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Energetics and nitrogen-use efficiency of *kharif* maize in conservation agriculture-based maize (*Zea mays*)–wheat (*Triticum aestivum*) sequence

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Abstract

Field experiments were conducted at ICAR-Indian Agricultural Research Institute, New Delhi to evaluate the effect of six combinations of tillage and crop establishment techniques, *i.e.* conventional tillage-flat bed (CT-F), CT-raised bed (CT-B), zero tillage-flat bed with crop residue (ZT-F+R) and without crop residue (ZT-F), ZT-raised bed with crop residue (ZT-B+R) and without crop residue (ZT-B) in conjunction with four N levels (0, 60, 120 and 180 kg N/ha) on energy relations and nitrogen-use efficiency (NUE) in *kharif* maize (*Zea mays* L.) grown in sequence with wheat (*Triticum aestivum* L. emend. Fiori & Paol). Significant ($p \leq 0.05$) effect of conservation agriculture (CA) on the energy indicators and NUE was observed during second year of the study. ZT practices saved on an average 22% input energy requirements over CT practices. The maximum input energy requirement was recorded under crop residue applied treatments followed by CT and least under ZT practices. ZT-B+R resulted the maximum gross output energy (153.7×10^3 MJ/ha) which was significantly higher (5-13%) over rest of the treatments, except CT-B. However, the maximum energy-use efficiency (EUE) was recorded under ZT-B (24.42). Different indicators of NUE was not influenced significantly, except physiological efficiency index of N (PEIN) due to different tillage and crop establishment techniques. However, in general, ZT-B+R resulted the maximum values of most of the indicators of NUE. The energy and NUE parameters were differed significantly due to N levels. The input and output energy 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. Considering all the parameters, the study recommends that permanent raised bed system is an energy efficient and could be adopted with surface retention of crop residues to improve the NUE of applied fertilizer-N in maize.

Keywords: Conservation agriculture, energy indicators, maize, nitrogen-use efficiency

Introduction

Intensive tillage and indiscriminate use of nitrogen (N)-fertilizers have substantially increased the production cost and energy uses in the conventional crop production systems. In this respect availability of energy is and will continue to be an important foundation in agriculture that can assure sustainable and reliable food production. Further, rational management of the N and energy are the two key issues for researchers who need proper consideration to reduce the cost of these commodities in such a way that the reduction in price should not result the decrease in agricultural productivity. Yield of different crops can be increased up to 30% by using optimal level of energy inputs (Chaudhary *et al.*, 2006) [6]. Conventional tillage (CT) practices have resulted the declined soil fertility and resource-use efficiencies in addition to degradation of ecosystem services and biodiversity (Choudhary and Behera, 2013 [3]; 2014; Jat *et al.*, 2019a [10]). Conventional production systems of maize have not only reduced the net profit, but also have been found input in-efficient practices (Parihar *et al.*, 2018) [16]. 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.*, 2019b) [11]. 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) [28]. 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 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) [8, 11]. Energy saving is one of the most important consideration for tillage. Studies from several locations in Indo-Gangetic plains showed that with zero-tillage technology farmers were able to save on land preparation costs by about 2500 ₹/ha and reduce diesel consumption by 50–60 litres/ha (Sangar *et al.*, 2005) [22]. Diesel saved through this technology can be put for others users that can lead to significant cut in import bill of the country.

Maize has a high N demand to attain high grain yields. The continual rises in N-fertilizer prices, combined with elevate environmental risk of NO₃⁻ contamination by leaching, leads to the necessity of better strategies to improve nitrogen-use efficiency (NUE). The world cereal grain NUE would therefore be estimated at 33% far less than the 50% generally reported (Raun and Johnson, 1999) [21]. Based on present fertilizer use, a 1% increase in the efficiency of N use for cereal production worldwide would lead to a \$ 234.7 million savings in N-fertilizer costs (Raun and Johnson, 1999) [21]. Further, increase in use of N usually increased the crop yield but reduce the energy-use efficiency. Though, higher crop yields could be achieved with judicious use of N which can reduce the energy consumption substantially. The zero-till raised bed planting system (permanent beds) of maize cultivation has been shown to result in saving of seed, water and nutrients without affecting the grain yield production (Parihar *et al.*, 2018; Jat *et al.*, 2019b) [16, 11]. 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 long-run (Choudhary *et al.* 2017) [5]. A major advantage of CA systems is that they generally maintain or increase soil organic matter content. 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 NH₃ volatilization compared with CT systems (Patra *et al.*, 2004) [17]. All these complexities with N in CA system indicate the need for more research to understand the response of N to maize 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. Therefore, present study was conducted with the objective to investigate the effect of conservation agricultural and N management practices on energy relations and NUE of *khariif* maize grown in sequence with wheat.

Materials and Methods

Field experiments were conducted on a fixed site during was conducted during the rainy seasons (June to October) of 2009 and 2010 at the ICAR-Indian Agricultural Research Institute, New Delhi (28.4° N, 77.1° E and 228.6 m above msl). The soil was sandy loam had 1.57 g/m³ bulk density, 17.48% (w/w) field capacity and 1.26 cm/h infiltration rate. It had low level of organic carbon (0.37%) and available nitrogen (147.6 kg/ha), medium level of available phosphorus (11.8 kg/ha),

high level of available potassium (235.1 kg/ha) with neutral pH (7.5) and 0.31 dS/m electrical conductivity at the start of the study. Experiment was laid out in a split plot design, by keeping tillage and crop-establishment techniques in main plot and N levels in sub-plot with three replications. There were six combinations of tillage and crop establishment techniques, viz. i) conventional tillage (CT) with sowing of maize on flat soil surface (CT-F), ii) CT with sowing of crop on raised bed (CT-B), iii) zero tillage (ZT) with sowing of crop on flat soil surface (ZT-F), iv) ZT with sowing of crop on raised bed i.e. permanent bed (ZT-B), v) ZT-F with crop residue (ZT-F+R) and vi) ZT-B with crop residue (ZT-B+R), and four N levels, viz. 0, 60, 120 and 180 kg/ha were further superimposed on the aforesaid tillage treatments. Chopped crop-residue (R) @ 5 t/ha of preceding wheat was mulched in maize as per treatments. The CT consisted of two pass of tractor-drawn disc harrow, followed by twice of cultivator with planking in the last pass, while in ZT no ploughing was done, only one pass of multi-crop planter with minimum soil disturbance was used for sowing and application of fertilizers. In CT plots, fresh raised beds were prepared for every crop with a raised bed planter which made beds at 67.5 cm distance from bed to bed with a bed height of 20 cm and 37.5 cm top width. However, in ZT-B (permanent raised bed) treatments, beds were made only once at start of the experiment, and beds were reshaped while sowing of succeeding crops. Optimum plant population of maize was maintained with planting geometry of 67.5 cm × 20 cm by using 20 kg/ha seed of hybrid 'Bio 9637' under both flat and bed-plantings. Full doses of P (26.2 kg/ha) and K (33.3 kg/ha) were applied basal at sowing of crop. However, N was applied in three equal splits at sowing, knee-high (30-35 DAS) and tasseling (55-60 DAS) stages of maize as per the treatments. The other standard and recommended practices of CA and CT were followed to harvest good crop.

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) [14]. EUE: [Energy Output (MJ/ha)/ Energy input (MJ/ha)] and Net energy (MJ/ha): [Energy output (MJ/ha) – Energy input (MJ/ha)]. 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 – Y₀) / N_a]; Physiological NUE (kg grain yield increase/ kg N uptake increase): [(Y_t – Y₀) / (U_t – U₀)]; Apparent N recovery (%): [(U_t – U₀) / N_a] × 100; 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_g/ N_t) × 100]. Where, Y_t: Grain yield in the test treatment (kg/ha); Y₀: 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); U₀: 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_g: N uptake by the grain at harvest (kg/ha) and; N_t: N uptake by the whole plant at harvest (kg/ha).

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* ≤ 0.05 probability level). The data were analyzed by two-way ANOVA technique using the PROC MIXED procedure of SAS package (*ver.* 9.3).

Table 1: Energy equivalents in maize 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 ₂ O ₅	Kg	11.10	a, d
3. K ₂ O	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. Stover	Kg	12.50	e, f

Where; a: Mittal and Dhawan (1988)^[14]; b: Deng (1982)^[6]; c: Devasenapathy *et al.* (2009)^[7]; d: Lal (2004)^[12]; e: Panesar and Bhatnagar (1994)^[15]; f: Singh *et al.* (1997)^[25]

Results

Energetics

Input energy

The input energy consumption (both renewable and non-renewable) estimated for production of maize was influenced due to different tillage and crop establishment techniques in both the years (Table 2). The total energy requirement of the maize was recorded the maximum under CT-F (11.98×10^3 MJ/ha) and ZT-F+R (70.68×10^3 MJ/ha) during 2009 and 2010, respectively. Whereas, the minimum input energy consumption was estimated under ZT-B during both the years. In the year 2010, ZT practices saved the energy requirement over CT practices by 20.25 and 23.18% under flat and bed planting systems, respectively. The input energy requirement for different levels of N varied from the minimum of 6.33×10^3 MJ/ha at 0 kg N/ha to the maximum 17.24×10^3 MJ/ha at 180 kg N/ha during 2009. Similarly, during 2010, the input energy requirement varied from minimum 24.21×10^3 MJ/ha at 0 kg N/ha to maximum 35.11×10^3 MJ/ha at 180 kg N/ha.

Gross output energy

The maximum gross output energy was estimated under ZT-B+R (150×10^3 and 153.7×10^3 MJ/ha) in both the years, respectively, which was significantly higher than CT-F, ZT-F and ZT-F+R during 2009, and in year 2010 it was also significantly higher than ZT-B, other than aforesaid treatments (Table 2). However, the minimum gross output energy was recorded under ZT-F in both the years. The gross output energy was positively correlated with the yield performance of the maize crop. Bed planting resulted significantly higher gross output energy than flat planting under respective tillage practices. Similarly, CT resulted higher energy production than ZT practices under respective planting systems. However, ZT+R practices significantly enhanced the gross energy production over ZT practices, but

similar to CT practices during 2010. Gross output energy production was also influenced significantly due to different levels of N the during both the years. It was increased significantly with each successive increase in level of N from control to 180 kg/ha. The maximum energy production was estimated at 180 kg N/ha (160.2 and 163.8×10^3 MJ/ha) during 2009 and 2010, respectively.

Net output energy and energy-use efficiency

During 2009, the maximum net energy as well as energy-use efficiency (EUE) were recorded under ZT-B+R, which was significantly higher than all flat planting treatments, but it remained similar with other bed planting treatments (Table 2). Whereas, during 2010, the maximum net energy was recorded under CT-bed (141.3×10^3 MJ/ha), which was significantly higher than the rest of the treatments, except ZT-B. While, ZT-F+R was recorded the minimum net energy (72.76×10^3 MJ/ha), which was significantly lower than the rest of treatments. Bed planting resulted significantly higher net energy than flat planting in respective tillage and residue management treatments during 2010. The maximum EUE was computed under ZT-bed (24.42), which was significantly higher than rest of treatments during 2010. The minimum EUE was recorded under ZT-F+R (2.022), which was also significantly lower than the rest of treatments, except ZT-B+R (2.172). However, ZT treatments resulted significantly higher EUE than CT practices by 34.88 and 46.67% under flat planting and bed planting systems, respectively. The net output energy was increased significantly with each increase in levels of N up to 120 kg/ha in both the years. However, the maximum net output energy 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. However, EUE decreased significantly with increase in levels of N. The lowest EUE was recorded at 180 kg N/ha.

Table 2: Effect of tillage and crop establishment techniques, and N levels on energy indicators of maize

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 (output/input ratio)	
	2009	2010	2009	2010	2009	2010	2009	2010
Tillage and crop establishment								
CT-F	11.98	10.23	130.8	144.3	118.9	134.1	11.85	16.20
CT-B	11.64	10.40	146.5	151.7	134.8	141.3	13.66	16.65
ZT-F	11.94	8.16	129.1	135.9	117.1	127.8	11.76	21.85
ZT-B	11.61	7.99	145.0	145.8	133.4	137.8	13.55	24.42
ZT-F+R	11.94	70.68	134.6	143.4	122.7	72.76	12.23	2.022
ZT-B+R	11.61	70.51	150.0	153.7	138.4	83.21	14.05	2.172
SEm \pm	-	-	2.790	1.966	2.790	1.966	0.295	0.182
LSD (P=0.05)	-	-	8.793	6.196	8.793	6.196	0.930	0.574
Nitrogen levels (kg/ha)								
0	6.33	24.21	109.6	117.8	103.2	93.6	17.33	23.30
60	9.97	27.84	134.8	142.6	124.8	114.7	13.53	13.75
120	13.61	31.48	152.8	159.2	139.2	127.7	11.24	10.34
180	17.24	35.11	160.2	163.8	142.9	128.7	9.30	8.148
SEm \pm	-	-	1.864	1.531	1.864	1.531	0.292	0.123
LSD (P=0.05)	-	-	5.346	4.392	5.346	4.392	0.838	0.353

Nitrogen use-efficiency

Agronomic N-use efficiency

The highest ANUE was recorded under CT-B followed by ZT-B systems in 2009, while, in 2010 the highest ANUE was recorded under ZT-B+R followed by ZT-B. While, ZT-F recorded the least ANUE in both the years (Table 3). In general bed planting resulted marginally higher ANUE than flat planting of maize. Similarly, residue application marginally enhanced the ANUE over no-residue under ZT practices. Yield increase due to per unit N applied was decreased with each increased level of N application. The highest ANUE was recorded with 60 kg N/ha followed by 120 kg N/ha in both the years. N level 180 kg/ha recorded the least ANUE.

Physiological N-use efficiency

In general bed planting resulted marginally higher physiological N-use efficiency (PNUE) than flat planting of maize. Similarly, residue application decreased the PNUE marginally over no-residue under ZT practices. PNUE was recorded marginally higher under ZT than CT practices

(Table 3). Yield increase due to per unit increase in uptake of N was decreased with increased levels of N application 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

The highest value of apparent N recovery (ANR) was observed with ZT-B (26.45%) followed by ZT-B+R (25.82%) in the year 2009, while in year 2010, the maximum ANR was recorded under ZT-bed+R (25.94%) followed by CT-bed (24.17%). The least value of ANR was recorded under ZT-flat (Table 3). In general bed planting resulted higher ANR than flat planting. Similarly, CT and ZT+R resulted similar values of ANR, but marginally higher than ZT practices. The ANR was decreased with increased levels of N. The highest ANR was recorded at 60 kg N/ha (37.92 and 37.19%; during 2009-10 and 2010-11, respectively) followed by at 120 kg N/ha (33.88 and 32.89%; during 2009-10 and 2010-11, respectively). The least value of ANR was found with 180 kg N/ha in both the years.

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

Treatment	ANUE ^a (kg grain yield increase/kg N applied)		PNUE ^b (kg grain yield increase/kg N uptake increase)		ANR (%) ^c	
	2009	2010	2009	2010	2009	2010
Tillage and crop establishment						
CT-F	8.74	7.65	29.14	24.31	22.39	23.13
CT-B	10.44	7.71	30.43	23.66	25.71	24.17
ZT-F	8.62	7.05	29.41	25.04	21.69	21.00
ZT-B	10.26	8.21	31.06	26.29	26.45	23.95
ZT-F+R	9.29	7.23	30.93	23.74	23.84	23.22
ZT-B+R	10.09	8.77	32.45	25.70	25.82	25.94
SEm \pm	1.07	0.91	5.01	2.47	2.48	1.90
LSD (P=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	15.02	12.89	43.18	34.92	37.72	37.19
120	13.20	10.48	39.65	32.40	33.88	32.89
180	10.07	7.71	39.45	31.83	25.67	24.19
SEm \pm	1.05	0.55	3.14	1.02	1.63	1.68
LSD (P=0.05)	3.02	1.57	9.02	2.94	4.67	4.82

where; ^aANUE: Agronomic N-use efficiency; ^bPNUE: physiological N-use efficiency; ^cANR: apparent N recovery

Nitrogen efficiency ratio

Nitrogen efficiency ratio (NER) which is expressed as unit dry matter production per unit uptake of N did not show any trend due to different continuous tillage and crop establishment techniques (Table 4). However, in most cases, flat planting resulted higher nitrogen efficiency ratio than bed planting. Similarly, CT and ZT+R resulted similar values of NER, but marginally lower than ZT practices. The maximum NER was recorded under ZT-F, while the minimum was recorded under ZT-B+R during 2010. The response of N in terms of dry matter production was also decreased with increased levels of N in both the years. The highest NER was recorded at 0 kg N/ha followed by 60 kg N/ha while, the least NER was recorded at 180 kg N/ha.

Physiological efficiency index of N

In general, flat planting resulted higher physiological efficiency index of N (PEIN) than bed planting (Table 4). Similarly, CT and ZT+R resulted similar values of PEIN, but

marginally lower than ZT practices. However, highest value of PEIN was recorded under ZT-F. The lowest value of PEIN was recorded with ZT-B and ZT-B+R during 2009 and 2010, respectively. With each successive increase in N levels there was decrease in PEIN in both the years. However, percent decrease was less with higher N dose beyond 60 kg/ha.

Nitrogen harvest index

The highest nitrogen harvest index (NHI) was found with CT-B (68.43%) and ZT-B+R (64.82%) in year 2009 and 2010, respectively. However, more or less similar NHI was observed among different continuous tillage and crop establishment practices during both the years (Table 4). NHI was influenced due to different levels of N in both the years. However, marginally higher values of NHI were recorded in the year 2009 than in 2010. In general, NHI was decreased with increase in N levels in year 2010, but there was no fixed trend observed during 2009.

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

Treatment	NER ^a (kg dry matter/kg N uptake)		PEIN ^b (kg grain yield/kg N uptake)		NHI ^c (%)	
	2009	2010	2009	2010	2009	2010
Tillage and crop establishment						
CT-flat	121.2	124.7	51.01	47.79	67.67	63.80
CT-bed	121.9	123.8	51.17	47.69	68.43	64.52
ZT-flat	123.1	133.1	51.51	50.91	67.92	64.12
ZT-bed	119.5	127.4	49.98	49.05	67.47	64.11
ZT-flat+R	123.5	125.9	51.36	48.34	67.28	64.57
ZT-bed+R	120.0	122.2	50.28	47.58	67.52	64.82
SEm±	7.80	1.90	3.36	0.66	4.03	1.11
CD (P=0.05)	NS	NS	NS	2.10	NS	NS
Nitrogen levels (kg/ha)						
0	137.0	143.0	55.84	54.33	67.78	65.03
60	122.8	127.2	51.18	49.16	67.20	64.65
120	113.3	118.0	48.42	45.72	67.90	64.00
180	112.9	116.5	48.09	45.04	67.98	63.61
SEm±	2.85	1.14	1.17	0.49	1.40	0.68
CD (P=0.05)	8.16	3.28	3.36	1.42	NS	NS

where; ^aNER: N efficiency ratio; ^bPEIN: physiological efficiency index of N; ^cNHI: N harvest index

Discussion

Energetics

Irrespective of tillage practices, the energy consumption was more under flat planting over bed planting due to the energy consumption for preparation of beds was nullified by saving of irrigation water energy under bed planting systems. 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. Choudhary and Behera (2013) [3] have reported a saving of 20% in inputs energy consumption due to adoption of ZT practices in maize. However, ZT+R increased the energy consumption due to recycling of high energetic crop residues. This is in conformity with the findings of Chaudhary *et al.* (2006) [2]. ZT-B recorded the lowest energy requirement which was 18% lesser than the CT-Bed. It was due to the saving of higher energy in ploughing, seed-bed preparation as well as in weeding operations. The similar results were also reported by Ram *et al.* (2010) [20]. The higher gross output energy was recorded under ZT-B+R due to better yield performance of maize. The lowest gross output energy in maize was estimated under ZT-F was also due to lower yield performance of the crop. However, the lowest net output energy as well as lowest energy-use efficiency were computed

under residue applied treatments even the best yields performance of the crop was due to recycling of wheat residue as it has high energy. The highest net output energy was recorded under CT-B due to comparatively better yields performance and saving of energy involved in irrigation water and its application, saving of human resource energy due to lower weed infestation. However, the maximum energy-use efficiency 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) [20]. More energy needed in the production of one unit of N-fertilizers. Therefore, input energy consumption increased with each successive increase in N levels. More gross output energy and net output energy at higher levels of N due higher yields performance of the crop. However, reverse trend was observed in energy-use efficiency with N levels, this was due input energy of N levels was increased linearly whereas yields of the crop increased with decreased pace with increase in levels of N. These results and reasons are congruous the findings of Prasad (2005) [18] and Gupta *et al.* (2007) [9].

Nitrogen use-efficiency

In general, bed planting registered the higher NUE of applied fertilizer N might be due to higher grain yield as well as higher uptakes of N. ANUE is positively related to yield performance of the crops. Similarly, ZT-B+R recorded the maximum ANUE was also due to significantly higher grain yield of maize. It also indicated that recycling of wheat residue in maize has contributed in enhancing the ANUE of maize. Sharma *et al.* (2010) [24] also reported that mulching is useful practice in rainfed areas for controlling erosion, weed growth and conserving moisture as well as nutrients in the soil profile. There was no much differences observed in PNUE of the applied fertilizer nitrogen in maize. However, ANR values were registered comparatively higher under bed planting over flat planting and more under residue applied treatments over without residue treatments in ZT practices. Rahman *et al.* (2005) [19] have 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) [27]. Marginally, lower values of NER and PEIN in maize under residue applied treatments were might be due higher uptake of applied N as well as higher dry matter production in the control plots (crop residue added). PEIN and NHI were found more or less similar in all the tillage and crop establishment practices, was might be due to all the treatments were equally partitioning of the N in grain and straw. However, the NUE were varied between the years. Lopez Bellido *et al.* (2006) [13] 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) [1]. Across the years, reverse to crops yields the NUE decreased with each increase in N levels and recorded the maximum at lower levels (0 or 60 kg N/ha) and minimum at 180 kg N/ha. This was possibly due to N losses via denitrification and ammonia volatilization (Raun and Johnson, 1999) [21]. Singh *et al.* (2009) [26] 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) [13] reported that the behaviour of NUE was erratic, and the highest value was recorded with zero N treatment. The similar results were also reported by Sharma and Behera (2009) [23].

Conclusion

The intensive conventional maize production system primarily relying on fossil fuel burning is the major contributor of the input energy consumption. In contrast to this, the permanent raised bed planting technique (ZT-B) reduced input energy requirements by around 23% and also found most energy efficient (24.22) system. However, crop residue recycling as a source of renewable energy input has greatly enhanced the total input energy consumption in ZT systems but have also improved the gross output energy production and NUE. Nevertheless, continuous recycling of crop residues for long-run would be beneficial in improving the soil health and could be helpful in reducing the dose of chemical fertilizers which was found not only the major component of input energy but also reduced the NUE in this study. Higher N rates resulted in lower NUE. Considering all the parameters, the study recommends that permanent raised bed system is an energy efficient and could be adopted with

surface retention of crop residues to improve the NUE of applied fertilizer-N in maize.

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