
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Grain Yield (kg ha^{-1})

Split application of nitrogen significantly affected wheat grain yield, while the tillage and tillage × split

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application of nitrogen interaction were not statistically significant (Table 6). Maximum grain yield (6250 kg ha^{-1}) was recorded when N fertilizer (150 kg N ha^{-1}) was applied in three splits i.e. 50 kg N ha^{-1} each at sowing, at first irrigation, and second irrigation (T3). The lowest grain yield (1393 kg ha^{-1}) was recorded in control where no N fertilizer was applied. The data also revealed that application of N fertilizer in three equal splits such as T3 (with sowing, first irrigation and second irrigation) and T4 (with first, second and third irrigation) produced higher grain yield than N fertilizer application in two splits i.e T1 (1/3rd with sowing and 2/3rd with 1st irrigation) and T2 (1/3rd with 1st irrigation and 2/3rd with 2nd irrigation). The higher grain yield obtained from T3 may be attributed to higher spikes m^{-2}, grains $spike^{-1}$ and 1000-grain weight which contributed to higher grain yield. The applied N in three equal splits viz., sowing, first irrigation (20 days after emergence), and second irrigation may have lower chances of N losses, higher NUE, and hence might have resulted in higher grain yield. The T4 application was not as efficient as T3 because late season N application may prompt increase in grain protein concentration rather than increase in grain yield (Gooding and Davies, 1997; Garrido-Lestache et al., 2004).

Table 6. *Effect of tillage and nitrogen application timing on grain yield (kg ha^{-1}).*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	1253	1375	1550	1393 e
T1	3561	3744	3704	3669 d
T2	4383	4524	4305	4404 c
T3	6741	6142	5866	6250 a
T4	5468	5485	5319	5424 b
Tillage mean	4281	4254	4149	

$LSD_{0.05}$ for Nitrogen = 418.4
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Harvest Index (%)

Harvest index was significantly affected by N timing and splitting while tillage and its interaction with N timing and splitting were not significant (Table 7). The mean H.I. was higher in T0 (37.5%) and T3 (34.4%) compared to other treatments. The lowest H.I. was recorded in T2 where 50 kg N was applied at first irrigation and 100 kg N ha^{-1} at second irrigation. The lowest H.I. in T2 may be attributed to lower partitioning of dry matter to grains which resulted in lower H.I. The variation in H.I. for different N application timings may be related to the relative increase in both grain and biomass yield due to N application as communicated by other researchers (Andersson and Johansson, 2006; Afridi et al., 2010).

Table 7. *Effect of tillage and nitrogen application timing on H.I (%).*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	39.5	40.3	32.7	37.5 a
T1	26.5	32.0	32.3	30.3 bc
T2	27.0	30.5	31.8	29.8 c
T3	34.5	34.8	34.0	34.4 ab
T4	31.3	33.0	33.5	32.5 bc
Tillage mean	31.8	34.1	32.9	

$LSD_{0.05}$ for Nitrogen =4.171
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Nitrogen Agronomic Efficiency (kg grain kg^{-1} N applied)

Nitrogen agronomic efficiency (NAE) indicates increase in grain yield per unit amount of N applied. The NAE was significantly affected by N timing and splitting, while tillage and tillage × N had no significant influence on NAE (Table 8). Mean values for N timing and splitting revealed highest NAE (32.4 kg kg^{-1}) with T3 followed by T4 (26.8 kg kg^{-1}). The data further indicate that NAE was higher in N fertilizer applied in three equal splits such as T3 and T4 than two unequal splits such as T1 and T2. The higher NAE with T3 may be attributed to higher N uptake and subsequent higher grain yield (Jan et al., 2010; López-Bellido et al., 2012). The lower NAE in T1 and T2 may be attributed to too early N application which might have resulted in significant N losses (Carefoot and Janzen, 1997).

Net Benefit (Rs. ha^{-1})

Tillage and tillage × N timing and splitting did not influence gross margin or net benefit (NB), however, N timing and splitting significantly affected NB (Table 9). Mean values revealed that T3 had the highest NB (Rs. 107044 ha^{-1}) while T0 had lowest NB (Rs. 3333 ha^{-1}). Since grain yield was higher when N fertilizer was applied in three equal splits compared to

N application in two unequal splits, similar pattern was observed in NB. The T3 and T4 had higher NB than T1 and T2. These results suggest that N fertilizer application in three equal splits i.e. 1/3rd of total N at sowing (drilling in soil), 1/3rd at first irrigation (side dressing), and 1/3rd at second irrigation (side dressing) is not only productive but highly economical and environmentally safe. Because higher N uptake and lower N losses may enhance N use efficiency, which in turn lead to higher production and higher income without jeopardizing environmental quality (López-Bellido et al., 2005).

Table 8. *Effect of tillage and nitrogen application timing on N agronomic efficiency.*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	-	-	-	-
T1	15.5	15.8	14.3	15.2 d
T2	20.8	21.0	18.3	20.0 c
T3	36.8	31.8	28.8	32.4 a
T4	27.8	27.5	25.0	26.8 b
Tillage mean	25.2	24.0	21.6	

$LSD_{0.05}$ for nitrogen=2.493
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Table 9. *Effect of tillage and nitrogen application timing on net benefit (Rs. ha^{-1}).*

N timing	Tillage			Nitrogen mean
	Zero	Reduced	Conventional	
T0	2125	2925	4950	3333 e
T1	47192	49401	46481	47690 d
T2	66115	67352	60303	64590 c
T3	120349	104566	96218	107044 a
T4	91070	89444	83626	88046 b
Tillage mean	65370	62737	58316	

$LSD_{0.05}$ for Nitrogen = 3043
Mean values in each category followed by same letter do not differ significantly at 5% level of probability.

Conclusions and Recommendations

Zero tillage in combination with T3 (50 kg N at sowing + 50 kg N at 1st irrigation + 50 kg N at 2nd irrigation) resulted in more grains spike^{-1} and heavier 1000-grain weight. Zero tillage also produced higher spikes m^{-2} and higher biological yield. Application of N fertilizer in three equal splits at sowing, at 1st irrigation (20 days after emergence), and at 2nd irrigation (30 days after 1st irrigation) resulted in highest yield and yield components, N agronomic efficiency, and highest net economic return. Hence zero tillage in combination with T3 is recommended for optimizing yield and economics of spring wheat in cotton based cropping system on silty clay soil of Dera Ismail Khan, Khyber Pukhtunkhwa, Pakistan.

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