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Research Article

Exploring the environment-friendly approaches for wheat production in cotton-wheat cropping system

Hafiz Naveed Ramzan[1], Naveed Akhtar[1], Muhammad Kashif Munir[2], Fahid Ihsan[1], Muhammad Kashif Hanif[3], Rabia Nadeem[1], Maham Sajid[1], Muhammad Faisal Shafiq[1], Nauman Ali[1], Hafiz Muhammad Ijaz[3]
[1]Agronomic Research Institute, Ayub Agricultural Research Institute, Faisalabad.
[2]Sugarcane Research Institute, Ayub Agricultural Research Institute, Faisalabad.
[3]Ayub Agricultural Research Institute, Faisalabad.

ABSTRACT

Wheat is the staple food of Pakistan and plays an important role in national food security. Changing climatic conditions, receding land availability due to increasing population, deficit in irrigation water availability during wheat season, and increasing cost of inputs are among the factors that are constraints on sustainable wheat production. Under these conditions, conventional wheat production system may no longer ensure food security and profitability. The Cotton-wheat system is the most important cropping system and the prime source of food supply in Pakistan. A field trial was conducted at Agronomic Research Institute, Faisalabad using strip plot design for evaluation of environment friendly and economically feasible approaches for wheat production in cotton-wheat cropping system. Three sowing methods viz bed planting, ridge planting (broadcast augmented with furrow) and flat planting were tested under three tillage levels: zero tillage (relay wheat sowing), conventional tillage and minimum tillage. Results revealed that zero tillage (relay wheat sowing) performed the best out of all tillage options keeping in view the yield and economic returns. It was also the best option for CO2 emission reduction due to the elimination of fuel consumption (for land preparation and sowing). Sowing methods showed variable response for yield as flat sowing and bed planting performed better than ridge planting in relay crop, but ridge planting was on top in both conventional and minimum tillage. It was concluded that relay planting under bed and flat sowing was the best environment-friendly and economically viable approach for wheat production in cotton-wheat cropping system.

Keywords: Relay wheat sowing; bed/ridge planting; resource conservation; CO_2 emission reduction.

INTRODUCTION

Wheat is the staple food of Pakistan and plays an important role in national food security and dominates all crops in acreage and production. It is grown on an area of 9.1 million hectares with an average yield of 3193 kg ha^{-1} in Pakistan and contributes 9% to the agricultural sector and 2.2% of the GDP of Pakistan (Government of Pakistan, 2025). Wheat is cultivated across the Punjab in various cropping systems (e.g. cotton-wheat, rice-wheat and mixed cropping system), with the cotton–wheat system being the primary contributor. One of the major reasons for low productivity and instability of wheat in cotton-wheat system, among others, is delayed harvesting of cotton leaving very narrow windows for wheat sowing and results in delayed wheat planting (Usman and Rehman, 2014). Wheat yield is generally decreased by 10-15% due to late planting of wheat in cotton-wheat cropping system. Farmers wait for last pick of cotton and late planting of wheat even continues to the end of December and in some cases till January resulting in yield loss of up to 50% (Tariq et al., 2022). Hussain et al. (2014) concluded that farmers

Correspondence
Hafiz Naveed Ramzan
naveedramzan_uaf@hotmail.com

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obtained wheat yield only one-half to two-third of the potential of the crop in main cropping zones of Punjab province and specifically in cotton-wheat zone the farmers have been taking only 43% of the wheat yield potential. The major constraints of lower wheat yield identified were limited availability of certified seed of the approved varieties, late planting, inappropriate sowing or plating methods, imbalance fertilizer use and inefficient water management (Mahapatra and Dey, 2022). Tillage is considered to be one of the most important management practices for increasing crop production (Khan et al., 2015). Liang et al. (2025) suggested to use conservation tillage to reduce greenhouse gas emissions up to 50%, CH_4 emissions by 75% and lower the global warming potential by 34%, while simultaneously improve soil health, enhance carbon sequestration, conserve water and maintain stable crop yields under intensive production systems. Conservation agriculture-based interventions have been promoted for sustaining crop productivity and safer environment (Erenstein, 2011). Akbarnia et al. (2010) compared zero tillage, reduced tillage against conventional tillage and resulted that zero tillage can replace the conventional tillage while reduced tillage has also the potential for different conditions due to low cost of production, lesser soil compaction and more financial profit. Considerable benefits, through adoption of zero till practices on large scale, can specifically be achieved for South Asia and overall, for the globe. Food security and alleviation of poverty in Pakistan can also be ensured through improved and sustainable wheat production by adopting resource conservation technologies. Relatively better yield was produced by zero till and bed planted wheat than conventional methods of wheat sowing. Zero tillage enhances root growth, improves soil structure, conserves moisture, reduces erosion and produces yields that equal or exceed those of conventional tillage and thereby boosting farmer’s profit (Kumar et al., 2022). In comparison of conventional tillage, significantly higher wheat yield and yield components were recorded in zero tillage (Ali et al., 2016). The minimum tillage and direct drilling system are cost effective, energy efficient and environment friendly approaches in contrast to traditional tillage practices (Ahmad et al., 2013).

Diversified response of wheat to various agro-management practices particularly planting methods has been noted (Aslam et al., 2014). Better wheat production depends largely upon the selection of appropriate sowing method (Subhan et al., 2017). The growing of crops by using raised bed planting is leading technique, amongst those, for saving of water and other inputs. Growing of wheat and maize by bed planting resulted in water saving of 30% (Taj et al., 2013) and is now widely recognized as a modern resource-efficient technology. It is imperative to focus on research regarding agronomic aspect of bed planting for the sake of sustainability of this premier cropping system (Ali et al., 2016). Efficient fertilizer use, early maturity, less prevalence of disease incidence are the chief benefits of the bed planting with 50% water saving as premier benefit of this technology (Hafiz et al., 2011). Bed planting is an option to be recommended for arid regions because of better grain yield, water use efficiency and economically viable approach (Subhan et al., 2017). Bed planting produced 24.46%, ridge sowing 20.86% and drill sowing 17.33% higher yield than conventional broadcast method (Ali et al., 2012). It was also noted that water saving of 22.47 and 13.26% occurred in raised bed planting and ridge sowing, respectively in wheat crop compared with traditional drill or broadcast sowing on flat and also resulted in higher net benefit cost ratio (Ali et al., 2012). Mahmood et al. (2013) reported 11-17% higher grain yield in bed planting method than that of flat sowing. Raised bed is being adopted by replacing the traditional flat basin irrigation system due to improved crop water productivity and to avoid irrigation water application losses (Akbar et al., 2016).

Although individual conservation practices have been studied extensively but there remains a significant research gap how conservation integrated practices like zero tillage, raised-bed planting, and timely sowing interact and can be optimized together under Punjab's cotton wheat system especially considering late cotton harvesting, high input cost and water scarcity. Most research has studied these practices in isolation, leading to uncertainty about their combined agronomic, economic, and environmental impacts on real smallholder field conditions (Tariq et al., 2022). Moreover, climate variability and increasing energy costs require updated field evaluations of these resource efficient practices to improve wheat productivity and profitability (Carrico, 2021).

MATERIALS AND METHODS

A field trial was conducted at Agronomic Research Institute, Faisalabad during Rabi growing seasons 2016-17, 2017-18 located between 31.4273° N latitude and 73.11° E longitudes. Weather conditions about temperature and rainfall of the experimental site during the study are given in figure 1 (a, b). The soil analysis of experimental field was done with standard protocols as physiochemical properties of soil samples are depicted in table (1), previously occupied by cotton crop.

Experimental design and treatments

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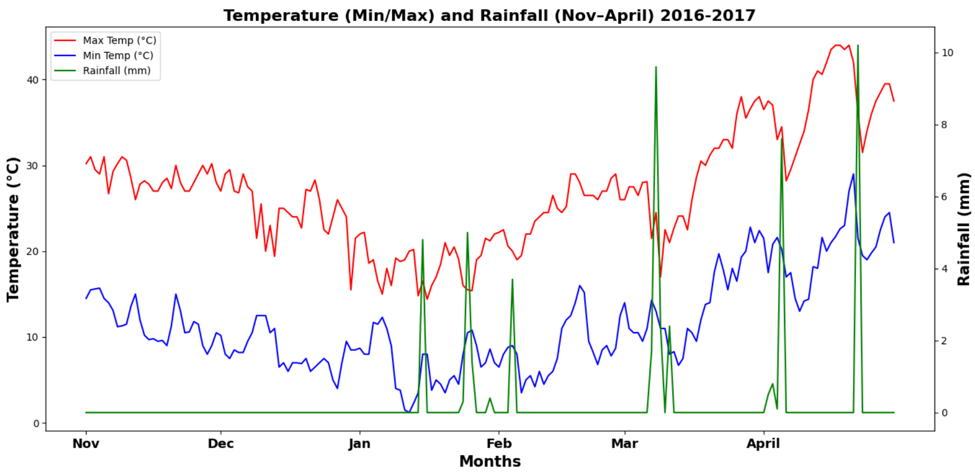

Figure 1-a. Weather condition during the study (Rabi 2016-17).

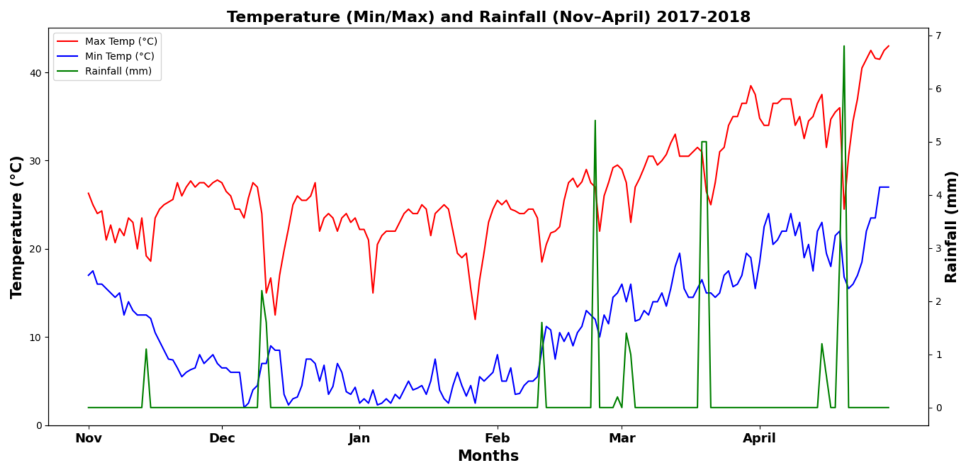

Figure 1-b: Weather condition during the study (Rabi 2017-18).

Table 1. Pre-sowing soil analysis (0-30 cm).

pH	EC_e (dS/m)	Organic matter (%)	Av. P (mg/kg)	Av. K (mg/kg)	Texture
7.9	1.15	0.75	8.2	180	Loam

The experiment was conducted using strip plot design with four replications and a plot size of 4.5 m × 9 m to evaluate environment-friendly and economically feasible approaches for wheat production in cotton-wheat cropping system. Three sowing methods viz bed planting, ridge planting (broadcast augmented with furrows in case of wheat sowing after cotton) and flat planting were tested under three tillage levels namely zero tillage (relay wheat sowing in standing cotton), conventional tillage and minimum tillage. All the treatments were randomized using lottery method. Nine treatments were allocated comprising of these factors as follows.

Tillage system

Zero tillage (relay wheat crop in standing cotton without any tillage operation) – wheat sowing in standing cotton during second week of November was made. The fields were heavily irrigated to soften/soaked the beds/ridges. Then hydro primed seed was broadcasted evenly throughout the field in crisscross fashion. Cotton sticks were removed in last week of December after last picking.

Conventional tillage (5 ploughing + 4 planking) - wheat sowing after cotton harvest during second week of December by thorough land preparation operations.

Minimum tillage (3 ploughing + 2 planking) - wheat sowing after cotton harvest during second week of December by minimum land preparation operations.

Sowing method

Bed planting - The crop was planted on beds formed by a specially designed bed and furrow planter. In wheat 4 rows of plants are sown in pairs on either side of a 60 cm beds alternated by 30 cm furrows as shown in the schematic diagram below. So, water, in contrast to flood irrigation, is applied to only furrows.

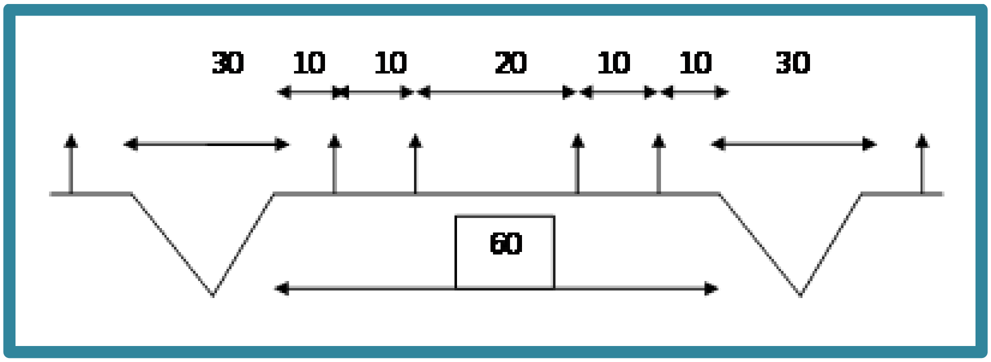

Figure 2. Schematic diagram of bed planting of wheat.

Broadcast augmented with furrow (ridge planting) – wheat was sown by traditional broadcast followed by ridge making with the help of traditional ridger.

Flat planting - planting in line by using seed drill with 22 cm row to row distance.

Agronomic practices

The Wheat cultivar Galaxy-2013 after the seed treatment at seed rate of 150 kg ha^{-1} was planted. Fertilizer dose of N, P and K at the rate of 120, 90 and 60 kg ha^{-1} respectively was applied. Four irrigations were applied to all the treatments. The crop was harvested during third week of April manually followed by mechanical threshing.

Data collection

The data regarding the yield of wheat crop was collected. The data regarding fuel used for land preparation and sowing was collected for each treatment and utilizing this data CO_2 emission due to fuel consumption (as one liter of diesel consumed results in Green House Gas Emission expressed as 2.7 kg CO_2 equivalent) was calculated. The data of fuel used for land preparation and sowing was also used to calculate the CO_2 emission reduction according to carbon footprint (CF) method as described by (Time for Change).

Economic analysis

The economic analysis was performed by calculating total expenditures, total income, net returns and benefit cost ratio of each treatment according to CIMMYT (1988). The gross income, fixed costs and variable costs of produce and inputs according to market values was determined. The benefit cost ratio was calculated by following formula;

[BCR = (Gross income/total cost)].

Statistical analysis

The Fisher's analysis of variance procedure was applied to determine significance of data using Statistix 10.0 software (Steel et al., 1997). Tukey's HSD test after ANOVA was used at a 5% probability level to assess significance of differences among the means of treatments. Data visualization was done by Python.

RESULTS AND DISCUSSION

Grain yield (kg ha^{-1})

Data regarding grain yield of wheat is presented in figure (3) and figure (4) for the year 2016-17 and 2017-18 respectively. In both years, analysis of the data revealed that difference was statistically significant ($p < 0.05$) for grain yield in case of tillage. Highest grain yield was 5600 kg ha^{-1} in 2016-17 and 5603 kg ha^{-1} in 2017-18 that was produced by zero tillage/relay cropping followed by conventional tillage (4777 kg ha^{-1} in 2016-17 and 4811 kg ha^{-1} in 2017-18) which is statistically at par with grain yield produced by minimum tillage (4670 kg ha-1 in 2016-17 and 4687 kg ha^{-1} in 2017-18). Analysis of the data revealed that no significant difference for grain yield in case of sowing methods. However, maximum grain yield recorded with ridge planting was 5040 kg ha^{-1} in 2016-17 and in 2017-18 maximum yield was with bed planting (5044 kg ha^{-1}) while lowest grain yield was noted in flat planting for both years.

The interaction of tillage and sowing methods for grain yield was significant as depicted in figure (3) and figure (4). Sowing methods in all tillage levels showed varied response as flat sowing in zero tillage recorded highest grain yield (5758 kg ha^{-1} in 2016-17 and 5720 kg ha^{-1} in 2017-18), amongst all sowing methods in all three tillage systems, which

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is statistically at par with bed planting in the zero tillage (5680 kg ha^{-1} in 2016-17 and 5717 kg ha^{-1} in 2017-18), while ridge planting performed better in minimum and conventional tillage than bed and flat planting. The lowest grain yield (4547 kg ha^{-1} in 2016-17 and 4593 kg ha^{-1} in 2017-18) was noted when flat planting was carried out in minimum tillage. These results are consistent with Singh et al. (2017) suggesting that relay seeding in wheat cotton system increase wheat yield by 18.8 % compared with conventional tillage system.

This in line with other study in rice-wheat system as Li et al. (2022) reported that no tillage significantly improved wheat growth and grain yield compared with rotary tillage and traditional plow. Hassan et al. (2024) likewise observed 4.79% increases in yield with no tillage. The increased grain yield in zero tillage might be due to prolong duration of the crop. Since the sowing of zero tillage was made in November when compared to the sowing of wheat in December for other tillage practices, thus prolong duration might have increased the wheat productivity in zero tillage system. Increasing the duration of the crop, the crop vegetative growth increased by interception of more light (Mao et al., 2014), increase the dry matter accumulation or photosynthate (Aslam et al., 2013), and thus ultimately increased the grain yield. Previously published research (Butter et al., 2013; Aslam et al., 2013; Aslam et al., 2014; Sajjad et al., 2018) are also of such opinions.

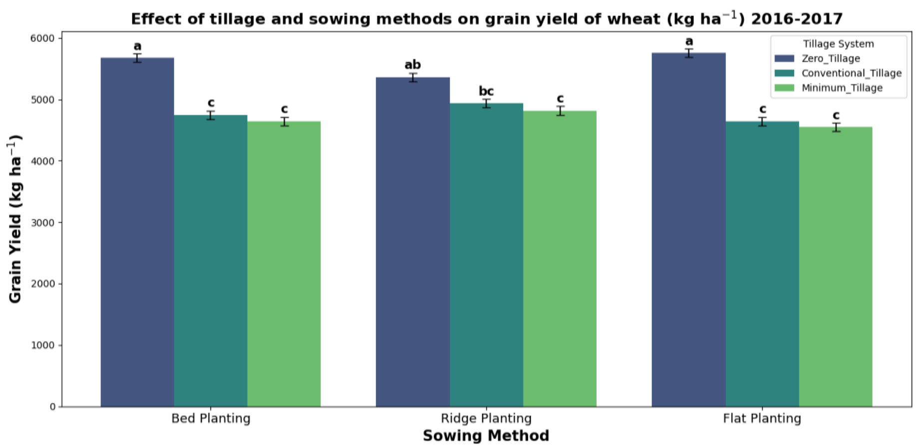

Figure 3. Effect of tillage and sowing methods on grain yield (2016-17).

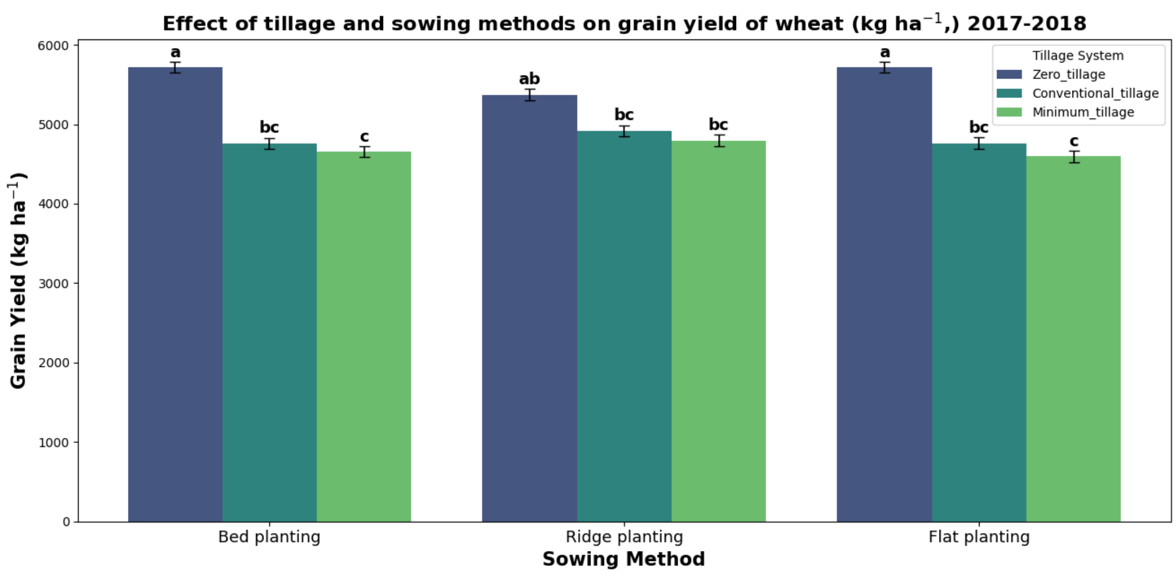

Figure 4. Effect of tillage and sowing methods on grain yield (2017-18).

Economic analysis

Economic analysis of data, as presented in table (2), showed that highest net return (86199 rupees per hectare) and benefit cost ratio (1.78) was obtained in zero tillage/relay cropping of wheat while conventional tillage recorded better net return (52141 rupees per hectare) than minimum tillage (51478 rupees per hectare). Similar results have been reported by (Ali et al., 2014). The greater benefit cost ratio in minimum tillage (1.46) than the conventional tillage (1.45) was due to less expenditure on land preparation and sowing operations (111970 rupees per hectare) as compared to conventional tillage (114996 rupees per hectare).

Table 2. Effect of various tillage and sowing methods on economics of wheat production.

	Zero tillage / Relay Cropping				Conventional Tillage				Minimum Tillage			
	TE (PKR ha^{-1})	TI (PKR ha^{-1})	NR (PKR ha^{-1})	BCR	TE (PKR ha^{-1})	TI (PKR ha^{-1})	NR (PKR ha^{-1})	BCR	TE (PKR ha^{-1})	TI (PKR ha^{-1})	NR (PKR ha^{-1})	BCR
Bed Planting	113485	198835	85350	1.75	114897	165984	51087	1.44	111891	162526	50635	1.45
Ridge Planting	107446	187769	80323	1.75	115490	172900	57410	1.50	112424	168750	56326	1.50
Flat Planting	108676	201601	92925	1.86	114601	162526	47925	1.42	111594	159068	47474	1.43
Avg	109869	196069	86199	1.78	114996	167137	52141	1.45	111970	163448	51478	1.46

TE: Total expenditure, TI: Total Income, NR: Net Return, BCR: Benefit Cost Ratio.

Table 3. Environmental aspect of tested tillage systems for wheat sowing in cotton-wheat cropping system.

Carbon foot print calculation	ZT	MT	CT
Fuel used for land preparation & sowing (L ha^{-1})	-	32.1	44.5
CO_2 emission (kg Equivalent ha^{-1})	-	86.7	120.0
CO_2 emission reduction in comparison with CT (kg Equivalent ha^{-1})	120.0	33.3	-

equivalent (kg ha^{-1}). The CF indicator has gained popularity in the recent years because of its relevance in various actions aimed to mitigate GHG emissions in the different sectors. According to this, we used CF methodology to determine GHG emissions of wheat production under various tillage systems (Weidema et al., 2008; Time for change). The calculated average carbon footprint regarding fuel used for land preparation and sowing in conventional tillage (CT), reduced tillage (RT), and no-tillage (NT), CO_2 emission due to fuel consumption and CO_2 emission reduction is presented in the Table 3. The results depicted that relay cropping of wheat/zero tillage had zero fuel use for land preparation and sowing operation, but minimum tillage used 32.1 liters of fuel and conventional tillage used 44.5 liters of fuel during the land preparation and sowing operations. The fuel used in conventional tillage and minimum tillage lead to CO_2 emission120 and 86.7 kg CO_2 equivalent ha^{-1}, respectively while relay cropping did not contribute CO_2 emission due to elimination of fuel use for land preparation and sowing. Conversely relay cropping reduced 120.0 kg ha^{-1} CO_2 equivalent emission, being environment friendly, in comparison with the conventional tillage and minimum tillage also reduced 33.3 kg ha^{-1} CO_2 equivalent emission in comparison with the conventional tillage. The difference between the CF values in wheat production by different sowing methods under study was due to the severity of soil-tillage activities. Increased GHG emissions in traditional conventional tillage and reduced tillage (RT) were mainly because of increased fuel consumption as compared to no-tillage (NT). The reason behind this was the high level of fuel consumption and the high use of machinery in CT than in RT and NT. These tillage systems had an effect on GHG emissions that might be attributed to mainly fuel consumption in the production life cycle of plants that was analogous to (Parajuli et al., 2017: Holka and Bieńkowski, 2020). The minimum tillage and direct drilling system as zero tillage is energy and cost saving and environmentally friendly as compared to conventional tillage practices (Ahmad et al., 2013).

CONCLUSION

Zero Tillage (sowing of wheat as relay crop in standing cotton) produced higher yield (19% and 17% higher in the respective years), more net income (65% and 67%) and reduced the CO_2 emission (100%) due to elimination of fuel used for land preparation and sowing compared to minimum and conventional tillage, respectively. Sowing methods of wheat under different tillage systems had significant difference for yield i.e. flat sowing and bed planting performed better than ridge planting in relay crop but ridge planting was on top in both conventional and minimum tillage. It was recommended that relay planting in standing cotton as zero tillage under bed and flat sowing may be used as best option among farmers to improve yield, more net income and may be considered an environment friendly approach for wheat production in cotton-wheat cropping system.

AUTHOR'S CONTRIBUTION

Hafiz Naveed Ramzan conducted the study, collected data and contributed in developing initial draft of the paper. Muhammad Faisal Shafiq analyzed the data; Rabia Nadeem and Maham Sajid prepared the final manuscript. Muhammad Kashif Munir guided for using the field equipment and also reviewed the paper. Naveed Akhtar, Fahid Ihsan, Nauman Ali, Hafiz Muhammad Ijaz and Muhammad Kashif Hanif critically reviewed the paper. All authors approved the final manuscript.

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There was no external funding agency for research trial.

AVAILABILITY OF DATA AND MATERIAL

All data produced throughout this research is presented in this published article as tables and figures.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

This study does not include any personal data from individuals in any capacity. All authors have consented to its publication.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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