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Effects of sowing date, tillage and residue management on productivity of cotton (*Gossypium hirsutum* L.)–wheat (*Triticum aestivum* L.) system in northwest India

S.K. Jalota [a], G.S. Buttar [b], Anil Sood [c,*], G.B.S. Chahal [a], S.S. Ray [d], S. Panigrahy [d]

[a] *Department of Soils, Punjab Agricultural University, Ludhiana, India*
[b] *Punjab Agricultural University Regional Research Station, Bathinda, India*
[c] *Punjab Remote Sensing Centre, Ludhiana, India*
[d] *Space Applications Centre, Ahmedabad, India*

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Abstract

In southwestern region of Punjab in north India, sowing dates of cotton crop in cotton (*Gossypium hirsutum* L.)–wheat (*Triticum aestivum* L.) system are staggered from last week of April to mid of May depending upon the surface water supply from canal as ground water is not fit for irrigation. Further, farmers practice intensive cultivation for seedbed preparation and burning of wheat straw before sowing of cotton crop. With the present farmers' practices, yields have become static and system has become non-profitable. Field experiments were conducted on Entisols for two rotations of cotton–wheat system during the years of 2004–2005 and 2005–2006 in split plot design to study the direct and interactive effects of date of sowing and tillage-plus-wheat residue management practices on growth and yield of cotton and wheat and to increase the profitability by reducing the tillage operations, which costs about 50% of the sowing cost. The pooled analysis showed that in cotton crop, there was a significant interaction between year × dates of sowing. Among different tillage-plus-wheat residue management practices yields were 23–39% higher in tillage treatments than minimum-tillage. In wheat, grain yield in tillage treatments were at par. Water productivity amongst the tillage treatments in cotton was 19–27% less in minimum tillage than others tillage treatments. Similar trend was found in wheat crop. Remunerability of the cotton–wheat system was more with a combination of reduced tillage in cotton and minimum tillage in wheat than conventional tillage.

Keywords: Cotton–wheat; Sowing time; Tillage; Crop residue; Entisols; Punjab

1. Introduction

Cotton–wheat is a dominant cropping system in semi-arid region of southwestern Indian Punjab. It covers 11% of the total cultivated area (4.6 m ha). In this cropping system, sowing of cotton is staggered from end of April to mid of May depending upon the surface water supply from canal as the ground water is not fit for irrigation (Singh et al., 2002). Seedbed for cotton is prepared with tillage operations consisting of two disking, two cultivators and one planking that costs about US$ 70 ha^{-1}, 50% of the total cost for sowing of cotton. The crop residues are not

* Corresponding author. Tel.: +91 161 2303484; fax: +91 161 2303483.
E-mail address: anilsood_prsc@rediffmail.com (A. Sood).

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incorporated in the field. The sticks of cotton are pulled out, removed from the field and used as fuel. In wheat crop following cotton, the same tillage operations as in cotton are repeated, but the straw of wheat is either removed from the fields or is burnt due to shortage of time between harvesting of wheat crop (mid April) and sowing of cotton crop (end of April to mid of May) that causes loss of carbon and other nutrients (Beri et al., 2003) and development of water repellency in soil (Singh et al., 2005). As a result, productivity of cotton–wheat system has become static or started declining and is showing the sign of fatigue. In the year 2001, area under cotton crop was reduced to 0.407 m ha from 0.71 m ha in 1991 (Statistical Abstract, 2005). The declining soil fertility, especially soil-organic matter, is one of the important factors responsible for this decline (Olk et al., 1996). Hence there is emphasis on building up soil organic matter and to improve organic matter in soil, organic and green manures and crop residues are commonly advocated. But in the era of intensive agriculture and demands of galloping population, the chances of leaving the soil fallow for green manuring is very little and the available practical option left only is the crop residue management. Therefore, it is envisaged that an economical tillage-plus-crop residue management practices should be devised to increase the profitability by reducing the cost of tillage. Keeping this in view, field experiments were conducted for 2 years with the objectives to (1) study the effects of date of sowing, tillage-plus-wheat residue management practices on the growth and yield of seed cotton and subsequent wheat. (2) Explore possibility of increasing profit by reducing the tillage operations.

2. Methods and materials

2.1. Site characteristics

Field experiments were conducted for two rotations of cotton–wheat system in years of 2004–2005 and 2005–2006 on Entisols, low in organic carbon (0.21%) and nitrogen (41 kg ha^{-1}), medium in available phosphorus (13.9 kg ha^{-1}) and high in potassium (431 kg ha^{-1}) at PAU Regional Research Station, Bathinda (30°58″ latitude, 74°18″ longitude and 211 m above mean sea level). Soil physical (texture, bulk density and hydraulic conductivity) and chemical (pH, EC, OC, ammonical nitrogen and nitrate nitrogen) properties of experimental field were determined up to 1.8 m with 0.15 m soil depth interval. The sand, silt and clay contents were determined by the International Pipette Method, bulk density with core method, hydraulic conductivity with constant head method (Jalota et al., 1998). EC was measured with solu bridge method (Chopra and Kanwar, 1976) and pH with potentiometric method (Jackson, 1973), OC by wet digestion method (Walkley and Black, 1934). Ammonical and nitrate nitrogen were determined by KCl method (Keeney, 1982). Physical properties of the soil profile showed that below 90 cm there is sharp increase in bulk density and decrease in hydraulic conductivity in soil layers (Table 1). The soil texture was loamy sand to sand for 0–45 cm of soil depth and thereafter texture changed to silt up to 180 cm of soil depth in the soil profile. The ground water at the experimental site was more than 10 m deep. The cumulative pan evaporation (Pan-E) and rainfall for 2 years of experimentation during cotton and wheat crops were recoded at meteorological laboratory situated at the experiment site and is presented in Figs. 1 and 2, respectively.

2.2. Treatments

Treatments in cotton comprised combination of 2 dates of sowing and 5 tillage-plus-residue management practices that are given below. Dates of sowing were kept in main plot and tillage cum residue treatments in the subplots with 6 replications.

- Main: two dates of sowing.
- 25–26 April (D_1) and 17–18 May (D_2).
- Sub: five tillage-plus-residue management.
- CTSB: conventional tillage (2 disking + 2 cultivator + 1 planking) + wheat straw[1] burnt.
- CTSI: conventional tillage (2 disking + 2 cultivator + 1 planking) + wheat straw incorporated.
- RTSI: reduced tillage (1 disking + 1 cultivator + 1 planking) + wheat straw incorporated.
- MTSAS: minimum tillage (no disking and no cultivator) + wheat straw on the soil surface as such.
- CTSR: conventional tillage (2 disking + 2 cultivator + 1 planking) + wheat straw removed from the field.

[1] The amount of wheat straw burnt, incorporated in conventional and reduced tillage and kept as such in minimum tillage was 2.5 t ha^{-1}. The depth of tillage was 0.15 m. The wheat straw comprised of 0.37, 0.51, 0.14, 0.88, 0.13, 0.23, 0.11 and 0.09% C, N, P, K, S, Ca, Mg and Na, respectively (Beri et al., 2003).

Table 1
Physical and chemical properties at the soil profile of the experiment site

Depth (m)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (Mg m^{-3})	Hydraulic conductivity (mm h^{-1})	pH	EC (dS m^{-1})	OC (%)
0–0.15	80.0	12.5	7.5	Loamy sand	1.58	8.7	8.8	0.366	0.420
0.15–0.30	92.5	5.0	2.5	Sand	1.58	39.3	8.9	0.284	0.315
0.30–0.45	81.2	10.0	8.8	Loamy sand	1.54	36.9	8.7	0.311	0.120
0.45–0.60	72.5	17.5	10.0	Silt	1.55	4.7	8.5	0.332	0.150
0.60–0.75	72.5	17.5	10.0	Silt	1.49	32.9	8.5	0.229	0.105
0.75–0.90	68.7	20.0	11.3	Silt	1.59	12.8	8.8	0.303	0.090
0.90–1.05	72.5	17.5	10.0	Silt	1.72	2.6	8.8	0.297	0.405
1.05–1.20	70.3	17.5	12.2	Silt	1.73	4.6	8.7	0.379	0.240
1.20–1.35	71.5	18.8	9.7	Silt	1.75	1.9	8.5	0.372	0.210
1.35–1.50	69.1	20.0	10.9	Silt	1.73	2.1	8.6	0.369	0.210
1.50–1.65	51.5	31.3	17.2	Silt	1.81	0.7	8.7	0.342	0.150
1.65–1.80	37.8	42.5	19.7	Silt	1.75	1.2	8.7	0.310	0.075

In the same layout of the field, wheat was sown with 12 replications (as there was only one date of sowing). Before sowing of wheat, tillage treatments were maintained in the respective plots (without cotton residue).

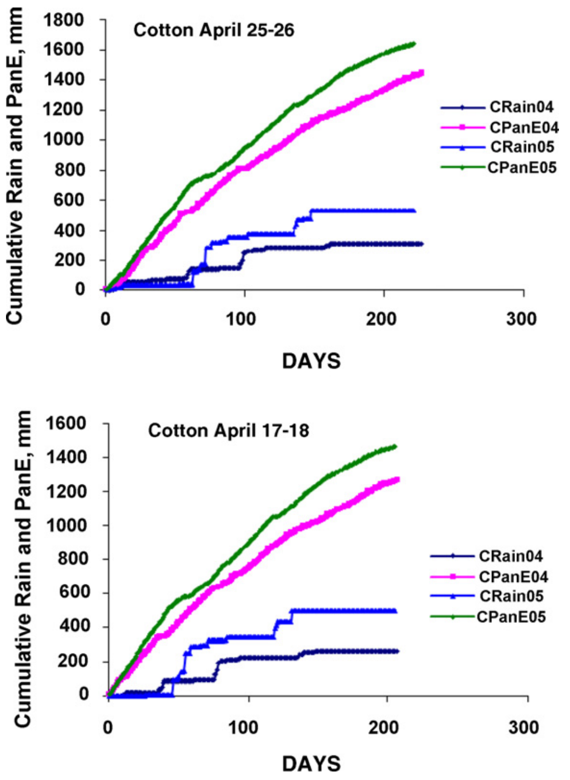

Fig. 1. Cumulative pan evaporation and rainfall data during cotton growing period in 2004 and 2005.

2.3. Crop management

Field was prepared for sowing of cotton crop by applying a pre-sowing irrigation of 10 cm on 22 April and 14 May for the two dates of sowing. When water content in surface soil dried to field capacity 30 plots of size 35 m^2 (5 m × 7 m) were made in the field for each date of cotton sowing. Earthen dikes of 30 cm height surrounding all the plots were made to check runoff due to rain and irrigation water. The *Gossypium hirsutum* variety LH 1556 was sown on 25 April and 17 May during 2004 and 26 April and 18 May during 2005 with drill at a spacing of 67.5 cm × 60 cm. As full dose of elemental phosphorus @ 17 kg ha^{-1} was applied to proceeding wheat crop, hence no phosphorus was applied to the crop as per recommendation of Punjab Agricultural University, Ludhiana. Half the dose of

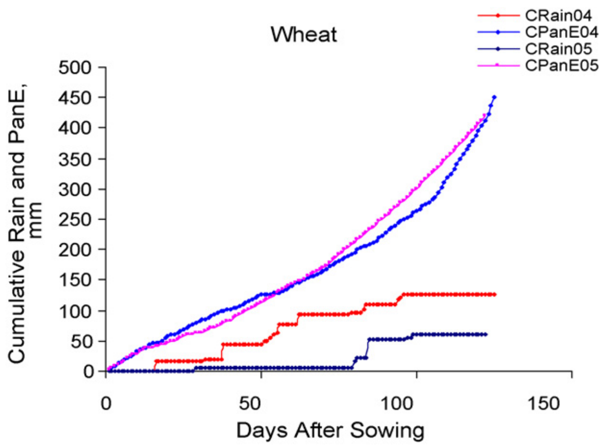

Fig. 2. Cumulative pan evaporation and rainfall data during wheat growing period in 2004–2005 and 2005–2006.

nitrogen @ 37.5 kg N ha^{-1} was applied to the cotton crop at the time of sowing and remaining half @ 37.5 kg ha^{-1} at the time of flowering of the crop (15–17 July during 2004 and 2–9 June during 2005). The dates of irrigations were 3 June, 15 July, 27 August and 27 September during 2004 and 2 June, 18 August and 25 August during 2005. Soil water content at sowing and at harvest was determined gravimetrically from 0 to 180 cm soil profile. Weeds were controlled with pre-emergence application of Stomp 30 EC (pendimethalin) @ 2.5 l ha^{-1} and two manual hoeings at 40 and 65 days after sowing of the crop. Insects and sucking pests and boll worms were controlled by adopting the recommended schedule (spray of confidor @ 100 ml ha^{-1}, Ethion and Endosulphon @ 2.5 l ha^{-1}, Thiodon @ 2.5 l ha^{-1}, Cypertherm @ 200 ml ha^{-1}, Hostathion @ 1.5 l ha^{-1} and Blitox @ 625 g ha^{-1} for plant protection as per Punjab Agricultural University, Ludhiana. The data on plant height, number of monopods per plant, number of sympods per plant, bolls per plant and shedded bolls per plant, were recorded as difference between total numbers of squares developed and converted into bolls on 10 plants. The crop was harvested on first week of December in both the years.

In the standing cotton an irrigation of 10 cm was applied for pulling out the cotton sticks and sowing of wheat. After pulling the cotton sticks the field was prepared as per tillage treatments and wheat crop (variety PBW 343) was sown on 13 December during 2004 and 20 December during 2005. In MTSAS treatment, wheat was sown with strip till drill developed by Punjab Agricultural University, whereas in other treatments sowing was done with normal drill. Recommended fertilizers of 60 kg N and 17 kg P ha^{-1} were applied at sowing and 60 kg N ha^{-1}were applied with first irrigation after 30 days of sowing. The crop was irrigated on 14 January, 3 March, 18 March and 31 March, during 2004–2005 and 19 January, 9 February and 9 March during 2005–2006. One hoeing was done on 20 January in both the years. The crop was harvested on 20 April. Apparent crop water productivity was estimated by dividing the seed cotton yield by the amount of water applied as irrigation (Jalota et al., 2006).

3. Results and discussion

3.1. Seed cotton yield

Seed cotton yield was affected by date of sowing differentially in the 2 years. The yield, averaged over tillage treatments, was higher in D_2 than D_1 during 2004 and in D_1 than D_2 during 2005 (Table 2). These trends in yield are in accordance with magnitude of the water deficit (PET-rain) during the initial period of plant growth, i.e. sowing to first irrigation. In this study, the values of water deficits in D_1 and D_2 were 247 and 281 mm in 2004 and 378 and 364 mm in 2005, respectively. The (unpublished) results from an independent experiment conducted during the years 2003–2004 also endorse these observations. These results support the contention that water stress at early stages of cotton stimulates the deeper penetration of rooting system, which can exploit more volume of the soil to withstand the water stress during mid season, and increase yield ultimately. The favorable effect of water stress of higher magnitude resulted from delayed first irrigation on cotton seed yield has been observed by a number of researchers (Buttar et al., 2007; Guinn and Mauney, 1984; Grimes et al., 1978; Dargan et al., 1965). They reported that delayed irrigation not only improves the seed yield but also increase water use efficiency. The effect of tillage on seed cotton yield was non-significant in 2004 and significant in 2005. Compared to MTSAS seed cotton yield in CTSB, CTSI, RTSI and CTSR treatments was more by 29, 8, 25 and 15% in 2004 and 39, 34, 40 and 29% in 2005, respectively. This may be ascribed to the reason that in the year 2005 evaporative demand was relatively more (180 cm) than in 2004 (Fig. 1). This information on interaction of tillage and season indicating more beneficial effects of tillage in cotton under higher evaporative demand supports the earlier observations made by Arora et al. (1991) and Gill et al. (1996) for maize crop grown under high evaporative demand. In general seed cotton yield was higher in tillage treatments than MTSAS. Higher yield obtained with tillage treatments might be due to favorable effect of these tillage practices on water availability for crops (Unger and Steward, 1983), hastening of organic matter decomposition and higher nutrient availability (Nehra et al., 2005), improvement in basic infiltration rate, hydraulic conductivity, soil pore geometry and enhanced root growth (Subramaniam et al., 1975; Jorge et al., 1984), for breaking hard setting and root restricting layers, mechanical loosening through tillage for conserving soil and water for optimum crop growth (Lal, 1989). The incorporation of crop residue with tillage in CTSB, CTSI and RTSI gave higher yield compared to CTSR (where wheat was harvested manually with sickles), though it was not significant in the present study. The beneficial effects of tillage-plus-residue management on crop yield confirm the observations of Nehra et al. (2005) that incorporation of shredded wheat straw in the soil on sandy loam soil at Sri Ganganagar in Rajasthan state with one

Table 2
Seed cotton yield (kg ha^{-1}) as influenced by date of sowing and tillage treatments in 2 years

Treatments	2004			2005			Pooled
	D_1 (April 20)	D_2 (May 17)	Mean	D_1 (April 27)	D_2 (May 18)	Mean	
CTSB: conventional tillage + wheat straw burnt	1153	1500	1327	2567	2062	2315	1820
CTSI: conventional tillage + wheat straw incorporated	938	1283	1111	2395	2002	2199	1655
RTSI: reduced tillage + wheat straw incorporated	1033	1524	1279	2576	2022	2299	1789
MTSAS: minimum tillage + wheat straw as such on soil surface	813	1236	1025	1812	1479	1646	1335
CTSR: conventional tillage + wheat straw removed	943	1405	1174	2363	1869	2116	1645
Mean for tillage-plus-residue management	976	1390		2343	1887		
Mean for year	1183	2115					
Mean for date of sowing	1649	1638					
LSD 0.05							
Year	–			–			135
Date of sowing	161			208			NS
Year × date of sowing	–			–			191
Tillage-plus-wheat residue management	NS			329			213
Year × tillage-plus-wheat residue management	–			–			NS
Date of sowing × tillage-plus-wheat residue management	NS			NS			NS
Year × date of sowing × date of sowing × tillage-plus-residue management methods	–			–			NS

disc + two cultivator produced higher seed cotton yield of cotton. Prasad and Power (1991) also reported beneficial effect of retaining crop residues in the field in a wide variety of crops, which increase organic matter, aggregation, water holding capacity and infiltration (Oades, 1984; Swift and Sanchez, 1984). The significantly lower seed cotton yield recorded in MTSAS than CTSB, CTSI, RTSI and CTSR treatments may be

Table 3
Apparent water productivity (kg m^{-3}) in seed cotton as influenced by date of sowing and tillage treatments in 2 years

Treatments	2004			2005			Pooled
	D_1 (April 20)	D_2 (May 17)	Mean	D_1 (April 27)	D_2 (May 18)	Mean	
CTSB: conventional tillage + wheat straw burnt	0.29	0.46	0.37	0.79	0.63	0.71	0.53
CTSI: conventional tillage + wheat straw incorporated	0.23	0.39	0.31	0.74	0.62	0.68	0.48
RTSI: reduced tillage + wheat straw incorporated	0.26	0.47	0.35	0.79	0.62	0.71	0.52
MTSAS: minimum tillage + wheat straw as such on soil surface	0.20	0.38	0.28	0.56	0.46	0.51	0.39
CTSR: conventional tillage + wheat straw removed	0.24	0.43	0.32	0.73	0.58	0.65	0.48
Mean	0.24	0.43	0.33	0.72	0.58	0.65	0.48
Irrigation water (mm)	0.29	0.46	0.37	0.79	0.63	0.71	0.53

Table 4
Grain yield and water productivity of wheat sown after cotton under different tillage treatments

Treatments	Grain yield (ha^{-1})			Water productivity ($kg\ m^{-3}$)		
	2004–2005	2005–2006	Mean	2004–2005	2005–2006	Mean
CTSB: conventional tillage + wheat straw burnt	3435	3397	3416	0.86	1.05	0.94
CTSI: conventional tillage + wheat straw incorporated	3382	3479	3430	0.85	1.07	0.94
RTSI: reduced tillage + wheat straw incorporated	3522	3496	3509	0.88	1.08	0.97
MTSAS: minimum tillage + wheat straw as such on soil surface	3626	3546	3586	0.91	1.09	0.99
CTSR: conventional tillage + wheat straw removed	3315	3367	3341	0.83	1.04	0.92
LSD (0.05)						
Tillage	NS	NS	NS			
Year × tillage	NS	NS	NS			

due to less proliferation of rooting system of the crop, as a result of which the crop might have suffered from water stress that caused less (8%) number of monopods, less (8%) number of bolls per plant and more (11%) shedding of bolls per plant (Table 3). The interactive effect of date of sowing and tillage was non-significant in both the years.

The pooled analysis showed that seed cotton yield in 2005 was significantly higher than 2004 (Table 2). This may be due to favorable climate (high evaporative demand) in the former year as indicated by 15% more cumulative pan evaporation, as low rainfall during initial stage of the crop that restricts its excessive vegetative growth and hastens deep penetration of roots during 2005. The difference in yield due to dates of sowing was non-significant. Amongst the various tillage treatments, CTSB, CTSI, RTSI and CTSR were significantly superior to MTSAS treatment. The mean seed cotton yield of tillage treatments gave 23–36% higher seed cotton yield than minimum tillage treatment (Table 2). There was a non-significant interaction between year and tillage treatments. The interaction between year, date of sowing and tillage treatments was found to be non-significant.

3.2. Wheat grain yield

Grain yields of wheat during both the years individually and pooled were not significantly affected by tillage treatments (Table 4). Unlike cotton, yield of wheat in MTSAS and other tillage treatments were statistically at par, but were 5–7% higher in former than other treatments. The moisture profiles were also identical at the time of harvest (Fig. 3). However the soil moisture in conventional and minimum-tillage was different after first irrigation. Soil moisture was more in conventional tillage as compared to minimum-tillage up to 180 cm soil profile (Fig. 3) indicating that MTSAS treatment received lesser amount of water applied as first irrigation than CTSB, CTSI, RTSI and CTSR treatment as soil surface remained undisturbed due to minimum-tillage in the former treatment, while in the other tillage treatments the surface soil was loosened with tillage operations. Heilman et al. (1991) also reported an improvement in soil physical parameters and increased soil moisture content in different soil layers of profile with tillage. Unger et al. (1997) also advocated that minimum tillage/low till farming is the most effective and practical approach for sustaining

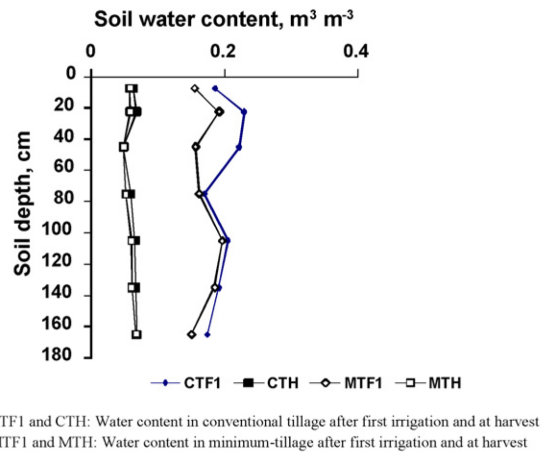

Fig. 3. Soil moisture profiles at sowing and at harvest in conventional tillage and no-tillage treatments in wheat after cotton during 2005–2006.

Table 5
Cost comparison in seedbed preparation (per ha) between conventional and optimum tillage

Name of operation	Conventional tillage (US$)	Reduced/minimum tillage (US$)
Cotton		
Discing	2 @ $ 35.7	1 @ $ 17.9
Cultivator	2 @ $ 23.8	1 @ $ 11.9
Planking	1 @ $ 8.9	1 @ $ 8.9
Total cost	$ 68.5	$ 37.5
Wheat		
Discing	2 @ $ 35.7	1 @ $ 17.9
Cultivator	2 @ $ 23.8	1 @ $ 11.9
Planking	1 @ $ 8.9	1 @ $ 8.9
Total cost	$ 68.5	$ 8.9

Net monitory saving under optimum tillage over conventional tillage: 31.0 US$ in cotton and 59.6 US$ in wheat.

food production and conservation of natural resources. Wruke and Arnold (1985) also reported that direct drilling of seed in no tillage caused changes in soil macroaggregates, reduced the evaporation rate, increased the microbial biomass, C, N and total organic carbon as compared with deep tillage.

3.3. Apparent water productivity

Year, dates of sowing and tillage affected the crop water productivity to a greater extent. Water productivity during the year 2005 was 78% more than 2004. During 2004, it was 30% more in May sown than April while during 2005 it was at par (Table 3). Amongst the tillage treatments water productivity in MTSAS was 26.7, 19.3, 25.4, 18.8 and 19.0% less than CTSB, CTSI, RTSI and CTSR treatments, respectively. Similar trend was found in wheat crop (Table 4), though the differences among different treatments were at par.

3.4. Monitory benefit

The comparison of cost of seedbed preparation between conventional tillage and optimum tillage resulted from the experiment, i.e. reduced tillage in cotton and minimum tillage in wheat can save 31.0 US$ and 59.6 US$, respectively totaling 90.6 US$ in the system (Table 5).

4. Conclusions

Tillage-plus-wheat residue in cotton–wheat system increases seed cotton yield by 23–39% than that in minimum-tillage practice. The reduced tillage (i.e. one disking, one cultivator and one planking) in cotton and minimum tillage (one planking only) in wheat are sufficient tillage operations to sustain yield and apparent crop water productivity in cotton–wheat system. This package of tillage operations increases net monitory saving and has a wide scope for adoption in cotton–wheat system by the farmers of Punjab in India and other countries where intensive tillage is practiced.

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