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Long-term tillage and nitrogen management for improving productivity and profitability of a rainfed maize-wheat system in north western Himalaya

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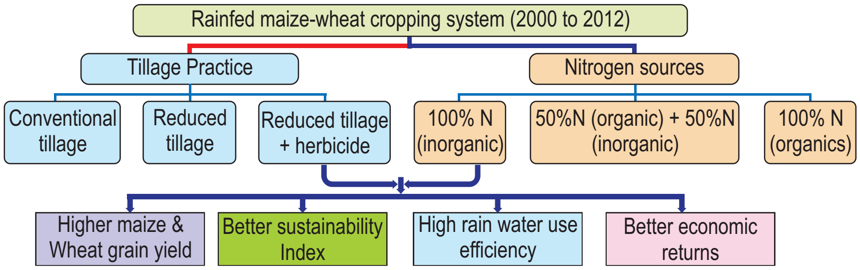
Abstract

Aim: The study aimed to identify the optimum tillage and source of nitrogen for refining yields, yield sustainability and rainwater-use efficiency, and to develop predictive models explaining the relationship between crop yield and monthly rainfall with main goal of reduced cost of cultivation and increased profitability for long-term sustainability of maize-wheat system.

Methodology: A long-term field experiment on maize-wheat system was conducted from 2000 to 2012 at Regional Research Station, Ballowal Saunkhri, Punjab Agricultural University, Ludhiana in split plot design with three replications. The treatment included three tillage practices, *viz.*, conventional tillage (CT), reduced tillage (RT$_1$) and RT$_1$ + herbicide (RT$_2$) in the main plots and three nitrogen (N) management practices, *viz.*, 100% N from organic source (F$_1$), 50% N from organic + 50% N from inorganic source (F$_2$) and 100% N from inorganic source (F$_3$) in the sub-plots. The parameters included maize and wheat yield, rainwater use efficiency, economics, sustainability yield index to develop predictive models.

Results: Prediction models expressing relation between yield and monthly rainfall showed beneficial effect of rainfall in June, July and September months on maize and January and February in wheat on crop productivity. RT$_2$ gave highest mean maize grain yield (2264 kg ha^{-1}) with 13.8 and 1.8% yield superiority over RT$_1$ and CT, respectively. However, in wheat, CT recorded highest grain yield (2110 kg ha^{-1}) with 7.9 and 1.7% higher yield than RT$_1$ and RT$_2$, respectively. The RT$_2$F$_3$ gave highest net returns of US$ 222.60 ha^{-1} with benefit-cost ratio (B:C) of 1.88, rain water use efficiency (RWUE) of 4.78 kg ha^{-1} mm^{-1} and a sustainable yield index (SYI) of 60.7% in maize, whereas in wheat it provided net returns of US$315.45 ha^{-1} with B:C of 2.28, RWUE of 23.0 kg ha^{-1} mm^{-1} and SYI of 47.4%.



Interpretation: The efficient rainwater use and optimum yields of rainfed maize-wheat system can be realised with reduced tillage + herbicide based weed management along with application of recommended nitrogen. The study suggests the shift from conventional tillage practices to reduced/conservation tillage practices.

Keywords : Economics, Nitrogen sources, Prediction model, Reduced tillage, Sustainability

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Introduction

Rainfed agriculture covers about 60% of the net sown area and supports 40% Indians (Maruthi Sankar *et al.,* 2012). Apart from the climatic constraints like erratic and unreliable spatio-temporal rainfall patterns, the soils are highly degraded in the rainfed areas (Sharma *et al.,* 2005; Maruthi Sankar *et al.,* 2010), which results in low productivity and profitability of crops (Sharma *et al.,* 2011). While conventional tillage and higher use of chemical fertilisers and pesticides increased crop yields and enhanced food security, at the same time these management practices have adversely affected soil quality in terms of decreased soil organic carbon, shrinking biodiversity and loss of surface crop residue, as well as productivity (Cruse and Colvin, 1989; Sundermeier *et al.,* 2011). Reduced tillage helps in reducing erosion losses, conserving soil moisture and obtaining yields similar to that with conventional tillage (Bhatt *et al.,* 2004).

The imbalanced use of fertilizers and meagre crop residues recycling has further intensified the problem of deteriorated soil quality leading to low crop productivity in rainfed regions (Sharma *et al.,* 2008). Small holder agriculture in the lower *Shivalik* foothill region is characterised by mouldboard ploughing and hand hoeing, which leads to land degradation and loss of excessive nutrient (Singh *et al.,* 2015). Primary tillage along with application of organic residues and nitrogen is essential to maintain high crop yield, as well as soil quality (Sharma *et al.*, 2005). Reduced or conservation tillage offer ecological, economic and organisational benefits (Hussain *et al.*, 1999). It has been reported that elimination of summer fallowing and adopting conservation tillage with residue mulching in arid and semi-arid regions improve soil structure, increases infiltration capacity, lowers bulk density (Shaver *et al.*, 2002; Lal, 2004) and ultimately enhances crop productivity. Thus, optimal tillage practices combined with fertiliser and weed management would be crucial, not only to increase crop productivity but also to retain soil health and sustainability (Nema *et al.*, 2008; Maruthi Sankar *et al.*, 2012).

The regression models for predicting the treatment effect on grain yield using monthly rainfall events of the actual growing season could be of interest to predict the final crop yield with the likely fluctuation. Similar regression models have also been successfully developed and used earlier by Sharma *et al.* (2009), Maruthi Sankar *et al.* (2010) and Maruthi Sankar *et al.* (2012) for soybean, pearlmillet and many other crops under semi-arid conditions of India.

Maize (*Zea mays L.*) – wheat (*Triticum aestivum L.*) rotation is the third most important cropping system in India and is grown on about 1.13 million ha. Rainfed maize-wheat is the major cropping system in foothill regions of India (Singh *et al.*, 2011). This region is suffering from number of biophysical and socio-economic problems and needs urgent attention to curtail cost of cultivation and increase profitability for sustainability of maize-wheat system by developing and adopting appropriate tillage and nutrient management strategies. In view of the above, the present study focused on the assessment of long-term effects of tillage and use of nitrogen from various sources on productivity and profitability of a rainfed maize-wheat system.

Materials and Methods

Experimental site : A long-term (2000-2012) field experiment was conducted at Punjab Agricultural University Regional Research Station, Ballowal Saunkhri, India to study the effect of tillage and nitrogen management through various sources on the productivity of maize-wheat rotation. The experimental site represents the lower *Shivalik* foothills of Indian Punjab and experiences sub-humid climate with dry and hot summer and extremely cold winter. The average annual rainfall of the region is around 1129 mm and about 80% of rainfall is received during a short span of July to mid September with very scanty rainfall during winter and spring seasons.

Experimental design, treatments, agronomic practices and soil characteristics : The field experiment was conducted with maize (*kharif*) and wheat (*rabi*) crops in a sequence using spilt-plot design. The experiment (Table 1) consisted of three tillage practices: conventional tillage (CT), reduced tillage (RT_1) and reduced tillage + herbicide (RT_2) in the main plot and three nitrogen (N) management practices: 100% N from organic source (F_1), 50% N from organic source + 50% N from inorganic source (F_2) and 100% N from inorganic source (F_3) in sub-plots.

The experimental soil was loamy, low in organic carbon (0.24%), very low in available N (98.3 kg ha^{-1}) and P (16.4 kg ha^{-1}), and medium in K (189.3 kg ha^{-1}). Soil moisture retention at permanent wilting point (15 bar) was 3.1 while field capacity (1/3 bar) was 10.4 with 24.8 cm/1.8 m of available water. The bulk density of soil was 1.38 Mg m^{-3} with pH 8.1 and electrical conductivity of 0.21 dS m^{-1}.

Sowing, harvesting and rainfall details : The sowing time of maize was influenced by the onset of monsoon rains during the study period. The onset of monsoon rains along with its withdrawal influenced crop duration and harvesting of maize crop, as well as sowing time of the succeeding wheat crop (Table 2). The monthly rainfall (June to March) and the crop season rainfall (CRF) for maize and wheat during 2000 to 2012 were considered independently for assessing the treatment effect. A rainfall event of $\geq$ 2.5 mm day^{-1} was considered for calculating the cumulative rainfall of a month. Total CRF over the study period for maize crop ranged from 388 to 870 mm with a mean of 552 mm and CV of 25.9% (Table 2).

Statistical analysis : The ANOVA of the experiment was performed in split plot design using SPSS version 16 (SPSS,

Table 1 : Details of treatments and agronomic practices followed

Treatments	Maize (July-October)	Wheat (October-April)
Tillage practices		
Conventional tillage (CT)	4 ploughings (1 summer ploughing + 2 disk harrowing + 1 cultivator ploughing followed by planking) + 1 interculture at 25 days after sowing (DAS)	4 ploughings (2 disk harrowing followed by planking+ 2 cultivator ploughings followed by 1 planking)+ 1 interculture at 25 DAS
Reduced tillage (RT_1)	2 ploughings (1 disk harrowing + 1 cultivator ploughing followed by planking) + 1 interculture at 25 DAS	2 ploughings (1 disk harrowing followed by planking+ 1 cultivator ploughing followed by planking)+ 1 interculture at 25 DAS
Reduced tillage + herbicide (RT_2)	RT_1 + pre-emergence herbicide spray (Atrazine @ 1.0 kg a.i. ha^{-1})	RT_1 + post-emergence herbicide spray (Isoproturon @ 0.94 kg a.i. ha^{-1})
Nitrogen application		
100% N from organic source (F_1)	80 kg N ha^{-1} through compost (organic)†	80 kg N ha^{-1} through compost (organic)†
50% N from organic source+50% N from inorganic source (F_2)	40 kg N ha^{-1} through compost (organic)† + 40 kg N ha^{-1} through urea (inorganic) ‡	40 kg N ha^{-1} through compost (organic)†+ 40 kg N ha^{-1} through urea (inorganic)‡
100% N from inorganic source (F_3)	80 kg N ha^{-1} through urea (inorganic) ‡	80 kg N ha^{-1} through urea (inorganic)‡
Hybrid/Variety	JH 3459* (hybrid)	PBW 175 (variety)
Seed rate (kg ha^{-1})	20	100
Spacing		
- Row-row (cm)	45.0	30
- Plant-plant (cm)	22.5	Approx 2.0
Fertilisation (applied at sowing time)	40 kg ha^{-1} P_2O_5 through single super phosphate (SSP) + 20 kg ha^{-1} K_2O through murate of potash (MOP)	40 kg ha^{-1} P_2O_5 through SSP + 20 kg ha^{-1} K_2O through MOP

†Compost (1.38 to 1.63 % N, 1.41 to 1.59% P_2O_5 and 1.50 to 1.95% K_2O) was applied about 3-4 weeks before sowing in both crops. Compost consisted of farm yard manure, green leaves of *Leucaena leucocephala* and wheat straw. ‡Half of the prescribed dose of urea (46 % N) to each crop was applied at the time of sowing and the remaining half was top dressed at knee height stage in maize and after winter rains in wheat *Single cross hybrid 'Parkash' was grown during *kharif* 2009

2007), and the differences among tillage and nitrogen treatments were compared by LSD at significance level of $p < 0.05$ (Gomez and Gomez, 1984).

Treatment-specific linear regression models were developed using grain yields and total monthly rainfall (RF) received for assessing the rainfall effect on crop yields (Draper and Smith, 1998). The expression of linear regression model for both maize and wheat are given as:

Maize : $Y - \pm\alpha \pm\beta_1$ (Jun RF) $\pm \beta_2$ (Jul RF) $\pm \beta_3$ (Aug RF) $\pm \beta_4$ (Sep RF) (1)

Wheat : $Y - \pm\alpha \pm\beta_1$ (Oct RF) $\pm \beta_2$ (Nov RF) $\pm \beta_3$ (Dec RF) $\pm \beta_4$ (Jan RF) $\pm \beta_5$ (Feb RF) $\pm \beta_6$ (Mar RF) (2)

where, α is intercept and βs are the slopes or regression coefficients measuring the change in yield for a unit change in the rainfall.

In order to identify the optimum combination of tillage and nitrogen practices for each crop, sustainability yield indices (SYI) were computed (Nema *et al.,* 2008; Maruthi Sankar *et al.,* 2012). An efficient tillage and nitrogen treatment could be identified based on SYI derived as 'SYI' of treatment 'k' given as:

$$SYI = ((Y_k - E_k) / (Y_{max})) \times 100 \quad (3)$$

Where, Y_k is the mean yield of k^{th} treatment, E_k is the prediction error based on the regression model of k^{th} treatment and Y_{max} is the maximum yield of a treatment in any year.

The rainwater use efficiency (RWUE) (kg ha^{-1} mm^{-1}) for each treatment was computed as a ratio of crop yield and crop seasonal rainfall. To compute the economics and profitability of tillage and nitrogen treatments over years, the gross monetary returns, net monetary returns and benefit-cost ratios were calculated (Nema *et al.,* 2008).

Results and Discussion

Reduced tillage + herbicide (RT_2) recorded maximum grain yield of maize (2264 kg ha^{-1}) which was 13.8 and 1.8% higher than reduced tillage (RT_1) and CT, respectively (Table 3). Among the nitrogen sources, application of 100% N from

Table 2 : Sowing and harvesting time, crop growth period and temporal distribution of rainfall during maize and wheat growing seasons (2000-01 to 2011-12)

Year	Sowing date	Harvest date	Crop growth period (days)	Rainfall (mm)						
				Jun	Jul	Aug	Sep			CRF*
Maize										
2000	07.07.00	28.09.00	84	146	486	312	102			870
2001	06.07.01	27.09.01	84	77	318	285	46			618
2002	04.07.02	01.10.02	90	111	66	212	298			574
2003	03.07.03	24.09.03	84	108	296	146	67			508
2004	10.07.04	28.09.04	81	42	179	354	9			497
2005	07.07.05	01.10.05	87	52	241	159	115			408
2006	15.07.06	06.10.06	84	23	167	306	80			497
2007	19.07.07	07.10.07	81	131	210	152	154			388
2008	14.07.08	10.10.08	89	435	75	295	257			589
2009	27.07.09	16.10.09	82	27	190	202	87			391
2010	17.07.10	11.10.10	87	80	347	171	219			542
2011	12.07.11	04.10.11	85	303	139	492	153			742
Mean	12 July	4 Oct	85	128	226	257	132			552
CV (%)	-	-	3.4	95.8	53.1	40.2	66.2			25.9
				Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**CRF***
Wheat										
2000-01	11.11.00	11.04.01	151	0	0	29	9	1	36	77
2001-02	17.11.01	10.04.02	145	0	0	8	22	25	13	68
2002-03	08.11.02	19.04.03	163	31	0	2	31	49	21	113
2003-04	15.11.03	06.04.04	144	0	8	7	118	7	0	139
2004-05	05.11.04	17.04.05	163	229	1	20	47	74	37	179
2005-06	07.11.05	07.04.06	152	0	0	0	30	0	67	96
2006-07	24.11.06	27.04.07	155	6	5	14	1	113	106	282
2007-08	08.11.07	11.04.08	156	0	4	13	21	7	0	73
2008-09	03.11.08	05.04.09	153	41	1	1	18	16	16	51
2009-10	19.11.09	06.04.10	139	11	14	0	7	19	3	29
2010-11	28.10.10	07.04.11	162	46	0	61	13	96	22	192
2011-12	09.11.11	13.04.12	157	0	0	30	48	12	5	105
Mean	11 Nov	12 Apr	153	30	3	15	30	35	27	117
CV (%)	-	-	5.0	214.4	160.3	115.5	103.0	111.8	115.9	60.9

CRF: Crop season rainfall (mm); CV: Coefficient of variation (%); *CRF is total rainfall received during sowing to harvesting of a crop and not total months

inorganic source (F_3) provided maximum mean grain yield of maize (2364 kg ha^{-1}) which was 18.9 and 8.81% higher than 100% N from organic source (F_1) *and* 50% N from organic source + 50% N from inorganic source (F_2), respectively. The interaction effect of tillage and nitrogen management was significant and RT_2 + F_3 recorded highest mean grain yield of maize to the extent of 2493 kg ha^{-1}. The maximum mean grain yield of wheat (2110 kg ha^{-1}) was observed with CT which was 7.9 and 1.7% higher than RT_1 and RT_2 (Table 3). The mean grain yield of wheat (2131 kg ha^{-1}) with F_3 was 11.6 and 2.1 % higher than F_2 and F_1, respectively. Positive interaction was observed among tillage and nitrogen management and CT/RT_2 + F_3 recorded highest mean grain yield of wheat (2175 kg ha^{-1}) and was identical to yield (2170 kg ha^{-1}) observed under CT + F_2.

Minimized soil disturbance, creation of viable seedbed, supportive soil physical condition and less crop-weed competition at critical stages of crop growth through reduced tillage resulted in better expressions of growth and yield parameters significantly contributing towards higher maize yield under modified reduced tillage (RT_2) (Sheoran *et al.,* 2009). Tolessa *et al.* (2014) also observed identical maize grain yield under minimum and CT in Ethiopia under rainfed conditions. Heavy flush of weeds (*Commelina benghalensis, Trainthema portulacastrum,* etc.) due to no herbicide application was the devastating factor for yield loss with RT_1 in maize. When compared to CT, RT_1 resulted into higher weed density and dry weight of weeds in maize, while in wheat it recorded lower density and dry weight of weeds. However, when RT_1 was integrated with chemical weed control (RT_2), it drastically reduced the density and dry weight of weeds in both the crops. However, wheat growth was positively affected due to higher moisture conservation under CT. More proliferation of roots leading to better extraction of moisture and nutrients under CT might be the possible reason for improving wheat yield

Table 3 : Effect of tillage and nitrogen application on the grain yield (kg ha^{-1}) of rainfed maize and wheat (2000-01 to 2011-12)

Treatments	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	Mean	CV (%)
Maize														
CT	1528	2455	2163	3025	1214	2090	2233	2699	2258	2251	2934	1825	2223	23.9
RT$_1$	1597	2422	2145	2557	950	1822	1857	2300	1904	1907	2375	1581	1951	23.0
RT$_2$	2166	2891	2287	2800	1161	1905	2073	2733	2305	2298	2650	1897	2264	21.4
F$_1$	1576	2334	1764	2971	937	1762	1867	2302	1930	1893	2122	1545	1917	26.0
F$_2$	1754	2597	2183	2705	1009	1930	2123	2688	2049	2197	2814	1840	2157	23.6
F$_3$	1961	2837	2645	2705	1380	2127	2173	2742	2488	2365	3023	1918	2364	19.9
LSD (T) ($p<0.05$)	140	243	n.s.	194	181	202	192	333	202	213	400	203	124	-
LSD (N) ($p<0.05$)	123	225	249	n.s	112	185	159	297	182	190	298	174	95	-
LSD (T×N) ($p<0.05$)	n.s.	n.s.	n.s	n.s	n.s	321	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-
Wheat														
CT	358	2510	2457	3357	2857	1442	3555	1523	1726	1249	2434	1852	2110	43.8
RT$_1$	369	2515	1929	2737	2924	1111	3467	1611	1800	1225	1988	1636	1943	44.3
RT$_2$	389	2637	2296	2889	3004	1500	3397	1516	1899	1374	2253	1744	2075	40.6
F$_1$	387	2010	2279	3101	2503	1256	3354	1567	1728	1228	1873	1627	1909	43.1
F$_2$	371	2816	2219	3043	3081	1311	3506	1517	1819	1293	2315	1754	2087	43.8
F$_3$	358	2836	2183	2840	3202	1486	3558	1566	1877	1326	2487	1851	2131	42.4
LSD (T) ($p<0.05$)	n.s.	n.s.	314	282	n.s.	275	n.s.	n.s.	n.s.	n.s.	250	n.s.	121	-
LSD (N) ($p<0.05$)	n.s.	174	n.s.	n.s.	377	148	166	n.s.	n.s.	n.s.	174	140	93	-
LSD (T×N) ($p<0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-

LSD : Least Significant Difference; T: Tillage; N: Nitrogen; n.s.: non-significant; CV: Coefficient of variation (%); CT: Conventional tillage; RT1: Reduced tillage; RT2: Reduced tillage + herbicide; F1: 100% N from organic source, F2: 50% N from organic source + 50% N from inorganic source; F3: 100% N from inorganic source

(Singh and Singh, 2008). The current findings are similar to Usman *et al.* (2012) and Mitra *et al.* (2014) who recorded similar wheat grain yields with reduced and conventional tillage.

Availability of sufficient moisture during monsoon season to maize crop ensured efficient utilisation of inorganic N fertiliser (F_3) resulting in higher yield. The wheat crop in the region is generally sown on conserved moisture and poor soil moisture conditions coupled with low temperature which might have delayed the transformation of nutrients to available form through F_1 fertilisation and ultimately resulting in low yield. Improved crop yield in manured plots reinforced with inorganic nitrogen application could be attributed to the carryover effects of minerals for efficient utilisation of growth resources, thus maintaining stable yield performance and substantial improvement in soil health and associated indices (Lemcoff and Loomis, 1994).

The RWUE during the study period ranged from 1.76 to 7.08 kg ha^{-1} mm^{-1} in maize and from 4.66 to 47.54 kg ha^{-1} mm^{-1} in wheat (Table 4). The rain water use efficiency (RWUE) of maize and wheat was significantly influenced among tillage and N treatments during individual year and for the pooled data. Both RT_2 and CT were statistically at par with each other but significantly superior to RT_1 for mean RWUE in both the crops. Tillage treatments of RT_2 and CT increased mean RWUE in maize by 13.3 and 12.9% over RT_1, respectively in maize and by 7.1 and 5.7% in wheat. Ghosh *et al.* (2015) also reported better moisture conservation under conservation tillage in maize-wheat cropping system. Better utilization of rainwater under RT_2 and F_3 reflected in terms of high yield resulted into high values of RWUE under these treatments due to interaction effect. Significantly higher mean RWUE (4.55 kg ha^{-1} mm^{-1}) in maize was recorded under F_3 than F_2 and F_1, while it was significantly superior to only F_1 in case of wheat. Dang *et al.* (2005) reported improved water use efficiency with nitrogen application in rainfed wheat-maize system.

The net returns in maize varied from US$ 70.96 ha^{-1} under CTF_1 to US$ 222.60 ha^{-1} under RT_2F_3 (CV 43.0%), while benefit-cost ratio (B:C) ranged from 1.15 under RT_1F_1 to 1.88 under RT_2F_3 (CV 16.4%). Among tillage treatments, RT_2 recorded the highest net returns (US$ 160.24 ha^{-1}) and B:C ratio (1.59) in maize, while under nitrogen management treatments, F_3 recorded the highest net returns (US$ 195.88 ha^{-1}) and B:C ratio (1.75).

In wheat, net returns of US$ 189.50 ha^{-1} obtained with RT_1F_1 increased to US$ 315.45 ha^{-1} under RT_2F_3 (CV 17.9%). The B:C ratio in wheat ranged between 1.65 under CTF_1 to 2.28 under RT_2F_3 (CV 16.4%). Wheat crop under tillage treatment RT_2 recorded the highest NR (US$ 268.98 ha^{-1}) and B:C ratio (20.3) while among nitrogen management treatments, F_3 recorded the highest net returns (US$ 303.81 ha^{-1}) and B:C ratio (2.21). The treatment combination RT_2F_3 recorded the highest net returns and

Table 4 : Effect of tillage and nitrogen application on the rain water use efficiency (kg ha^{1} mm^{1}) of maize and wheat grown under rainfed conditions (2000-01 to 2011-12)

Treatments	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	Mean	CV (%)
Maize														
CT	1.76	3.98	3.77	5.95	2.44	5.12	4.49	6.96	3.83	5.76	5.41	2.46	4.33	36.7
RT_1	1.84	3.92	3.74	5.03	1.91	4.47	3.74	5.94	3.23	4.88	4.38	2.13	3.77	34.5
RT_2	2.49	4.68	3.99	5.51	2.34	4.67	4.17	7.05	3.91	5.88	4.89	2.56	4.35	32.9
F_1	1.81	3.78	3.07	5.84	1.89	4.32	3.76	5.94	3.28	4.85	3.92	2.08	3.71	37.6
F_2	2.02	4.21	3.80	5.32	2.03	4.73	4.27	6.94	3.48	5.63	5.19	2.48	4.18	36.2
F_3	2.25	4.59	4.61	5.32	2.78	5.21	4.37	7.08	4.22	6.05	5.58	2.59	4.55	31.9
LSD (T) ($p<0.05$)	0.16	0.39	n.s.	0.38	0.36	0.49	0.39	0.86	0.34	0.55	0.74	0.27	0.22	-
LSD (N) ($p<0.05$)	0.14	0.36	0.43	n.s.	0.23	0.45	0.32	0.77	0.31	0.49	0.55	0.23	0.19	-
LSD (T × N) ($p<0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	0.79	n.s.	n.s.	n.s	n.s.	n.s.	n.s.	n.s.	-
Wheat														
CT	4.66	37.07	21.76	24.22	15.95	14.96	12.62	20.87	33.91	43.21	12.71	17.67	21.63	52.2
RT_1	4.82	37.15	17.09	19.75	16.33	11.52	12.31	22.07	35.36	42.37	10.38	15.61	20.40	57.8
RT_2	5.07	38.94	20.34	20.84	16.77	15.56	12.06	20.77	37.30	47.54	11.76	16.64	21.97	57.7
F_1	5.05	29.69	20.19	22.37	13.97	13.02	11.91	21.46	33.96	42.50	9.78	15.53	19.95	54.5
F_2	4.84	41.59	19.66	21.95	17.20	13.60	12.44	20.78	35.74	44.74	12.09	16.73	21.78	57.1
F_3	4.66	41.89	19.34	20.49	17.88	15.42	12.63	21.45	36.87	45.88	12.99	17.67	22.26	56.6
LSD (T) ($p<0.05$)	n.s.	n.s.	2.78	2.03	n.s.	2.86	n.s.	n.s.	n.s.	n.s.	1.30	n.s.	1.22	-
LSD (N) ($p<0.05$)	n.s.	2.57	n.s.	n.s.	2.10	1.53	0.59	n.s.	n.s.	n.s.	0.91	1.33	1.02	-
LSD (T×N) ($p<0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-

LSD : Least Significant Difference; T: Tillage; N: Nitrogen; n.s.: non-significant; CV: Coefficient of variation (%); CT: Conventional tillage; RT_1: Reduced tillage; RT_2: Reduced tillage + herbicide; F_1: 100% N from organic source; F_2: 50% N from organic source + 50% N from inorganic source; F_3: 100% N from inorganic source

benefit-cost ratio in both maize and wheat. Hashim *et al*. (2017) reported improved economic returns with the nitrogen management in maize-wheat system.

The mean reduction in cost of cultivation due to reduced tillage (RT_1 and RT_2) over CT was 10.2 and 9.6% in maize and wheat, respectively and the treatment RT_2F_3 proved most economical in terms of net returns and benefit-cost ratio in both crops. The average price of per kg nutrient supplied through organic fertilizer was higher (US$ 0.4702) than the inorganic fertilizer (US$ 0.2296). The comparatively lower cost of inorganic fertilizers than organic was responsible for higher net returns and benefit-cost ratio of all the treatment combinations involving inorganic fertilizers in both the crops. Mitra *et al.* (2014) also reported a higher B : C ratio in RT against CT in wheat despite lesser yield, which was mainly due to huge curtailment in the cost of land preparation under RT. Landers *et al.* (2001) have also recorded higher net income in no-tillage through reducing production cost by 15-20% compared with CT. Kelava *et al.* (2000) also achieved higher economic efficiency with non-conventional tillage systems than CT system.

The regression model in maize provided a non-significant yield predictability and higher prediction error for different treatments over years, while in wheat it gave significantly higher yield predictability and lower prediction error (Table 5). The rainfall received in June and July had a positive effect (non-significant) on yield produced in all treatments, except a negative effect in case of RT_1F_3 in June and CTF_1 in July. However, rainfall in August had a significant negative effect on yield produced under F_1 in combination with all the three tillage treatments whereas it caused inconspicuous effect on the remaining treatments. September rainfall also favourably though non-significantly influenced the yield with F_1 and F_2 sources of nitrogen but caused a non-significant negative effect with F_1 in combination with all the three tillage treatments.

In wheat, the rainfall received in October and November had a non-significant negative effect on yield obtained under all the treatments, except positive effect in RT_1F_3 in November. Also December rainfall had a negative effect on yield of all treatments but the effect was significant only in CTF_1, CTF_2, RT_1F_1 and RT_2F_1. The rainfall received in January and February had a significant positive effect on yield produced by all treatments, except in RT_1F_2, RT_1F_3 and RT_2F_3 in January. However, rainfall received in March caused a non-significant negative effect on yield under all treatments of tillage and nitrogen sources.

The sustainability yield index (SYI) was highest (60.7%) in maize under RT_2F_3 and in wheat (51.5%) with CTF_2. The results showed a large variation in the SYI values of tillage and nitrogen treatments in both crops owing to variation in crop seasonal rainfall, besides erratic distribution of monthly rainfall received during June to September in maize and October to April in wheat

Table 5 : Effect of monthly rainfall on grain yield of maize and wheat under different tillage and nitrogen application treatments (2000 to 2012)

Treatment	Regression model	R^2	Error	SYI
Maize				
CTF_1	Y = 3348** + 2.50 (Jun) – 0.14 (Jul) – 5.26* (Aug) – 2.37 (Sep)	0.52	521.7	0.430
CTF_2	Y = 2930** + 0.73 (Jun) + 0.32 (Jul) – 3.71 (Aug) + 0.89 (Sep)	0.52	469.1	0.526
CTF_3	Y = 2743** + 1.01 (Jun) + 0.68 (Jul) – 3.38 (Aug) + 1.63 (Sep)	0.50	487.4	0.552
RT_1F_1	Y = 2433** + 1.96 (Jun) + 0.61 (Jul) – 3.60* (Aug) – 1.57 (Sep)	0.52	390.4	0.383
RT_1F_2	Y = 2054* + 0.88 (Jun) + 1.35 (Jul) – 2.91 (Aug) + 1.46 (Sep)	0.49	463.1	0.427
RT_1F_3	Y = 2303** – 0.01 (Jun) + 0.73 (Jul) – 2.48 (Aug) +2.82 (Sep)	0.62	367.4	0.536
RT_2F_1	Y = 2456** + 2.61 (Jun) + 1.37 (Jul) – 3.69* (Aug) – 1.03 (Sep)	0.57	408.6	0.473
RT_2F_2	Y = 2231* + 1.05 (Jun) + 1.75 (Jul) – 2.66 (Aug) + 1.28 (Sep)	0.48	466.6	0.521
RT_2F_3	Y = 2372** + 1.26 (Jun) + 1.64 (Jul) – 2.54 (Aug) + 1.73 (Sep)	0.56	403.2	0.607
Wheat				
CTF_1	Y = 1079** – 3.57 (Oct) – 14.41 (Nov) – 21.54* (Dec) + 21.08** (Jan) + 25.79** (Feb) – 3.52 (Mar)	0.95**	309.7	0.487
CTF_2	Y = 1335** – 2.72 (Oct) – 46.48 (Nov) – 24.07* (Dec) + 18.71** (Jan) + 31.08** (Feb) – 6.85 (Mar)	0.93*	399.3	0.515
CTF_3	Y = 1349* – 3.12 (Oct) – 41.06 (Nov) – 20.65 (Dec) + 18.58* (Jan) + 28.43** (Feb) – 5.64 (Mar)	0.87*	498.8	0.487
RT_1F_1	Y = 1169* – 1.87 (Oct) – 16.85 (Nov) – 23.75* (Dec) + 13.68* (Jan) + 23.17** (Feb) – 2.80 (Mar)	0.88*	406.7	0.407
$RT_1\ F_2$	Y = 1281* – 0.95 (Oct) – 18.61 (Nov) – 22.78 (Dec) + 14.19 (Jan) + 25.01* (Feb) – 4.97 (Mar)	0.74	696.7	0.372
RT_1F_3	Y = 1375* + 0.21 (Oct) – 32.95 (Nov) – 20.48 (Dec) + 11.87 (Jan) + 25.57* (Feb) – 5.46 (Mar)	0.80	608.2	0.417
RT_2F_1	Y = 1258** – 2.54 (Oct) – 21.81 (Nov) – 24.41** (Dec) + 16.49** (Jan) + 24.32** (Feb) – 4.21 (Mar)	0.95**	278.4	0.482
RT_2F_2	Y = 1499** – 1.09 (Oct) – 43.26 (Nov) – 24.18 (Dec) + 14.50* (Jan) + 26.30* (Feb) – 6.88 (Mar)	0.85*	507.5	0.467
RT_2F_3	Y = 1575** – 0.11 (Oct) – 42.68 (Nov) – 23.92 (Dec) + 11.52 (Jan) + 25.94* (Feb) – 4.93 (Mar)	0.83	542.6	0.474

*, ** significant at $p < 0.05$ and $p < 0.01$, respectively; R^2: Coefficient of determination; SYI: Sustainability yield index; CT: Conventional tillage; RT_1: Reduced tillage; RT_2: Reduced tillage + herbicide; F_1: 100% N from organic source; F_2: 50% N from organic source + 50% N from inorganic source; F_3: 100% N from inorganic source

in each year. Among tillage practices, RT_2 was superior in maize while CT was superior in wheat. Among nitrogen sources, F_3 was superior in both crops. Thus, RT_2 together with F_3 showed its long-term superiority for attaining maximum productivity, profitability and RWUE in maize, as well as wheat crop and it was closely followed by CTF_3. Sheoran *et al.* (2009) reported higher SYI under minimum tillage and nitrogen management.

Rainfall events in June, July and September played a vital role in increasing maize yields under sub-humid conditions. Rainfall in June coincided with preparatory tillage and consequently led to moisture conservation in the soil profile. Spatio-temporal distribution of rainfall in July is the determining factor for timely sowing of maize crop ensuring improved germination and desired crop stand. The anticipated adverse effect of August rainfall could be ascribed to water stagnation owing to occasional high rainfall events (2001, 2002, 2004, 2006, 2008 and 2011) as maize crop is highly sensitive to excess moisture conditions. The positive impact of rains in September could be attributed to the moisture availability during reproductive (cob formation, tasseling, silking, pollination and grain formation) stages of the crop, which is the most significant phase in the ontogeny of maize plant (completed in a time span of 15–20 days), and shortage of water at this stage causes a drastic reduction in cob yield (Rashid and Rasul, 2012). It was observed that rainwater stored in the soil profile during September supplied soil moisture to the crop upto physiological maturity.

Rains are normally received in the region during January and February months of the winter season which proved vital for growth and yield improvement in wheat. The temperature during December and January remains low resulting in negligible evapotranspiration losses and whatever little precipitation was received during this period was efficiently utilised by the growing plants. Any rainfall received in February is quite useful as the wheat plant passes through booting, flowering and heading stages, and thus requires adequate moisture to sustain growth. The water stress at anthesis may reduce pollination resulting in higher pollen sterility, shrivelled grains and reduction in test weight and reduced crop yields (Ashraf, 1998). Recharging of soil profile with rains in February assured crop moisture needs upto mid March. In March, temperature starts rising; however, wheat reaches maturity during this month and water demand is reduced (Singh *et al*., 2005; Deo *et al*., 2017).

The present study demonstrates that RT_2 in combination with F_3 resulted in higher grain yield, RWUE, net profit and B:C ratio of maize and wheat compared to other treatments. Similar superior performance of reduced tillage + herbicide and/or CT over reduced tillage has been previously reported (Sheoran *et al.*, 2009; Akbarnia *et al.*, 2010; Rusu *et al.*, 2013). Singh *et al.* (2011) also reported significantly higher productivity of both maize and wheat with CT than minimum tillage under rainfed sub-humid conditions of north-western Himalayas. Most of the rainfed soils in the region are low in fertility, especially nitrogen and the response and performance of inorganic fertilisers remain superior than organic sources in the short run due to fast release and availability of the nutrients. Probably, for this reason, application of nitrogen through F_3 proved to be superior to other sources. These results coincide with those of Díaz-Zorita *et al.* (2002) who reported in a review that maize yields increased more by nitrogen fertilisation than by tillage application under sub-humid and semi-arid regions of Argentina.

It is likely that the short-term nitrogen locking in reduced tillage systems compared with conventional tillage systems did not prevail for long-term, as indicated by yield levels in different treatments in the present study. Fertiliser nitrogen management can be greatly influenced by changes in tillage. Soils in the present study have a loamy texture with more than 1 m depth, and consequently have fair water retention capacity to support crop growth under rainfed conditions. Similar to CT and RT_1, the RT_2 was also able to capture enough rainwater during pre- and post-monsoon rains to replenish the soil profile, but it was better in controlling weeds through herbicide application, thus, supporting good crop growth and performing better in combination with inorganic nitrogen (F_3). Ghosh *et al.* (2017) has also reported the beneficial effect of nitrogen application on maize crop.

The study shows promising possibilities for energy and labour saving due to the utilisation of non-conventional soil tillage systems and would help farmers in *Shivalik* foothills of northern India to curtail production expenses with the shift of conventional tillage to reduced/conservation tillage practices.

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