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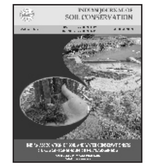

Conservation agricultural and nitrogen management practices in maize-wheat cropping system: Effect on productivity, nutrient uptake and profitability of maize

R.L. Choudhary[1,*] and U.K. Behera[2]

[1]*ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan;* [2]*College of Agriculture, Kyrdemkulai, CAU, Umiam, Meghalaya.*

**Corresponding author:*
E-mail: rl.choudhary@icar.gov.in (R.L. Choudhary)

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ABSTRACT

Performance of maize (*Zea mays* L.) grown in sequence with wheat (*Triticum aestivum* L.) was evaluated under conservation agriculture and nitrogen management practices for two consecutive years. The experiment was conducted in split plot design with six main plot treatments of tillage and crop establishment practices, *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), and four sub-plot treatments of fertilizer-nitrogen (N), *i.e.* 0, 60, 120 and 180 kg N ha^{-1}. Significant ($p \leq 0.05$) effect of conservation agriculture (CA) on performance of maize was observed during second year of the study. Significantly higher values of plant height and yield attributes, *viz.,* grains grain-row^{-1}, grains cob^{-1} and cobs ha^{-1} were recorded under ZT-B+R than rest of the treatments, except CT-B. ZT-B+R recorded significantly higher grain, stover and biological yields and improved nitrogen, phosphorus and potassium uptake as compared to other treatments, except CT-B in case of yields. Grain yield with ZT-B+R improved significantly by 7.9% to 15.5%, 15.0% to 16.0% and 8.6% to 12.1% over CT-F, ZT-F and ZT-F+R, respectively. ZT-F and ZT-B practices reduced the cost of cultivation on an average by 18.9% as compared to CT practices. ZT-B registered the maximum net returns (₹ 29.17×10^{3} ha^{-1}), B:C ratio (1.98) and economic efficiency (₹ 291.7 ha^{-1}day^{-1}). Significantly higher values of most of the growth, yields, nutrient uptake and monetary parameters were recorded at 120 kg N ha^{-1} as compared to other N levels. However, the economic optimum dose of N derived from quadratic response function was 142 kg N ha^{-1} for the best yield producing treatment, *i.e.* ZT-B+R. Therefore, the maximum maize productivity with higher nutrient content and gross returns could be achieved with CA (ZT-B+R) and optimum N fertilization.

1. INTRODUCTION

The monoculture of rice–wheat cropping system (RWCS) of north-western India with resource intensive crop management practices though provide food security in India, but also has resulted into many problems. Soil health degradation, higher production cost, decline of factor productivity and water table, loss of biodiversity, poor resource-use efficiency, and environmental pollution owing to crop residue burning have been occurred due to continuous RWCS with intensive conventional tillage practices (Gathala *et al.,* 2011; Jat *et al.,* 2013; Jat *et al.,* 2019). Since, intensive conventional tillage (CT) negatively influences the soil properties, it is important to adopt alternative tillage practices that improve soil quality, maintain crop yield as well as ecosystem stability, which can be one option for sustainability of existing RWCS (Jat *et al.,* 2017). Further, diversification of RWCS with alternative remunerative, more environmentally friendly and less water requiring crops like maize, soybean and cotton can be better options in water scarce areas (Verhulst *et al.,* 2011). Recently, maize has been found to be a good alternative to *kharif* (rainy) season rice (Das *et al.,* 2018). Maize is third most important food crop after rice and wheat in India with 27.8 Million tonnes (M t) annual production from 9.2 Million ha (M ha) area (USDA, 2019). In comparison to rice, maize with significant lower labour and water requirements, greater yield potential and almost equal minimum support price, having adaptability to diverse agro-ecologies and seasons, can enhance system productivity, and sustain soil health and environment quality.

However, full yield potential of maize is yet to be realized by the Indian farmers as it is still being cultivated under conventional crop management without optimal supply of nutrients, particularly nitrogen. Hence, development of technologies that conserve soil, protect environment and provide adequate profit to farmers is needed to ensure food security. Therefore, to offset the production cost and environmental footprints, CA has been promoted and adopted for climate resilient sustainable production of crops (Sharma *et al.,* 2012; Bhan and Behera, 2014; Sekar *et al.,* 2015). Minimal soil movement by reduction in tillage intensity and retention of crop-residues on soil surface along with crop rotations and diversification to economically benefit the farmers are the key principles of CA (Verhulst *et al.,* 2011). The yield enhancements of crops under CA systems have been described mainly owing to the improvement in soil health (Choudhary and Behera, 2014; Choudhary *et al.,* 2017). Other benefits of CA are enhanced resource-use efficiency (Choudhary and Behera, 2013), higher profitability resulting in reduced machinery and other costs, besides being more environment friendly (Komatsuzaki and Ohta, 2007).

It has been also observed that crops, particularly cereals, exhibit reduced yields during early phase of conversion of production system from CT to CA because of lesser nitrogen (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 in CA system indicate the need for more research to understand the response of N to crops under CA systems so that optimal supply of N can be ensured. Accordingly, present study was conducted with the objective to determine the effect of conservation agricultural and N management practices on growth, productivity, profitability and nitrogen response functions of maize grown in sequence with wheat.

2. MATERIALS AND METHODS

Study Area

A field experiment on CA practices with maize in maize-wheat cropping system (MWCS) 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 mean sea level). The soil was sandy loam having 1.57 g m^{-3} bulk density, 17.48% (w/w) field capacity, and 1.26 cm h^{-1} infiltration rate. It had low level of organic carbon (0.37%) and available nitrogen (147.6 kg ha^{-1}), medium level of available phosphorus (11.8 kg ha^{-1}), high level of available potassium (235.1 kg ha^{-1}) with neutral pH (7.5) and 0.31 dS m^{-1} electrical conductivity at the start of the study. During 2009, the rainfall was erratic with total 520 mm received during rainy season, which was 18% deficit from the normal rainfall (650 mm), whereas during 2010, it was good in amount with 916 mm during the same period with good distribution, being 52% surplus than the normal rainfall. The values of USWB class a open pan evaporation were 157.5 and 129.1 mm for the crop growing period of the year 2009 and 2010, respectively. Whereas, daily minimum temperature, maximum temperature and mean relative humidity ranged between 6.5°C-28.4°C, 25.3°C-42.3°C and 46-94% during the 2009, and 11.8°C-29.2°C, 23.8°C-43.9°C and 42-97% during the 2010, respectively. Rainfall distribution and other weather parameters that prevailed during the crop-growing duration are presented in Fig. 1.

Experimental Design and Treatments

Experiment was laid out in a split plot design, by keeping tillage and crop-establishment techniques in main plot (23.0 m × 3.5 m) and N levels in sub-plot (5.0 m × 3.5 m) with three replications in a fixed layout. 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^{-1} were further superimposed on the aforesaid tillage treatments. All plots received the same treatment throughout the period of study, except ZT in first crop. Chopped crop-residue (R) @ 5 t ha^{-1} of preceding wheat was mulched in maize as per treatments.

Tillage, Residue Management, Crop Establishment and Crop Culture

The CT consisted of two passes 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 (www.nationalagroindustries.com) 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 (www.nationalagroindustries.com) 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^{-1} seed of hybrid 'Bio 9637' under both flat and

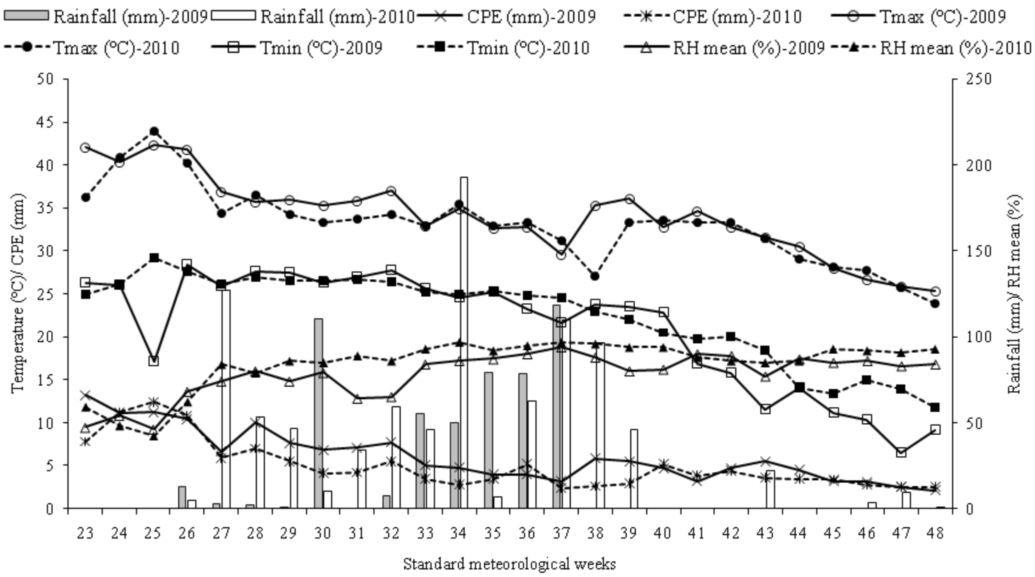

Fig. 1. Weather conditions during crop growing periods of years 2009 and 2010

bed-plantings. Full doses of P (26.2 kg ha^{-1}) and K (33.3 kg ha^{-1}) were applied basal at sowing of crop. However, urea as a source of 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 crops.

Measurement of Growth, Yield Parameters and Yields

Crop was harvested manually at physiological maturity, and measurement of growth, yield attributes and yield parameters were recorded by following the recommended standard procedures. The maize cobs harvested from 9 m^2 areas of each sub-plot were sun dried, after separating from stalk and shelling of husk and silk, and then threshed by a mechanical thresher to estimate the grain yield. Moisture content in grains was determined and grain yield of maize was adjusted at 12.5% moisture content. Stover yield was computed by subtracting the weight of grains from total dry matter yield (biological yield) of each sub-plot.

Nutrient Uptake

Plant samples collected at harvest were dried in hot air oven at 67°C for 24 hours. The oven dried plant sample and grain samples were ground in a Macro-Wiley Mill and used for the determination of total nitrogen (N), phosphorus (P) and potassium (K) contents. Concentrations of N, P and K in grain and stover samples were determined by modified Kjeldahl method, vanadomolybdo phosphoric acid yellow colour method (spectrophoto meter) and flame photometer, respectively (Prasad *et al.,* 2006). Accordingly, nutrient uptake by crop was calculated by multiplying nutrient concentration with respective grain and stover yields.

Response Function of N Fertilization and Economics

Response functions of N fertilization in maize were worked out by quadratic equations between the grain yields and N levels. Saving of N through different CA practices was worked out based on the relative yields of crops under varying N levels, and through calculation of economic optimum yield (Y_{opt}) based on economic optimum dose of N (N_{opt}) derivations from quadratic response equations as:

$$N_{opt} = \{(P_x \div P_y) - b\} \div 2c \quad ...(1)$$

$$Y_{opt} = a + b(x) + c(x^2) \quad ...(2)$$

$$\text{Response at } N_{opt} \text{ (kg grain ha}^{-1}) = (Y_{opt} - Y_{con}) \quad ...(3)$$

$$\text{Response at } N_{opt} \text{ (kg grain per kg N)} = (Y_{opt} - Y_{con}) \div N_{opt} \quad ...(4)$$

$$\text{Net profit (₹ ha}^{-1}) = \{(Y_{opt} - Y_{con}) \times P_y\} - (N_{opt} \times P_x) \quad ...(5)$$

$$\text{Returns in ₹ per ₹ invested on N (₹)} = \{(Y_{opt} - Y_{con}) \times P_y\} \div (N_{opt} \times P_x) \quad ...(6)$$

Where *a, b* and *c* are the coefficients of quadratic equations, P_x and P_y are the cost of N (₹ 15.19 and 16.49 kg^{-1} N during 2009 and 2010, respectively) and the price of produce (₹ 8.40 and 8.80 kg^{-1} grain of maize during 2009 and 2010, respectively), and Y_{con} is the grain yield at 0 kg N ha^{-1}. The economics of cultivation was worked out on the basis of prevailing market price of produce and cost of inputs. Net returns were estimated by deducting the total cost of cultivation from gross returns, and benefit: cost (B:C) ratio was calculated by dividing net returns with total of fixed and variable costs. Price of stover was ₹ 1.0 kg^{-1} during both the years. The ratio of net returns and crop growing period was expressed in terms of economic efficiency.

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 twoway ANOVA technique using the PROCMIXED procedure of SAS package (ver. 9.3).

3. RESULTS AND DISCUSSION

Growth, Yield Attributes and Yields

The tillage, crop establishment and N management effects on growth and yield attributes of maize were significant during both the years of experimentation. ZT-B+R recorded significantly ($p \leq 0.05$) higher values of the plant height and yield attributes of maize, *viz.,* grains cob^{-1}, grains grain-row^{-1}, cobs ha^{-1} and cob yield (t ha^{-1}) over other treatments, except CT-B and ZT-B in case of plant height and CT-B in case of yield attributes (Table 1). However, 1000-grain weight was not influenced significantly. Plant height and all the yield attributes including 1,000-grain weight responded greatly to different levels of N in both the years (Table 1). Nitrogen at 120 kg ha^{-1} resulted in significantly higher values of these parameters than 0 and 60 kg N ha^{-1}, but remained statistically at par with 180 kg N ha^{-1}.

The maize grain, stover and biological yields were significantly influenced with different tillage and crop establishment techniques during the experimentation (Table 2), whereas, harvest index of maize was not influenced significantly by the applied treatments during all the years. During 2010, the highest grain yield was recorded with ZT-B+R (4.49 t ha^{-1}), which was significantly higher by 6.4% to 15.0% over rest of the treatments, except CT-B treatment. The lowest grain yield of maize was observed with ZT-F. Irrespective of tillage practices, the performance of maize was significantly higher with raised bed (7.4-12.2%) over flat planting technique during the course of study. Establishment of maize on raised bed resulted in comparatively better yield performance over flat planting technique during rainy season (Singh *et al.,* 2007; Behera and Sharma, 2010), since maize is highly sensitive crop to water logging, particularly during the early growth stages. ZT with residue (ZT-B+R and ZT-F+R) proved significantly superior over ZT without residue (ZT-B and ZT-F), which showed that irrespective of planting techniques, crop residue application resulted in significant increase in grain yield of maize to the tune of 5.9-6.4% over ZT without crop residue treatments. A similar trend was also observed of stover and biological yields of maize. Our findings of higher yields of maize under ZT-B+R are in agreement with Jat *et al.* (2013); Gathala *et al.* (2011) and Parihar *et al.* (2018). Yield enhancement under residue applied treatments might be due to higher soil moisture content (Govaerts *et al.,* 2009), moderated soil temperature, and improved soil fertility due to constant supply of nutrients through mineralization of applied crop residues (Singh *et al.,* 2009), reduced competition for resources due to lesser weed population (Ozpinar, 2006; Chauhan *et al.,* 2007), and improved soil physical health (Jat *et al.,* 2013).

The grain, stover and biological yields and harvest index of maize also differed significantly due to N fertilization. Grain, stover and biological yields significantly improved with 120 kg N ha^{-1} by 11.2-16.3%, 10.9-11.2%

Table: 1
Effect of tillage and crop-establishment techniques, and nitrogen levels on growth and yield attributes of maize in maize-wheat cropping system

Treatments	Plant height at maturity (cm)		Grains grain-row^{-1}		Grains cob^{-1}		Cobs ha^{-1} (×10^3)		1,000-grain weight (g)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tillage and crop establishment										
CT-F	171.0	197.9	23.27	25.82	276.1	295.8	53.66	65.15	226.0	254.6
CT-B	178.9	205.1	26.87	28.07	289.0	309.8	60.97	69.95	225.2	256.9
ZT-F	169.2	184.2	23.03	23.63	280.3	275.0	53.20	54.36	225.1	249.5
ZT-B	179.2	201.2	27.04	25.93	286.4	297.5	59.46	65.50	225.6	255.7
ZT-F+R	172.0	193.7	23.48	25.80	279.0	292.2	55.23	64.20	224.3	251.9
ZT-B+R	179.5	204.6	26.65	29.66	291.5	310.7	61.43	71.21	224.9	257.5
SEm±	2.18	2.12	0.98	0.64	1.86	4.07	1.35	1.47	1.13	2.79
LSD ($P \leq 0.05$)	6.85	6.66	3.09	2.01	5.88	12.82	4.26	4.62	NS	NS
Nitrogen (kg ha^{-1})										
0	157.5	181.4	19.17	20.94	196.2	202.5	42.81	50.52	220.9	249.3
60	172.4	198.8	24.79	25.65	298.7	312.8	54.80	63.07	225.4	254.2
120	182.3	204.5	27.35	29.17	318.3	332.7	64.39	71.73	227.5	257.0
180	187.7	206.5	28.93	30.18	321.6	339.4	67.31	74.94	227.1	256.6
SEm±	2.12	1.77	0.75	0.56	1.51	2.97	1.05	1.33	0.67	1.04
LSD ($P \leq 0.05$)	6.08	5.07	2.16	1.60	4.34	8.53	3.00	3.82	1.93	2.97

CT-F: conventional tillage with sowing of crops on flat soil surface; CT-B: conventional tillage with sowing of crops on raised bed; ZT-F: zero tillage with sowing of crops on flat soil surface; ZT-B: zero tillage with sowing of crops on raised bed i.e. permanent bed; ZT-F+R: ZT-F with crop residue, ZT-B+R: ZT-B with crop residue.; SEm± : standard error of mean; LSD: least significant difference.

Table: 2
Effect of tillage and crop-establishment techniques, and nitrogen levels on yield performance of maize in maize-wheat cropping system

Treatments	Grain yield (t ha^{-1})		Stover yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest index (%)	
	2009	2010	2009	2010	2009	2010	2009	2010
Tillage and crop establishment								
CT-F	4.08	4.16	5.67	6.66	9.75	10.81	41.69	38.40
CT-B	4.58	4.39	6.32	6.97	10.91	11.36	41.83	38.59
ZT-F	4.06	3.90	5.55	6.28	9.61	10.19	42.09	38.28
ZT-B	4.54	4.22	6.26	6.71	10.80	10.92	41.90	38.54
ZT-F+R	4.20	4.13	5.83	6.62	10.03	10.75	41.72	38.41
ZT-B+R	4.71	4.49	6.46	7.02	11.17	11.51	41.96	38.93
SEm±	0.10	0.07	0.15	0.10	0.24	0.17	0.49	0.32
LSD ($P\leq0.05$)	0.33	0.22	0.43	0.31	0.76	0.53	NS	NS
Nitrogen (kg ha^{-1})								
0	3.29	3.36	4.90	5.47	8.19	8.83	40.15	38.03
60	4.19	4.13	5.86	6.55	10.04	10.68	41.69	38.66
120	4.87	4.62	6.50	7.30	11.37	11.92	42.86	38.72
180	5.10	4.75	6.82	7.52	11.92	12.27	42.76	38.69
SEm±	0.08	0.05	0.11	0.08	0.21	0.12	0.39	0.19
LSD ($P\leq0.05$)	0.24	0.15	0.32	0.23	0.59	0.36	1.13	0.53

CT-F: conventional tillage with sowing of crops on flat soil surface; CT-B: conventional tillage with sowing of crops on raised bed; ZT-F: zero tillage with sowing of crops on flat soil surface; ZT-B: zero tillage with sowing of crops on raised bed i.e. permanent bed; ZT-F+R: ZT-F with crop residue, ZT-B+R: ZT-B with crop residue.; SEm± : standard error of mean; LSD: least significant difference.

and 11.6-13.2% compared to 60 kg N ha^{-1} and by 37.5-48.1%, 32.6-33.5% and 35.0-38.8% compared to control (0 kg N ha^{-1}), respectively, but remained at par with 180 kg N ha^{-1}. Harvest index also improved up to 120 kg N ha^{-1}, but it did not differ significantly during 2010 over 60 kg N ha^{-1}. Being a cereal, maize is nutrient-responsive crop, particularly for N, therefore it responded well up to 120 kg N ha^{-1}. This might be due to the fact that N supply boosts the crop growth and developmental processes because it is involved in a number of physiological and biochemical processes in plant system (Stitt and Krapp, 1999). Consequently, benefit derived by the crop in vegetative and reproductive developments due to optimal N supply might be the reason for higher yields of maize at 120 kg N ha^{-1}.

Nutrient Uptake

The total N, P and K uptakes by maize were significantly influenced due to different tillage and crop establishment techniques and N levels during both the years of study (Table 3). ZT-B+R recorded the maximum total (grain + stover) N, P and K uptake of 95.79, 21.27 and 114.18 kg ha^{-1}, respectively, which was on par with ZT-B and CT-B during 2009 and CT-B during 2010, and significantly higher than other treatments during both the years. Irrespective of tillage practices, maize sown on raised beds significantly improved total N, P and K uptake over flat-planting by 11.0%, 15.7% and 8.9%, respectively. The higher N, P and K uptake by maize under bed planting might be due to better root growth, leading to more extraction of nutrients from soil, lower weed infestation and better yield performance. Singh *et al.* (2007) also reported that total N uptake by maize was highest (67.46 kg ha^{-1}) under raised beds than flat sowing of maize. ZT with residue *i.e.* CA practices (ZT-B+R and ZT-F+R) significantly improved the N, P and K uptake over corresponding ZT without residue (ZT-B and ZT-F). The higher uptake of these nutrients in maize under CA practices might be due to better root development, which enhanced nutrient density in maize crop due to increased forage area for nutrient extraction. In addition to this, the application of wheat residue added the nutrients in soil layers and ultimately enhanced nutrient availability in crop root zone which might have lead to more nutrient uptake. A similar finding of higher N, P and K uptake under CA practices was reported by Alam *et al.* (2014); Naresh *et al.* (2014); Yadav *et al.* (2016) and Jakhar *et al.* (2017).

The total N, P and K uptake in maize also increased significantly at 120 kg N ha^{-1} over 0 and 60 kg N ha^{-1}, but remained at par with 180 kg N ha^{-1}. The higher concentration of N, P and K in grain and stover along with higher biomass yields of maize could be the reason for higher uptake of these nutrients in maize at 120 kg N ha^{-1}. Further, these nutrients (N, P and K) are synergistic to each other in nature and uptake of one enhances the uptake of other as well.

Economics

The cost of cultivation for maize varied considerably with ₹ 18.33–20.19 × 10^3 ha^{-1} and ₹ 14.63–22.51 × 10^3 ha^{-1} during 2009 and 2010, respectively under different tillage and crop establishment treatments. During 2010, the cost of cultivation was 18.9% less under ZT practices compared to CT practices (Table 4). Thus, the ZT technology reduced production costs by ₹ 3430 ha^{-1} mainly due to reduced

Table: 3
Effect of tillage and crop-establishment techniques, and nitrogen levels on nutrient uptake of maize in maize-wheat cropping system

Treatment	Total nitrogen (kg ha^{-1})		Total phosphorous (kg ha^{-1})		Total potassium (kg ha^{-1})	
	2009	2010	2009	2010	2009	2010
Tillage and crop establishment						
CT-F	82.68	88.17	17.30	18.71	92.93	106.48
CT-B	93.37	93.26	20.20	21.22	103.48	111.38
ZT-F	81.39	77.93	17.10	16.80	91.02	101.02
ZT-B	92.40	87.33	20.17	19.43	102.35	108.49
ZT-F+R	84.75	87.21	17.74	18.71	95.40	106.47
ZT-B+R	94.87	95.79	20.74	21.27	106.11	114.18
SEm±	2.32	1.39	0.59	0.68	2.39	1.63
LSD ($P\leq0.05$)	7.33	4.39	1.85	2.13	7.53	4.79
Nitrogen (kg ha^{-1})						
0	60.87	61.95	13.65	14.01	78.26	85.85
60	83.50	84.27	18.15	18.84	95.54	104.98
120	101.52	101.42	21.29	21.95	107.41	118.38
180	107.08	105.48	22.41	22.62	112.98	122.80
SEm±	2.35	1.48	0.41	0.37	2.09	1.61
LSD ($P\leq0.05$)	6.74	4.26	1.17	1.05	6.00	4.60

CT-F: conventional tillage with sowing of crops on flat soil surface; CT-B: conventional tillage with sowing of crops on raised bed; ZT-F: zero tillage with sowing of crops on flat soil surface; ZT-B: zero tillage with sowing of crops on raised bed i.e. permanent bed; ZT-F+R: ZT-F with crop residue, ZT-B+R: ZT-B with crop residue.; SEm± : standard error of mean; LSD: least significant difference.

Table: 4
Effect of tillage and crop-establishment techniques, and nitrogen levels on economics of maize in maize-wheat cropping system

Treatment	Cost of cultivation (× 10^3 ₹ ha^{-1})		Gross returns (× 10^3 ₹ ha^{-1})		Net returns (× 10^3 ₹ ha^{-1})		B:C ratio		Economic efficiency (₹ ha^{-1}day^{-1})	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tillage and crop establishment										
CT-F	20.01	17.89	39.91	43.23	19.90	25.34	0.99	1.41	193.2	253.4
CT-B	20.19	18.31	44.84	45.58	24.65	27.28	1.21	1.48	239.3	272.8
ZT-F	18.33	14.71	39.64	40.63	21.31	25.91	1.15	1.75	206.9	259.1
ZT-B	18.51	14.63	44.39	43.81	25.87	29.17	1.38	1.98	251.2	291.7
ZT-F+R	18.33	22.51	41.10	42.97	22.77	20.45	1.23	0.90	221.0	204.5
ZT-B+R	18.51	22.43	46.02	46.50	27.50	24.06	1.47	1.06	267.0	240.6
SEm±	-	-	0.95	0.67	0.95	0.67	0.05	0.04	9.3	6.7
LSD ($P\leq0.05$)	-	-	3.00	2.11	3.00	2.11	0.17	0.11	29.2	21.1
Nitrogen (kg ha^{-1})										
0	17.39	16.71	32.51	35.02	15.12	18.32	0.87	1.16	146.8	183.2
60	18.60	18.00	41.04	42.90	22.44	24.91	1.21	1.45	217.8	249.1
120	19.51	18.99	47.41	47.93	27.89	28.94	1.43	1.58	270.8	289.4
180	20.42	19.98	49.65	49.29	29.22	29.31	1.43	1.52	283.7	293.1
SEm±	-	-	0.70	0.50	0.70	0.50	0.04	0.03	6.8	5.0
LSD ($P\leq0.05$)	-	-	2.02	1.42	2.02	1.42	0.11	0.07	19.6	14.2

CT-F: conventional tillage with sowing of crops on flat soil surface; CT-B: conventional tillage with sowing of crops on raised bed; ZT-F: zero tillage with sowing of crops on flat soil surface; ZT-B: zero tillage with sowing of crops on raised bed i.e. permanent bed; ZT-F+R: ZT-F with crop residue, ZT-B+R: ZT-B with crop residue.; SEm± : standard error of mean; LSD: least significant difference.

tractor costs associated with conventional practice of tilling the soil. The maximum gross returns was obtained under ZT-B+R (₹ 46.50 × 10^3 ha^{-1}), which was significantly higher than rest of the treatments, except CT-B. However, the highest net returns (₹ 29.17×10^3 ha^{-1}) and economic efficiency (₹ 291.7 ha^{-1} day^{-1}) were obtained with ZT-B, and these were recorded significantly higher (12.6-42.6%) than rest of the treatments, except CT-B during the year 2010; though, the B:C ratio (1.98) was recorded significantly higher with ZT-B by 13.1-120% over rest of the treatments. Residue-applied treatments exhibited higher cost of production and lower net returns owing to higher prices of crop-residues. These treatments have other advantages of more carbon and nutrient build-up in the soil, which could be taken into consideration for calculating net benefit. The highest net returns and B:C ratio under ZT-B was because of comparatively higher yields and lesser cost incurred in seed, irrigation water, weed control and manpower. This was in agreement with the findings of Zentner *et al.* (2002). Yadav *et al.* (2016) also reported that ZT and PB planting in maize registered 34.2-40.2%, 18-29.2% and 26-38.1% higher energy efficiency, net returns and B:C ratio over to CT planting, respectively. Hence, cultivation of maize under permanent bed system (ZT-B) was found most profitable.

The cost of cultivation increased linearly with each successive increase in N level from 0 to 180 kg ha^{-1} due to increase in cost of nitrogen fertilizer. Similarly, the gross returns, net returns, B:C ratio and economic efficiency also increased significantly with each successive increase in N level from 0 to 120 kg ha^{-1} during both the years.

Response Function of N Fertilization

Maize responded differentially to N levels under different tillage and crop-establishment techniques. The response of maize to N was quadratic (Fig. 2). The greater response to N was observed under CT and raised beds than ZT and flat planting techniques, respectively. Response of N applied to maize improved further due to residue application. Crop-residue applied treatments responded differentially in terms of yield enhancement under varying levels of N, indicating that the beneficial effect of crop-residue recycling was more discernible when N levels were increased from zero to highest. The response functions of N fertilization in maize were worked out by quadratic equations between the grain yield and N levels (Table 5). The N_{opt} for maize under all the treatments was higher than the recommended doses of N (120 kg N ha^{-1}), indicating that little higher doses of N are needed to achieve higher yields. The N_{opt} for maize was recorded least under CT-F, indicating that yields could not be increased further under these practices even with the application of higher dose of N. The highest N_{opt} for maize was recorded under bed-planting technique, which illustrates the importance of beds for maize in achieving the higher yield levels. Furthermore, crop residue recycled in maize, particularly under bed-planting (ZT-B+R), reduced the N_{opt} for maize and saved around 20-25 kg N ha^{-1}, indicating the role of crop residue in N economy. Moreover, this aforesaid treatment (ZT-B+R) also resulted into maximum values of grain yield, response in kg grain per kg N, net profit and also highest returns in ₹ per ₹ invested on N over the CT-B and ZT-B without residue-applied treatments. Evidently, the N contribution from recycled crop-residues increased 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. Thus, the N economy under residue-applied treatments was affected not only due to direct application of N but also due to addition of mineralized-N from crop residues. Sharma and Behera (2009) reported that N economy in wheat was 21 kg N ha^{-1} owing to residue incorporation of intercropped greengram, cowpea and groundnut; and 49–56 kg N ha^{-1} of sole cropped greengram and groundnut.

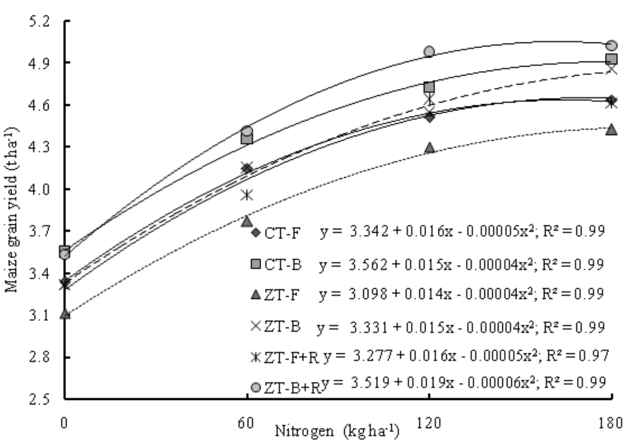

Fig. 2. Response of maize to varying levels of N as influenced by different tillage and crop-establishment techniques

4. CONCLUSIONS

The ZT-B practices reduced production cost, and increased crop productivity and economic returns significantly. Crop residues significantly improved crop produc-

Table: 5

Effect of tillage and crop-establishment techniques on response function of nitrogen fertilization of maize in maize-wheat cropping system during 2010

Treatments	Regression equation	N_{opt} (kg ha^{-1})	Y_{opt} (kg grain ha^{-1})	Response at N_{opt} (kg grain ha^{-1})	Response at N_{opt} (kg grain kg N^{-1})	Net profit (₹ ha^{-1})	Return in ₹ $₹^{-1}$ invested on N
CT-F	Y = 3.342+0.0157x-0.00005x2, R^2 = 0.99	138.3	4557.2	1214.9	8.8	8411.1	3.7
CT-B	Y = 3.562+0.0151x-0.00004x2, R^2 = 0.99	165.3	4965.6	1403.1	8.5	9621.2	3.5
ZT-F	Y = 3.098+0.0142x-0.00004x2, R^2 = 0.99	154.1	4336.3	1238.3	8.0	8356.4	3.3
ZT-B	Y = 3.331+0.0150x-0.00004x2, R^2 = 0.99	164.1	4714.9	1384.3	8.4	9476.3	3.5
ZT-F+R	Y = 3.277+0.0160x-0.00005x2, R^2 = 0.97	141.3	4539.3	1262.4	8.9	8780.1	3.8
ZT-B+R	Y = 3.519+0.0189x-0.00006x2, R^2 = 0.99	141.9	4992.6	1473.7	10.4	10629.3	4.5

CT-F: conventional tillage with sowing of crops on flat soil surface; CT-B: conventional tillage with sowing of crops on raised bed; ZT-F: zero tillage with sowing of crops on flat soil surface; ZT-B: zero tillage with sowing of crops on raised bed i.e. permanent bed; ZT-F+R: ZT-F with crop residue, ZT-B+R: ZT-B with crop residue; N_{opt}: economic optimum dose of fertilizer N; Y_{opt}: grain yield at N_{opt}.

tivity further, but also increased the cost of cultivation. However, increase in cost of cultivation due to crop residues could be compromised/compensated through improved soil fertility and nutrient economy as crop residues could reduce the external fertilizer requirement of maize substantially. Therefore, based on the present study, it is suggested that conservation agriculture (ZT-B+R) based production system along with 142 kg N ha^{-1} should be promoted among the farmers of Indo Gangetic Plains for improving productivity, profitability and long-term sustainability of the maize based cropping systems.

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