

Tillage and nutrient-management practices for improving productivity and soil physico-chemical properties in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system under rainfed conditions in *Kandi* region of Punjab

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Received : February 2017; Revised accepted : May 2018

ABSTRACT

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons from 2012–13 to 2014–15 at Ballawal Saunkhri, Punjab, to study the effect of tillage and sources of nitrogen (N) on crop productivity and soil health in maize (*Zea mays* L.) – wheat (*Triticum aestivum* L.) cropping system. The experiment was conducted under rainfed conditions in a split-plot design with 3 replications. In the main plots 2 tillage practices, viz. rotavator and conventional tillage, were assigned and in the subplots 6 nutrient-management practices, viz. control, 40 kg N/ha through urea, 80 kg N/ha through urea, 20 kg N/ha through compost + 20 kg N/ha through urea, 40 kg N/ha through urea + 40 kg N/ha through compost and 20 kg N/ha through compost + 20 kg N/ha through *Leucaena* leaves, were allotted. Conventional tillage resulted in 15.5 and 0.44 % higher grain yield of maize and wheat (3.10 and 2.26 t/ha respectively) over rotavator (2.62 and 2.25 t/ha respectively). Consequently, system productivity of conventional tillage (5.58 t/ha) in terms of wheat-equivalent yield was 9.7% higher than that with rotavator (5.04 t/ha). Application of 80 kg N/ha through urea increased the maize yield by 45% and wheat yield by 43% over the control. System productivity was significantly higher when N was applied either through urea (5.65 to 6.51 t/ha) or through urea and organic sources (4.89 to 6.19 t/ha) than the control (3.61 t/ha). The input-energy requirement in conventional tillage was 6.3 and 4.4% higher in maize and wheat than rotavator. In maize, output energy, energy balance, energy-use efficiency and energy productivity were significantly higher in conventional tillage than rotavator. While in wheat energy values were higher in rotavator, these were at par with conventional tillage. Bulk density (1.44 Mg/m³) and soil organic carbon (0.59%) with rotavator improved significantly. Application of 40 kg/ha N from urea + 40 kg N/ha from compost recorded the highest bulk density (1.41 Mg/m³), organic carbon (0.60%), available N (199 kg/ha) and P (29.6 kg/ha). Benefit: cost ratio of the system was significantly higher with rotavator (1.70) and application of 80 kg N/ha (2.07) from urea.

Key words : Energetics, Maize–wheat cropping system, N sources, Nutrient management, Rainfed, Tillage

Maize is one of the most important cereal crops in India, cultivated over an area of 9.26 million ha with production and productivity of 23.67 million tonnes and 2,557 kg/ha respectively. Wheat is the most important winter (*rabi*) cereal in India, is cultivated over an area of 30.97 million ha with production and productivity of 88.94 million ha and 2,872 kg/ha respectively (DES, 2015).

Maize–wheat system is common in *Kandi* region of Punjab under rainfed situations but with lower productivity. The constraints in production are less moisture due to dry spells in maize and poor conserved moisture during the sowing of wheat, improper nutrient management and higher energy consumption. Generally, maize and wheat are grown by broadcasting seed after 2–3 tillage operations and the conventional method of growing these crops is laborious, costly and time consuming. In conventional tillage, more energy and labour is required for crop production resulting in lower economic returns (Chaudhary and Behera, 2013). Moreover, intensive tillage results in reduction in soil organic matter due to accelerated oxida-

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tion and breakdown of organic matter (Shekhar *et al.*, 2014). It also leads to compaction and eventually soil loss through wind and water erosion (Ji *et al.*, 2013). Success of the wheat crop depends on the proper moisture conservation after the harvesting of the maize crop. Rotavator is a useful implement to conserve energy and moisture. It pulverizes the soil in a single pass, forms uniform and fine size clods, incorporates the stubbles into the soil and creates soil mulch to conserve moisture for sowing wheat (CIAE, 2002). Further, maize-wheat cropping system is highly nutrient exhaustive. The integrated use of organic materials and inorganic nitrogenous fertilizers meets the crop needs as well as maintains favourable ecological conditions on long-term basis (Kumar and Kumar, 2016). It helps restore and sustain fertility and crop productivity and checks the emerging deficiency of nutrients other than N, P and K. Hence the present investigation was undertaken to study the effects of tillage and nutrient-management practices on crop productivity and soil quality in maize-wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) and rainy (*kharif*) seasons from 2012–13 to 2014–15 at the Regional Research Station (PAU), Ballawal Saunkhri (31°5.87' N, 76°23.37' E, 348 m above the mean sea-level). The climate of the site is sub-humid with mean annual rainfall of 1,056 mm. About 80% rain occurs in the *kharif* season (July–September) and rest 20% occurs in the *rabi* season. Soil of the experimental site was sandy loam in texture, with pH 8.3, electrical conductivity (EC) 0.24 dS/m and containing 0.54 % organic C, 197 kg/ha available N, 22.4 kg/ha available P and 142 kg/ha available K in the top 0–15 cm surface soil. The rainfall received during the crop growing period in *kharif* 2012, 2013 and 2014 was 383.6 mm, 601.3 mm and 427.6 mm respectively, and during corresponding *rabi* season it was 165.6 mm, 226.0 mm and 324.2 mm respectively. The experiment was conducted under rainfed conditions in a splitplot design with 3 replications. In the main plots 2 tillage practices, viz. rotavator (RTV) and conventional tillage (CT), were assigned and in the subplots 6 nutrient-management practices, viz. control, 40 kg N/ha through urea (40 kg NU), 80 kg N/ha through urea (80 kg NU), 20 kg N/ha through compost + 20 kg N/ha through urea (20 kg NU + 20 kg NC), 40 kg N/ha through urea + 40 kg N/ha through compost (40 kg NU + 40 kg NC) and 20 kg N/ha through compost + 20 kg N/ha through *Leucaena* leaves (20 kg NC + 20 kg NSL), were allotted. In conventional tillage field is prepared by 2 ploughings followed by planking to obtain fine seed-bed for sowing. Both the tillage and nutrient-management treatments were applied in maize and

wheat. Maize variety 'JH 3459' was sown using 20 kg seed/ha on 23, 7 and 16 July and harvested on 12 October, 26 September and 6 October during 2012, 2013 and 2014 respectively. After harvesting of maize wheat variety 'PBW 175' was sown using 100 kg seed/ha on 8, 5 and 11 November 2012, 2013 and 2014 and harvested on 20, 21 and 23 April 2013, 2014 and 2015, respectively. Maize crop was sown at a row and plant spacing of 45 cm and 22.5 cm and wheat was sown in rows, 25 cm apart. The N was applied as per treatment and recommended P (40 kg/ha) was applied through single superphosphate to both the crops and recommended K (20 kg/ha) was applied through muriate of potash to maize and 30 kg/ha to wheat. The organic manures were applied as per their nutrient content on oven dry-weight basis. The compost and fresh *Leucaena* leaves contained 0.6% and 3.2% N respectively. The compost and green leaves were applied at sowing and mixed thoroughly in the soil. Other cultural practices, viz. weed management and plant-protection measures, were followed as per package of practices for *kharif* and *rabi* crops of the Punjab Agricultural University, Ludhiana, India. The soil samples were collected from 0–15 cm soil depth after the harvesting of wheat crop and were used for the estimation of organic carbon (OC), EC, pH, available N (KMnO₄ method), P (Olsen method) and K by using standard methods. The bulk density (BD) of soil was determined by using core sampler. Water use by the crops was computed as the sum of rain during the growing season plus soil water depletion from 180 cm profile between sowing and harvesting of the crops. Water-use efficiency was calculated as grain yield divided by water use. Yield attributes and grain yield of maize and wheat were recorded at maturity. System productivity was worked out in terms of wheat grain-equivalent yield (WEY) by taking the market price of maize and wheat grains. Energy values of various inputs and outputs used were calculated as suggested by Devasenapathy *et al.* (2009). Energy balance was calculated by subtracting the input energy from the output energy and energy use-efficiency was computed by dividing output energy with input energy. The energy productivity was estimated by dividing grain yield (kg/ha) with input energy (MJ/ha). Various N-use efficiencies, viz. agronomic efficiency of nitrogen (AEN) and partial factor productivity (PFP) of applied nitrogen were worked out on the basis of system productivity as suggested by (Dobermann, 2007). Benefit: cost ratio for different treatments was calculated by dividing the net returns by the cost of cultivation of that treatment. Data were statistically analyzed using the F-test procedure given by Gomez and Gomez (1984). Critical difference values at $P=0.05$ were used to determine the significance of difference between means.

RESULTS AND DISCUSSION

Growth, yield attributes, yields and system productivity of maize and wheat

Effect of tillage practices: The tillage practices significantly increased the plant height of maize but had no significant effect on the plant height of wheat (Table 1). The maximum height of maize was recorded in CT, being significantly higher over RTV by 4.2%. The yield attributes of both maize and wheat were not influenced by the tillage practices, i.e. CT and RTV. The maximum cob length, cob girth, grains/cob and test weight of maize were recorded in CT. This resulted in significant increase in grain yield of maize with CT over RTV. In wheat, the maximum ear length, grains/ear and test weight were recorded with RTV, but effective tillers/m row were maximum in the conventional tillage. Thus, in wheat the tillage practice had no significant effect on the grain yield. In conventionally tilled maize and wheat, the maximum yield was recorded and it was 15.5 and 0.44% higher than tillage by RT. System productivity was significantly affected by tillage practices. Among the 2 tillage practices, the maximum system productivity in terms of wheat-equivalent yield (WEY) was recorded in CT and it was 9.7% higher than tillage with RTV. The RTV though resulted in fine soil tilth at top layer but did not affect the soil at depth and high speed rotating action of blade may even compact the soil beneath

its operational depth, thus causing low yield (Ahmad *et al.*, 2010). Higher yield in CT is owing to the availability of water to the maize crop during dry spells, as more water is stored in the profile due to deeper ploughing in conventional tillage as compared to the RT. Hadda and Arora (2006), Bhushan *et al.* (2009) and Kaushal *et al.* (2012) also reported higher infiltration rate and increased soil moisture storage in conventional tillage.

Effect of nitrogen sources: Application of N in maize and wheat either through urea alone or through combination of urea and organic sources significantly improved the growth and yield attributes of both the crops as compared to the control. In maize, the maximum plant height, cob length, cob girth, grains/cob and test weight were recorded with the application of 80 kg NU and it was at par with application of 40 kg NU + 40 kg NC but significantly higher over the control and all other sources of N. Similarly, in wheat the maximum values of yield attributes, viz. plant height, ear length, effective tillers/m and 1,000-grain weight recorded with the application of 80 kg NU were significantly higher over the control, 20 kg NU + 20 kg NC and 20 kg NU + 20 kg NL, but at par with 40 kg NU + 40 kg NC. Application of nitrogen either through urea or through combination of urea and organic sources produced significantly higher grain yield of maize and wheat and thereby resulted in significantly higher system produc-

Table 1. Effect of tillage and nutrient management on growth and yield attributes of maize and wheat in maize–wheat cropping system (pooled data of 3 years)

Treatment	Maize					Wheat				
	Plant height at harvesting (cm)	Cob length (cm)	Cob girth (cm)	Grains/cob	1,000-grain weight (g)	Plant height at harvest (cm)	Ear length (cm)	Effective tillers/m row	Grains/ear	1,000-grain weight (g)
<i>Tillage</i>										
Conventional tillage	186.8	13.4	11.3	361.7	195.4	82.8	8.9	65.4	39.2	41.8
Rotavator	178.9	13.1	11.0	351.9	188.5	82.3	9.0	62.4	40.1	41.9
SEm±	1.56	0.16	0.09	6.03	2.05	0.74	0.13	0.88	0.58	0.39
CD (P=0.05)	5.43	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Source of N</i>										
Control	172.9	12.6	10.6	330.1	179.6	76.4	8.1	52.9	34.3	39.2
40 kg N/ha (urea)	184.1	13.1	11.1	358.6	192.2	84.4	9.1	63.7	40.1	42.2
80 kg N/ha (urea)	193.6	14.1	11.6	381.2	202.0	86.8	9.7	73	41.2	44
20 kg N/ha (compost) + 20 kg N/ha (urea)	177.9	13.1	11.1	352.6	190	80.9	8.7	63	41.8	41.3
40 kg N/ha (compost) + 40 kg N/ha (urea)	189.1	13.8	11.3	362.3	199.7	86.2	9.6	71.5	40.4	43.4
20 kg N/ha (compost) + 20 kg N/ha (<i>Leucaena</i> leaves)	179.4	12.9	11.0	356.2	188.2	80.6	8.3	59.4	40.1	41.0
SEm±	2.31	0.17	0.13	6.70	2.63	0.90	0.14	1.28	0.72	0.49
CD (P=0.05)	6.50	0.48	0.36	19	7.44	2.56	0.40	3.62	2.05	1.40

NS, non-significant

tivity (Table 2). The maximum grain yield of maize recorded with the 80 kg NU was significantly higher than all other treatments except 40 kg NU + 40 kg NC (189.1 kg/ha) and increased the yield by 45, 24, 24, 15 and 5% respectively, over the control, 20 kg NU + 20 kg NC, 20 kg NC + 20 kg NL, 40 kg NU and 40 kg NU + 40 kg NC. Similarly, in wheat application of 80 kg NU resulted in grain yield at par with 40 kg NU + 40 kg NCUa but significantly higher than all other N sources. The grain yield reduced when N level was reduced from 80 kg/ha to 40 kg/ha supplied either through urea alone (2.46 t/ha) or through combination of urea and compost (2.17 t/ha) or *Leucaena* leaves (2.01 t/ha). The per cent reduction in grain yield was 76, 36, 26, 10 and 4%, respectively, with control, 20 kg NC + 20 kg NU, 20 kg NC + 20 kg NL, 40 kg NU, 40 kg NC + 40 kg NU as compared to 80 kg NU. System productivity in terms of wheat-equivalent yield increased significantly owing to the application of N through organic and inorganic sources alone as well as in combination (4.89 to 6.51 t/ha) to maize and wheat as compared to the control (3.61 t/ha). Application of 80 kg NU recorded significantly highest system productivity followed by 40 kg NC + 40 kg NU and both these treatments recorded corresponding increase of 45 and 42% over the control, 25 and 21% over 20 kg NU + 20 kg NL, 23 and 19% over 20 kg NU + 20 kg NC and 13 and 9% over 40 kg NU. The results indicate that application of recom-

mended dose of N (80 kg/ha) to maize and wheat crops through inorganic source alone and 50% through organic + 50% through inorganic source maintained the proper nutrient supply throughout the crop-growing period. The treatments receiving suboptimal dose of N could not meet the crop nutrient requirement and thus resulted in lower yields (Sutaria *et al.*, 2010; Upadhyay and Vishwakarma, 2014).

Soil health

Effect of tillage practices: Tillage practices exhibited significant effect on bulk density and organic matter. There was not much variation in the pH, EC and available N, P and K status of the soil recorded after the harvesting of wheat crop (Table 3). Bulk density in conventionally tilled soils was significantly higher than RTV. The mixing of stubble in the upper parts of the soil by rotary tillers might have resulted in the lower soil density (Yavuzcan *et al.*, 2002). The RTV also had a positive effect on the soil organic carbon, being significantly higher than conventionally tilled plots (0.53%). Increase in organic carbon might be attributed to the cutting and incorporation of the weeds as well as residues of the previous crop by the RTV (Sharma and Behera, 2008). Zhao *et al.* (2015) also reported increase in soil organic carbon under rotary tillage as compared to CT with plough.

Effect of nitrogen sources: Nitrogen supply through

Table 2. Effect of tillage and nutrient management on yield of maize and wheat and system productivity in maize–wheat cropping system (pooled data of 3 years)

Treatment	Maize grain yield (t/ha)				Maize stover yield (t/ha)	Wheat grain yield (t/ha)				Wheat straw yield (t/ha)	System productivity (t/ha)
	2012–13	2013–14	2014–15	Pooled		2012–13	2013–14	2014–15	Pooled		
<i>Tillage</i>											
Conventional tillage	2.77	3.21	3.31	3.10	6.31	2.06	2.09	2.64	2.26	3.94	5.58
Rotavator	1.91	3.07	2.88	2.62	5.21	1.80	2.23	2.71	2.25	4.00	5.04
SEM±	0.05	0.07	0.11	0.05	0.03	0.06	0.08	0.05	0.04	0.06	0.07
CD (P=0.05)	0.33	NS	NS	0.16	0.28	0.39	0.49	NS	NS	NS	0.26
<i>Source of N</i>											
Control	1.44	2.46	1.88	1.93	3.85	1.38	1.41	1.87	1.55	2.78	3.61
40 kg N/ha (urea)	2.48	3.04	3.45	2.99	5.98	2.02	2.50	2.84	2.46	4.22	5.65
80 kg N/ha (urea)	2.88	3.57	4.14	3.53	7.07	2.04	2.77	3.38	2.73	4.90	6.51
20 kg N/ha (compost) + 20 kg N/ha (urea)	2.13	3.16	2.73	2.67	5.48	1.93	2.05	2.52	2.17	3.77	5.02
40 kg N/ha (compost) + 40 kg N/ha (urea)	2.67	3.48	3.86	3.34	6.76	2.35	2.38	3.15	2.63	4.64	6.19
20 kg N/ha (compost) + 20 kg N/ha (<i>Leucaena</i> leaves)	2.42	3.12	2.53	2.69	5.43	1.87	1.88	2.29	2.01	3.51	4.89
SEM±	0.07	0.08	0.16	0.07	0.09	0.08	0.09	0.07	0.05	0.08	0.09
CD (P=0.05)	0.21	0.25	0.48	0.18	0.36	0.23	0.26	0.22	0.13	0.23	0.24

NS, non-significant

organic sources alone and in combination with urea showed significant improvement in the physico-chemical properties of the soil like bulk density, organic carbon and available N and P as compared to the control. Soil bulk density decreased from 1.47 Mg/m³ in the control and 1.48 Mg/m³ in 80 kg NU to 1.41 Mg/m³ in 40 kg NU + 40 kg

NC and 1.43 Mg/m³ in 20 kg NC + 20 kg NSL treatments. The maximum organic carbon and available N and P recorded in 40 kg NU + 40 kg NC were significantly higher than the control and 40 kg NU treatments but at par with all other treatments. This improvement in soil properties could be owing to the addition of organic matter through

Table 3. Effect of tillage and nutrient management on soil physico-chemical properties and soil nutrient status after crop harvesting

Treatment	Physico-chemical properties of soil			Soil nutrients status				AEN	PFP
	pH	EC (ds/m)	Bulk density (Mg/m ³)	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)		
<i>Tillage</i>									
Conventional tillage	8.18	0.29	1.47	0.53	179	26.0	139	17	48
Rotavator	8.12	0.28	1.44	0.59	200	25.5	139	15	43
SEm±	0.02	0.01	0.005	0.01	4.0	0.3	4.3	–	–
CD (P=0.05)	NS	NS	0.03	0.06	NS	NS	NS	–	–
<i>Source of N</i>									
Control	8.18	0.28	1.47	0.52	172	17.0	126	–	–
40 kg N/ha (urea)	8.13	0.29	1.48	0.54	182	24.9	135	25	71
80 kg N/ha (urea)	8.05	0.29	1.48	0.57	188	27.9	143	19	41
20 kg N/ha (compost) + 20 kg N/ha (urea)	8.18	0.29	1.46	0.58	198	29.5	148	18	63
40 kg N/ha (compost) + 40 kg N/ha (urea)	8.15	0.30	1.41	0.60	199	29.6	142	17	39
20 kg N/ha (compost) + 20 kg N/ha (<i>Leucaena</i> leaves)	8.20	0.28	1.43	0.57	199	25.8	139	16	61
SEm±	0.05	0.01	0.01	0.01	5.7	2.0	7.0	–	–
CD (P=0.05)	NS	NS	0.03	0.04	17.0	5.8	NS	–	–
Initial value	8.3	0.24	1.48	0.54	197	22.4	142	–	–

AEN, Agronomic efficiency of nitrogen; PFI, partial factor productivity; NS, non-significant

Table 4. Effect of tillage and nutrient management on energetic of maize and wheat in maize–wheat cropping system (pooled data of 3 years)

Treatment	Input energy (× 10 ³ MJ/ha)		Output energy (× 10 ³ MJ/ha)		Energy balance (× 10 ³ MJ/ha)		Energy use-efficiency (output/input)		Energy productivity (kg/MJ)	
	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat
<i>Tillage</i>										
Conventional tillage	9.47	9.38	124.5	82.6	115	73.2	13.4	8.96	0.33	0.25
Rotavator	8.87	8.97	103.6	83	94.8	74	12.3	9.85	0.31	0.27
SEm±	–	–	1.64	1.03	1.64	1.03	0.16	0.14	0.006	0.005
CD (P=0.05)	–	–	5.66	NS	5.66	NS	0.57	0.48	0.01	0.02
<i>Source of N</i>										
Control	5.48	5.59	76.5	57.5	71	51.9	14.0	10.51	0.35	0.28
40 kg N/ha (urea)	7.93	8.02	118.7	88.9	110.8	80.9	15.0	11.19	0.38	0.31
80 kg N/ha (urea)	10.36	10.44	140.3	101.3	129.9	90.8	13.5	9.76	0.34	0.26
20 kg N/ha (compost) + 20 kg N/ha (urea)	10.26	10.21	107.8	79	97.5	68.8	11.2	8.12	0.28	0.22
40 kg N/ha (compost) + 40 kg N/ha (urea)	9.3	9.22	133.6	96.7	124.3	87.4	14.4	10.51	0.38	0.28
20 kg N/ha (compost) + 20 kg N/ha (<i>Leucaena</i> leaves)	11.66	11.59	107.4	73.4	95.7	61.9	9.2	6.36	0.23	0.17
SEm±	–	–	2.27	1.31	2.27	1.31	0.27	0.17	0.008	0.006
CD (P=0.05)	–	–	6.43	3.72	6.43	3.72	0.76	0.47	0.02	0.02

NS, non-significant

compost releases organic acids in the soil which helps in the release of the fixed nutrients. Jat *et al.* (2012) and Manjhi *et al.* (2014) also reported improvement in organic carbon and available nutrients with combined use of organic and inorganic nutrients.

Efficiency indices: Both agronomic efficiency of nitrogen (AEN) and partial factor productivity were higher in CT. Application of N either through urea alone or through urea + organic source, AEN and PFP reduced as the N level increased from 40 kg/ha to 80 kg/ha. In 80 kg NU alone, AEN and PFP reduced by 32 and 73%, respectively, as compared to 40 kg NU. In integrated application of 40 kg NU + 40 kg NC AEN and PFP reduced by 6 and 62%, respectively, as compared to 20 kg NU + 20 kg NC.

Energetics

Effect of tillage practices: The input-energy requirement was the highest for maize and wheat crop sown with CT which was 6.3 and 4.4% higher than sowing with RTV. Maize crop sown with CT resulted in significantly higher (16.8%) energy output, than RTV (Table 4). However, in wheat energy output was higher with RTV but at par with CT. The net energy, energy-use efficiency and energy productivity were influenced significantly by tillage practices in maize and wheat (Table 4). In maize, CT resulted in 20.2×10^3 MJ/ha higher net energy than RTV, which was 17.6% higher. The energy-use efficiency in maize was higher with CT, while in wheat RTV resulted in higher energy-use efficiency. The maximum energy pro-

ductivity in maize was recorded with CT which was 6.1% higher than RTV. However, in wheat RTV resulted in significantly higher energy productivity and it was 7.4% higher than CT.

Effect of nitrogen sources: Among the N sources, highest input energy was required for maize and wheat with the application of 20 kg NU + 20 kg NL and the lowest input energy for maize and wheat cultivation was consumed in the control (no nitrogen application) treatment. All the N sources recorded significantly higher output energy as compared to the control. Application of 80 kg NU recorded the maximum output energy in maize and wheat which was significantly higher than all other treatment and 45.5 and 43.2% higher over the control. However, significantly higher energy-use efficiency of 15.0 in maize and 11.2 in wheat was recorded with the application of 40 kg NU and it was at par with 40 kg NU + 40 kg NC (14.4 and 10.51% respectively). Application of 40 kg NU recorded significantly higher energy productivity in maize and wheat than the control and all other N sources, except supply of 40 kg NU + 40 kg NC to maize and wheat.

Economics

Effect of tillage practices: The cost of cultivation of maize–wheat system was significantly higher in CT (Table 5) than RTV. Though significantly higher gross returns were obtained in CT, but difference in net returns was non-significant. In maize, the highest benefit: cost ratio was recorded in CT than rotavator and in wheat benefit: cost

Table 5. Effect of tillage and nutrient management on economics of maize–wheat cropping system (pooled data of 3 years)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit : cost ratio									
				Maize				Wheat					System Pooled
				2012–13	2013–14	2014–15	Pooled	2012–13	2013–14	2014–15	Pooled		
<i>Tillage</i>													
Conventional tillage	59.3	96.6	37.3	1.87	1.83	1.69	1.80	1.35	1.48	1.52	1.45	1.63	
Rotavator	51.4	88.6	37.2	1.54	2.02	1.68	1.74	1.37	1.80	1.81	1.66	1.70	
SEM \pm	0.06	1.16	1.10	0.03	0.04	0.05	0.02	0.04	0.04	0.01	0.02	0.02	
CD (P=0.05)	0.20	4.01	NS	0.19	0.23	0.30	NS	0.27	0.26	0.07	0.07	0.06	
<i>Source of N</i>													
Control	47.6	62.7	15.2	1.18	1.68	1.14	1.33	1.15	1.35	1.38	1.29	1.32	
40 kg N/ha (urea)	52.8	98.5	45.8	1.92	2.00	1.98	1.97	1.50	1.91	1.85	1.75	1.86	
80 kg N/ha (urea)	54.5	113.8	59.3	2.15	2.26	2.30	2.24	1.50	2.10	2.12	1.91	2.07	
20 kg N/ha (compost) + 20 kg N/ha (urea)	55.9	87.7	31.7	1.54	1.93	1.51	1.66	1.34	1.55	1.52	1.47	1.56	
40 kg N/ha (compost) + 40 kg N/ha (urea)	61.6	108.1	46.6	1.76	1.94	1.91	1.87	1.46	1.60	1.80	1.62	1.75	
20 kg N/ha (compost) + 20 kg N/ha (<i>Leucaena</i> leaves)	59.7	84.7	24.9	1.65	1.75	1.28	1.56	1.22	1.33	1.31	1.29	1.43	
SEM \pm	0.07	1.31	1.24	0.05	0.05	0.08	0.03	0.04	0.06	0.03	0.03	0.02	
CD (P=0.05)	0.21	3.70	3.50	0.14	0.14	0.23	0.10	0.13	0.17	0.09	0.07	0.06	

NS, non-significant

ratio was the highest in rotavator than CT. The overall benefit: cost ratio of the system was significantly higher with RTV than CT. As the RTV performs the primary and secondary tillage operations simultaneously there was saving of ₹7,900/ha with RTV as compared to CT for land preparation (Table 5).

Effect of nitrogen sources: Among the N sources, the highest cost of cultivation for maize–wheat system was recorded with the combined application of 40 kg NC + 40 kg NU which was significantly higher than control and all N sources. However, the highest gross returns, net returns, and benefit: cost ratio were recorded with the application of 80 kg NU followed by 40 kg NU and 40 kg NC + 40 kg NU. Higher yield coupled with lower cost of cultivation resulted in higher gross returns, net returns and benefit: cost ratio in inorganic treatments (urea) than integrated nutrient-management treatments (compost/green leaves + urea).

Thus in maize–wheat cropping system, adoption of CT during the *kharif* and RTV during the *rabi* season along with the application of 80 kg NU or 40 kg NU + 40 kg NC to each crop not only saves energy and resources but also improves soil health and results in higher crop yield and economic benefits under rainfed conditions.

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