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EFFICIENT TILLAGE AND NUTRIENT MANAGEMENT PRACTICES FOR SUSTAINABLE YIELDS, PROFITABILITY AND ENERGY USE EFFICIENCY FOR RICE-BASED CROPPING SYSTEM IN DIFFERENT SOILS AND AGRO-CLIMATIC CONDITIONS

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SUMMARY

Long-term tillage and fertilizer experiments were conducted in rice in *kharif* followed by lentil in dry subhumid Inceptisols at Varanasi and Faizabad; horse gram at Phulbani and linseed at Ranchi in moist subhumid Alfisols in *rabi* during 2001 to 2010. The study was conducted to assess the effect of conventional tillage (CT), low tillage + interculture (LT1) and low tillage + herbicide (LT2) together with 100% N (organic) (F1), 50% N (organic) + 50% N (inorganic) (F2) and 100% N (inorganic) (F3) on productivity, profitability, rainwater and energy use efficiencies. The results at Varanasi revealed that CT was superior with mean yield of 2389 kg ha^{-1}, while F1 was superior with 2378 kg ha^{-1} in rice. At Faizabad, CT was superior with mean rice yield of 1851 kg ha^{-1} and lentil yield of 977 kg ha^{-1}, while F1 was superior with 1704 and 993 kg ha^{-1} of rice and lentil, respectively. At Phulbani, F2 was superior with rice yield of 1170 kg ha^{-1}. At Ranchi, F2 with rice yield of 986 kg ha^{-1} and F3 with linseed yield of 224 kg ha^{-1} were superior. The regression model of crop seasonal rainfall and yield deviations indicated an increasing trend in rice yield over mean (positive deviation) with increase in rainfall at all locations; while a decreasing trend (negative deviation) was found for lentil at Faizabad, horse gram at Phulbani and linseed at Ranchi. Based on economic analysis, CTF1 at Varanasi and Faizabad, CTF2 at Phulbani and LT2F2 at Ranchi were superior.

INTRODUCTION

Rainfed agriculture plays an important role in contributing to world food security. In India, the land area under rainfed agriculture is 85 million ha representing

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60% of net cultivated area and supports 40% population of the country. Apart from climatic constraints of erratic and uncertain rainfall, soils are highly degraded physically, chemically and biologically in rainfed regions (Maruthi Sankar *et al.*, 2010; Sharma *et al.*, 2005; Vittal *et al.*, 2003). The intensive tillage practices employing inversion implements such as mould board plough result in loss of surface crop residue and subsequent loss of soil organic carbon (SOC) from soil aggregates. This in combination with imbalanced fertilization and poor recycling of crop residues resulted in deterioration of soil quality leading to low crop productivity in rainfed regions (Campbell *et al.*, 2001; Roldan *et al.*, 2003; Sharma *et al.*, 2008b). Practices, such as zero or reduced tillage, green manuring, recycling of residues, proved effective in improving soil fertility and quality in irrigated and temperate regions (Unger, 1990). No-tillage (NT) farming practiced in combination with growing a cover crop in rotation is widely recognized as a viable alternative to 'plough tillage' as a way to improve the environment and sustain natural resources.

Lal (2007) reported that the benefits of zero till farming in combination with residue retention are substantial in terms of erosion control, water conservation, soil fertility enhancement and C sequestration. After harvesting, the crop residue is removed from the soil surface for feeding livestock and used as fuel for domestic cooking. Due to moisture scarcity in rainfed areas, there is little scope to grow green manure and biomass generating crops without incurring loss on account of losing cropping season. Consequently, there is very low residue recycled back to fields. Sharma *et al.* (2005), reported that minimum tillage, when practiced in combination with 90 kg N ha^{-1} in castor–sorghum system, maintained desirable soil quality index of 1.10 in rainfed Alfisols. Further, they reported that to maintain higher yield as well as soil quality, primary tillage along with organic residues and N application are crucial. Reports also revealed that elimination of summer fallowing in arid and semi-arid regions and adopting NT with residue mulch improved soil structure, reduced bulk density, increased infiltration rate and productivity (Lal, 2004; Shaver *et al.*, 2002). Minimum tillage maintains lower temperature, water, oxygen and thereby induces suitable environment for growth and activity of microflora and microfauna (Blevins and Frye, 1993; Follet, 1990). Thus, optimum tillage combined with weed and fertilizer would be essential not only to enhance crop productivity but also to maintain soil health and sustainability (Maruthi Sankar *et al.*, 2006; Nema *et al.*, 2008).

Camara *et al.* (2003) studied long-term effects of tillage, nitrogen and rainfall on wheat yields and found that despite beneficial effects on soil properties, conservation tillage tended to be less productive than ploughing with mould board due to poor control of downy brome weed control under low-tillage treatment. Sharma *et al.* (2011) found that minimum tillage in combination with mulches had pronounced effect on soil physical properties, productivity, energy requirement, monetary returns of maize–wheat system in subhumid Inceptisols. Experience of Watts *et al.* (2008) revealed that long-term application of poultry litter resulted in higher C and N mineralization compared to inorganic fertilizer. They found that as depth increased, more C and N mineralization occurred under conventional tillage (CT) due to plough layer mixing, apart from increased nutrient retention and organic matter. Videnovic *et al.* (2011) attained significantly higher maize yields with CT compared to reduced tillage and NT, irrespective of fertilizer application in a Chernozem soil. Though much effort have gone into such studies in temperate regions, systematic long-term studies in rainfed semi-arid tropical regions are rare, especially in developing countries because of difficulties in controlling weeds, less water infiltration in compacted soil and non-availability of appropriate seeding implements (Sharma *et al.*, 2008b).

Rice, in general, is an important crop of tropical and subtropical countries. In Asia, India and China are leading countries where rice contributes significantly towards food basket. In India, rice is grown in an area of 43.77 million ha with production of 96.43 million tones. The productivity of rice during 2007 was 3208 kg ha^{-1}. The low rice productivity is attributed to low and erratic rainfall distribution, inappropriate tillage, low soil fertility and suboptimal fertilizer levels used by farmers. The long-term effects of tillage and fertilizer practices on productivity and profitability of rice in *kharif* at all locations and lentil in *rabi* in Inceptisols of Varanasi and Faizabad; horse gram and linseed in Alfisols of Phulbani and Ranchi, respectively, are assessed in this study. The objectives of the study were: (i) to identify an efficient tillage and nutrient management treatment for sustainability of productivity, profitability and energy use efficiency (EUE) in different cropping systems for different locations.

MATERIALS AND METHODS

Field experiments were conducted at four locations of All India Coordinated Research Project for Dryland Agriculture to identify efficient tillage and fertilizer treatments for maximum productivity, profitability and EUE in: (i) rice (*Oryza sativa*) in *kharif* (*June to October*) at all locations followed by (ii) lentil (*Lens esculentus*) in *rabi* (*October to February*) at Varanasi and Faizabad, and (iii) horse gram (*Dolichos biflorus*) at Phulbani and linseed (*Linum usitatissimum* L.) at Ranchi during 2001 to 2010. The climate and soil types representing the study locations were dry subhumid Inceptisols at Varanasi and Faizabad and moist subhumid Alfisols at Phulbani and Ranchi. The experiments were conducted in a split-plot design with three replications. The treatments were randomized and superimposed to plots in the first year and continued every year in the same plots in subsequent years. These were only to the *kharif* crop, and the *rabi* crop was raised under residual soil fertility. The main plot treatments were: (i) conventional tillage (CT), (ii) low tillage + interculture (LT1) and (iii) low tillage + herbicide (LT2). The subplot treatments were: (i) 100% N (organic) (F1), (ii) 50% N (organic) + 50% N (inorganic) (F2) and (iii) 100% N (inorganic) (F3). The details of tillage operations performed and fertilizer treatments applied are given in Table 1. Farmyard manure (FYM) was used as organic source at all locations. Nitrogen @ 60 kg ha^{-1} was applied at Phulbani and Faizabad, while 80 and 50 kg ha^{-1} was applied at Varanasi and Ranchi, respectively. Standard crop management practices were adopted at each location from sowing to harvest (Vittal *et al.*, 2002).

Table 1. Tillage practices and fertilizer treatments adopted at different locations.

Tillage	Varanasi (Rice–Lentil)	Faizabad (Rice–Lentil)	Phulbani (Rice–Horse gram)	Ranchi (Rice–Linseed)
CT – Conventional tillage	1 Criss-cross cultivator + 2 harrowings (disking) + 2 intercultures (30 and 45 days after sowing (DAS))	1 Ploughing + 2 harrowings + 2 hand weedings (20 and 40 DAS)	Summer ploughing (country plough) + 2 power tiller ploughings + 2 intercultures (20 and 35 DAS)	Summer ploughing (mould board plough) + 2 ploughings (Birsa Ridger plough) + 2 hand weedings (15–20 and 40–45 DAS)
LT1 – Low tillage-1	1 Criss-cross cultivator + 1 harrowing (disking) + 1 interculture (30 DAS)	1 Ploughing + 1 harrowing + 2 hand weedings (20 and 40 DAS)	Summer ploughing (country plough) + 1 power tiller ploughing + 1 interculture (20 DAS)	Summer ploughing (mould board plough) +1 ploughing (Birsa Ridger plough) + 2 hand weedings (15–20 and 40–45 DAS)
LT2 – Low tillage-2	1 Harrowing (disking) + herbicide	1 Ploughing + 1 harrowing + herbicide + 1 hand weeding (30 DAS)	Summer ploughing (country plough) + 1 power tiller ploughing +1 interculture (20 DAS) + herbicide	Summer ploughing (mould board plough) +1 ploughing (Birsa Ridger plough) +1 hand weeding (15–20 DAS) + herbicide
F1 – 100% N (inorganic) + P_2O_5 + K_2O	80:40:30 kg ha^{-1}	60:40:30 kg ha^{-1}	60:30:30 kg ha^{-1}	50:30:20 kg ha^{-1}
F2 – 50% N (inorganic) + 50% N (organic)	40:40:30 kg NPK + FYM @ 5 t ha^{-1}	30:40:30 kg NPK + FYM @ 7.5 t ha^{-1}	30:30:30 kg NPK + FYM @ 6 t ha^{-1}	25:30:20 kg NPK + FYM @ 5 t ha^{-1}
F3 – 100% N (organic)	FYM @ 10 t ha^{-1}	FYM @ 15 t ha^{-1}	FYM @ 12 t ha^{-1}	FYM @ 10 t ha^{-1}

Soil and agronomic details

Soil samples were collected from experimental sites before the start and at the end of the study and analyzed for physical and chemical parameters *viz.,* soil pH and electrical conductivity (Rhoades, 1982), organic C (Walkley and Black, 1934), available N (Subbaiah and Asija, 1956), P (Olsen *et al.*, 1954), K (Hanway and Heidel, 1952) and bulk density using soil cores (Blake and Hartge, 1986). Soil water retention at permanent wilting point (PWP) and field capacity (FC) was measured using pressure plate apparatus at −1.5 MPa and −0.033 MPa (Cassel and Nielsen, 1986). The details pertaining to the initial soil fertility status of different locations are given in Table 2.

Rainfall and its distribution

The data on monthly rainfall from sowing to harvest of crops during 2001 to 2010 were considered for assessing tillage and fertilizer treatments at different locations. In

Table 2. Details of initial soil characteristics of different locations.

Soil texture	Varanasi Sandy loam	Faizabad Silt loam	Phulbani Sandy loam	Ranchi Sandy loam
AWC (%)	35.5	45.0	13.1	22.3
Soil reaction (pH)	7.4	8.0	5.6	6.4
EC (ds m^{-1})	0.11	0.47	0.03	1.32
Organic carbon (%)	0.35	0.38	0.32	
Soil N	218	185	150	190
Soil P	18.0	19.5	19	16.5
Soil K	117	270	171	110

Table 3. Monthly rainfall (mm) received at different locations during 2001 to 2010.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						Varanasi							
Minimum	0	0	0	0	0	0	107	71	56	0	0	0	503
Maximum	69	89	67	19	54	223	417	328	382	142	29	4	1316
Mean	14	29	13	4	22	93	262	234	178	40	4	1	893
CV	147.4	113.3	166.2	161.5	72.4	89.6	44.5	38.1	65.2	109.0	261.6	138.1	26.2
						Faizabad							
Minimum	0	0	0	0	0	49	72	106	39	0	0	0	674
Maximum	35	36	40	12	114	377	426	489	308	133	5	7	1227
Mean	11	13	6	3	40	126	256	238	184	38	1	1	917
CV	116.9	102.5	199.9	134.6	78.9	84.9	41.3	50.5	60.9	96.5	187.1	245.6	17.7
						Phulbani							
Minimum	0	0	0	0	0	94	129	140	125	1	0	0	888
Maximum	61	38	56	59	139	505	798	987	465	218	35	48	2031
Mean	13	9	12	17	46	232	406	375	292	98	7	9	1567
CV	146.2	142.2	140.5	124.9	92.7	60.2	62.5	61.0	53.8	97.9	167.5	211.4	21.4
						Ranchi							
Minimum	0	0	2	0	0	72	149	121	28	0	0	0	683
Maximum	29	97	93	73	57	513	340	464	330	318	30	16	1580
Mean	10	32	31	18	31	212	271	284	158	77	4	8	1137
CV	104.4	106.6	91.6	132.8	72.4	74.9	32.2	37.3	68.0	137.7	255.8	110.2	24.4

kharif, the total rainfall at Varanasi ranged from 453 to 1249 mm with mean of 806 mm and coefficient of variation (CV) of 29%, while it ranged from 547 to 1194 mm with mean of 842 mm (CV 22%) at Faizabad. At Phulbani, rainfall ranged from 753 to 1886 mm with mean of 1402 mm (CV 26%), while it ranged from 509 to 1242 mm with mean of 790 mm (CV 31%) at Ranchi. About 80% of annual rainfall was received in *kharif* (*June to October*) at all locations. The descriptive statistics of monthly rainfall received in different years at the four locations are given in Table 3.

Statistical analysis

The analysis of variance (ANOVA) was performed by using SPSS version 16 to test the tillage and fertilizer treatment effects. The treatment differences could be compared based on least significant difference (*l.s.d.*) criteria (Gomez and Gomez, 1984).

One of the criteria adopted to identify an efficient tillage and fertilizer treatment was sustainability yield index (SYI), which is derived as a 'ratio of the difference of mean yield and prediction error based on regression model and maximum yield attained by any treatment over years' (Behera *et al.*, 2007; Maruthi Sankar *et al.*, 2011; Vittal *et al.*, 2003). The rainwater use efficiency (RWUE; kg ha^{-1} mm^{-1}) of the treatments was also computed, which is expressed as a ratio of yield (kg ha^{-1}) and crop seasonal rainfall (CRF; mm) (Rockstrom *et al.*, 2003).

In order to establish a relationship between CRF and performance of each treatment, we calculated the deviations between the mean yields of each treatment from overall mean of the treatments for a given year. The effect of CRF on the deviations of individual treatment yields from the overall mean was assessed based on a linear regression model as follows:

$$Yd = \pm\alpha \pm \beta\,(\mathrm{CRF}), \qquad (1)$$

where α is the intercept, β is the slope of the rainfall effect on yield deviations of a treatment and CRF is the crop seasonal rainfall from sowing to harvest of a crop. Those treatments, which maintained positive β values under different rainfall conditions, were considered quite superior from the viewpoint of sustainability and efficient use of natural resources.

In order to compute the profitability of tillage and fertilizer treatments over years, the gross and net returns and benefit-cost (BC) ratio were calculated (Maruthi Sankar *et al.*, 2012; Nema *et al.*, 2008). The gross returns (Rs ha^{-1}) were computed as a product of mean yield of each treatment over years and value of the crop at each location. The net returns (Rs ha^{-1}) were computed as a difference of gross returns and cost of cultivation (Rs ha^{-1}) for each treatment. The BC ratio was derived as a ratio of gross returns and cost of cultivation for each treatment.

The input energy (MJ ha^{-1}) was computed for each treatment by cumulating all the energy values (MJ ha^{-1}) used for different inputs like seed, fertilizer, herbicide, labour, animal and implements for land preparation, sowing, interculture, harvesting and other agricultural operations. The output energy was computed from the grain and straw yield harvested and expressed in terms of MJ ha^{-1}. The EUE could be derived as a ratio of output and input energy for each treatment in *kharif* and *rabi* crops. The test for significance of the treatments for profitability and energy use was performed using $\mu \pm$ SD criterion. Based on these criteria, tillage and fertilizer treatments were grouped into:

(i) a ($<\mu -$ SD), (ii) b ($\mu \pm$ SD) and (iii) c ($>\mu +$ SD),

where μ is the mean and SD is the standard deviation.

The treatments whose profitability and EUE values were $>\mu +$ SD were ranked significantly superior.

Table 4. ANOVA of the effect of treatments on yield over years at different locations.

Source	df	MSS	F	df	MSS	F
Varanasi	Rice			Lentil		
Replication	9	6 739 054.0	1358.19**	7	271 707.00	199.74**
Tillage	2	139 408.0	28.10**	2	28 580.00	21.01**
Error (a)	18	4961.78		14	1360.29	
Fertilizer	2	138 320.0	57.59**	2	18 502.00	10.01**
T × F	4	304.0	0.13NS	4	1.00	0.01NS
Error (b)	54	2401.78		42	1847.52	
Total	89			71		
Faizabad	Rice			Lentil		
Replication	9	2 261 749.00	291.90**	9	514 190.20	1215.26**
Tillage	2	190 344.00	24.57**	2	2732.00	6.46**
Error (a)	18	7748.45		18	423.11	
Fertilizer	2	8472.00	0.95NS	2	19 864.00	4.48*
T × F	4	24.00	0.01NS	4	6.00	0.01NS
Error (b)	54	8910.81		54	4434.96	
Total	89			89		
Phulbani	Rice			Horse gram		
Replication	9	1 108 680.0	31.19**	8	339 810.90	32.70**
Tillage	2	28 488.0	0.80NS	2	8373.25	0.81NS
Error (a)	18	35 550.22		16	10 392.97	
Fertilizer	2	138 172.00	5.40**	2	5845.50	0.43NS
T × F	4	11 732.00	0.46NS	4	9571.38	0.70NS
Error (b)	54	25 584.00		48	13 660.89	
Total	89			80		
Ranchi	Rice			Linseed		
Replication	6	2 182 223.0	735.75**	4	55 122.60	37.55**
Tillage	2	112.0	0.04NS	2	841.313	0.57NS
Error (a)	12	2966.0		8	1467.922	
Fertilizer	2	483 342.0	7.49**	2	2896.250	22.30**
T × F	4	0.00	0.01NS	4	0.094	0.01NS
Error (b)	36	64 500.11		24	129.875	
Total	62			44		

LSD ($p < 0.05$)	Varanasi (Rice)	Varanasi (Lentil)	Faizabad (Rice)	Faizabad (Lentil)	Phulbani (Rice)	Phulbani (Horse gram)	Ranchi (Rice)	Ranchi (Linseed)
Tillage	38.194	22.835	47.729	11.153	102.234	58.793	36.630	32.268
Fertilizer	25.371	25.032	48.868	34.476	82.804	63.939	158.894	8.589

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level, respectively.

RESULTS

Effect of tillage and fertilizer treatments on crop yield

Based on the pooled analysis of long-term data (2001 to 2010), using standard analysis of variance of a split-plot design, the effects of tillage, fertilizer and their interactions were tested (Table 4). Significant ($p < 0.05$) tillage effect was observed in Inceptisols at Varanasi and Faizabad, while it was non-significant in Alfisols at Phulbani and Ranchi. The fertilizer effect was significant ($p < 0.05$) at Varanasi for

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rice and lentil, Ranchi for rice and linseed and also for rice at Phulbani and lentil at Faizabad. There was no significant interaction of tillage and fertilizer at all locations. At Varanasi, tillage and fertilizer treatments significantly ($p < 0.05$) influenced the rice yield over years. CT was found superior with maximum mean yield of 2389 kg ha^{-1}, while F1 was superior with yield of 2378 kg ha^{-1}. When the effects of tillage and fertilizer treatments were seen on the succeeding lentil crop, significant ($p < 0.05$) influence was observed on crop yield. CT gave maximum mean lentil yield of 927 kg ha^{-1}, while F3 gave mean yield of 917 kg ha^{-1}. At Faizabad, significant ($p < 0.05$) effect of tillage and fertilizer on rice yield was observed over years. CT was superior with mean rice yield of 1851 kg ha^{-1}, while F1 was superior with 1704 kg ha^{-1}. In lentil, CT was superior with mean yield of 977 kg ha^{-1}, while F1 was superior with 993 kg ha^{-1} yield.

At Phulbani, only fertilizer treatments showed significant ($p < 0.05$) effect on rice yield over years. F2 was found superior with mean rice yield of 1170 kg ha^{-1}. At Ranchi, fertilizer treatments significantly influenced the crop yield. F2 was superior in rice with mean yield of 986 kg ha^{-1}, while F3 was superior in linseed with mean yield of 224 kg ha^{-1} over years.

Relationship between crop seasonal rainfall and crop yields in different treatments

In order to assess the effect of CRF on the performance of a treatment for sustainability and resource use efficiency, models were developed between the mean yields of each treatment from overall mean of the treatments for a given year (Table 5). These linear regression models helped in understanding the performance of treatments with changing CRF. The slope of the model equations reflected the increasing trend in rice yield over mean (positive deviations) with an increase in CRF at most of the locations. However, the decreasing trend in yield over mean (negative deviation) with the increase in CRF was observed at Faizabad for lentil, Phulbani for horse gram and Ranchi for linseed except for lentil in Varanasi. Beside this, it was also observed that fertilizer treatments comprising of either organic nutrient source (F1) alone or in combination with inorganics (F2) in rice tended to reflect significant positive influence on yield deviations over mean with increase in CRF.

Rainwater use efficiency of tillage and fertilizer treatments

CT was superior for maintaining significantly higher RWUE of 3.35 kg ha^{-1} mm^{-1} for rice and 20.35 kg ha^{-1} mm^{-1} for lentil at Varanasi; 2.76 kg ha^{-1} mm^{-1} for rice and 15.27 kg ha^{-1} mm^{-1} for lentil at Faizabad. The tillage treatments were at par for both rice and horse gram at Phulbani and rice at Ranchi, while LT2 was superior with RWUE of 3.07 kg ha^{-1} mm^{-1} for linseed at Ranchi (Table 6). F1 was superior with RWUE of 3.33 kg ha^{-1} mm^{-1} at Varanasi and 2.54 kg ha^{-1} mm^{-1} at Faizabad for rice; while F2 was superior with 0.91 kg ha^{-1} mm^{-1} at Phulbani and 1.34 kg ha^{-1} mm^{-1} at Ranchi. In *rabi*, F1 was superior with RWUE of 15.52 kg ha^{-1} mm^{-1} for lentil at Faizabad and 0.89 kg ha^{-1} mm^{-1} for horse gram at Phulbani; while F3 was superior with 20.43 kg ha^{-1} mm^{-1} for lentil at Varanasi and 2.91 kg ha^{-1} mm^{-1} for

Table 5. Effect of crop seasonal rainfall on the deviation of mean yield with different tillage and fertilizer treatments at different locations.

Statistic	T1	T2	T3	T4	T5	T6	T7	T8	T9
					Varanasi: Rice				
Intercept	81.3	−23.5	20.7	56.3	−48.1	−3.7	28.3	−101.7	−10.0
Slope	0.055	0.134**	−0.039	0.007	0.087	−0.087	−0.048	0.050	−0.159
R^2	0.03	0.55**	0.05	0.01	0.33	0.21	0.07	0.03	0.32
Error	81.1	30.1	40.4	42.2	30.3	41.2	43.9	67.8	57.4
					Varanasi: Lentil				
Intercept	14.6	15.5	65.0	−25.6	−24.2**	25.3	−41.0	−39.8*	9.9
Slope	−0.053	0.193	0.005	0.008	0.249**	0.060	−0.250	−0.011	−0.196
R^2	0.01	0.18	0.01	0.01	0.84**	0.01	0.06	0.01	0.05
Error	46.7	22.1	54.8	49.9	5.8	42.0	54.5	23.2	45.4
					Faizabad: Rice				
Intercept	212.9	99.2*	−20.4	81.3	−30.9	−151.2	51.1	−61.5	−182.1
Slope	−0.128	−0.007	0.109	−0.110	0.009	0.125	−0.117	0.002	0.119
R^2	0.10	0.01	0.03	0.05	0.01	0.04	0.04	0.01	0.06
Error	77.9	28.5	121.1	100.2	55.8	120.5	119.1	52.1	91.8
					Faizabad: Lentil				
Intercept	30.7	21.4**	−31.9	24.9	15.5	−38.2	16.8	7.5	−45.9
Slope	−0.017	−0.006	0.206	−0.139	−0.131	0.088	−0.082	−0.071	0.142
R^2	0.01	0.01	0.02	0.01	0.11	0.01	0.01	0.09	0.01
Error	67.6	9.5	74.6	73.8	16.1	68.2	64.9	9.7	75.8
					Phulbani: Rice				
Intercept	418.1	305.4	−273.2	449.9	−242.4	−289.8*	6.5	−165.4	−209.9
Slope	−0.328	−0.160	0.243	−0.366	0.150	0.235*	−0.088	0.116	0.199
R^2	0.36	0.08	0.35	0.34	0.26	0.46*	0.07	0.14	0.27
Error	166.5	207.4	125.4	194.6	95.8	96.8	123.8	109.3	124.7
					Phulbani: Horse gram				
Intercept	−73.3	−28.2	79.4	−57.8	−36.3	95.0	−50.7	−29.7	102.3*
Slope	0.200*	−0.012	−0.146	0.160	−0.020	−0.186	0.176	−0.003	−0.170
R^2	0.56*	0.01	0.23	0.42	0.03	0.30	0.37	0.01	0.37
Error	37.5	38.5	55.8	39.9	23.2	59.9	48.2	24.9	46.6
					Ranchi: Rice				
Intercept	127.9	131.1	−184.4	102.9	105.8	−210.0	78.9	82.0	−234.5
Slope	−0.093	−0.019	0.015	−0.057	0.017	0.051	−0.032	0.042	0.076
R^2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Error	226.9	85.6	310.8	245.8	112.2	291.4	214.3	86.8	321.1
					Ranchi: Linseed				
Intercept	85.8	94.8	85.2	71.6	84.2	73.9	42.1	66.1	44.6
Slope	−1.261	−1.100	−0.929	−0.942	−0.819	−0.642	−0.532	−0.531	−0.231
R^2	0.61*	0.57*	0.52*	0.54*	0.48	0.32	0.27	0.23	0.05
Error	48.4	45.7	42.5	41.7	40.5	44.0	41.6	46.1	48.7

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level, respectively. R^2: Coefficient of determination.

linseed at Ranchi (Table 6). There was no significant interaction of tillage and fertilizer treatments in influencing RWUE at all locations.

Profitability of tillage and fertilizer treatments

There was a marginal variation in the cost of cultivation and value of rice, lentil, horse gram and linseed grain and fodder in different years. The cost of cultivation

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Table 6. Effect of tillage and fertilizer treatments on mean rainwater use efficiency (kg ha^{-1}–mm^{-1}) of crops at different centres.

	Varanasi		Faizabad		Phulbani		Ranchi	
Treatments	Rice	Lentil	Rice	Lentil	Rice	Horse gram	Rice	Linseed
CT	3.35	20.35	2.76	15.27	0.76	0.78	1.13	2.30
LT1	3.17	18.62	2.41	14.84	0.73	0.79	1.13	2.66
LT2	2.97	17.41	2.31	14.70	0.79	0.85	1.12	3.07
F1	3.33	17.66	2.54	15.52	0.60	0.89	0.93	2.40
F2	3.22	18.25	2.50	15.25	0.91	0.76	1.34	2.78
F3	2.95	20.43	2.44	14.01	0.78	0.77	1.09	2.91
LSD (T) ($p < 0.05$)	0.21	1.94	0.30	0.56	n.s.	n.s.	n.s.	0.57
LSD (F) ($p < 0.05$)	0.20	2.40	0.10	1.48	0.17	0.12	0.29	0.50
LSD (T × F) ($p < 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD (F × T) ($p < 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

differed for treatments in rice. However, it was the same for all treatments in *rabi*, since the crop was sown under zero-tillage with residual soil fertility condition.

The mean value of rice was Rs 11.5 kg^{-1} for all locations and the cost of cultivation differed according to the tillage and fertilizer treatments in *kharif* season. The cost of cultivation was Rs 10 700 ha^{-1} for lentil at Varanasi and Faizabad; Rs 2000 ha^{-1} for horse gram at Phulbani; and Rs 2400 ha^{-1} for linseed at Ranchi (Table 7).

At Varanasi, rice crop had mean cost of cultivation of Rs 13 463 ha^{-1} and attained net returns of Rs 12 508 ha^{-1} and BC ratio of 1.93. The lentil crop gave mean net returns of Rs 8138 ha^{-1} and BC ratio of 1.76. The analysis indicated that CTF1 was superior with total net returns of Rs 21 965 ha^{-1} from the rice–lentil cropping system. At Faizabad, rice crop had mean cost of cultivation of Rs 10 764 ha^{-1} resulting in net returns of Rs 8469 ha^{-1} and BC ratio of 1.79. In lentil, net returns of Rs 10 800 ha^{-1} and BC ratio of 2.01 were attained (Table 7). Using the $\mu \pm$ SD criteria, CTF1 was found superior with total net returns of Rs 20 659 ha^{-1} from rice and lentil crops grown in sequence. At Phulbani, rice crop had mean cost of cultivation of Rs 10 026 ha^{-1} and attained net returns of Rs 434 ha^{-1} and BC ratio of 1.04. In horse gram, net returns of Rs 1760 ha^{-1} and BC ratio of 1.88 were attained. CTF2 was significantly superior with total net returns of Rs 3476 ha^{-1} from rice and horse gram cropping sequence.

At Ranchi, rice crop had mean cost of cultivation of Rs 9144 ha^{-1} with net returns of Rs −492 ha^{-1} and BC ratio of 0.95. In linseed, net returns of Rs 4007 ha^{-1} and BC ratio of 2.67 were attained. LT2F2 was found significantly superior with total net returns of Rs 5383 ha^{-1} from rice and linseed crops under moist subhumid Alfisols. When the yield sustainability was considered, in *kharif*, CTF1 at Varanasi and Faizabad, CTF2 at Phulbani, LT1F2 at Ranchi were superior in maintaining relatively higher SYI. In *rabi*, CTF1 maintained higher SYI at Varanasi; CTF2 at Faizabad for lentil; LT2F1 for horse gram at Phulbani and LT2F3 for linseed at Ranchi (Table 7).

Table 7. Profitability (Rs) and SYI of tillage and fertilizer treatments at different locations.

Treatment	Yield	CC	GR	NR	BC	Yield	GR	NR	BC	SYI	
Varanasi			Rice			Lentil (CC: Rs 10 700 ha^{-1})				Kharif	Rabi
CT F1	2383^{c}	13 825^{b}	27 410^{c}	13 585^{c}	1.98^{b}	867^{b}	19 080^{b}	8380^{b}	1.78^{b}	35.4	77.5
CT F2	2343^{c}	13 963^{c}	26 945^{c}	12 982^{b}	1.93^{b}	885^{b}	19 466^{b}	8766^{b}	1.82^{b}	35.3	74.4
CT F3	2247^{b}	14 100^{c}	25 845^{b}	11 745^{b}	1.83^{a}	922^{c}	20 276^{c}	9576^{c}	1.89^{c}	33.0	72.8
LT1 F1	2321^{b}	13 325^{b}	26 687^{b}	13 362^{c}	2.00^{b}	831^{b}	18 290^{b}	7590^{b}	1.71^{b}	34.9	74.7
LT1 F2	2280^{b}	13 463^{b}	26 222^{b}	12 759^{c}	1.95^{b}	849^{b}	18 677^{b}	7977^{b}	1.75^{b}	34.7	72.7
LT1 F3	2185^{a}	13 600^{b}	25 122^{b}	11 522^{a}	1.85^{a}	886^{b}	19 487^{b}	8787^{b}	1.82^{b}	32.5	71.2
LT2 F1	2248^{b}	12 825^{a}	25 852^{b}	13 027^{b}	2.02^{c}	798^{b}	17 562^{a}	6862^{a}	1.64^{a}	33.5	72.2
LT2 F2	2197^{b}	12 963^{a}	25 266^{b}	12 303^{b}	1.95^{b}	816^{a}	17 948^{a}	7248^{a}	1.68^{b}	33.0	70.7
LT2 F3	2121^{b}	13 100^{b}	24 386^{b}	11 286^{a}	1.86^{b}	853^{b}	18 758^{b}	8058^{b}	1.75^{b}	31.4	68.9
Mean	2258	13 463	25 971	12 508	1.93	856	18 838	8138	1.76		
SD	83.6	444.3	960.9	838.0	0.07	38.5	847.7	846.4	0.08		
Faizabad			Rice			Lentil (CC: Rs 10 700 ha^{-1})					
CT F1	1778^{c}	11 250^{b}	20 442^{c}	9192^{c}	1.82^{b}	985^{c}	22 167^{c}	11 467^{c}	2.07^{c}	47.3	48.1
CT F2	1765^{c}	11 375^{c}	20 297^{c}	8922^{c}	1.78^{b}	976^{b}	21 970^{b}	11 270^{b}	2.05^{b}	44.4	49.6
CT F3	1743^{c}	11 500^{c}	20 045^{c}	8545^{b}	1.74^{b}	937^{b}	21 080^{b}	10 380^{b}	1.97^{b}	40.2	48.5
LT1 F1	1661^{b}	10 500^{b}	19 102^{b}	8602^{b}	1.82^{b}	971^{b}	21 858^{b}	11 158^{b}	2.04^{b}	43.5	46.9
LT1 F2	1648^{b}	10 725^{b}	18 956^{b}	8231^{b}	1.77^{b}	963^{b}	21 661^{b}	10 961^{b}	2.02^{b}	40.6	48.6
LT1 F3	1630^{a}	10 850^{b}	18 745^{a}	7895^{a}	1.73^{a}	923^{a}	20 771^{a}	10 071^{a}	1.94^{a}	47.0	47.4
LT2 F1	1625^{b}	10 100^{a}	18 683^{b}	8583^{b}	1.85^{c}	967^{b}	21 759^{b}	11 059^{b}	2.03^{b}	42.1	46.6
LT2 F2	1612^{b}	10 225^{b}	18 537^{b}	8312^{b}	1.81^{b}	958^{b}	21 562^{b}	10 862^{b}	2.02^{b}	39.3	48.0
LT2 F3	1590^{b}	10 350^{b}	18 286^{b}	7936^{a}	1.77^{b}	919^{a}	20 672^{a}	9972^{a}	1.93^{a}	35.1	46.9
Mean	1672	10 764	19 233	8469	1.79	955	21 500	10 800	2.01		
SD	70.2	576.7	807.8	423.5	0.04	23.9	537.5	529.2	0.05		
Phulbani			Rice			Horse gram (CC: Rs 2000 ha^{-1})					
CT F1	867^{b}	10 300^{b}	9974^{b}	−326^{a}	0.97^{b}	257^{b}	3858^{b}	1858^{b}	1.93^{b}	35.7	7.7
CT F2	990^{c}	10 350^{c}	11 387^{c}	1037^{b}	1.10^{b}	296^{c}	4439^{c}	2439^{c}	2.22^{c}	42.3	1.5
CT F3	978^{b}	10 425^{b}	11 245^{b}	820^{b}	1.08^{b}	255^{b}	3821^{b}	1821^{b}	1.91^{b}	37.2	−3.0
LT1 F1	846^{a}	9900^{b}	9730^{a}	−170^{b}	0.98^{b}	255^{b}	3822^{b}	1822^{b}	1.91^{b}	37.8	8.1
LT1 F2	877^{b}	9950^{b}	10 087^{b}	137^{b}	1.01^{b}	196^{a}	2933^{a}	933^{a}	1.47^{a}	36.6	−1.1
LT1 F3	949^{b}	9980^{b}	10 914^{b}	934^{b}	1.09^{b}	252^{b}	3784^{b}	1784^{b}	1.89^{b}	41.0	−3.2
LT2 F1	793^{b}	9725^{a}	9120^{b}	−606^{a}	0.94^{a}	269^{b}	4038^{b}	2038^{b}	2.02^{b}	30.2	10.1
LT2 F2	906^{b}	9775^{b}	10 424^{b}	649^{b}	1.07^{b}	210^{a}	3148^{a}	1148^{a}	1.57^{a}	37.5	1.4
LT2 F3	979^{c}	9825^{c}	11 255^{c}	1430^{c}	1.15^{c}	267^{b}	4000^{b}	2000^{b}	2.00^{b}	41.7	−0.4
Mean	909	10 026	10 460	434	1.04	251	3760	1760	1.88		
SD	69.1	260.7	795.0	699.6	0.07	30.4	458.7	457.6	0.22		
Ranchi			Rice			Linseed (CC: Rs 2400 ha^{-1})					
CT F1	806^{b}	9300^{b}	9267^{b}	−33^{b}	1.00^{b}	189^{a}	5676^{a}	3276^{a}	2.37^{a}	10.7	51.9
CT F2	868^{b}	9350^{c}	9984^{b}	634^{b}	1.07^{b}	212^{b}	6351^{b}	3951^{b}	2.65^{b}	12.7	52.9
CT F3	580^{a}	9400^{c}	6668^{a}	−2732^{a}	0.71^{b}	215^{b}	6438^{b}	4038^{b}	2.68^{b}	11.2	54.5
LT1 F1	810^{b}	9000^{b}	9311^{b}	311^{b}	1.03^{b}	200^{b}	6003^{b}	3603^{b}	2.50^{b}	11.0	53.8
LT1 F2	872^{b}	9100^{b}	10 028	928^{b}	1.10^{b}	223^{b}	6678^{b}	4278^{b}	2.78^{b}	12.9	54.8
LT1 F3	584^{a}	9200^{b}	6711^{a}	−2489^{a}	0.73^{b}	226^{b}	6765^{b}	4365^{b}	2.82^{b}	11.1	56.4
LT2 F1	805^{b}	8925^{a}	9261^{b}	336^{b}	1.04^{b}	204^{b}	6105^{b}	3705^{b}	2.54^{b}	9.5	53.5
LT2 F2	868^{b}	8975^{b}	9978^{b}	1003^{b}	1.11^{b}	226^{b}	6780^{b}	4380^{b}	2.83^{b}	11.4	54.2
LT2 F3	579^{a}	9050^{b}	6661^{a}	−2389^{a}	0.74^{b}	229^{c}	6867^{c}	4467^{c}	2.86^{c}	9.5	56.1
Mean	752	9144	8652	−492	0.95	214	6407	4007	2.67		
SD	131.6	173.7	1514.1	1566.52	0.17	13.7	410.1	408.7	0.17		

CC: Cost of cultivation (Rs ha^{-1}); GR: Gross returns (Rs ha^{-1}); NR: Net returns (Rs ha^{-1}); BC: Benefit-cost ratio. a: $<\mu - SD$; b: $\mu \pm SD$; c: $>\mu + SD$.

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Energy use efficiency of tillage and fertilizer treatments

The data pertaining to input energy (MJ ha^{-1}) of different agricultural operations from sowing to harvest, output energy (MJ ha^{-1}) attained and EUE of treatments at different locations are given in Table 8. At Varanasi, with input energy of 11 856 MJ ha^{-1}, output energy of 92185 MJ ha^{-1} was attained in rice with EUE of 7.78. In lentil, with input energy of 4305 MJ ha−1, output energy of 21 539 MJ ha^{-1} was attained with EUE of 5.00. Based on $\mu \pm$ SD criteria, CTF1 and LT2F2 gave significantly higher maximum output energy in *kharif* and *rabi*, respectively. However, CTF2 gave maximum EUE in both the seasons.

At Faizabad, in rice, with input energy of 8545 MJ ha^{-1}, output energy of 33 536 MJ ha^{-1} was attained, the mean EUE being 3.95. In lentil, with input energy of 4021 MJ ha^{-1}, output energy of 20 737 MJ ha^{-1} was attained and EUE observed was 5.16. CTF3 in *kharif* and CTF2 in *rabi* gave maximum output energy, while LT1F3 and LT1F2 gave maximum EUE in *kharif* and *rabi*.

At Phulbani, with input energy of 8756 MJ ha^{-1}, output energy of 14 031 MJ ha^{-1} was attained while mean EUE observed was 2.21. In horse gram, with input energy of 1839 MJ ha^{-1}, output energy of 5203 MJ ha^{-1} with EUE of 2.83 were attained. LT2F3 gave maximum output energy and LT2F2 gave maximum EUE in rice, while LT2F1 gave maximum of both the parameters in horse gram.

At Ranchi, with mean input energy of 8181 MJ ha^{-1} in rice, output energy of 14 478 MJ ha^{-1} was attained with EUE of 1.78. In linseed, with input energy of 1725 MJ ha^{-1}, output energy of 4163 MJ ha^{-1} and EUE of 2.41 were attained. LT2F2 gave maximum EUE in rice and maximum of both the parameters in linseed.

DISCUSSION

The critical analysis of data obtained from 10-year long study with tillage and fertilizer treatments in a permanent site using different yardsticks *viz*., crop response in terms of yield indicated that CT maintained 5.56 and 12.80% higher rice yield over low tillage levels *viz*., LT1 and LT2, respectively, at Varanasi. Similarly, F1 was found superior over F2 and F3 by maintaining 3.53 and 12.9% higher rice yield, respectively. The succeeding lentil crop got benefited by CT resulting in 14.9 and 7.8% higher yield over LT2 and LT1, respectively. However, in this case, among the fertilizer treatments, the benefit of organic manure alone and their conjunctive use with inorganics was higher. CTF1 found superior in terms of attaining maximum productivity besides improving RWUE and EUE in rice–lentil system. This implies that tilling of rainfed Inceptisol soils of Varanasi conventionally and adding 100% N through organic source was beneficial for sustaining yield and profitability of crop for a longer period. At Faizabad, CT gave 14.4 and 19.80% higher rice yield and 2.84 and 3.82% higher lentil yield over LT1 and LT2, respectively. Similarly, F1 gave 4.2 and 1.48% higher rice yield and 1.7 and 10.7% lentil yield over F2 and F3, respectively. In this case also, CTF1 combination was found superior for attaining maximum productivity besides giving advantage in terms of RWUE of rice and lentil crops. Earlier study has also revealed the importance of organics on rice–lentil system in Inceptisols (Singh *et al*., 2004).

Table 8. Effect of tillage and fertilizer treatments on input and output energy at different locations.

	Kharif			Rabi		
Treatments	IE (MJ ha-1)	OE (MJ ha-1)	EUE	IE (MJ ha-1)	OE (MJ ha-1)	EUE
Varanasi						
CTF1	12 783^{b}	100 097^{c}	7.84^{b}	4305	21 310^{b}	4.95^{b}
CTF2	12 178^{b}	97 839^{c}	8.04^{c}	4305	23 097^{b}	5.37^{c}
CTF3	11 572^{b}	92 886^{b}	8.02^{c}	4305	21 611^{b}	5.02^{b}
LT1F1	12 462^{c}	95 208^{b}	7.65^{b}	4305	20 427^{a}	4.75^{a}
LT1F2	11 856^{b}	92 950^{b}	7.84^{b}	4305	22 214^{b}	5.16^{b}
LT1F3	11 251^{a}	87 997^{b}	7.83^{b}	4305	20 729^{b}	4.82^{b}
LT2F1	12 140^{b}	90 719^{b}	7.47^{a}	4305	20 793^{b}	4.83^{b}
LT2F2	11 535^{b}	88 460^{b}	7.66^{b}	4305	22 580^{c}	5.25^{c}
LT2F3	10 929^{a}	83 507^{a}	7.65^{b}	4305	21 095^{b}	4.90^{b}
Mean	11 856	92 185	7.78		21 539	5.00
SD	592.8	5162.4	0.19		904.64	0.23
Faizabad						
CTF1	9387^{c}	32 596^{b}	3.47^{a}	4021	20 710^{b}	5.15^{b}
CTF2	9050^{c}	35 989^{b}	3.98^{b}	4021	22 541^{b}	5.61^{b}
CTF3	8713^{b}	37 610^{c}	4.36^{b}	4021	20 710^{b}	5.15^{b}
LT1F1	8606^{b}	31 292^{b}	3.68^{b}	4021	19 788^{b}	4.92^{b}
LT1F2	8269^{b}	34 685^{b}	4.20^{b}	4021	21 618^{b}	5.38^{b}
LT1F3	7932^{a}	36 306^{b}	4.58^{c}	4021	19 788^{b}	4.92^{b}
LT2F1	8654^{b}	28 313^{a}	3.29^{a}	4021	19 882^{b}	4.94^{b}
LT2F2	8317^{b}	31 705^{b}	3.80^{b}	4021	21 712^{b}	5.40^{b}
LT2F3	7980^{a}	33 326^{b}	4.18^{b}	4021	19 882^{b}	4.94^{b}
Mean	8545	33 536	3.95		20737	5.16
SD	478.52	2917.63	0.43		1016.1	0.75
Phulbani						
CTF1	8975^{c}	12 915^{b}	1.95^{a}	1839	5914^{c}	3.22^{c}
CTF2	9030^{c}	12 970^{b}	2.29^{b}	1839	5064^{b}	2.76^{b}
CTF3	9085^{c}	13 025^{b}	1.86^{a}	1839	4791^{b}	2.61^{b}
LT1F1	8527^{a}	13 599^{b}	2.13^{b}	1839	5607^{b}	3.05^{b}
LT1F2	8582^{b}	13 654^{b}	2.47^{c}	1839	4757^{b}	2.59^{b}
LT1F3	8637^{b}	13 709^{b}	2.04^{b}	1839	4484^{a}	2.44^{a}
LT2F1	8603^{b}	15 414^{c}	2.32^{b}	1839	6061^{c}	3.30^{c}
LT2F2	8658^{b}	15 469^{c}	2.66^{c}	1839	5211^{b}	2.84^{b}
LT2F3	8713^{b}	15 524^{c}	2.23^{b}	1839	4938^{b}	2.69^{b}
Mean	8756	14 031	2.21		5203	2.83
SD	210.1	1122.5	0.25		546.3	0.30
Ranchi						
CTF1	8893^{c}	13 815^{a}	1.55^{a}	1725	3791^{a}	2.20^{a}
CTF2	8568^{b}	15 241^{b}	1.80^{b}	1725	3829^{a}	2.22^{b}
CTF3	8466^{b}	13 093^{b}	1.55^{a}	1725	3644^{a}	2.11^{a}
LT1F1	8291^{b}	14 593^{b}	1.77^{b}	1725	4301^{b}	2.49^{b}
LT1F2	7966^{b}	16 019^{c}	2.01^{c}	1725	4339^{b}	2.52^{b}
LT1F3	7863^{b}	13 871^{b}	1.76^{b}	1725	4154^{b}	2.41^{b}
LT2F1	8113^{b}	14 324^{b}	1.78^{b}	1725	4506^{c}	2.61^{c}
LT2F2	7788^{b}	15 750^{c}	2.02^{c}	1725	4544^{c}	2.64^{c}
LT2F3	7685^{a}	13 602^{b}	1.77^{b}	1725	4359^{b}	2.53^{b}
Mean	8181	14 478	1.78		4163	2.41
SD	400.9	1013.5	0.16		328.9	0.19

a: $<\mu - \text{SD}$; b: $\mu \pm \text{SD}$; c: $> \mu + \text{SD}$.

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Sharma and Mitra (1991) and Das and Mandal (1986) reported that organic manure decomposition induced transformation and modified the mechanics and dynamics of nutrient mobilization. In this process, the part of nutrients remained unutilized by the main crop is expected to help growth and development of succeeding crop in addition to advantages associated with improved physical properties of soil. In the present study also, residual effect of organic manure has benefited the succeeding crop.

At Phulbani, LT2 recorded 8.33 and 3.57% higher rice yield compared to LT1 and CT, respectively. F2 was found superior with 54.76 and 16.76% higher yield compared to F1 and F3, respectively. Similarly, in case of horse gram, LT2 was superior and recorded 13.65 and 3.08% higher yield over LT1 and CT, while F1 gave 29.64 and 46.5% higher horse gram yield over F2 and F3, respectively. In case of rice in Alfisol soils of Phulbani, the higher yield advantage accrued under LT2 and F2 (integrated nutrient use, 50:50) could be due to better microbial biodiversity and activity, better soil structure, reduced soil loss through erosion and release and availability of nutrients synchronizing with plant uptake (Kihara *et al.*, 2012; Landers, 2008). The succeeding horse gram crop at this location got more benefited from LT2 with F1. This could be possibly due to better soil condition under LT2 and sustained release of nutrients through organic manures. Horse gram being a sturdy rainfed legume crop relatively needs less tillage and low but sustained nutrient supply. Thus, it performed well under LT2 and F1 combination. At Ranchi, despite non-significant effect of tillage and fertilizer, LT2F2 combination helped in achieving higher yield benefits in rice–linseed system. Earlier studies of Roul and Mahapatra (2006) have revealed the higher residual fertility effects of conjunctive use of organic and inorganic source of nutrients in linseed when grown after the harvest of rice. This may be attributed to slow and sustained release of nutrients, enhanced nutrient use efficiency and improved soil properties (Sarkar and Singh, 1997).

The increasing trend in yield of rice crop and decreasing or negative trend in succeeding crops like lentil, horse gram and linseed with increase in rainfall was obviously due to more requirement of water in main crop (rice) and relatively less water requirement in succeeding crops. It is important to emphasize here that, lentil, horse gram and linseed crops are mostly raised on residual moisture available after the harvest of rice crop. Whenever, there are more rains leading to water stagnation in the field during *rabi* season, these crops grown after rice are severely affected, if there is no adequate provision for drainage.

Though, productivity and resource use efficiency parameters such as RWUE, EUE are important but the fact remains that farmers' prime motive to do agriculture is to earn higher income and profitability. Thus, in the present study, finally, we considered economics or profitability analysis as more important and relevant criteria to narrow down the recommendations for the farming community. CTF1 performed better in terms of net returns and BC ratio in rainfed Inceptisol soils at Varanasi and Faizabad. When profitability was taken as the criteria, at Phulbani, CTF2 recorded significantly higher net returns and BC ratio, hence proved superior and could be considered for recommendation in rainfed Alfisol soils of this region. LT2F2 combination in moist subhumid Alfisols at Ranchi was superior for net returns and BC ratio and could be considered for recommendation to the farmers.

In general, in rainfed agriculture, two cardinal principles that help in growing a weed-free good crop are: practicing summer tillage (conventional method) to kill the weed seeds by exposing them to hot weather and capture pre-monsoon and monsoon rainwater in profile by way of loosening soil surface and enhancing infiltration rate. The CT also helps in loosening seedbed for good soil aeration, better root growth and ultimately bumper crop growth. The importance of tillage in weed control was highlighted by Richey *et al.* (1977) and Hatfield (1990). They reported that tillage aids in weed control by killing emerging seedlings, burying seeds, delaying growth of perennials and providing loose surface soil for efficient action of herbicide. Perhaps, because of some of these above benefits, CT at Varanasi, Faizabad and Phulbani proved effective in giving higher returns. In Alfisols of Ranchi, LT2 was found superior in terms of profitability probably due to better plant growing environment and effective weed control through herbicides owing to higher productivity and saving energy on tillage operations.

In general, it is well established that beneficial effects of low tillage can be accrued more effectively, if adequate amount of crop residue is retained on the soil surface on a long-term basis (Lal, 1989, Sharma *et al.*, 2005, 2008b). Unger (1990) reported that surface residue along with low tillage reduced runoff and increased infiltration. At all the four locations, we could not maintain crop residue on the surface since it is generally used for feeding livestock. Further, while highlighting the importance of tillage in dryland crops such as sorghum and pearl millet earlier, Vittal *et al.* (1983) reported that deep tillage up to 23.3 cm helped in improving grain yield by better moisture recharge of soil profile and enhancing rooting depth in Alfisols. The rainfed soils, in general, are low in organic C and fertility, especially N, the response and performance of organics alone and in conjunction with inorganic fertilizers remain superior because of improved soil conditions and sustained release and availability of nutrients resulting in higher use efficiency (Nambiar, 2002; Sharma *et al.*, 2008a). Although, in the long-term, tilling the soil more and more or using inversion tillage with implements like mould board plough may be harmful to soil quality, but in the short-run, yield gains remain higher with CT than under low tillage, owing to factors mentioned above (Sharma *et al.*, 2008b; Venkateswarlu *et al.*, 2010).

CONCLUSION

Based on the study conducted under dry subhumid Inceptisols with rice–lentil at Varanasi and Faizabad; and moist subhumid Alfisols with rice–horse gram at Phulbani and rice–linseed at Ranchi during 2000 to 2010, suitable tillage and fertilizer practices have been identified for recommendation. On the basis of net returns and BC ratio, CTF1 could be recommended in rainfed Inceptisol soils at Varanasi and Faizabad. Similarly, in rainfed Alfisol soils of Phulbani, CTF2 recorded significantly higher net returns and BC ratio and could be considered for recommendation for this region.

LT2F2 in moist subhumid Alfisols at Ranchi was found superior in terms of net returns and BC ratio and could be considered for recommendation to the farmers.

In the Indian subcontinent, which represents mostly subtropical and tropical environment, where lands are mostly at the verge of degradation and soil quality has deteriorated, such studies that warrant the shift of CT to reduced tillage or NT should be very relevant for future. However, such studies need to be conducted on long-term basis using appropriate low tillage levels. The results of the present study are not only useful to the given location but can also work as analogy for developing similar relationship for other crops in various part of the rainfed tropics across the world.

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