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Research Paper

Effect of sequential tillage practices and N levels on energy relations and use-efficiencies of irrigation water and N in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

Field experiments were conducted during 2009-10 and 2010-11 at New Delhi to evaluate the effect of four sequential combinations of conventional tillage (CT) and zero tillage (ZT) practices in conjunction with N levels (0, 60, 120 and 180 kg N/ha) on energy relations and use-efficiencies of irrigation water (IWUE) and N (NUE) in maize (*Zea mays* L.)–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol} cropping system. ZT practices saved on an average 20 and 15 % input energy requirements over CT practices in maize and wheat, respectively. The maximum input energy requirement in maize–wheat cropping system was recorded under CT–CT tillage sequence, whereas the minimum was recorded with ZT–ZT sequential tillage system. The gross and net output energy productions by the maize-wheat cropping system were not influenced significantly due to different sequential tillage practices, however these were recorded maximum under CT–ZT sequential tillage system. Significantly maximum energy-use efficiency in maize–wheat cropping system was recorded with ZT–ZT sequence, which was 29.76, 19.44 and 11.49 % higher than the CT–CT, CT–ZT and ZT–CT sequential tillage practices, respectively during the year 2010-11. ZT sown wheat based tillage sequences (CT–ZT and ZT–ZT) resulted 4–6 % higher IWUE than CT sown wheat based tillage sequences (CT–CT and ZT–CT). The energy relations, IWUE and NUE parameters of both the crops differed significantly due to various N levels. The input and output energy and IWUE increased significantly with each successive increase in levels of N from 0 to 120 kg N/ha, while reverse trends were observed with energy-use efficiency and NUE, which were decreased significantly from 0 to 180 kg N/ha. Consequently ZT involving sequential tillage practices in conjunction with application of 120 kg N/ha may be adopted to enhance resource-use efficiency in maize–wheat cropping system.

***Key words* :** Energy, IWUE, Maize–wheat cropping system, Nitrogen levels, NUE, Sequential tillage

Intensive tillage and improper application of irrigation and nitrogen (N) fertilizer in conventional crop production systems results in higher cost of production and energy consumption, water scarcity, decline in soil fertility and reduced nitrogen-use efficiency. Yield of different crops can be increased up to 30 % by using optimal level of energy input (Chaudhary *et al.*, 2006). In present method of crop production, major portion of energy (25–30 %) is utilized for field preparation and crop establishment which can be minimized by reducing the tillage operations. Zero tillage (ZT) technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield (Jain *et al.*, 2007) and is also energy efficient as compared to conventional tillage (CT) practices (Filipovic *et al.*, 2006). Research findings from several locations in the Indo-Gangetic plains showed that with ZT technology, farmers were able to save on land preparation costs by about ₹ 2500/ha and reduce diesel consumption by 50–60 litres/ha. Judicious use of fertilizers and irrigation water reduce the energy cost of irrigation and fertilizers. Significantly higher water productivity (kg grain/m^3 water) of maize and wheat had been recorded in furrow irrigated raised bed (FIRB) planting followed by in ZT flat planting as compared to CT system possibly due to increase in grain yield as well as saving in irrigation water (Jat *et al.*, 2005). Maize and wheat crops have a high N demand to achieve higher productivity. The continual rises in prices of nitrogen fertilizer, combined with elevated environmental risk of nitrate contamination of ground water by leaching,

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needs better N management strategies to improve nitrogen-use efficiency (NUE) (Prasad, 2005).

Major advantages of no-till systems are that they can reduce N loses and can also increase soil organic matter (SOM) content. However, building SOM through conservation tillage practices requires time, possibly decades. Hence fertilizer N needs to be added to zero and minimum tillage systems to prevent the crop suffering from inadequate amounts of available N, particularly during initial years of start of ZT practices. Reduced tillage combined with application of optimum nitrogen fertilizer can help to mitigate the adverse effects of conventional farming practices. Continuous tillage in both the season i.e *kharif* and *rabi* is found to have detrimental effect in soil structure and health and energy requirement is quite high (Gupta *et al.*, 2007). At the same time adoption of double zero tillage both in *kharif* and *rabi* is found to be difficult to manage the weeds. Under such situations skipping tillage either in *kharif* to maize or in *rabi* to wheat may be beneficial through better input-use efficiency, economics and energy saving. Similarly the detrimental effect of intensive tillage can also be reduced to some extent. Thus, the present work was undertaken to determine the effect of sequential tillage practices and N levels on the energy relations, and use-efficiencies of irrigation water and N in maize–wheat cropping system.

MATERIALS AND METHODS

Field experiments were conducted on a fixed site during rainy season (June to October) and winter season (November to April) of 2009-10 and 2010-11 at the research farm of Indian Agricultural Research Institute, New Delhi (28.4^o N latitude, 77.1^o E longitude and 228.6 m above mean sea level). During 2009-10, the rainfall was erratic with total 520 mm and 13 mm received during *kharif* and *rabi* seasons, respectively which was 18 % deficit from the normal rainfall (650 mm), whereas during 2010-11 it was received in good amount (916 and 69 mm during the same periods) with well distribution, which was 52 % greater than the normal rainfall. Rainfall distribution and other weather parameters prevailed during the crop growing durations are presented in Fig 1. The soil at site was sandy loam with bulk density of 1.57 g/cm^3, field capacity 17.48 % (w/w) and infiltration rate 1.26 cm/hr. It had 0.37 % organic carbon, 147.6 kg $KMnO_4$ oxidizable N/ha, 11.8 kg 0.5 N $NaHCO_3$ extractable P/ha, 235.1 kg 1.0 N NH_4OAc exchangeable K/ha, 7.5 pH and 0.31 dS/m EC at the start of the study. The experiments were conducted in split plot design with three replications in a fixed layout with plot size of 17.5 m^2 for both maize and wheat crops. There were four main plot treatments comprising of sequential tillage practices: conventional tillage (CT) in maize followed by CT in wheat (CT–CT); CT in maize followed by zero tillage (ZT) in wheat (CT–ZT); ZT–CT and; ZT–ZT, while subplot treatments consisted of four nitrogen levels, viz. 0, 60, 120 and 180 kg/ha.

The CT consisted of two pass of a disc harrow, followed by two pass of cultivator with planking in the last pass. Whereas, ZT consisted of no-tillage with minimum soil disturbance and one pass of ZT seed drill for sowing of crop. The hybrid maize (‘Maharaja’ also known ‘Bio 9637’) was established under flat planting technique of crop establishment at a spacing of 67.5 cm from row to row and 20 cm from plant to plant by dibbling the seeds (20 kg/ha). After harvesting of maize, wheat (‘PBW 550’) was also sown under flat planting at a spacing of 18 cm from row to row with 100 kg seed/ha. Full dose of P (26.2 kg/ha) and K (33.3 kg/ha) applied at the time of sowing in both the crops. Whereas, nitrogen was applied in three equal splits (at sowing as basal and, top dressed at knee-high and tasseling stages) to maize and in two equal splits (at sowing as basal and top dressed after first irrigation) to wheat as per the treatments. For calculating the energy input and output and energy-use efficiency from different power sources, viz. labour, fuel, machinery, fertilizer, seeds, pesticides, irrigation and crop yield standard energy

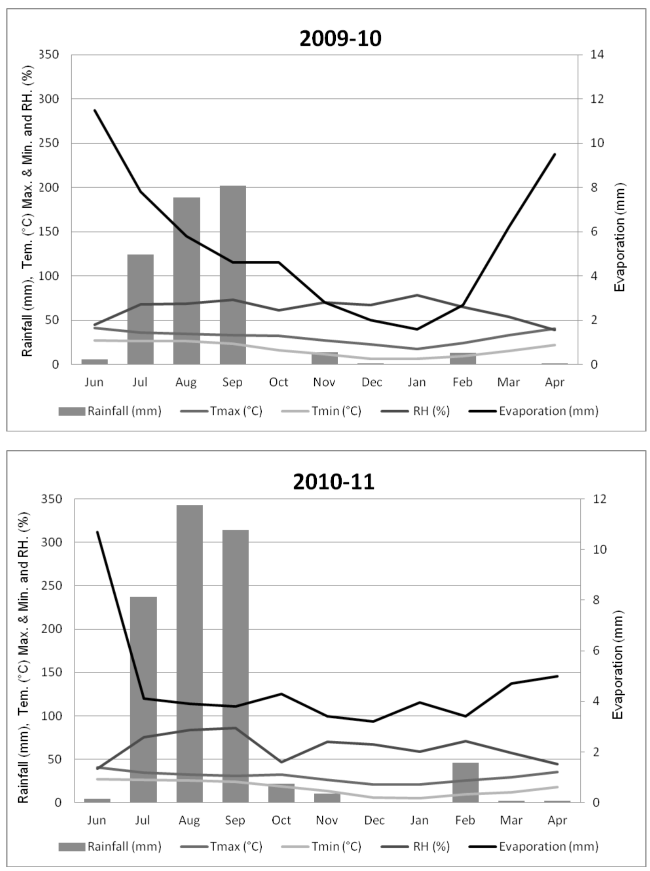

Fig. 1. Weather conditions during the crop growing period in 2009-10 and 2010-11

coefficients were used as suggested by Mittal and Dhawan (1988). Net energy production was calculated by subtracting the energy input from the energy outputs. Total four irrigations to maize and four irrigations to wheat were applied during the year 2009-10, while only one irrigation to maize and three irrigations to wheat were applied during the year 2010-11. In each irrigation 7 cm of water was applied. The irrigation water-use efficiency (IWUE) was calculated as the grain yield (kg/ha) divided by the irrigation water applied (ha-cm) as suggested by Ibragimov *et al*. (2011). The following N-use efficiencies were computed with the formulae as given: Agronomic N-use efficiency (kg grain yield increase/ kg N applied): $[(Y_t - Y_0)/N_a)]$; Physiological N-use efficiency (kg grain yield increase/ kg N uptake increase): $[(Y_t - Y_0)/(U_t - U_0)]$; Apparent N recovery (%): $[(U_t - U_0)/N_a)*100]$ and; N harvest index (%): $[(N_s/N_t)*100]$. Where, Y_t: Grain yield in the test treatment (kg/ha); Y_0: Grain yield in the control plot (kg/ha); N_a: Units of N applied in the test treatment (kg/ha); U_t: Uptake of N in the test treatment (kg/ha); U_o: Uptake of N in the control plot (kg/ha); N_s: N uptake by the grain at harvest (kg/ha) and; N_t: N uptake by the whole plant at harvest (kg/ha). The data recorded for different parameters were analysed through analysis of variance (ANOVA) technique for a split plot design using MSTAT-C software. The result are presented at 5% level of significance (P=0.05).

RESULTS AND DISCUSSION

Energy relations

In maize, input energy consumption (both renewable and non-renewable) under various sequential tillage practices was similar in the year 2009-10 due to adoption of similar tillage practices, though considerable differences were observed in the year 2010-11 (Table 1). The input energy requirements were 25.40 % higher under CT sown maize based tillage sequences (CT–CT and CT–ZT) than ZT sown maize based tillage sequences (ZT–CT and ZT-ZT) during the year 2010-11. Similarly, in wheat (Table 2) and in maize–wheat cropping system (Table 3) the input energy requirements were higher under CT sown wheat based tillage sequences (CT–CT and ZT–CT) and CT sown maize–wheat tillage sequence (CT–CT) than the remaining other sequential tillage practices during both the years, respectively. ZT sown wheat based tillage sequences (CT–ZT and ZT–ZT) saved 14.99 and 15.66 % input energy requirements over CT sown wheat based tillage sequences during 2009-10 and 2010-11, respectively. The maximum input energy requirement in maize–wheat cropping system was recorded under CT–CT tillage sequence, whereas the minimum under ZT–ZT sequential tillage system. ZT–ZT tillage sequence saved 8.08 and 17.67 % input energy compared to CT–CT during the years 2009-10 and 2010-11, respectively. Adoption of ZT practices either in *kharif* for maize (ZT–CT) or in *rabi* for wheat (CT–ZT) or in both the seasons (ZT–ZT) reduced the input energy requirement than adoption of CT practices in both the seasons (CT–CT), this was due saving of energy in tillage practices as well as in intercultural operations (herbicides were used for weed management). Jain *et al*. (2007) reported that ZT technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield. The input energy requirement for the maize–wheat system was higher during the year 2009-10 than 2010-11, due to establishment of maize only under CT practices and more numbers of irrigations (4 irrigations to maize and 4 irrigations to wheat during the year 2009-10; 1 irrigation to maize and 3 irrigations to wheat during the year 2010-11) were applied in the year 2009-10 due aberrant weather conditions.

Both gross output energy and net output energy productions by maize (Table 1), wheat (Table 2) and maize–wheat cropping system (Table 3) did not vary significantly due to different sequential tillage practices during both the years, except gross output energy production by maize during the year 2010-11. Statistically similar yields performance of wheat under all the tillage sequences and adoption of similar tillage practices in maize during the year 2009-10 resulted in non-significant variations in the energy outputs under all the treatments. The gross output energy production by maize during the year 2010-11 was recorded highest with CT–ZT (145.4×10^3 MJ/ha) followed by CT–CT (144.3×10^3 MJ/ha) tillage sequences, both were significantly higher (5.25–6.99 %) than ZT–CT and ZT–ZT sequential tillage practices due to better yields performance of the maize under these tillage sequences. The least gross output energy generation by maize was obtained with ZT–ZT tillage sequence, which was 6.53 % lower than the CT–ZT tillage sequence due to poor yields production. In general higher gross output energy as well as net output energy production by the maize–wheat cropping system under CT–ZT sequence was due to relatively higher yields performance by both the crops and saving of input energy requirement in ZT practices in wheat. The higher input energy consumption and lower output energy production under CT–CT sequence than the ZT involving tillage sequences in maize–wheat cropping system also has been reported by Ram *et al.* (2010). The higher energy production in 2010-11 over 2009-10 were resulted due to higher biomass yield of crops during 2010-11 due to favourable weather environment including good distribution with sufficient amount of rainfall.

The energy-use efficiency of maize (Table 1), wheat (Table 2) and maize–wheat cropping system (Table 3) was influenced significantly due to different sequential tillage practices during both the years, except in first year maize due to similar tillage treatments. The maximum energy-use efficiency of maize was recorded under ZT–CT (22.04) followed by ZT–ZT (21.85) and both the tillage sequences resulted significantly higher (33.80–36.04 %) energy-use efficiency than CT–CT and CT–ZT sequential tillage practices in the year 2010-11 due to lower input energy consumption under ZT practices. The lowest energy-use efficiency of maize was obtained with CT–CT followed by CT–ZT sequential tillage practices. In wheat the energy-use efficiency was recorded maximum under ZT sown wheat based tillage sequences during both the years, which were significantly higher i.e. 23.15–25.64 and 25.17–29.08 % than CT sown wheat based tillage sequences during the years 2009-10 and 2010-11, respectively (Table 2). Similarly, in maize–wheat cropping system ZT involving sequential tillage practices (ZT was not adopted for maize in the year 2009-10) resulted significantly higher (on an average 12.32 and 18.99 % during 2009-10 and 2010-11, respectively) energy-use efficiency than the continuous CT practices (CT–CT). However, maximum energy-use efficiency in maize–wheat cropping system was recorded with continuous ZT practices (ZT–ZT) during the year 2010-11, which was 29.76, 19.44 and 11.49 % higher than the CT–CT, CT–ZT and ZT–CT se-

Table 1. Effect of sequential tillage practices and N levels on energy indicators of maize[1]

Treatment	Input energy ($\times 10^3$ MJ/ha)		Gross output energy ($\times 10^3$ MJ/ha)		Net output energy ($\times 10^3$ MJ/ha)		Energy-use efficiency	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage practices								
CT – CT	11.98	10.23	130.8	144.3	118.9	134.1	11.84	16.20
CT – ZT	11.98	10.23	131.3	145.4	119.3	135.1	11.90	16.33
ZT – CT	11.94	8.16	131.9	137.1	119.9	129.0	12.01	22.04
ZT – ZT	11.94	8.16	129.1	135.9	117.1	127.8	11.76	21.85
SEm±	-	-	5.25	1.80	5.25	1.80	0.48	0.23
CD (P=0.05)	-	-	NS	6.22	NS	NS	NS	0.78
Nitrogen levels (kg/ha)								
0	6.51	3.74	102.9	113.9	96.3	110.2	15.81	32.65
60	10.14	7.38	130.8	137.4	120.6	130.0	12.89	18.91
120	13.78	11.01	144.3	153.8	130.6	142.8	10.48	14.06
180	17.41	14.65	145.1	157.6	127.7	142.9	8.334	10.80
SEm±	-	-	3.06	1.42	3.06	1.42	0.39	0.19
CD (P=0.05)	-	-	8.92	4.16	8.92	4.16	1.15	0.55

[1] Zero tillage treatment was not applied in maize during 2009–10

Table 2. Effect of sequential tillage practices and N levels on energy indicators of wheat

Treatment	Input energy ($\times 10^3$ MJ/ha)		Gross output energy ($\times 10^3$ MJ/ha)		Net output energy ($\times 10^3$ MJ/ha)		Energy-use efficiency	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage practices								
CT – CT	13.61	13.03	121.7	126.2	108.1	113.2	9.36	10.11
CT – ZT	11.57	10.99	126.1	131.5	114.6	120.5	11.76	12.98
ZT – CT	13.61	13.03	122.5	129.5	108.9	116.5	9.42	10.37
ZT – ZT	11.57	10.99	124.4	131.5	112.8	120.6	11.60	13.05
SEm±	-	-	2.71	2.76	2.71	2.76	0.22	0.20
CD (P=0.05)	-	-	NS	NS	NS	NS	0.74	0.70
Nitrogen levels (kg/ha)								
0	7.14	6.55	90.5	89.3	83.4	82.8	12.96	14.03
60	10.77	10.19	123.9	132.6	113.1	122.4	11.62	13.16
120	14.41	13.83	138.4	146.6	124.0	132.7	9.66	10.67
180	18.04	17.46	141.9	150.4	123.9	132.9	7.90	8.65
SEm±	-	-	1.34	2.60	1.34	2.60	0.12	0.23
CD (P=0.05)	-	-	3.91	7.58	3.91	7.58	0.35	0.68

quential tillage practices, respectively (Table 3). The higher energy-use efficiency of maize–wheat cropping system under ZT involving sequential tillage practices was due to lower input energy consumption under ZT practices as well as it further benefited by higher output energy production due to good yields performance of the wheat under ZT practices. The ZT method of sowing is energy efficient and beneficial to environment as compared to conventional practices of sowing reported by Filipovic *et al.* (2006). Gupta *et al.* (2007) and Ram *et al.* (2010) also have been reported significantly more energy-use efficiency and energy productivity under ZT than CT practices.

The input energy consumption by maize (Table 1), wheat (Table 2) and maize–wheat cropping system (Table 3) was increased linearly with each increased level of N in both the years. The lowest and highest energy consumption were estimated at 0 (without N application) and 180 kg N/ha, respectively during both the years. The input energy requirement at same level of N was recorded higher in wheat as compared to maize due to higher seed requirement (20 and 100 kg/ha for maize and wheat, respectively; energy consumed in each kg seed of maize/ wheat = 14.7 MJ) and more energy was consumed in sowing of wheat by tractor operated seed drill (675.7 MJ/ha) as compared to manual dibbling of seeds of maize (47.04 MJ/ha). Similarly, marginally higher input energy was consumed in the production of maize, wheat and system as a whole during 2009-10 than 2010-11 at the same levels of N due to establishment of maize only with CT practices as well as more numbers of irrigations were applied to both the crops due to peculiar weather conditions prevailed during the year 2009-10. In contrast to the effects of different sequential tillage practices, the effects of different levels of N on gross and net output energy productions by maize (Table 1), wheat (Table 2) and maize–wheat cropping system (Table 3) were observed significant during both the years. Both gross and net output energy productions by both the crops and system as a whole enhanced significantly with each increased levels of N from 0 to 120 kg/ha in both the years. However, maximum gross output energy production by both the crops and system as a whole was obtained at 180 kg N/ha, which was statistically on par with 120 kg N/ha but was significantly higher than 0 and 60 kg N/ha. More gross and net output energy at higher levels of N due to higher yields performance of the crops. The influence of different levels of N on the energy-use efficiency of maize (Table 1), wheat (Table 2) and maize–wheat cropping system (Table 3) were observed reverse as compared to their effects on energy productions during both the years. The energy-use efficiency was decreased significantly with each increased levels of N from 0 to 180 kg/ha. However, percent decrease was less with higher levels of N i.e. beyond 60 kg N/ha. The energy-use efficiency was decreased with each higher levels of N owing to input energy consumption in terms of nitrogen was increased linearly, whereas energy generation by crops in terms of biomass production was increased with decreased pace with each increased levels of N. These results are congruous the findings of Gupta *et al.* (2007).

Irrigation water-use efficiency

The IWUE of wheat crop was not influenced significantly due to various sequential tillage practices in both the years, whereas it varied significantly with different levels of N during both the years (Fig 2). However, ZT sown wheat based tillage sequences resulted 4.22–6.02

Table 3. Effect of sequential tillage practices and N levels on energy indicators of maize–wheat cropping system

Treatment	Input energy ($\times 10^3$ MJ/ha)		Gross output energy ($\times 10^3$ MJ/ha)		Net output energy ($\times 10^3$ MJ/ha)		Energy-use efficiency	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage practices								
CT–CT	25.59	23.26	214.7	228.4	189.1	205.2	8.92	10.62
CT–ZT	23.55	21.22	219.5	234.5	196.0	213.3	10.08	12.29
ZT–CT	25.55	21.18	216.3	226.6	190.8	205.4	9.00	11.84
ZT–ZT	23.52	19.15	216.2	227.8	192.7	208.7	9.95	13.78
SEm±	-	-	4.78	3.46	4.78	3.46	0.20	0.15
CD (P=0.05)	-	-	NS	NS	NS	NS	0.70	0.51
Nitrogen levels (kg/ha)								
0	13.64	10.29	163.5	169.9	149.9	159.7	12.06	16.86
60	20.92	17.56	216.9	229.9	196.0	212.4	10.40	13.18
120	28.19	24.84	241.2	255.5	213.0	230.7	8.57	10.32
180	35.46	32.11	245.2	262.0	209.8	229.9	6.92	8.18
SEm±	-	-	2.67	2.73	2.67	2.73	0.15	0.16
CD (P=0.05)	-	-	7.79	7.97	7.79	7.97	0.43	0.45

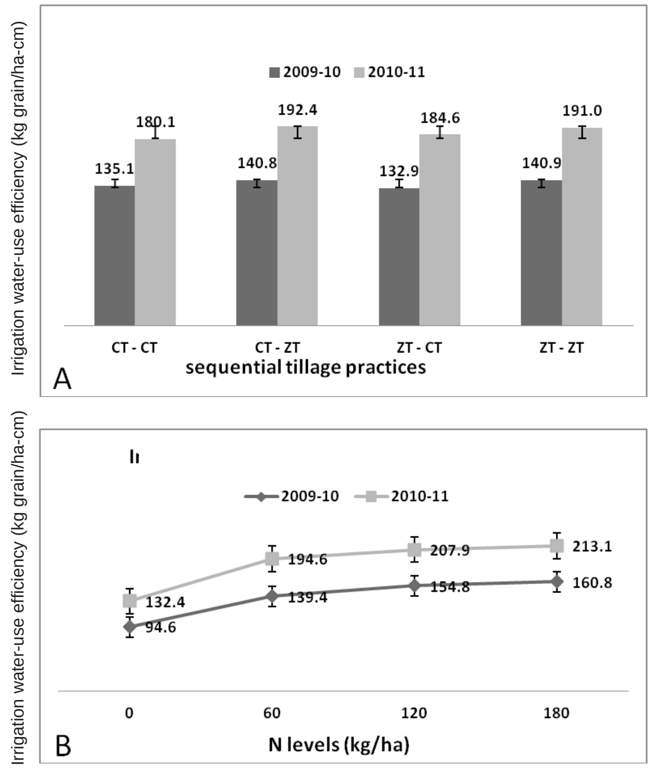

Fig. 2. Effect of sequential tillage practices (A) and N levels (B) on IWUE of wheat

and 3.47–6.83 % higher IWUE during 2009-10 and 2010-11, respectively than CT sown wheat based tillage sequences. The IWUE of wheat was recorded 27.82–44.77 % higher during 2010-11 than 2009-10 due to saving of water in terms of number of irrigations. In the year 2009-10 total 4 irrigations, while during 2010-11 only 3 irrigations were applied to wheat due to good amount with well distribution of rainfall. Jat *et al.* (2005) reported that that irrigation water use (m^3/ha) in both maize and wheat was highest (3231 and 3700) under CT followed by ZT (2723 and 2934) and the lowest being (2030 and 2619) under FIRB planting system. Consequently higher water productivity (kg grain/m^3 water) of maize and wheat was recorded in FIRB planting followed by ZT and the lowest in CT system possibly due to increase in grain yield as well as saving in irrigation water. The effects of different levels of N on IWUE were as similar as observed on grain yield. The IWUE of wheat was increased significantly with each increased level of N from 0 to 120 kg/ha in both the years. However, the maximum IWUE was recorded at 180 kg N/ha, which was statistically on par with 120 kg N/ha, but significantly higher than at 0 and 60 kg N/ha in both the years. In general, more grain yield per unit consumption of irrigation water at similar levels of N was recorded during 2010-11 than 2009-10 due to saving of 0.7 million litres of irrigation water.

Nitrogen-use efficiency

The NUE of applied fertilizer N in terms of agronomic N-use efficiency (ANUE), physiological N-use efficiency (PNUE), apparent N recovery (ANR) and nitrogen harvest index (NHI) in both maize and wheat crops did not vary due to different sequential tillage practices during both the years. Data on NUE under different sequential tillage practices are not presented due to non significant variation among the treatments.

In contrast to different sequential tillage practices, the effects of different levels of N on NUE of both maize (Table 4) and wheat (Table 5) crops were found significant during both the years. However, NHI of both the crops did not influence significantly due to different levels of N during both the years. The NUE is positively correlated with the yield performance and N uptake in the test treatment and negatively correlated with yield performance and N uptake in the control treatment, as well as with amount of applied fertilizer N. The ANUE and ANR of applied N decreased significantly with each successive increased N level in both the crops during both the years. The highest

Table 4. Effect of N levels on nitrogen-use efficiencies of maize under different sequential tillage practices

Treatment	ANUE[a] (kg grain yield increase/kg N applied)		PNUE[b] (kg grain yield increase/kg N uptake increase)		ANR[c] (%)		NHI[d] (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Nitrogen levels (kg/ha)								
0	0.00	0.00	0.00	0.00	0.00	0.00	69.79	64.95
60	15.01	12.07	42.93	34.56	36.32	34.41	67.50	64.21
120	12.53	10.05	40.12	32.45	31.57	30.99	68.07	63.65
180	8.18	7.28	37.36	31.94	21.97	22.76	67.69	63.34
SEm±	0.69	0.51	1.84	0.81	1.55	0.88	1.81	0.51
CD (P=0.05)	2.01	1.50	5.36	2.36	4.52	2.56	NS	NS

[a]ANUE: Agronomic N-use efficiency; [b]PNUE: physiological N-use efficiency; [c]ANR: apparent N recovery; [d]NHI: N harvest index

Table 5. Effect of N levels on nitrogen-use efficiencies of wheat under different sequential tillage practices

Treatment	ANUE[a] (kg grain yield increase/kg N applied)		PNUE[b] (kg grain yield increase/kg N uptake increase)		ANR[c] (%)		NHI[d] (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Nitrogen levels (kg/ha)								
0	0.00	0.00	0.00	0.00	0.00	0.00	74.09	75.70
60	20.93	21.77	41.26	35.40	50.54	58.75	74.24	73.20
120	14.06	13.22	37.52	34.53	38.02	38.45	72.44	72.52
180	10.31	9.42	38.03	35.62	27.29	26.73	73.31	72.34
SEm±	1.20	1.12	2.10	1.68	1.90	3.06	1.40	1.52
CD (P=0.05)	3.51	3.45	6.14	4.90	5.56	8.92	NS	NS

[a]ANUE: Agronomic N-use efficiency; [b]PNUE: physiological N-use efficiency; [c]ANR: apparent N recovery; [d]NHI: N harvest index

values of ANUE and ANR were recorded at 60 kg N/ha in both the crops, while lowest values of these indices were recorded at 180 kg N/ha which were on an average 42.58 and 36.69 % lower in maize and 53.73 and 50.25 % lower in wheat as compared to at 60 kg N/ha, respectively. The PNUE of both the crops were recorded statistically similar at all higher levels of N, though it was significantly higher at 60 kg N/ha than at control. The NHI values did not vary significantly with varying levels of N, though highest values were recorded at 0 kg N/ha in both the crops. In most of the cases the NUE decreased with each increased levels of N and recorded maximum at lower levels (0 or 60 kg N/ha) and minimum at 180 kg N/ha in both the crops possibly due to N losses via leaching, denitrification and ammonia volatilization (Prasad, 2005). This was also possibly due to the fact that at lower levels of N application, plant used nitrogen efficiently and rapidly for their growth with less wastage. A comparatively lower NUE at higher fertilizer dose could be attributed to less yield advantages for unit quantity of nutrient applied. Singh *et al.* (2009) reported that recovery efficiency was decreased with the application of 150 kg N/ha compared with 90 and 120 kg N/ha on both sandy loam and silty loam soils. Lopez Bellido *et al.* (2006) reported that the behaviour of NUE was erratic, and the highest value was recorded with zero N treatment. In most of cases NUE was decreased in the year 2010-11 over 2009-10 might be due to comparatively higher grain yield and better nutrient utilization by the crops in the control (without N) in the year 2010-11 due to favourable microclimatic conditions. Lopez Bellido *et al.* (2006) reported that NHI was significantly affected by the years, and the highest value was recorded with lowest biomass and grain yield. Moreover, in ZT practices crops were harvested 6 to 8 cm above from the soil surface that lead to leave considerable quantities of residues including root stubbles of the crops in the field, this might helped in improving physico-chemical and biological environment of the soil leading to improved supply of nutrients during 2010-11. The build-up of the soil organic matter and increased in readily mineralized organic soil N with residue recycling suggest the potential for reducing fertilizer N rates for optimal yield of following crop after several years of residue incorporation (Thuy *et al.*, 2008).

Consequently ZT involving sequential tillage practices in conjunction with application of 120 kg N/ha may be adopted in maize–wheat cropping system as recorded comparatively higher yield and use efficiency of irrigation water and nitrogen in maize and wheat crops and also economized the energy consumptions by the system.

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