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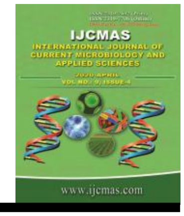

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Resource-use Efficiency of Wheat: Effect of Conservation Agriculture and Nitrogen Management Practices in Maize (*Zea mays*)–Wheat (*Triticum aestivum*) Cropping System

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A B S T R A C T

A study on evaluation of conservation agriculture and nitrogen management practices in wheat (*Triticum aestivum* L.) under maize ((*Zea mays* L.)-wheat cropping system was undertaken at the ICAR-Indian Agricultural Research Institute, New Delhi. Experiments were conducted in split-plot design with six main-plot treatments of tillage and crop establishment techniques, viz. conventional tillage-flat (CT-F), zero tillage-flat (ZT-F), CT-bed (CT-B), ZT-B, ZT-F with residue (ZT-F+R) and ZT-B with residue (ZT-B+R), while sub-plot treatments consisted of four nitrogen (N) levels, viz. 0, 60, 120 and 180 kg/ha. The results revealed that the minimum energy requirement for the production of wheat crop was estimated with ZT-B system which saved on an average 19.1 % input energy over the CT practices. Residue applied treatments (ZT-F+R/ZT-B+R) resulted the maximum gross output energy, but also significantly reduced the net output energy and energy-use efficiency (EUE) due to high energy involved in crop residues. The net output energy was recorded the maximum under ZT-F, whereas, the maximum EUE was estimated under ZT-B which was significantly higher than CT (27.8-31.4 %) and residue applied treatments. The highest irrigation water-use efficiency (IWUE) was recorded under ZT-B+R (26.0 % higher) and also saved 16.7 % irrigation water over the CT-based systems. Different indices of nitrogen-use efficiency (NUE) were observed statistically similar under different tillage and crop establishment techniques. However, in general, ZT-F resulted the maximum values of most of the indices of NUE. The energy indicators, IWUE and NUE were differed significantly due to N levels. The input and output energy and IWUE were increased significantly with each successive increase in levels of N from 0 to 120 kg N/ha, while reverse trends were observed with EUE and NUE, which were decreased significantly from 0 to 180 kg N/ha. Thus, considering the saving of inputs *viz.*, energy-use and irrigation water, the study recommends that ZT-based system is an energy efficient and could be adopted with surface retention of crop residues to improve the water and nitrogen-use efficiencies in wheat.

Introduction

The wider adaptability of wheat to different climatic and edaphic conditions makes it world's most widely cultivated food crop with 246,618,023 ha area (FAO, 2016). With 728,966,757 million tonnes of production at global level, it is feeding more than one-third of the world's population. In India, wheat is the second most important staple food crop after rice, adding about 35% in the national food grain basket, thus it playing an important role in its food and nutritional security. However, adoption of energy intensive conventional tillage (CT) practices and mismanagement of irrigation and nitrogen (N)-fertilizers have led to sharp rise in the cost of production and energy-use, water scarcity, deteriorated soil health and poor input-use efficiency of conventional wheat-based cropping systems in India (Choudhary and Behera, 2014, 2019; Jat *et al.,* 2019a). Tillage practices contribute greatly to the labour cost and energy-use in field crop production systems resulting in to lower economic returns and energy-use efficiency (EUE) (Choudhary and Behera, 2013; Choudhary *et al.,* 2020). Intensive CT practices not only negatively influences the soil properties but also results in plateauing of crop yields (Choudhary and Behera, 2014; Jat *et al.,* 2017). In addition to above issues, the environmental pollution owing to crop residue burning have been resulted due to lack of mechanism for safe disposal of huge quantities of crop residues generated through monoculture of conventional wheat-based cropping systems (Gathala *et al.,* 2011;Jat *et al.,* 2013). Alternative agronomic practices that could improve soil health, maintain crop yield as well as ecosystem stability are needed. Therefore, to offset the production cost, energy use and environmental footprints, the conservation agriculture (CA) has been promoted and adopted for climate resilient sustainable production of the crops (Jat *et al.,* 2013; Jat *et al.,* 2019b). Minimal soil movement by reduction in tillage intensity and retention of crop-residues on the soil surface along with crop rotations and diversification to economically benefit the farmers are the key principles of CA (Verhulst *et al.,* 2011). In recent years, CA systems have gained importance owing to the need of farmers to reduce variable cultivation cost, as major portion of energy (25–30 %) is utilized for field preparation and crop establishment. The zero-tillage (ZT) method of sowing is cost effective, energy efficient and beneficial to environment as compared to CT practices of crop production (Filipovic *et al.,* 2006; Jat *et al.,* 2019b). Further, increase in either fertilizers or irrigation water increased the crop yield but reduced the EUE. Judicious use of fertilizers and irrigation water reduced the energy cost of irrigation plus fertilizers (Aggarwal, 1995). Water is and will expect to be the scarcest ecological factor and costly input in determining agricultural production. Therefore, it will be important to increase water-use efficiency (WUE) of irrigation (Gomiero *et al.,* 2011). The furrow irrigated raised bed (FIRB) planting systems are reported to help in more efficient use of water (Chauhan *et al.,* 2001) because of optimum water storage and safe disposal of excess water. The FIRB system of wheat cultivation has been shown to result in saving of seed by 25–40 %, water by 25–40 % and nutrients by 25%, without affecting the grain yield production (Jat *et al.,* 2005; Jat *et al.,* 2013).

Increase in use of N usually increased the crop yield but it reduces the nitrogen-use efficiency (NUE) (Choudhary and Behera, 2019). Though, higher crop yields could be achieved with judicious use of N which can reduce the energy consumption and improve the NUE substantially. Recycling of plant biomass in the soil is a promising option for replenishing soil fertility, improving physico-chemical properties, and enhancing/sustaining crop yield and reducing the quantity of N use in log-run (Choudhary *et al.,* 2017; Jat *et al.,* 2019b). In CA systems, crop residue left on the surface, as a result of less tillage, affects soil temperature and moisture content, which affects both N mineralization and the efficiency of N-fertilizer use. However, it is also observed that crops particularly cereals exhibit reduced yields during the early phase of conversion of production system from CT to CA because of lesser N availability due to slower soil N mineralization, and greater immobilization, denitrification and NH_3 volatilization compared with CT systems (Patra *et al.,* 2004). All these complexities with N under CA indicate the need for more research to understand the response of N to wheat under CA systems so as optimal supply of N could be ensured. Thus, CA with optimal N supply could help to mitigate the adverse effects of CT practices. In view of the above issues, present study was conducted with the objective to investigate the effect of conservation agricultural and N management practices on energy relations, WUE and NUE of wheat grown in sequence with maize.

Materials and Methods

Experimental site, soil and weather

Field experiments were conducted on a fixed site during winter seasons (November to April) of 2009-10 and 2010-11 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi (28.4^o N latitude, 77.1^o E longitude and 228.6 m above mean sea level). The mean annual rainfall of Delhi is 672 mm and more than 80% generally occurs during the monsoon season (July-September) with mean annual evaporation 850 mm. 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 experiment.

Experimental detail and crop culture

The experiments were conducted in split plot design with three replications in a fixed layout with plot size of 17.5 m^2. All plots received the same treatment throughout the period of study. There were six main plot treatments comprising of different combinations of tillage and crop establishment techniques: conventional tillage-flat (CT-F), zero tillage-flat (ZT-F), conventional tillage-bed (CT-B), zero tillage-bed (ZT-B), ZT-flat with residue (ZT-F+R) and ZT-bed with residue (ZT-B+R), while subplot treatment 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. Raised beds (fresh bed) were made with a bed planter which made beds at distance of 67.5 cm from bed to bed with a bed height of 8″. The ZT consisted of no-tillage with minimum soil disturbance and one pass of ZT seed drill for sowing of crop. In ZT-beds (permanent beds) one pass of bed planter was made for sowing of crop and reshaping of beds. The fresh and permanent raised beds were of 67.5 cm width having 37.5 cm top and 30 cm furrow, which was used for irrigation purposes. The wheat crop (var. PBW 550) was sown at a spacing of 18 cm from row to row with 100 kg seed/ha in flat planting, while three rows of wheat crop was established on top of the raised beds by keeping plant spacing of 5 cm. The chopped residue of the previous maize crop was applied at 5.0 t/ha as per the treatments. Full dose of P (26.2 kg/ha) and K (33.3 kg/ha) applied at the time of sowing, while, N was applied in two equal splits (one at sowing and other after first irrigation) to wheat as per the treatments. The other standard and recommended practices of CA and CT were followed to harvest good crops.

Estimation of energy requirement

The energy inputs referred to the both renewable and non-renewable energy. Renewable energy constituted manual, animal/bullock, seed, manure etc. Whereas non-renewable energy encompassed chemical fertilizer (NPK), tractor, diesel, electricity, lubricants, machinery and agro-chemical etc. Total physical, output referred to both grain and by-product yields. The energy output from the economic and by-product yields was also estimated.

For estimation of energy inputs and outputs (expressed in MJ/ha) for each item of inputs and agronomic practices equivalents were utilized as given in Table 1. Energy-use efficiency (EUE) was calculated using the following formula as suggested by Mittal and Dhawan (1998). EUE: [Energy Output (MJ/ha)/ Energy input (MJ/ha)] and Net energy (MJ/ha): [Energy output (MJ/ha) – Energy input (MJ/ha)].

Irrigation water-use efficiency (IWUE)

Irrigation water-use efficiency (IWUE, kg/ha-cm) was calculated as the grain yield (kg/ha) divided by the irrigation water applied (ha-cm) (Ibragimov *et al.,* 2011).

Nitrogen-use efficiency (NUE)

The NUE was computed with the formulae as mentioned here: The following N-use efficiencies were computed with the formulae as given here: Agronomic NUE (kg grain yield increase/ kg N applied): $[(Y_t – Y_0)/ N_a)]$; Physiological NUE (kg grain yield increase/ kg N uptake increase): $[(Y_t – Y_0)/ (U_t – U_0)]$; Apparent N recovery (%): $[(U_t – U_0)/ N_a)\times100]$; N efficiency ratio (kg dry matter/ kg N uptake): (Y_d/N_h); Physiological efficiency index of N (kg grain/ kg N uptake): (Y_g/N_b) and; N harvest index (%): $[(N_s/ N_t)\times100]$. 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); Y_d: Dry matter yield (kg/ha); N_h: N accumulated at harvest (kg/ha); Y_g: Grain yield (kg/ha); N_b: N absorbed by biomass (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).

Statistical analysis

Analysis of variance was used to determine the effect of each treatment. When F ratio was significant, a multiple mean comparison was performed using Fisher's LSD Test ($p \leq 0.05$ probability level). The data were analyzed by two-way ANOVA technique using the PROCMIXED procedure of SAS package (*ver.* 9.3).

Results and Discussion

Energy indicators

Input energy

The input energy consumption (both renewable and non-renewable) estimated for production of wheat was influenced due to different tillage and crop establishment techniques in both the years (Table 2). ZT practices saved the energy requirement over CT practices by 15.7 and 18.5 % under flat and bed planting systems, respectively. The minimum energy requirement for the production of wheat crop was estimated with ZT-B (10.90×10^3 and 10.48×10^3MJ/ha) during 2009-10 and 2010-11, respectively which saved on an average 19.1 % input energy over the CT practices. Whereas, the maximum energy consumption was recorded under ZT-F+R with 74.09×10^3 and 73.51×10^3MJ/ha during 2009 and 2010, respectively. The input energy of wheat crop was also increased with increased level of N from 0 to 180 kg N/ha.

Gross output energy

The gross output energy production was not influenced significantly due to different tillage and crop establishment techniques during both the years (Table 2). However, the maximum gross energy output was produced under ZT-F + R with 132.6 × 10^3 and 136 × 10^3MJ/ha during 2009-10 and 2010-11, respectively, which was closely followed by ZT-B+R. The minimum gross energy output was produced under CT-B and CT-F during 2009-10 and 2010-11, respectively. Effect of different levels of N was significant on the production of gross output energy during both the years. Gross output energy from wheat was increased significantly with each increased level of N up to 120 kg during 2009-10 and up to 60 kg in year 2010-11. However, maximum gross output energy was recorded with 180 kg N/ha (143.6 × 10^3 and 150.5 × 10^3MJ/ha) during both the years, respectively.

Net energy and energy-use efficiency

Net output energy and energy-use efficiency (EUE) were influenced significantly due different tillage and crop establishment techniques during both the years (Table 2). The net output energy was recorded the maximum under ZT-F with 112.9 × 10^3 and 120.6 × 10^3MJ/ha during 2009-10 and 2010-11, respectively, which was significantly higher than the residue applied treatments. Whereas, the maximum EUE was estimated under ZT-B with 12.11 and 13.47during 2009-10 and 2010-11, respectively, which was significantly higher than CT (27.8-31.4 %) and residue applied treatments. The minimum net output energy and EUE were registered under ZT-B+R, which were significantly lower than rest of the treatments, except ZT-F+R.Net output energy productions as well as EUE of wheat were influenced significantly due to different levels of N. The net output energy was increased significantly with each increased levels of N up to 120 kg /ha. However, the highest value of net output energy was observed at 180 kg N/ha, but it was statistically similar with 120 kg N/ha. In contrast to net output energy, EUE decreased significantly with each increased level of N from control to 180 kg N/ha during both the years.

Irrigation water-use efficiency

Irrigation water-use efficiency (IWUE) of wheat was significantly influenced due to different tillage and crop establishment techniques during both the years (Fig. 1A). In general bed planting gave significantly higher values of IWUE than flat sowing. The highest IWUE was observed under ZT-B+R (202.5 and 275.0 kg/ha-cm; during 2009-10 and 2010-11, respectively), which saved up to 28.6 % irrigation water over the flat planting. The lowest IWUE was recorded under CT-F (135.1 and 180.1 kg/ha-cm; during 2009-10 and 2010-11, respectively). IWUE was also significantly influenced due to different levels of N in both the years (Fig. 1B). As grain yield increased with each increased level of N, the IWUE was also increased. The highest IWUE was recorded at 180 kg N/ha, which was significantly higher than at 0 and 60 kg N/ha, but it was remained statistically similar with 120 kg N/ha during both the years. The IWUE was found more in year 2010-11 than 2009-10; this was due to saving of irrigation water due to good rainfall as well as better performance of wheat crop in year 2010-11.

Nitrogen-use efficiency

Agronomic N-use efficiency

Agronomic N-use efficiency (ANUE) in wheat was observed statistically similar under different tillage and crop establishment techniques during both the years (Table 3). However, in general flat planting resulted marginally higher values of ANUE than bed planting. The maximum ANUE was found under ZT-flat + R and ZT-flat during 2009-10 and 2010-11, respectively. The least ANUE was found with ZT-bed and ZT-flat + Rin year 2009-10 and 2010-11, respectively. A unit increase in grain yield of wheat per unit of applied N was decreased with increased levels of N in both the years. The highest ANUE was recorded with 60 kg N/ha, followed by 120 kg N/ha during both the years. The lowest ANUE was recorded at 180 kg N/ha.

Physiological N-use efficiency

The physiological N-use efficiency (PNUE) in wheat was not influenced due to different tillage and crop establishment techniques during both the years (Table 3). However, the highest PNUE was recorded under CT-F during 2009-10, contrary to this, during2010-11 it was recorded the maximum under ZT-F. The least value of PNUE was found under CT-B and ZT-B in year 2009-10 and 2010-11, respectively. Yield increase due to per unit increase in uptake of N was decreased with increased levels of N in both the years. The highest PNUE was recorded with 60 kg N/ha, followed by 120 kg N/ha during both the years. The PNUE recorded least at 180 kg N/ha in both the years.

Apparent N recovery

Hardly any trend was found in case of apparent N recovery (ANR) under different tillage and crop establishment techniques (Table 3). However, the maximum ANR recorded with ZT-F+R (31.42 %) and CT-B (31.81%) in the year 2009-10 and 2010-11, respectively. Whereas, least values of ANR was found with ZT-B (26.41%) and ZT-B+R (28.14%) in the year 2009-10 and 2010-11, respectively. The ANR was decreased with increased levels of N in both the years. The highest ANR was recorded at 60 kg N/ha with 50.89 and 55.30% during 2009-10 and 2010-11, respectively, followed by at 120 kg N/ha. The least value of ANR was found with 180 kg N/ha in both the years.

Nitrogen efficiency ratio

The nitrogen efficiency ratio (NER) in wheat was also not influenced significantly due to different tillage and crop establishment techniques during both the years (Table 4). However, the maximum NER was recorded under ZT-F followed by CT-F during both the years. Moreover, crop residue application resulted marginally lower values of NER than no-residue during 2010-11. In general, higher values of NER were recorded in flat planting of wheat. The least value of NER was registered with CT-Band ZT-B+R in the year 2009-10 and 2010-11, respectively. A unit dry matter production per unit N uptake was decreased with increased levels of N in both the years. The highest value of NER was observed in un-fertilized treatment followed by at 60 kg N/ha in both the years. N levels of 180 kg/ha produced lowest value of NER in both the years.

Physiological efficiency index of N

No-significant variation was observed among different tillage and crop establishment techniques with respect to physiological efficiency index of N (PEIN) in both the years (Table 4). However, the highest and lowest values of PEIN was recorded under ZT-F and CT-B in both the years, respectively. With each successive of increase in N levels, resulted in decrease of PEIN values in both the years. However, percent decrease was found less with higher N doses beyond 60 kg N/ha in both the years.

Nitrogen harvest index

The nitrogen harvest index (NHI) in wheat was recorded statistically similar under different tillage and crop establishment techniques in both the years (Table 4). The highest value of NHI was recorded with CT-B (79.0%) and ZT-F+R (74.41%) in the year 2009-10 and 2010-11, respectively. The least value of NHI was recorded with ZT-B+R (74.04%) and CT-B (72.03%) in year 2009-10 and 2010-11, respectively. In general, NHI was decreased as the N level increased from control to 180 kg N/ha during both the years.

Table.1 Energy equivalents in wheat production system in relation to present study

Particulars	Units	Equivalent energy (MJ)	References
A. Inputs			
a. Human labour			
1. Adult man	Man-h	1.96	a
2. Women	Woman-h	1.57	a
b. Diesel	L	56.31	a, b
c. Electricity (5 Hp motor)	H	44.74	c
d. Irrigation water	M^3	1.02	c
e. Chemical fertilizer			
1. N	Kg	60.60	a, d
2. P_2O_5	Kg	11.10	a, d
3. K_2O	Kg	6.70	a, d
f. Chemicals			
1. Herbicides	Kg/L	254.45	a, d
2. Insecticides	Kg/L	184.63	a, d
g. Seed	Kg	14.70	e, f
h. Crop residue	Kg	12.50	e, f
B. Outputs			
1. Grain	Kg	14.70	e, f
2. Straw	Kg	12.50	e, f

Where; a: Mittal and Dhawan (1988); b: Deng (1982); c: Devasenapathy et al (2009); d: Lal (2004); e: Panesar and Bhatnagar (1994); f: Singh et al (1997)

Table.2 Effect of tillage and crop establishment techniques, 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 and crop establishment								
CT-F	13.61	13.03	121.7	126.2	108.1	113.2	9.36	10.11
CT-B	13.28	12.86	119.9	129.3	106.6	116.4	9.48	10.53
ZT-F	11.57	10.99	124.4	131.5	112.9	120.6	11.60	13.05
ZT-B	10.90	10.48	120.2	128.4	109.3	117.9	12.11	13.47
ZT-F+R	74.09	73.51	132.6	136.0	58.5	62.5	1.78	1.84
ZT-B+R	73.42	73.01	130.5	132.4	57.0	59.4	1.77	1.80
SEm±	-	-	3.837	2.865	3.837	2.865	0.343	0.172
LSD ($p \leq 0.05$)	-	-	NS	NS	12.09	9.028	1.081	0.543
Nitrogen levels (kg/ha)								
0	27.36	26.86	91.7	93.0	64.4	66.1	9.34	10.12
60	30.99	30.49	125.5	132.7	94.6	102.2	8.44	9.50
120	34.63	34.13	138.6	146.3	104.0	112.2	7.04	7.81
180	38.27	37.77	143.6	150.5	105.4	112.8	5.91	6.43
SEm±	-	-	1.501	1.888	1.501	1.888	0.133	0.151
LSD ($p \leq 0.05$)	-	-	4.305	5.414	4.305	5.414	0.381	0.435

Table.3 Effect of tillage and crop establishment techniques, and N levels on nitrogen-use efficiencies of wheat

Treatment	ANUE[a] (kg grain yield increase/kg N applied)		PNUE[b] (kg grain yield increase/kg N uptake increase)		ANR (%)[c]	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment						
CT-F	11.55	11.44	31.02	24.97	28.41	31.71
CT-B	9.14	11.13	23.89	26.22	28.24	31.81
ZT-F	11.57	11.49	29.41	27.90	28.43	29.61
ZT-B	8.60	9.35	25.15	23.98	26.41	29.75
ZT-F+R	11.79	9.26	28.94	24.00	31.42	28.62
ZT-B+R	11.08	9.55	28.58	25.86	29.98	28.14
SEm±	2.29	2.22	2.83	2.62	3.68	4.21
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS
Nitrogen levels (kg/ha)						
0	0.00	0.00	0.00	0.00	0.00	0.00
60	19.57	19.72	38.77	34.64	50.89	55.30
120	13.25	12.58	36.20	32.80	37.36	38.08
180	9.68	9.17	36.36	34.51	27.01	26.39
SEm±	1.15	1.04	1.80	1.16	2.35	2.18
LSD ($p \leq 0.05$)	3.30	2.99	5.17	3.32	6.73	6.25

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

Table.4 Effect of tillage and crop establishment techniques, and N levels on nitrogen-use efficiencies of wheat

Treatment	NER[a] (kg dry matter/kg N uptake)		PEIN[b] (kg grain yield/kg N uptake)		NHI[c] (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment						
CT-F	115.9	115.4	47.42	46.24	75.46	73.06
CT-B	113.8	112.5	46.56	45.37	79.00	72.03
ZT-F	116.5	116.6	49.16	47.49	75.66	73.85
ZT-B	115.7	112.3	47.04	45.82	77.80	72.87
ZT-F+R	115.4	113.9	48.60	46.96	75.16	74.41
ZT-B+R	114.5	109.3	47.19	45.41	74.04	72.91
SEm±	4.20	4.70	0.94	0.76	4.80	0.83
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen levels (kg/ha)						
0	132.3	124.1	52.29	51.61	77.72	75.17
60	114.4	111.9	48.09	45.85	77.95	73.34
120	107.0	107.9	45.40	43.40	74.82	72.20
180	107.5	109.4	44.87	44.00	74.27	72.05
SEm±	3.17	2.78	0.59	0.53	2.45	0.71
LSD (P=0.05)	9.09	7.98	1.68	1.53	NS	2.04

[a]NER: N efficiency ratio; [b]PEIN: physiological efficiency index of N; [c]NHI: N harvest index

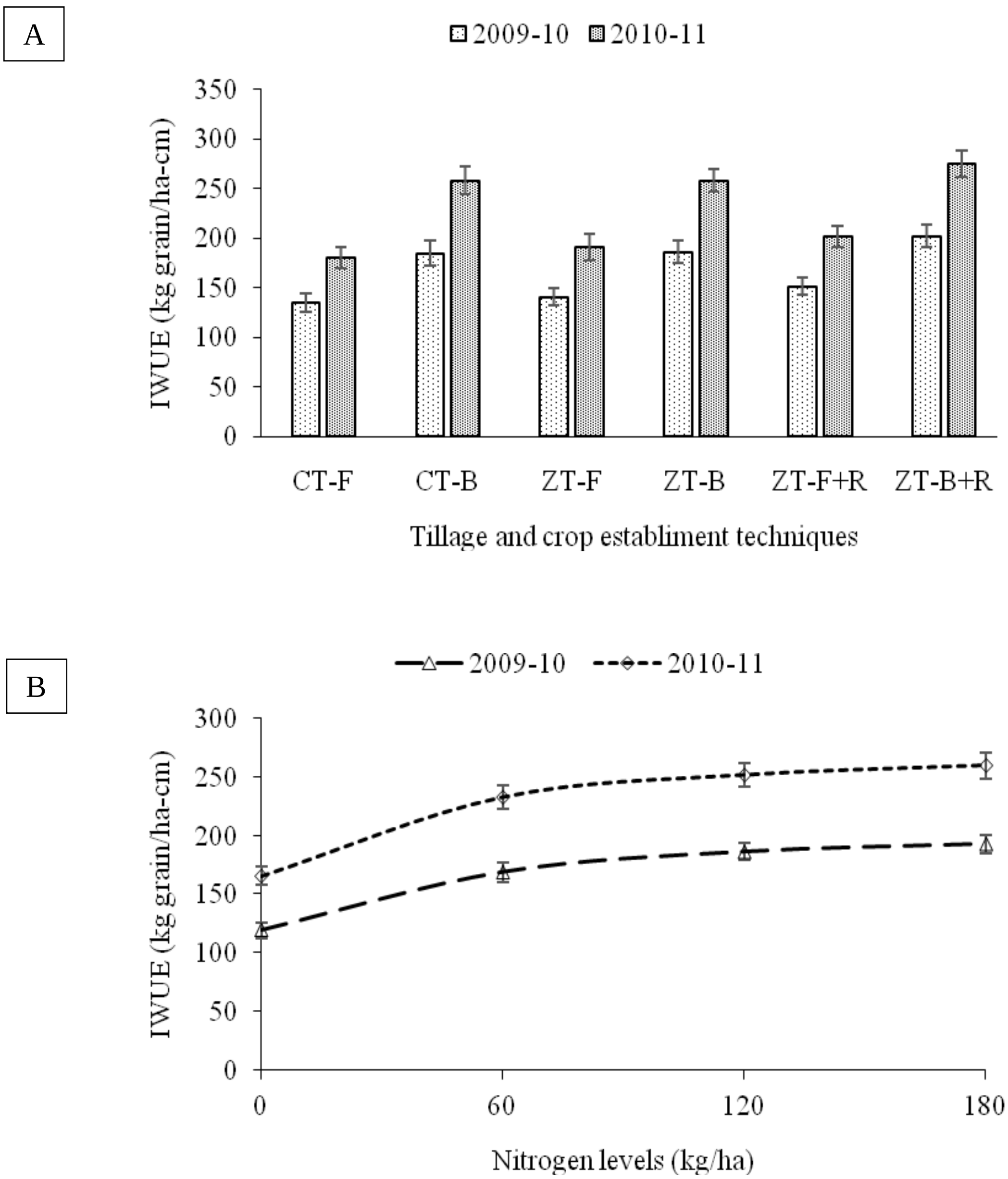

Fig.1 Effect of tillage and crop establishment techniques (A), and N levels (B) on IWUE of wheat

Energetics

Raised bed planting technique of crop establishment was found as input energy saver technique for wheat production over the flat planting technique primarily due to saving of energy consumption in terms of irrigation water. As bed planting saved the irrigation water requirement by up to 28.6 %. ZT practices reduce the energy requirement due to saving of energy in tillage practices as well as in weeding operations (herbicides were used for weed management) than CT practices (Jain *et al.*, 2007). Choudhary and Behera (2013) have reported a saving of 15.3 % in inputs energy consumption due to adoption of ZT practices in wheat. However, ZT practices with residue; the effect of energy saving by ZT practices was nullified by the application of heavy energetic crop residues (62.52 x 10^3 MJ/ha).Our results also corroborated the findings of Chaudhary *et al.*, (2006). ZT-B recorded the lowest energy requirement which was 19.1 % lesser than the CT practices. It was due to the saving of higher energy in ploughing and for seed-bed preparation as well as no manual weeding was done in this treatment. The similar results were also reported by Ram et al (2010). The gross output energy was not differed significantly under different tillage and crop establishment techniques due to similar yield performance of the wheat. However, the lowest net output energy as well as lowest EUE were computed under residue applied treatments even the best yields performance of the crop was due to too much higher energetic residue application. The maximum net output energy was recorded under ZT-F due to comparatively better yield performance and saving of energy involved in tillage practices. However, the maximum EUE was recorded under ZT-B due to lower input energy requirement than CT practices and comparatively higher yields performance as well as saving of energy in irrigation water than flat planting treatments. The similar results were also reported by Ram et al (2010). Gupta *et al.,* (2007) also reported significantly more EUE and energy productivity under ZT than CT. More energy needed in the production of one unit of Nitrogen. Therefore, input energy consumption increased with each successive increase in N levels in both the years. More gross output energy and net output energy at higher levels of N were due higher yields performance of the crops. However, reverse trend was observed in EUE with N levels, this was due input energy of N levels was increased linearly whereas yields of the crop increased with decreased pace with increased levels of N. These results and reasons are congruous the findings of Gupta et al (2007) and Choudhary and Behera (2013).

Irrigation water-use efficiency

Irrigation water-use efficiency (IWUE) is positively correlated with grain yield of wheat and negatively correlated with amount of irrigation water applied. The highest IWUE with ZT-B+R was due to reduction in irrigation water requirement in bed than the flat system. Similarly, a higher WUE was also reported in no-tillage (Choudhary and Behera, 2013) and bed planting (Kaur and Mahey, 2005; Ram *et al.,* 2010). The better root growth (Aggarwal *et al.,* 2006) and lower infestation of weeds on the beds was might be other possible reasons of higher IWUE under ZT-B+R. ZT-F+R also resulted higher IWUE than the CT-F, this was might be due to residue retention, which might be suppressed the weed growth and also helped in soil moisture conservation that made available for the longer durations to the crop.The increase in water productivity is the resultant of both increase in yield and saving in irrigation water. Jat *et al.*, (2005) reported 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, respectively. They further reported that remarkably higher water productivity (kg grain/m^3 water) of either crop of maize and wheat was recorded in FIRB planting (2.79 and 1.98) followed by ZT-F (1.74 and 1.89) and the lowest (1.36 and 1.38) in CT systems. The IWUE was increased with increased levels of N levels due to higher grain yield of wheat crop at each increased levels of N. IWUE was higher during 2010-11 than 2009-10 due to higher grain yield as well as less numbers of irrigations were applied due to good rainfall.

Nitrogen use-efficiency

The different indices of nitrogen-use efficiency (NUE) *viz.,* ANUE, PNUE, ANR, NER, PEIN and NHI were observed more or less similar under different tillage and crop establishment techniques. However, most of these indices were recorded the maximum under ZT-F which might be due to higher grain yield as well as higher uptake of N. The highest grain yield was recorded with ZT-F+R, but it resulted relatively poor NUE as compared to ZT-F due to marginally higher grain yield and corresponding higher uptake of N in control (0 kg N/ha) plots. It indicated that crop residue has contributed in enhancing the supply of nutrients as well as yields. Choudhary and Behera (2019) reported a N economy of 20-25 kg/ha due to recycling of wheat residue in maize. They further reported that N contribution from recycled crop-residues is increases progressively with each successive increase in N level, since higher level of N helped in faster decomposition of crop residues by meeting microbial requirement of nutrients. Sharma et al (2010) also reported that mulching is useful practice in for controlling erosion, weed growth and conserving moisture as well as nutrients in the soil profile. Similarly, Rahman *et al.,* (2005) also observed larger apparent recovery of fertilizer-N under mulch than no-mulch conditions. 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). PEIN and NHI were found more or less similar in all the tillage and crop establishment techniques, was might be due to all the treatments were equally partitioning the N in grain and straw. However, these NUEs were varied between the years. Lopez Bellido *et al.,* (2006) reported that NHI was significantly affected by year, and the highest value was recorded with lowest biomass and grain yield. The similar results were also reported by Bandyopadhyay *et al.,* (2010). Across the years, reverse to crops yields 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. This was probably due to N losses via denitrification and ammonia volatilization (Raun and Johnson, 1999). Lopez Bellido *et al.,* (2006) reported that the behaviour of NUE was erratic, and the highest value was recorded with zero N treatment. 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.

In conclusion the CT-based wheat production system is found the most energy in-efficient as the CT practices have contributed the maximum in input energy consumption. ZT-based systems (ZT-F/ZT-B) reduced the input energy requirements by 16.7 % and improve the net output energy production and energy-use efficiency by 4.9 and 27.2 % over CT-based systems (CT-F/CT-B). However, crop residue recycling enhanced the total input energy consumption in ZT-based systems but have also improved the gross output energy production and IWUE. ZT-B+R improved the IWUE on an average by 26.0 % and also saved 16.7 % irrigation water over the CT-based systems. Nonetheless, continuous recycling of crop residues for long-run would be beneficial in improving the soil health and could be helpful in reducing the quantity of chemical fertilizers and irrigation water use. Higher N levels resulted in poor NUE and EUE. Considering the saving of inputs *viz.*, energy-use and irrigation water, the study recommends that ZT-based system is an energy efficient and could be adopted with surface retention of crop residues to improve the water and nitrogen efficiencies in wheat.

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