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Full Length Article

Impact of Planting Techniques on the Productivity of the Cotton-Wheat Rotation in Punjab, Pakistan

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Abstract

Wheat following cotton covers around 2.15 – 2.30-million-hectare area annually in Pakistan. After last picking of cotton, cotton sticks are removed for land preparation that causes delayed planting of wheat in cotton – wheat cropping system. Sowing wheat later than November 20, after the autumn cotton crop, can reduce wheat yields by 1% or more per day because of poor crop stands and exposure to terminal heat at grain-filling stage. This can be addressed through "relay planting" of wheat in standing cotton, which also allows a final picking of cotton. In this study, cotton was planted on wide beds manually, on narrow beds mechanically, or hand-drill planted on the flat surface during three seasons (2014–2017). Wheat was drill sown following the removal of cotton sticks and land preparation or into standing cotton on narrow beds, wide beds, or flat fields. Results indicated that higher cotton emergence and seed yield with manual planting on wide beds and mechanized bed planting on prepared land than with planting on the flat. Relay planting of wheat helped to complete planting in standing cotton during November 04–14, a month earlier than farmers' conventional practice. Average wheat grain yield was significantly higher (5.0–5.2 t ha^{-1}) in relay-planted wheat under three management settings (narrow beds, wide beds and flat fields) than in conventionally-sown wheat after cotton stick removal (4.1–4.3 t ha^{-1}). Relay planted wheat had 10% higher tillering and 20% more grains per spike and saving of USD 90 (Pak Rs. ~ 14,000) per hectare from land preparation costs. The benefit-cost ratio (BCR) for relay planting of wheat on wide beds was 1.61, superior to the BCRs for all other planting/management methods tested and suggesting that cotton-wheat farmers in Punjab Province should adopt this more productive and profitable option.

Keywords: Wheat production systems; Environment; Crop rotation; Profitability; Sustainability and management

Introduction

Wheat (*Triticum aestivum* L.) is grown on around 9 million hectares (nearly 40% of cropped land) in Pakistan, with an average annual production exceeding 25 million tons during 2016-2017 (PES 2016–2017). This production accounts for more than 70% of the nation's staple food, over 10% of value added in the agriculture sector and 2.2% of the GDP (Usman 2016). With regards to cotton (*Gossypium hirsutum* L.), Pakistan was the 4th largest producer after China, USA and India, with a 7.4% share in the global market during 2016–2017. Cotton exports accounted for 46% of Pakistan's total exports and provided 35% employment to the labor force (PES 2016–2017). Around 2.49 million hectares are currently under cotton, which accounts for 15% of Pakistan's total cropped area (PES 2016–2017).

The cotton–wheat (CW) rotation (2.49 million ha) is the widely practiced cropping system in Pakistan. Farmers lack of suitable machinery for the direct drilling of wheat into heavy cotton stubble after the last picking of cotton necessitates the removal of cotton sticks and preparation of a seed bed, prior to sowing wheat. Moreover, farmers always wanted to have last picking of cotton that result in delayed planting of wheat. Studies have shown a 1–1.5% per ha/day yield reduction for wheat sown after 20 November (Nasrullah *et al.* 2010; Hussain *et al.* 2012a), largely due the crop's exposure to high temperatures at grain filling stage during March–April (Hussain *et al*. 2012b;

Shirdelmoghanloo *et al.* 2016; Mastilovic *et al*. 2018).

Relay cropping of wheat, whereby the seed is sown directly into standing cotton sticks, could help to address these issues. Relay planting facilitates sowing of wheat in cotton and allows farmers to pick cotton right up to the end of the crop cycle and thereby capture the full market price for their produce. Resource-conserving management practices such as reduced or zero tillage can increase productivity while lowering economic or environmental costs, improving soil health and promoting timely planting of wheat (Singh *et al.* 2018; Page *et al.* 2020; Kumar *et al*. 2021). Growing crops on beds has been shown to save irrigation water and labor costs, without sacrificing crop productivity as well as facilitating fertilization applications and improving nutrient uptake and use (Naresh *et al*. 2017; Ahmed *et al*. 2018).

Most farmers in Pakistan grow cotton on flat fields, where light rain showers after planting can cause soil surface crusting that restricts seedling emergence and results in poor plant stands, a critical constraint to profitable yields. Growing cotton on raised beds, rather than flat fields or ridges, has been shown to improve seedling emergence and germination, partly by eliminating soil surface crusting (Gursoy *et al*. 2011; Ahmed *et al*. 2013), as well as increasing soil moisture content, reducing root penetration resistance, and improving cotton seed yields by 30–35% and lint yields by 25% (Akbar *et al*. 2015; Aslam *et al*. 2018).

In cotton-wheat system of the Punjab, all of the studies were conducted either on wheat or cotton crop. Information regarding planting technique effects on the productivity of both crops of cotton-wheat system is lacking. Keeping in view this situation, various planting techniques of cotton and wheat were studied in cotton – wheat system of the Punjab with objectives of evaluation of planting techniques effects on the productivity of cotton-wheat system and select suitable techniques for farming community in cotton-wheat cropping system.

Materials and Methods

Field trial was conducted for three years (2014–2017) at the Agronomic Research Station (ARS), Bahawalpur, Punjab (29.38°N Latitude, 71.65°E Longitude and 116 m Altitude). The climate there is hot and dry in summer and cold and dry in winter, with maximum temperature of 48ºC and minimum temperature of 7ºC. Wind and dust storms are frequent during the summer and average annual rainfall is around 200 mm. Samples from the trial-area soils (0–15 and 15–30 cm depths) show them to be loam of pH 7.9, organic matter content of 0.66% and total soil Nitrogen 0.05%, available phosphorus of 10 mg kg^{-1} and available potassium of 70 mg kg^{-1}.

Starting in June 2014 with cotton as the first crop, we tested seven sowing/cropping combinations for the cotton-wheat rotation in three successive years (T_1 to T_7; three for cotton and four for wheat), under a randomized complete block design with three replications. The area of each plot was 550 m^2. The techniques tested for cotton were manual planting on wide beds (75 cm, including furrow); planting with hand drill on prepared flat surface and mechanized bed planting of cotton with bed planter. For wheat the techniques tested were broadcasting of wheat after land preparation; bed planting of wheat after land preparation; relay planting of wheat in standing cotton on flat surface, wide beds (75 cm, including furrow) and narrow beds and zero till planting on bed using a bed planter. The details regarding various practices used in different planting combinations are described below and summarized in Table 1.

Crop husbandry

After harvest of a preceding wheat crop, wheat residues were rotavated into the soil and broadcasted 60 kg ha^{-1} of phosphorous as diammonium phosphate (DAP) and 50 kg ha^{-1} nitrogen (N) in the form of urea. Potassium was applied 40 kg ha^{-1} in the form of Sulphate of Potassium (SOP). The seedbed was prepared with two cultivator operations followed by planking. In treatments T_1 and T_2, wide (75 cm, including furrow) beds / ridges were made using a cotton ridger and cotton variety FH-142 (bushy, heat tolerant, yellow pollen) was manually sown at a rate of 8 kg of seed ha^{-1}, dropping 2–3 seeds into holes 23 cm apart. In treatments T_3 and T_4, variety FH-142 was sown with a hand drill at a rate of 18 kg of seed ha^{-1} on the flat, with 75 cm between rows and 23 cm between plants. In treatment T_5, cotton seed was sown in a single row on each raised bed using a National Multicrop zero-till bed planter (National Agro Industries, Ludhiana, India) with 75 cm between rows. In treatments T_6 and T_7, the bed planter was used in one operation to shape the beds, apply DAP, and sow cotton seed at 18 kg seed ha^{-1} directly into standing wheat residues in single rows on each bed, with a separation of 75 cm between rows.

During the growing season, 57, 28 and 28 kg N ha^{-1} were applied as urea at square initiation, flowering and boll development, respectively. Cotton planting and harvesting dates are mentioned in Table 2 and 3.

Wheat planting after the cotton crop

After cotton picking, cotton sticks were removed in treatments T_1, T_3 and T_5. Land was prepared using one rotavator pass and afterwards 115 kg ha^{-1} P_2O_5 in the form of DAP was broadcasted and a seedbed prepared through two cultivator passes and planking. Seed of wheat variety Jauhar-16 was broadcasted, followed by shallow cultivator tillage and planking to incorporate the seed. In treatments T_5, wheat seed of same variety was sown with DAP fertilizer (115 kg ha^{-1} P_2O_5) into standing cotton residues/sticks in two rows on each bed, the tops of which are 75 cm apart, using the National Multi-crop zero-till bed planter. Afterwards, in treatment T6, wheat seed were drilled in two rows on each raised bed with the help of National

Table 1: Planting techniques tested in a cotton-wheat cropping system trial in Bahawalpur

Method	Cotton	Wheat
T_1-Farmer practice for cotton and wheat (wide beds)	Land prepared and manual planting on edges of 75 cm wide beds	Land prepared and seed broadcasted
T_2-Farmer practice for cotton, relay planted wheat (wide beds)	Land prepared and manual planting on edges of 75 cm wide beds	Relay cropping of wheat in standing cotton, seed broadcasted
T_3-Farmer practice for cotton and wheat (flat)	Land prepared and planting with hand drill on flat surface with row-to-row distance of 75 cm	Land prepared and seed broadcasted
T_4-Farmer practice for cotton, relay planted-wheat (flat)	Land prepared and planting with hand drill on flat surface with row-to-row distance of 75 cm	Relay cropping of wheat in standing cotton, seed broadcasted
T_5-Mechanized sowing for cotton and wheat (beds)	Land prepared and planting with multi-crop bed planter and row to row distance of 75 cm	Land prepared and planting in two rows using a multi-crop bed planter
T_6- Mechanized ZT for cotton and wheat (beds)	Zero till bed planting using a multi-crop bed planter into residues, with a row-to-row distance of 75 cm	Zero till planting in two rows using a multi-crop bed planter after cotton sticks removed
T_7-Mechanized ZT for cotton and relay-planted wheat (beds)	Zero till bed planting using a multi-crop bed planter into residues, with a row-to-row distance of 75 cm	Relay cropping of wheat in standing cotton, seed broadcasted

Table 2: Sowing and harvesting dates of the cotton and wheat crops

Season	Crop	Sowing date	Harvesting date
Kharif 2014	cotton	10. 05. 2014	29.10.2014
Kharif 2015	cotton	14. 05. 2015	22.10.2015
Kharif 2016	cotton	16. 05. 2016	25.10.2016
Rabi 2014-15	wheat	Relay: 15.11.2014 Normal: 02.12.2014	Relay: 12.04.2015 Normal: 18.04.2015
Rabi 2015-16	wheat	Relay: 05.11.2015 Normal: 04.12.2015	Relay: 10.04.2016 Normal: 16.04.2016
Rabi 2016-17	wheat	Relay: 12.11.2016 Normal: 28.11.2016	Relay: 11.04.2017 Normal: 19.04.2017

Table 3: Comparison of meteorological data during the growing cycle at ARS Bahawalpur for 2014-15, 2015-16 and 2016-17

	Average minimum temperature (°C)			Average maximum temperature (°C)			Rainfall (mm)		
Month	2014	2015	2016	2014	2015	2016	2014	2015	2016
January	6.5	6.9	7.5	19.3	17.4	18.5	0.0	0.0	0.0
February	9.4	11.3	9.2	21.4	22.8	24.7	71.9	15.0	38.4
March	14.6	15.0	16.2	27.0	26.0	28.7	49.3	104.6	105.2
April	20.6	22.6	21.6	35.1	35.7	36.5	32.5	53.3	13.0
May	25.5	25.7	27.8	38.4	39.9	41.3	220.0	234.3	107.1
June	30.1	27.3	30.1	41.6	38.6	41.4	0.0	109.9	72.9
July	29.7	27.3	29.4	38.8	35.7	39.0	182.9	115.1	340.1
August	28.0	27.5	28.4	37.5	36.2	37.2	39.9	71.0	44.5
September	25.9	24.8	26.2	35.3	35.3	37.4	48.0	64.8	0.0
October	20.7	20.7	21.3	32.9	33.2	35.3	39.9	22.1	0.0
November	13.1	13.9	13.9	28.2	27.6	29.0	0.0	0.0	0.0
December	8.0	8.1	10.6	20.2	22.2	24.2	0.0	0.0	0.0
Total Rainfall (mm)							684.3	790.1	721.2

Multi-crop Zero till bed planter. The seed rate for wheat for the above treatments was 125 kg ha^{-1}. In treatments T_2, T_4 and T_7, wheat was relay cropped, sowing the seed into the standing cotton crop. In this technique, wheat seeds were soaked in water for 5 to 6 h and dried in the open air for 5 to 6 h. The field was irrigated and the previously soaked and dried wheat seed was broadcasted in standing cotton in early November (05 November) at a rate of 136 kg of seed ha^{-1}. After the last picking of cotton in December, cotton sticks were removed from the field. Fertilizer (P_2O_5, K_2O and 50 kg ha^{-1} N in the form of urea) was applied after removal of cotton sticks with a post-planting irrigation. After removal of the cotton sticks the herbicide Pendimethaline was applied at 3 l ha^{-1}. For relay-planted wheat, 80 kg of urea per ha was applied with the second irrigation. In the other management systems, N was applied as urea at a rate of 70 kg ha^{-1} in the first and second irrigations. Wheat planting and harvesting dates are shown in Table 2.

Economic analysis

Economic analysis was carried out using actual expenditures for activities and inputs and prevailing prices for cotton and wheat in National market. A simple economic analysis such as total cost (TC), gross return (GR), net return (NR) and benefit-cost ratio (BCR) for wheat and cotton planted under different methods are shown in Table 6. Costs of cultivation under various treatments were estimated using approved rates for inputs fixed by the RARI, Bahawalpur, Punjab. Inputs include seed, pesticide, fertilizer, labor and machinery for land preparation, irrigation, harvesting and threshing. Gross returns were calculated for cotton and wheat based on national market rate in all years. Net income was calculated as the difference between gross income and total costs (Cameron and Trivedi 2009; Hussain *et al.* 2020).

Statistical analysis

Analysis of variance (ANOVA) was conducted on recorded data using statistix v. 8.1 software, according to Paolo (2002) for genotype-by-environment (G × E) interactions over years (Table 4). Means were compared using the least significant differences (LSD) test at a 5% level of probability. Where G × E was significant, we further analyzed data using a GGE-biplot, a graphical approach to identify the responsive planting methods for wheat and cotton (Yan and Kang 2003).

Results

Wheat yield and yield contributing traits

The ANOVA revealed significant ($P \leq 0.01$) differences in seedling emergence, tiller m^{-2}, thousands grain weight and grain yield in different year and planting method as well as interaction of year and planting method (Table 4). While comparing different planting method means, number of seedlings ranged from 191 to 219 m^{-2}, number of tillers 373 to 427 m^{-2}, thousand grain weights 40.9 to 42.8 g and grain yield 4073 to 5221 kg ha^{-1}. The fewest wheat seedlings (191) were observed in T_5 (Mechanical planting of wheat on beds), while the greatest emergence (219) was observed in T_4 (relay planting on the flat land; Table 5). Due to significant G×E for seed emergence, data was further analyzed using GGE biplot. All planting method combinations in the biplot arranged in a way that the most responsive are placed on the vertices and the remainder inside the polygon (Fig. 1). Responsive planting systems were those having either the best or the poorest performance in one or both years (Yan and Rajcan 2002).

Data for different years are labelled in uppercase letters. The whole biplot is divided into various sectors and the most important one is vertex 6, where data of both years are present. The presence of number of seedlings of both years data in this sector 6, showed that T_2 (relay planting on wide beds) has out-performed all other planting systems across years. Furthermore, T_4 (relay planting on the flat) also performed well (Fig. 1). Whereas, T_6 (mechanized ZT on narrow beds) had the fewer number of tillers (373 m^{-2}) and T_2 (relay planting on wide beds) had the highest number of 427 tillers m^{-2} (Fig. 2). Lower thousand grain weight (40.9 g) was in T_5 (mechanized wheat planting on beds) while thousand grain weight (42.8 g) was highest in T_2 (relay planting of wheat). The whole biplot for thousand grain weight has two important sectors (1 and 5) where data of all years are present. In Sector 1, T_2 (relay planting of wheat) has the highest thousand grain weight across both years. T_4 and T_7 (relay planting of wheat on the flat and raised beds) appeared in Sector 5, suggesting their good performance for this trait in year 3 (Fig. 3). The lowest wheat grain yield (4,073 kg ha^{-1}) was recorded in farmer practice (T_3), which was due to late planting of wheat. However, Relay planting of wheat in residue after mechanized planted cotton (T_7) produced a maximum grain yield of 5,221 kg ha^{-1} (Table 5). The biplot showed that treatment T_7 (relay planting on beds with residue) outyielded all other methods across years. Moreover, yields of relay planted wheat on flat and beds (T_2 and T_4) were at par with relay planting on beds with residue T_7 (Fig. 4).

Cotton yield and yield contributing traits

The ANOVA revealed significant ($P \leq 0.01$) differences in plants ha^{-1}, bolls $plant^{-1}$, 100-boll weight (HBW) and cotton grain yield in different year and planting method as well as interaction of year and planting method (Table 4). While comparing planting methods and year's effect, number of plants ha^{-1} ranged from 37,400 to 51,900, number of bolls $plant^{-1}$ ranged from 35 to 40, hundred boll weight ranged from 320 to 337 g and cotton grain yield ranged from 2,114 to 2,983 kg ha^{-1} (Table 5). The lowest plant stand of 37,400 ha^{-1} was recorded in T_6 (ZT mechanized bed planting), whereas the best cotton stand 51,900 plants ha^{-1} was observed in T_2 (manual planting on wide beds). Because of significant interaction effects between planting methods and years, data was further analyzed using GGE biplot method. Cotton plant stand was higher in Treatment T_2 (manual planting on wide beds) followed by T_1 (manual planting on wide beds) and T_5 (mechanized bed planting) (Fig. 5) in comparison with rest of planting methods. Resultantly, cotton planted with T_2 (manual planting on wide beds) produced the highest (40 bolls $plant^{-1}$) that were also at par with T_5 (mechanized bed planting; Fig. 6). Lower number (35 bolls $plant^{-1}$) was recorded in T_4 (cotton planted on flat surface) and T_6 (cotton planted with ZT mechanized bed). Hundred cotton boll weight of (337g) was recorded under T_5 (mechanized bed planting) that was also at par with T_2 (manual planting of cotton on wide beds; Fig. 7). While comparing cotton grain yield, highest grain yield of 2,983 kg ha^{-1} was observed with T_2 (manual planting on wide beds) and this planting system for cotton proved the best across years. In addition, T_1 (manual planting on wide beds) similar to T_2 and T_5 (mechanized bed planting on prepared land) also performed well across years (Fig. 8).

Economic analysis

The highest cost of production (USD 1,478.6 ha^{-1}) was observed for T_5, followed by T_1 (USD 958.7 ha^{-1}) and T_3 (USD 958.7 ha^{-1}). T_2 and T_4 had the lowest costs of production (USD 920.0 ha^{-1}). Resultantly, T_2 provided the

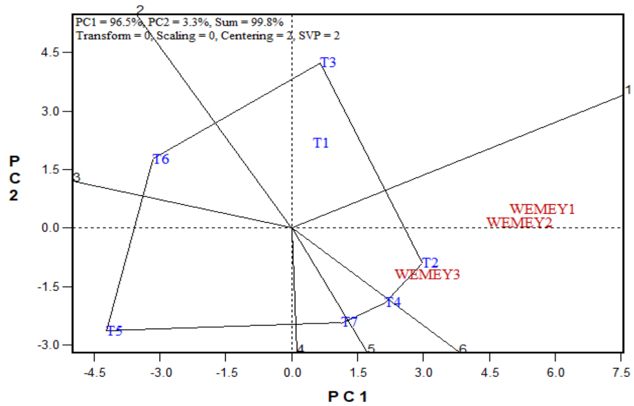

Fig. 1: Biplot based on emergence data of wheat planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

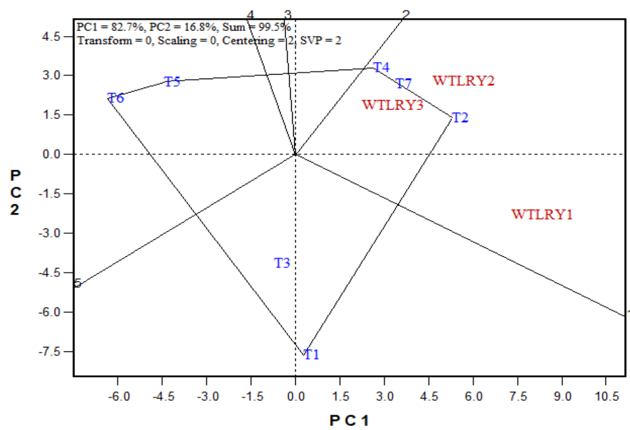

Fig. 2: Biplot based on tillers data of wheat planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

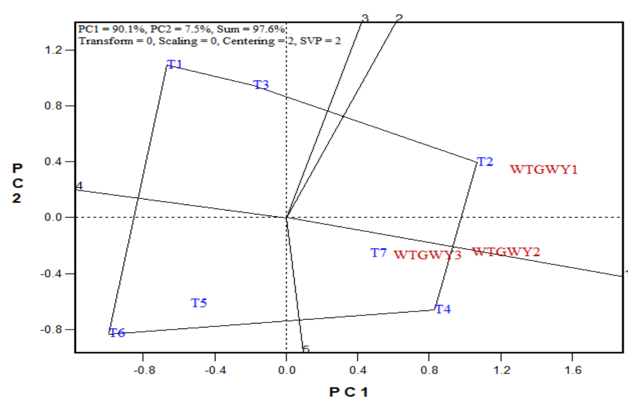

Fig. 3: Biplot based on 1000-grain weight data of wheat planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

highest net return (USD 1,478.6 ha^{-1}), followed by T_4 (USD 1,252.6 ha^{-1}) and T_6 had the lowest net returns (USD 859.2 ha^{-1}). In term of cotton-wheat system, the cost-benefit ratio for T_2 (1.61) was the highest, followed by T_4 (1.36). In these

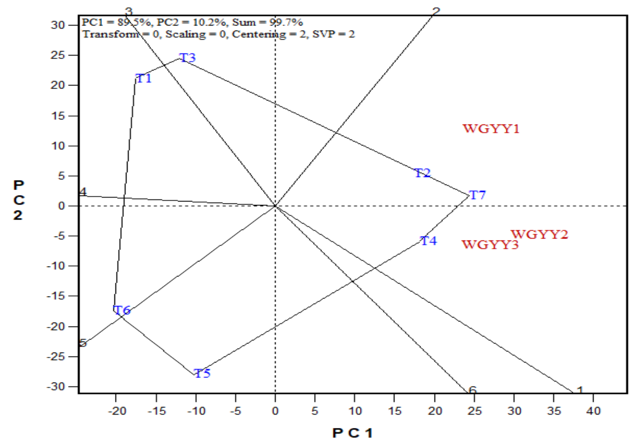

Fig. 4: Biplot based on grain yield data of wheat planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

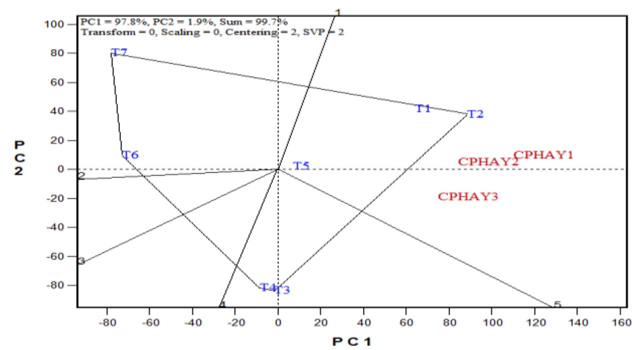

Fig. 5: Biplot based on plants per hectare data of cotton planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

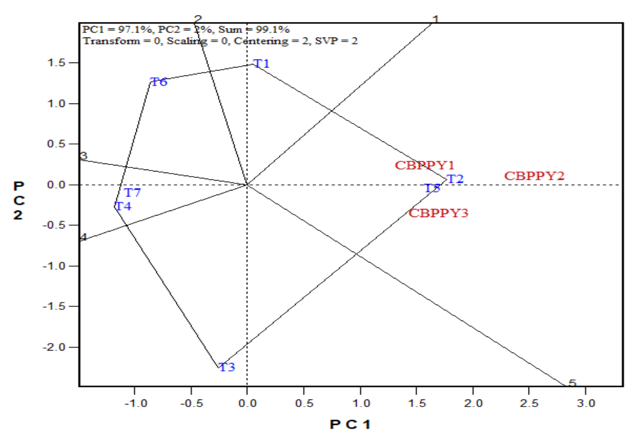

Fig. 6: Biplot based on bolls per plant data of cotton planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

systems where relay planting of wheat was done after farmer practice of cotton planting, yields were higher with low cost of cultivation (Table 6).

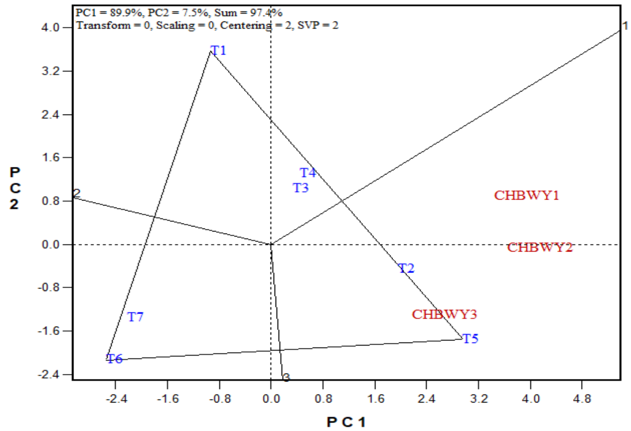

Fig. 7: Biplot based on 100 boll weight data of cotton planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

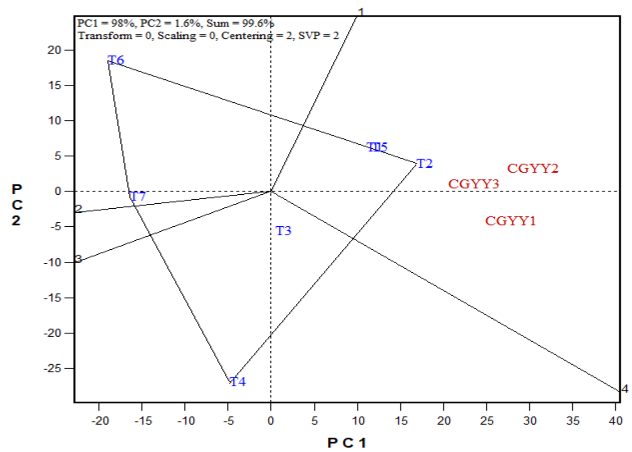

Fig. 8: Biplot based on grain yield data of cotton planted under seven different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

Discussion

This study was focused to find the best method for planting cotton and wheat in cotton-wheat cropping system. The yield of any crop is primarily dependent upon plant population that is affected by planting technique. In South Asia and Pakistan, suitable planting machinery is not available for sowing of crop in standing cotton residue, so early sowing of wheat into standing cotton is possible only by by broadcasting of seed. Tillering determines the green photosynthetic area responsible for carbohydrate formation, grain filling and final grain yield. In this study, manual planting of cotton on wide beds followed by relay wheat provided suitable conditions for germination of both cotton and wheat, as well as better wheat tillers per unit area, cotton bolls per plant. Better tillering of wheat might be due to early sowing of wheat in standing cotton, as compared to the delayed sowing in other planting treatments that required time for cotton sticks removal and land preparation for wheat planting. Higher thousand grain weight for relay-cropped wheat could be attributed to a longer grain filling period available to the early sown crop. These results are in accordance with Hassan *et al*. (2020) and Buttar *et al*. (2013). Hossain *et al*. (2012) who reported that 1000-grain weight decreased significantly in wheat with delay in sowing. This is because delay in sowing shortens the duration of each development phase which ultimately reduces the grain filling period leading to lower grain weight (Al-Karaki *et al*. 2007). Relay seeding of wheat increased cotton grain yield by creating opportunity for one additional picking, which was made possible due to the extended growing period of the cotton for about 30 days. This extra growing period for cotton helped in opening of the majority of the immature bolls at the time of pulling out of cotton stalks leading to 11–14% increase in seed cotton yield over conventional tillage wheat. Consistent with our study, Shah *et al*. (2016) and Mubeen *et al*. (2022) recorded significantly higher seed cotton yield under the relay seeding of wheat, compared with cotton followed by conventional tillage wheat.

Grain yield of wheat is a product of spike density, number of grains/spike and grain weight. Relay planting of wheat into standing cotton help to plant wheat one month earlier than the typical farmer practice of removal of cotton sticks and planting after land preparation boosted all three yield parameters and increasing grain yield by 19%. (Khan and Khaliq 2005) reported that the relay seeded wheat produced 13.2% higher grain weight as compared to CTW. This is consistent with the observation made by Buttar *et al*. (2013) who reported 25% higher grain yield of wheat sown with a manual, walk-behind, self-propelled relay planting machine than with CTW. Likewise, García *et al*. (2016) and Nuttall *et al*. (2018) reported that wheat growing season was reduced by about 12 days and grain yield of wheat declined significantly due to higher average night temperatures during March. Relay seeding would allow farmers to advance the planting date to the first week of November, significantly improving wheat productivity. Relay seeding also promote adoption of conservation agriculture practices that hold promise as an adaptive strategy for climate change. The optimum time of wheat sowing in these areas is from first week of November to third week of November. Seed cotton yield was also significantly higher with relay seeding due to opportunity for one additional picking, a result that accords with Shah *et al*. (2016) and Mubeen *et al*. (2022).

This study showed that relay planting of wheat in standing cotton so there is need to develop appropriate planting machinery that can help to plant wheat into standing cotton. Cotton grown on raised bed provide adequate space between the plants for mechanical weed control and lessens competition for moisture, light and nutrients, as well as fostering better translocation of photosynthates and increased yields (Sayre 2004). Ahmed *et al*. (2013) found that wider spacing significantly increased sympodial branches, total

Table 4: Pooled analysis of variance for wheat and cotton under different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

Source	DF	Cotton				Wheat			
		Plant ha^{-1}	Bolls plant^{-1}	HBW (g)	GY (kg ha^{-1})	Emer m^{-2}	Tiller m^{-2}	TGW (g)	GY (kg ha^{-1})
Year (Y)	2	3.21E+08**	21.3**	726.4**	821641**	257.4**	2364.1**	2.9**	2660877**
Y*Rep	6	2258513	0.63	22.5	2435	18.8	637.4	0.2	19298
Planting Methods (PM)	6	2.84E+08**	38.0**	361.8**	1060364**	992.8**	3695.5**	5.3**	2153218**
Y*PM	12	7221355**	1.87**	28.7**	18369**	58.8**	744.7**	0.5**	141714**
Error	36	1478911	0.69	8.7	1962	20.3	176.2	0.2	28587

*, ** = significant at 5 and 1% level of probability respectively, whereas NS = non-significant
HBW = Hundred boll weight; GY = Grain Yield; Emer m^{-2} = Emergence m^{-2}; TGW = 1000-grain Weight

Table 5: Mean values for various traits of wheat and cotton planted under different planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

Treatments		Wheat				Cotton			
		Emergence m^{-2}	Tillers m^{-2}	TGW (g)	GY (kg ha^{-1})	Plants ha^{-1} (000)	Bolls Plant^{-1}	HBW (g)	GY (kg ha^{-1})
T_1	Y1	209	411	41.0	4089	47.4	36	321	2616
	Y2	213	381	40.8	4007	50.3	37	325	2911
	Y3	212	397	41.2	4367	51.2	37	326	2996
	Mean	*212*	*396*	*41.0*	*4155*	*49.6*	*37*	*324*	*2841*
T_2	Y1	221	427	43.0	4729	49.6	38	328	2772
	Y2	223	429	42.5	5051	53.0	41	335	3067
	Y3	222	426	42.8	5367	53.0	40	338	3110
	Mean	*222*	*427*	*42.8*	*5049*	*51.9*	*40*	*334*	*2983*
T_3	Y1	213	396	41.7	4272	38.8	35	323	2412
	Y2	212	384	40.9	4089	44.3	36	330	2607
	Y3	210	405	42.1	4546	48.7	38	332	2730
	Mean	*212*	*395*	*41.6*	*4302*	*43.9*	*36*	*328*	*2583*
T_4	Y1	216	403	42.3	4589	37.9	34	326	2356
	Y2	219	422	42.6	5216	44.0	34	327	2349
	Y3	221	422	42.8	5366	48.1	36	334	2675
	Mean	*219*	*416*	*42.6*	*5057*	*43.3*	*35*	*329*	*2460*
T_5	Y1	185	352	40.7	3650	39.8	38	330	2630
	Y2	191	389	41.1	4407	46.7	40	339	2923
	Y3	207	404	42.1	4924	47.5	40	342	3020
	Mean	*194*	*382*	*41.3*	*4327*	*44.7*	*39*	*337*	*2858*
T_6	Y1	191	340	40.0	3544	31.5	35	310	1810
	Y2	197	375	40.7	4079	39.3	35	320	2104
	Y3	204	404	41.8	4595	41.5	36	330	2429
	Mean	*197*	*373*	*40.9*	*4073*	*37.4*	*35*	*320*	*2114*
T_7	Y1	211	410	42.0	4838	32.0	34	314	1973
	Y2	214	421	42.2	5295	38.7	34	318	2166
	Y3	219	428	42.4	5529	39.8	36	331	2370
	Mean	*215*	*420*	*42.2*	*5221*	*36.8*	*35*	*321*	*2170*
$LSD_{(0.05)}$ for Y		*2.8*	*8.3*	*0.3*	*105.8*	*0.76*	*0.5*	*1.8*	*27.7*
$LSD_{(0.05)}$ for PM		*4.3*	*12.7*	*0.5*	*161.7*	*1.16*	*0.8*	*2.8*	*42.3*
$LSD_{(0.05)}$ for Y × PM		*7.5*	*22.0*	*0.8*	*280.0*	*2.01*	*1.4*	*4.9*	*73.4*

T_1 = Manual planting on wide beds for cotton and wheat; T_2 = Manual planting on wide beds for cotton, relay planted wheat on wide beds; T_3 = Manual planting on flat for cotton and wheat; T_4 = Hand drill planting on prepared land for cotton, relay planting on the flat; T_5 = Mechanized bed planting on prepared land for cotton and wheat; T_6 = Mechanized ZT on narrow beds for cotton and wheat; T_7 = Mechanized ZT for cotton and relay planting on beds with residue for wheat

Table 6: Budget analysis of various planting and management methods in cotton-wheat rotations in Punjab, Pakistan, 2014-2017

Treatments	TC (US$ ha^{-1})	GR (US$ ha^{-1})	NR (US$ ha^{-1})	BCR
T_1	958.7	2141.2	1182.7	1.23
T_2	920.0	2398.4	1478.6	1.61
T_3	958.7	2061.7	1103.2	1.15
T_4	920.0	2172.4	1252.6	1.36
T_5	1027.1	2186.6	1160.8	1.13
T_6	949.7	1807.5	859.2	0.91
T_7	927.7	2081.6	1154.6	1.25
LSD (0.05)	1.6	107.1	107.1	0.113

TC= Total cost, GR= Gross return, NR= Net return, BCR = Benefit-cost ratio
T_1 = Manual planting on wide beds for cotton and wheat; T_2 = Manual planting on wide beds for cotton, relay planted wheat on wide beds; T_3 = Manual planting on flat for cotton and wheat; T_4 = Hand drill planting on prepared land for cotton, relay planting on the flat; T_5 = Mechanized bed planting on prepared land for cotton and wheat; T_6 = Mechanized ZT on narrow beds for cotton and wheat; T_7 = Mechanized ZT for cotton and relay planting on beds with residue for wheat

number of bolls per plant, and seed cotton weight per plant. Cotton sown into permanent beds has better crop growth, higher lint yield, and better fiber quality than cotton sown under conventional tillage (Roth *et al.* 2005). There is also a need to develop appropriate planting machinery to plant cotton on raised bed.

Our economic analyses show that relay planting of wheat into standing cotton on wide beds produced higher yields with less expenditure. Many researchers also reported lower costs of production in bed planting as compared to conventional method (Reeves *et al*. 2000; David *et al*. 2003). Similarly, in several studies intercropping gave higher economic returns than monoculture (Wasaya *et al*. 2013; Shah *et al*. 2019).

Conclusion

This three-year study shows that manual planting of cotton on wide beds and mechanized bed planting of cotton on tilled fields would help to improve cotton productivity. In addition, relay planting of wheat in standing cotton on narrow, wide beds and even on the flat surface outperformed conventional wheat planting, after cotton stick removal and land preparation. The productivity of cotton-wheat system was higher using zero-tillage to sow cotton on beds, followed by relay cropping of wheat in standing cotton through broadcasting and manual planting of cotton on wide beds followed by relay cropped wheat in standing cotton through broadcasting. Relay cropping can boost yields of both wheat and cotton and thus should be promoted in cotton-wheat regions of South Asia including Pakistan.

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Author Contributions

Imtiaz Hussain, Ansaar Ahmed and Muhammad Imtiaz conceived and designed the trial. Hafiz Nasrullah, Basharat Ali and Abdul Hamid performed experiments and collected data. Ansaar Ahmed and Ibni Amin Khalil analyzed the data. Ansaar Ahmed, Imtiaz Hussain and Muhammad Imtiaz wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest. The founding-sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript and in the decision to publish the results.

Data Availability

All relevant data are within the paper and its supporting information files.

Ethics Approval

Not applicable in this paper.

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