Research Article

A Systematic Evaluation of Growth, Phenology, and Yield Responses of Wheat to Various Tillage Practices and Row Spacing

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Abstract | To assess the yield response of wheat to various tillage practices and row spacing, a field experiment was conducted with randomized complete block design with split plot arrangement replicated thrice. Tillage practices were assigned to main plots and row spacing were allocated to sub plots. The results of the experiment revealed that tillage practice, comprising of one time Cultivator + one time Rotavator enhanced days to emergence (13), emergence m^{-2} (82), spikes m^{-2} (214), grains spike^{-1} (44), thousand grains weight (42.4 g), grain yield (2864 kg ha^{-1}), biological yield (8361 kg ha^{-1}) and harvest index (34.3%) with retaining minimum number of weeds (107 m^{-2}), weeds fresh weight (175.6 g m^{-2}) and weeds dry weight (61.3 g m^{-2}) in wheat crop. Considering row spacing treatment, maintaining 30 cm row to row distance in wheat crop improved spikes m^{-2} (218), grains spike^{-1} (45), thousand grains weight (42.8 g), grain yield (2911 kg ha^{-1}) and harvest index (36.1%). Maximum biological yield (8270 kg ha^{-1}) and straw yield (5883 kg ha^{-1}) was recorded in wheat crop with 25 cm and 15 cm row spacing respectively. Higher number of weeds (132 m^{-2}), weeds fresh weight (197.6 g m^{-2}) and weeds dry weight (68.3 g m^{-2}) was observed in plots in which 40 cm row to row distance was maintained. It is concluded that tillage practice consisting of one time Cultivator + one time Rotavator with 30 cm row spacing improved wheat yield and thus recommended for increasing wheat grain yield in the study area.

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Introduction

Wheat (*Triticum aestivum* L.) is the well-known cereal crop belongs to family Poaceae. It is extensively used throughout the globe in various forms, including Pakistan and known as king of cereals. It can be grown in various soils and climatic conditions. Wheat serves as a staple food for human population and is a good source of essential nutrients, including protein and carbohydrates (Khalil and Jan, 2002). However, inappropriate cultural practices, low seed quality, poor plant protection strategies and imbalance use of fertilizers are reasons for low wheat yield in Pakistan. The factors affecting crop yield performance include the use of proper spaces between crop rows, balanced fertilizer, recommended seed rate, proper seed bed preparation, timely irrigation in appropriate way and insects, pests and weeds control

(Chen *et al*., 2009).

Tillage is the agricultural preparation of soil mechanically through different implements, and it contains chain of operations to handle crop production (Muqaddas *et al*., 2005). Tillage practices are responsible for water storage and conservation coupled with soil physiochemical characteristics. Tillage improves bulk density of soil, soil aeration, soil porosity, soil structure, water related characteristics of soil, nutrients availability, microbial activity, emergence of young seedling and root penetration (Hussain *et al*., 2014). Proper tillage operations and suitable production technology can optimize crop yield through improving the physio-chemical status and water holding capacity of soil (Pandey *et al*., 2013). A wide range of tillage practices from zero tillage (with no tillage practice) to deep tillage are used for getting high yield. However, in most cases, tillage operation used are inappropriate concerning the physical condition of a particular soil and no proper attention has been paid to the suitability of tillage for a particular soil and crop condition (Ahmad *et al*., 2018). In South Asia, the soil tillage along with crop establishment cost was 25-30% of the total cost of wheat production in rice-wheat cropping system (Saharawat *et al*. 2011). The tillage practices need energy and inputs and become difficult to adjust cost of producing a particular crop. Conservation tillage is a terminology which is broadly used for practices such as shallow or minimum tillage and zero tillage (Ghafari *et al*., 2017).

In Pakistan, most of the farmers use to broadcast wheat seed in the soil for the purpose of sowing and line sowing is practiced by progressive farmers and the people linked to research community (Ahmad *et al*., 2018). The increasing problem of weed infestation emphasize the need of appropriately spaced crop rows which can make possible the use of improved inter-cultural practices along with efficient and convenient use of herbicides for weeds control (Bakht *et al*., 2007). Effective method of weed control can enhance the wheat yield up to 40.6 % (Mali and Chouhdri, 2012) and thus having a considerable importance, particularly under the system of reduced tillage. Spacing between crop rows is significantly associated with weeds densities. Increasing the population of crop plants per unit area through keeping less space among the crop rows, can significantly affect the weeds population while it is associated with the crop yield as well. An appropriate spacing between wheat rows can make it more convenient to intercrop without affecting the grain yield of wheat. Closer rows of wheat can suppress weeds by many means including shading effect and causing more competition for nutrients, light and water (Drewes and Wiener *et al*., 2001). Numerous studies held in diverse climatic conditions indicated that more yield can be achieved from bringing the crop rows closer than broader crop rows (Chen *et al*., 2008). However, in contrast, some studies suggests that more apart rows of wheat ensures greater yield or a yield similar to that in narrowly spaced rows (Hiltbrunner *et al*., 2005). Thus, it can be argued that the association between wheat yield and row spacing depends upon the environment and genotype (Wiener *et al*., 2001).

Thus, keeping in view the above discussed significance of row spacing and soil tillage, it can be argued that both of these factors, if optimized, can play a significant role in wheat yield improvement. Therefore, the recent study was designed to investigate the response of wheat crop to different tillage methods and row spacing for enhancing grain yield of wheat.

Materials and Methods

Experimental design and plant material

The experiment was laid out in randomized complete block (RCB) design with split plot arrangement having three replications. Tillage practices were allocated to main plots and row spacing to sub plots. Every sub plot had six (6) rows with variable row spacing. Variable row spacing values were 15 cm, 20 cm, 25 cm, 30 cm, 35 cm and 40 cm. The recommended dose of nitrogen 120 kg ha^{-1}, phosphorus 90 kg ha^{-1} and potassium 60 kg ha^{-1} were applied from urea, single super phosphate and sulfate of potash, respectively. All the phosphorus, potassium and half of the nitrogen were applied at sowing time. The remaining N was applied at tillering stage. Wheat variety Atta-Habib was sown at the rate of 120 kg ha^{-1}. Considering tillage methods in T1 Chisel plough was used for deep tillage three times to the depth of 50cm followed by Rotavator two times to break up and churn the soil. In T2 Mould board plough was used twice to invert the soil up to 30cm followed by Rotavator three times. In T3 Disc harrow was used three times to till the soil to the depth of 20 cm followed by Rotavator once. In T4 Cultivator was used to stir the soil up to 20cm followed by Rotavator. Different row spacings were maintained in each subplot with the help of measuring tape and rows were made through hand hoe. All other agronomic practices (weeding, irrigation and harvesting etc.) were kept uniform for all the treatments (Table 1).

Early growth and morphological traits

Days to emergence were calculated from the difference in days from sowing date to the date when 80 % seedlings emerged in each sub plot. Data on emergence (m^{-2}) were recorded by counting seedlings in a meter long row at three randomly selected places in each sub plot and data were converted into emergence m^{-2}. Leaf number per tiller was calculated by counting leaves in randomly selected ten plants in each experimental unit and then average was calculated. About 10 plants were randomly selected in each experimental unit. Their height was measured through measuring tape from base to the tip of the plant and average plant height was calculated. The formula used for emergence m^{-2} is given below:

$$Emergence\ (m^{-2}) = \frac{Number\ of\ Seedlings\ Counted}{Row - Row\ Distance\ \times Row\ Length\ \times Number\ of\ Rows}$$

Phenological development stages

Days to booting were calculated from the difference in days from sowing date to the date when 80 % plants reached boot stage in each sub plot. The data were observed through regular inspection and visit to field. Data on days to anthesis in each sub plot were taken by counting days from sowing date to the date till 80% plant produced anthers. Days to Anthesis was subtracted from days to maturity for finding grain filling duration. Days to physiological maturity were calculated from sowing date till 80% plants got matured in each sub plot. Physiological maturity was determined by the disappearance of green color from glumes.

Weed competition dynamics

The data on number of weeds were recorded at tillering stage of wheat crop from randomly selected three sampling units in each sub plot through a quadrate iron frame having each side 50 cm. The number of weeds were counted and averaged. After counting the number of weeds, they were uprooted and their fresh weight was recorded with a digital balance. Then, average fresh weight of weeds (g m^{-2}) was calculated. Weeds collected for fresh weight from each experimental unit were oven dried at 65 ◦C for 72 hours and their dry weight was measured through electronic balance. Then average dry weight of weeds (g m^{-2}) was calculated.

Yield components, yield and harvest index

Number of spikes were counted in three randomly selected central rows in each sub plot and converted into spike (m^{-2}) accordingly. In each sub plot ten spikes were selected randomly. The selected spikes were threshed and the grains in each spike were counted and averaged for grains spike^{-1}. After threshing, a random sample was taken from produce of each experimental unit. Thousand grains were counted through grain counter and weighed through electronic balance. Biological yield was computed by harvesting central four rows in each sub plot at maturity. Plants were weighed and data were converted into kg ha^{-1}. After taking biological yield, the harvested material was threshed by a mini thresher and the grains of each experimental unit were cleaned, dried and weighed. The data were converted to grain yield (kg ha^{-1}). The straw yield was calculated by subtracting grain yield from biological yield in each experimental unit. Harvest index was calculated for each sub plot by dividing grain yield on biological yield and then multiplied with 100 to get harvest index in percentage (%).

Statistical analysis

Data were statistically analyzed by ANOVA procedure suggested for the RCB design having split plot arrangements. Upon significant F-test results, means were matched using LSD test (Steel and Torrie, 1996).

Table 1: *The experimental treatments assigned to main plot and sub plots.*

Factor A	**Tillage Practices (Main plot)**	**T1**	**T2**	**T3**		**T4**	
		Three times Chisel plough + Two times Rotavator	**Two times Mould board plough + Three times Rotavator**	**Two times Disc harrow + One time Rotavator**		**One time Cultivator + One time Rotavator**	
Factor B	Row Spacing (Sub plot)	R1	R2	R3	R4	R5	R6
		15 cm	20 cm	25 cm	30 cm	35 cm	40 cm

Results

Early growth and morphological traits

Statistical analysis of the data regarding days to emergence of wheat as affected by various tillage practices and row spacing depicted that tillage practices significantly influenced days to emergence of wheat crop. Whereas, row spacing and interaction between tillage practices and row spacing had non-significant effect on days to emergence of wheat. Mean comparison of the data showed that among tillage practices using one time Cultivator with one time Rotavator resulted in more days to emergence (13) of wheat seedlings as compared to rest (Table 2). Data pertaining to effect of tillage practices and row spacing on emergence (m^{-2}) of wheat showed that different tillage practices had significantly ($P \leq 0.05$) affected emergence (m^{-2}) of wheat while row spacing and interactive effect of tillage and row spacing was found non-significant. Maximum emergence (m^{-2}) (67) was recorded in plots that received tillage method as one time Cultivator + one time Rotavator. While minimum emergence (m^{-2}) (68) was observed in plots treated with Chisel plough three times with two times Rotavator and two times Mould board plough with three times Rotavator (Table 2). Statistical analysis of the data regarding number of leaf tiller^{-1} of wheat crop as influenced by different tillage practices and row spacing showed that row spacing, tillage operations and their interaction had non-significant effect on the number of leaf tiller^{-1} (Table 2). Data regarding the effect of row spacing and tillage practices on plant height of wheat indicated that tillage practices had significant effect ($P \leq 0.05$) on plant height of wheat. While effect of row spacing and the interaction of tillage and row spacing was found non-significant. Average values of plant height showed that taller wheat plants (100 cm) were recorded in tillage treatment of two times Mould board plough + three times Rotavator which is statistically similar with two times Disc harrow + one time Rotavator and three times Chisel plough + two times Rotavator produced dwarf plants (95 cm) (Table 2).

Phenological development stages

Analysis of the data regarding days to booting as affected by various tillage operations and row spacing showed that row spacing and various tillage practices had non-significant effect on days to booting. The interaction between tillage practices and row spacing was also found non-significant (Table 3). Days to anthesis of wheat as affected by different tillage practices and row spacing revealed non-significant differences of tillage practices and row spacing on days to anthesis of wheat crop. All possible interactions were also found non-significant (Table 3). Days to physiological maturity of wheat as affected

Table 2: *Early growth and morphological traits of wheat grown with various tillage practices and row spacing. Means of each category followed by different letter(s) are significantly different at 5 % level of probability using LSD test ($P \leq 0.05$).*

	Treatments	Days to emergence	Emergence (m^{-2})	Number of leaf tiller^{-1}	Plant height (cm)
Factor A (T-Tillage)	T1	12.00 b	64.00 c	5.30	95.00 c
	T2	12.00 b	64.00 c	5.60	100.00 a
	T3	12.00 b	66.00 b	5.40	96.00 b
	T4	13.00 a	67.00 a	5.60	95.00 c
Factor B (R-Row Spacing)	R1	12.00	68.00	5.50	96.00
	R2	12.00	66.00	5.40	97.00
	R3	12.00	66.00	5.60	96.00
	R4	12.00	65.00	5.80	97.00
	R5	12.00	63.00	5.50	98.00
	R6	12.00	62.00	5.20	96.00
F-value	T	8.00^{*}	3.41^{*}	1.60^{NS}	100.90^{***}
	R	1.39^{NS}	1.04^{NS}	1.40^{NS}	1.40^{NS}
	T × R	1.35^{NS}	1.01^{NS}	0.40^{NS}	1.50^{NS}

Table 3: *Phenological development stages of wheat grown with various tillage practices and row spacing. Means of each category followed by different letter(s) are significantly different at 5 % level of probability using LSD test ($P \leq 0.05$).*

	Treatments	Days to booting	Days to anthesis	Days to physiological maturity
Factor A (Tillage)	T1	111.0	126.0	154.0
	T2	112.0	127.0	153.0
	T3	111.0	127.0	154.0
	T4	112.0	127.0	153.0
Factor B (Row Spacing)	R1	112.0	127.0	153.0
	R2	112.0	127.0	154.0
	R3	111.0	126.0	154.0
	R4	111.0	126.0	154.0
	R5	111.0	126.0	153.0
	R6	112.0	126.0	153.0
F-value	T	0.60^{NS}	4.60^{NS}	1.00^{NS}
	R	1.00^{NS}	0.40^{NS}	0.70^{NS}
	T × R	1.00^{NS}	0.80^{NS}	0.50^{NS}

by different tillage practices and row spacing revealed non-significant differences for tillage practices and row spacing. All possible interactions were also found non-significant for days to physiological maturity of wheat crop (Table 3).

Weed competition dynamics

Statistical analysis of the data showed that tillage practices and row spacing had a significant ($P \leq 0.05$) impact while their interaction has non-significant effect on weeds number m^{-2} in wheat crop. Comparison of mean values showed that wheat sown at 40 cm spaced rows was infested with more weeds (132 m^{-2}) followed by wheat sown in 35 cm apart rows (130 m^{-2}). Whereas closer rows of wheat (15 cm) accommodated lower weeds m^{-2} (101 m^{-2}) which was statistically at par with 20, 25 and 30 cm row spacing. In case of tillage practices more number of weeds (130 m^{-2}) were observed in those plots where the tillage operation was done with three times Chisel plough and two times Rotavator which is statistically similar with the tillage operation two times mould board plough with three times Rotavator. While the minimum weeds infestation (105 m^{-2}) was found in the soil tilled with Cultivator once and one time Rotavator (Table 4). Fresh weight of weeds g m^{-2} as influenced by various tillage and row spacing treatments revealed that both of the factors had significantly affected ($P \leq 0.05$) fresh weight of weeds g m^{-2}. The combined effect of row spacing and tillage practices was found non-significant for weeds fresh weight. More fresh weight of weeds (210.0 g m^{-2}) was found when wheat rows were kept 40 cm apart followed by (192.3 g m^{-2}) 35 cm apart wheat rows. Weeds fresh weight was reduced (158.0 g m^{-2}) by narrow row spacing 15 cm. Weeds fresh weight data further explored that soil operation including running three times Chisel plough + two times Rotavator resulted in more fresh weight of weeds (194.1 g m^{-2}) whereas tillage operation done with one time Cultivator + one time Rotavator reduced the fresh weight of weeds (180.0 g m^{-2}) (Table 4). Analysis of the data regarding dry weight of weeds (g m^{-2}) as affected by various tillage practices and wheat row spacing showed after statistical analysis that row spacing and tillage practices had significantly affected the weeds dry weight m^{-2} ($P \leq 0.05$) while their interaction had non-significant effect on weeds dry weight. Weeds dry weight (72.4 g m^{-2}) was maximum in wider rows of wheat 40 cm followed by dry weight of weeds (65.3 g m^{-2}) recorded in 35 cm spaced rows. Row spacing of 15 cm resulted into minimum weeds dry weight (55.5 g m^{-2}). Data also showed that shallow tillage through one time Cultivator + one time Rotavator decreased the dry weight of weeds (61.1 g m^{-2}) which is statistically similar with tillage operation through two times Disc harrow + one time Rotavator. However, tillage operations including two times Mould board plough + three times Rotavator produced the maximum weeds dry weight (65.9 g m^{-2}) (Table 4).

Table 4: *Weed competition dynamics with wheat grown with various tillage practices and row spacing. Means of each category followed by different letter(s) are significantly different at 5 % level of probability using LSD test ($P \leq 0.05$).*

	Treatments	Number of weeds (m^{-2})	Weeds fresh weight (g m^{-2})	Weeds dry weight (g m^{-2})
Factor A (Tillage)	T1	130.0 a	198.90 a	65.60 a
	T2	128.0 a	190.10 b	65.90 a
	T3	112.0 b	180.80 c	63.60 b
	T4	105.0 c	180.00 c	61.10 c
Factor B (Row Spacing)	R1	101.0 c	158.00 d	55.50 c
	R2	117.0 b	180.20 c	64.30 b
	R3	115.0 b	182.90 c	63.60 b
	R4	117.0 b	181.80 c	63.30 b
	R5	130.0 a	192.30 b	65.30 b
	R6	132.0 a	210.90 a	72.40 a
F-value	T	22.10**	18.90**	10.60**
	R	12.30**	03.10*	05.90**
	T × R	0.90^{NS}	01.70^{NS}	01.00^{NS}

Yield components, yield and harvest index

Analysis of the data regarding spikes (m^{-2}) of wheat as influenced by different tillage practices and row spacing treatments showed that row spacing treatments and tillage practices significantly ($P \leq 0.05$) influenced the spike m^{-2} of wheat. Whereas the interaction of tillage practice and row spacing was found non-significant. Wheat rows spaced at 30 cm produced more spikes (m^{-2}) (218) followed by wheat sown in 25 cm apart rows (208 m^{-2}). While the minimum spikes (m^{-2}) (203) were found in 15 cm row spacing. In case of tillage operations higher number of spikes (m^{-2}) (214) were observed in one time Cultivator + one time Rotavator treatment. Three times Chisel plough + two times Rotavator resulted in lower spikes (m^{-2}) (204). Observed by one time Cultivator + one time Rotavator. Among the tillage treatments, three times Chisel plough + two times

Rotavator resulted into less (204) spikes m^{-2} (Table 5). Data regarding grain filling duration of wheat crop as affected by tillage practices and row spacing revealed that row spacing, tillage treatments and their interaction had no significant effect on grain filling duration of wheat crop (Table 5). Data of grains spike^{-1} of wheat as influenced by various row spacing and tillage methods showed that row spacing and tillage treatments significantly varied ($P \leq 0.05$) the grains spike^{-1} of wheat but the interaction were found non-significant for tillage practices and row spacing. Wheat rows spaced at 30 cm produced more grains per spike (45) followed by the row spacing treatment of 25 cm which resulted into 43 grains spike^{-1}. Fewer grains per spike of wheat (40) were recorded in wheat rows which were 15 cm apart. Among the tillage practices, one time Cultivator + one time Rotavator enhanced the number of grains spike^{-1} (44) which is statistically similar with two times Disc harrow + one time Rotavator with 43 grains spike^{-1}. Fewer grains spike^{-1} (40) was recorded in plots received three times Chisel plough + two times Rotavator (Table 5). Data concerning various tillage practices and row spacing treatments on weight of thousand wheat grains reflected that weight of thousand grains of wheat were significantly influenced ($P \leq 0.05$) by tillage as well as row spacing. The interactive effect of tillage and row spacing was also found significant on wheat thousand grains weight. The rows of wheat spaced at 30 cm produced heavier grains (42.8 g) followed by row spacing of 25 cm. Narrow row spacing of 15 cm resulted in lower thousand grains weight (38.3 g). Among the studied tillage treatments, one time Cultivator + one time Rotavator maintained maximum grains weight (42.8 g) while minimum grain weight (38.4 g) was observed from tillage operation with three times Chisel plough + two times Rotavator. Among the interactive effect, heavier wheat grains (45.3 g) were achieved from 30 cm row spacing with tillage operation one time Cultivator + one time Rotavator (Table 5).

Consequently, data pertaining to grain yield of wheat as influenced by various row spacing and tillage practices were statistically analyzed which revealed that wheat grain yield was significantly varied by row spacing and tillage practices. However, the interaction was not significant between the row spacing treatments and soil tillage operations. Wheat grown in 30 cm spaced rows resulted in maximum grain yield (2911 kg ha^{-1}) among all the row spacing treatments, followed by 25 cm spaced rows (2715 kg ha^{-1}). Row spacing of 15 cm produced the lowest grain yield (2512 kg ha^{-1}). Tillage operation done through one time Cultivator + one time Rotavator enhanced wheat grain yield (2864 kg ha^{-1}) as compared with other tillage practices studied. Whereas soil tilled with three times Chisel plough + two times Rotavator produced lowest wheat grain yield (2542 kg ha^{-1}) (Table 6).

Table 5: *Yield components of wheat grown with various tillage practices and row spacing. Means of each category followed by different letter(s) are significantly different at 5 % level of probability using LSD test (P ≤ 0.05).*

	Treatments	Spikes (m^{-2})	Grain filling duration	Grains spike^{-1}	Thousand grains weight (g)
Factor A (Tillage)	T1	204.0 c	24.0	40.0 c	38.40 d
	T2	209.0 b	24.0	42.0 b	39.40 c
	T3	210.0 ab	23.0	43.0 a	40.40 b
	T4	214.0 a	24.0	44.0 a	42.40 a
Factor B (Row Spacing)	R1	203.0 c	23.0	40.0 d	38.30 d
	R2	207.0 bc	23.0	42.0 c	38.90 cd
	R3	208.0 bc	24.0	43.0 b	40.00 bc
	R4	218.0 a	24.0	45.0 a	42.80 a
	R5	209.0 b	24.0	42.0 c	41.00 b
	R6	210.0 b	24.0	42.0 c	40.00 bc
F-value	T	11.70**	0.40NS	20.90*	50.80*
	R	7.20*	0.80NS	19.00*	29.60*
	T × R	0.70NS	1.50NS	1.70NS	4.80NS

Table 6: *Yield and harvest index of wheat grown with various tillage practices and row spacing. Means of each category followed by different letter(s) are significantly different at 5 % level of probability using LSD test (P ≤ 0.05).*

	Treatments	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
Factor A (Tillage)	T1	2542 c	7951 c	5409	32.0 b
	T2	2632 bc	8007 c	5375	32.9 ab
	T3	2719 b	8192 b	5473	33.2 ab
	T4	2864 a	8361 a	5496	34.3 a
Factor B (Row Spacing)	R1	2512 d	8395 a	5883 a	29.9 d
	R2	2632 bc	8242 a	5610 b	32.0 c
	R3	2715 bc	8270 a	5555 b	32.8 bc
	R4	2911 a	8064 b	5153 c	36.1 a
	R5	2763 b	8014 b	5251 c	34.5 ab
	R6	2602 cd	7782 c	5180 c	33.5 bc
F-value	T	20.80*	36.5*	2.03NS	6.50*
	R	8.50*	12.60*	11.24*	9.00*
	T × R	0.70NS	1.40NS	0.92NS	0.60NS

Statistical analysis of the recorded data for biological yield of wheat as affected by tillage and row spacing treatments revealed that biological yield was significantly altered ($P \leq 0.05$) by row spacing and tillage practices. The combined effect was found non-significant. Row spacing treatment of 15 cm produced the highest biological yield (8405 kg ha^{-1}) which is statistically similar with 20 cm and 25 cm of row spacing, respectively. Lowest biological yield of wheat (7782 kg ha^{-1}) was observed from wheat rows spaced at 40 cm. Soil tillage done through running one time Cultivator + one time Rotavator maintained maximum biological yield (8767 kg ha^{-1}) while soil tilled through three times Chisel plough + two times Rotavator produced lowest (7986 kg ha^{-1}) biological yield (Table 6). Data analysis of straw yield of wheat crop as influenced by various tillage practices and row spacing treatments showed that wheat straw yield was significantly ($P \leq 0.05$) affected by row spacing treatments. Whereas straw yield was not significantly affected by tillage operations and interaction among tillage practices and row spacing. Average mean comparison of the data showed that wheat grown with narrow row spacing 15 cm resulted in higher straw yield (5882 kg ha^{-1}) while lower straw yield (5180 kg ha^{-1}) was observed with broad row spacing 40 cm which is statistically at par with 35 cm and 30 cm row spacing (5251 and 5153 kg ha^{-1}, respectively) (Table 6). Data for harvest index (%) of wheat crop as affected by various tillage practices and row spacing practices was statistically analyzed which revealed that harvest index was significantly affected by row spacing and tillage methods. However, the interaction was observed not significant between the row spacing treatments and soil tillage operations. Highest harvest index (36.1 %) was achieved with 30 cm row spacing followed by 35 cm row space (34.5 %) while lowest harvest index (29.9 %) was recorded from narrow distance of rows 15 cm. In case of tillage operations, maximum harvest index was recorded when tillage operation was done with one time Cultivator + one time Rotavator followed by two times Disc harrow and one time Rotavator (33.2 %). Minimum harvest index (32 %) was recorded from those plots where tillage operations were done with three times Chisel plough and two times Rotavator (Table 6).

Discussion

Days to emergence of wheat were significantly affected by different tillage practices. The combined impact of tillage practices and row spacing, on the other hand, had no significant effect on days to emergence. Among tillage practices using one time Cultivator with one time Rotavator resulted in more days to emergence of wheat seedlings as compared to rest. The adequate water provided by soil operations resulted in a suitable moist environment for seed coat softening and rapid emergence. It is due to better soil conservation that there has been less evaporation and leaching of soil water. Our findings are consistent with those of Ramazan *et al.* (2014), who found that using Mould board plough followed by a Rotavator delayed the emergence of wheat seedlings. According to Khan *et al.* (2008) earlier emergence occurred in plots that were lightly tilled. Different tillage practices had a significant impact on wheat emergence m^{-2}, but row spacing and their interactive effect were non-significant. More wheat seedlings emerged per square meter of cultivated area tilled by one-time Rotavator + one-time Cultivator. Tillage practices including three-time Chisel plough and two times Rotavator showed lower emergence m^{-2}. Seedling emergence was uniform due to the soil's higher water and nutrient retention ability. This may be due to favorable soil condition for seedling emergence. Our findings are in line with that of Hussain *et al.* (2011). It's possible that the adequate amount of moisture retention in the soil, as well as the softness of the soil, caused rapid root expansion into moist soil to meet plant water requirements, which directly influenced emergence m^{-2}. Chiroma *et al.* (2006) found that Cultivator and Rotavator tillage activities resulted in better seedling emergence. In comparison to traditional and deep tillage, minimum tillage resulted in better crop establishment (Imran *et al.*, 2013). Days to booting of wheat crop were non-significantly affected by row spacing and various tillage practices. The interaction between tillage and row spacing were also found non-significant. This might be due to equal proportion of fertilization to all of the experimental units that induced uniform crop growth and development in the experimental units despite treated with different tillage practices. Similar results were reported by Usman *et al.* (2013) that tillage practices had non-significant influence on days to booting of wheat crop. Our results are supported by the findings of Laghari *et al.* (2011). For days to anthesis, tillage practices, row spacing, and their interaction were found non-significant. This may be due to consistent crop growth and development in the experimental units although subjected to various tillage practices. Contradictory results were reported by Abdipur *et al.* (2012), who studied that tillage had significant effects on days to anthesis, booting, and maturity. They also noted that traditional tillage plots take longer to boot, anthesis, and mature than zero tillage plots. Our findings were supported by Laghari *et al.* (2011), who found that tillage activities had no effect on days to anthesis and booting.

Tillage practices and row spacing had a major impact on the number of weeds per (m^{-2}) of wheat crop according to statistical analysis of the results. Their interaction was found non-significant. Wheat sown in 40 cm rows was infested with greater number of weeds. Closer rows of wheat were found having lower weeds m^{-2}. Regarding tillage activities, more weeds were found in plots where the tillage operation was performed three times with a Chisel plough and two times with a Rotavator. The soil tilled with one time Cultivator + one time Rotavator had the least number of weeds. The drastic reduction in weed population caused by a single Cultivator, once Rotavator and their interaction may be attributed to minimal soil disturbance, which prevented weed emergence to a greater extent. These results are consistent with those of Usman *et al.* (2013). According to Usman *et al.* (2013), weed populations are reduced when row spacing was reduced and tillage is done with one Cultivator and one Rotavator. Alvi *et al.* (2004) found that plots with tillage practices of one Cultivator and one Rotavator had less weed invasion. Gangwar *et al.* (2004) found that wider row spacing resulted in more weeds than narrow spacing. According to Tiwari and Keawat (2011) tillage operations and row spacing yielded similar results. Weeds fresh weight (g m^{-2}) was significantly affected by row spacing and tillage practices. When wheat rows were held 40 cm apart produced more fresh weight of weeds was recorded. Narrow row spacing decreased the fresh weight of the weeds. Tillage comprised of three-time Chisel plough + two-time Rotavator resulted in more fresh weight of weeds, while tillage with a one-time Cultivator + one-time Rotavator resulted in less fresh weight of weeds. Since only one Cultivator and one Rotavator were used, there was a significant decrease in weed density and fresh biomass. This may be attributed to limited soil disturbance, which prevented weed emergence to a greater degree. Tiwari and Keawat (2011) found similar results for tillage operations, reporting that when one Cultivator and one Rotavator were used, weeds fresh biomass was reduced. Khurshid *et al.* (2006) Discovered that wider rows spacing of 45 cm resulted in the highest fresh and dry biomass of weeds. In comparison to zero and reduced tillage, Usman *et al.* (2009) stated that traditional tillage resulted in the highest weed density, fresh and dry weed biomass. Row spacing and tillage activities had significant impact on weeds dry weight (g m^{-2}), but their relationship had no effect on weeds dry weight. The dry weight of weeds was increased by planting wheat in wider rows, i.e. (40 cm). The minimum weeds dry weight was achieved with a row spacing of 15 cm. The dry weight of weeds was also reduced by shallower tillage with one-time Cultivator + one-time Rotavator, according to the data. Tillage operations using a three-time Chisel plough and a two-time Rotavator, on the other hand, produced high weeds dry weight. The increased soil disruption caused by the mould board plough created an atmosphere conducive to weed emergence and development. Knezevic *et al.* (2003) proposed that weeds dry biomass declines after tillage operations with one Rotavator and one Cultivator. Khurshid *et al.* (2006) Discovered that wider rows spacing of 45 cm resulted in the highest fresh and dry biomass of weeds. In contrast to zero or reduced tillage practices, Usman *et al.* (2009) reported that traditional tillage resulted in the highest weed population, dry and fresh biomass. Tillage practices had a major effect on weed dry weight, according to Tiwari and Keawat (2011). These results are similar to those of Khalil *et al.* (2008).

Row spacing and various tillage operations had no effect on wheat leaf number tiller^{-1}, and their interaction was also found non-significant. It may be attributed to favorable environmental conditions during the plant's vegetative period. Leghari *et al.* (2015) found no statistically significant variations between traditional and reduced tillage in terms of wheat leaves per tiller. It may be due to the fact that all the experimental units had the same climatic conditions, resulting in the same number of leaf per tiller. The non-significant effect of row spacing on wheat leaf number per tiller was also recorded by Kaleem *et al.* (2009). Statistical analysis of the data showed that row spacing and tillage treatments had little impact on the grain filling duration. Both factors combined effects were also found to be non-significant. According to Ali *et al.* (2010), tillage practices had no effect on the number of leaves per tiller in wheat crops. Tillage practices and row spacing had no impact on days to reach physiological maturity of wheat, and their interaction was also found non-significant. This may be due to consistent crop growth and development in the experimental units that were subjected to various tillage practices. Our findings are in line with those of Laghari *et al.* (2011), who found that tillage practices had no effect on days to anthesis, booting or maturity. Knezevic *et al.* (2003) proposed similar results, claiming that tillage operations had no substantial impact on days to maturity. Our findings are supported by Irena *et al.* (2011), who found non-significant effect of tillage on days to physiological maturity of wheat. Our findings contradict those of Faeznia and Shamabadi (2010), who reported that improved soil conditions and increased nutrient availability as a result of tillage resulted in vigorous crop and that matures later. Ali *et al.* (2010) suggested that tillage operations had no effect on days to physiological maturity of wheat. Tillage significantly affects plant height. However, plant height remained unaffected by row spacing and their interactive effect. Changes in tillage practices resulted in a substantial increase in plant height. This may be due to higher levels of organic matter and moisture retention in various tillage practices, which had a direct impact on wheat vegetative development. Alvarez and Steinbach (2009) reported significant effects of various tillage practices on wheat crop yield. These findings are close to those of Gangwar *et al.* (2004), who found positive effects of tillage practices on crop development. According to Khurshid *et al.* (2006), wheat crop plant height varies significantly depending on row spacing. Row spacing and tillage methods had a major impact on wheat crop spikes m^{-2} of wheat while the interactive effect had no effect on spike m^{-2}. Spikes m^{-2} may increase as a result of various tillage operations that loosen the soil, allowing for proper root growth and nutrient uptake. According to Gangwar *et al.* (2004) spikes m^{-2} increased with deep and shallow tillage operations. These findings are in line with those of Shaukat *et al.* (1999) and Saeed *et al.* (2012), who found that skip row planting resulted in substantially more spikes per m^{-2}.

Row spacing and tillage methods had a significant impact on wheat grains weight and grains $spike^{-1}$. The findings of our study are consistent with those of Dalga *et al.* (2014), who found that row spacing and row orientation could improve wheat crop thousand grain weight and number of grains $spike^{-1}$. Crop is able to take in more nutrients because there is no competition from weeds or other crop species, and therefore more assimilates are translocated towards the grain, resulting in higher grain weight. In plots with more weed infestation and narrow row spacing, on the other hand, lower grain weight and fewer grains per spike were observed. As a result, there was more competition for resources such as light, water, nutrients and space among crop plants and weeds, resulting in crop plant resources being limited. As a result, the grain weight was reduced. Our findings are in line with those of Naveed *et al.* (2008), who found that weeds are efficient plants capable of competing with crop plants for soil, space, nutrients, light and other resources reducing grain and biomass yield. According to Chiroma *et al.* (2006), proper row spacing and good tillage practices increased wheat yield attributes such as grains per spike, spike (m^{-2}), and grains weight. Tillage operations, according to Slawinski *et al.* (2012), enhanced soil physical properties and aided plants in making optimal use of nutrients and moisture in the soil.

The effects of row spacing and tillage methods on wheat biological yield were found significant, but the interaction of tillage practices and row spacing on biological yield was found non-significant. Plots tilled with one Cultivator and one Rotavator maintained significantly higher biological yield. This may be due to the crop plants overall better output in terms of generating more tillers per acre, taller plants and higher grain yield. Plant height, leaf area, leaf expansion and stem girth are among factors that contribute to differences in biological yield. Hussain *et al.* (2005) found similar findings. According to Naveed *et al.* (2008), Rotavator followed by Cultivator resulted in higher biological yield. By subtracting grain yield from biomass, straw yield is calculated. Straw yield is a measure of a crop ability to accumulate photosynthates and assimilate them to contribute to biomass yield, such as plant height, leaf area, and biomass accumulation. Apart from tillage methods, statistical analysis of the data revealed that narrow and wide spacing had a major effect on straw yield. According to Kaleem *et al.* (2009), the growth and development of wheat crop improved as a result of tillage operations and the maintenance of adequate row spacing, resulting in large accumulation of dry matter output and growth-related attributes. Our findings are consistent with those of Chhokar *et al.* (2007), who reported similar findings from tillage operations.

Statistical analysis of the data revealed that different row spacing and tillage practices had a major impact on wheat grain yield, but their interaction had no effect on grain yield. The data showed that row spacing (30 cm) and tillage practices (Cultivator + Rotavator) resulted in the highest grain yield. This may be due to minimal tillage practices, which soften the seed bed, break up soil compaction and create a favorable environment for plant root growth. Plant establishment, canopy cover, dry matter partitioning and accumulation, and light usage efficiency were all affected by row spacing (30 cm). Rows with a smaller inter row spacing have a higher density of spikes than rows with a greater inter row spacing (Arif *et al*., 2007). Tillage operations, according to Slawinski *et al*. (2012) enhance soil physical properties and assist plants in making productive use of nutrients and moisture in the soil. These findings are consistent with those of Naveed *et al*. (2008), who found similar results. However, there are more nutrients available which are resulting in a higher harvest index. The one time Cultivator and one time Rotavator tillage treatment resulted in maximum grain yield. Row spacing and tillage methods have a significant impact on harvest index, while their interaction has a non-significant effect on harvest index. This is attributed to the lack of moisture at grain filling duration of the crop which resulted in heavy grains. Consequently, this led to a higher grain yield. High sunlight penetration caused an increase in harvest index with tillage operations and row spacing. When more space is available, there is less competition, and hence more nutrients are available, resulting in a higher harvest index. Kaleem *et al*. (2009) supported these findings, explaining that rise in harvest index as a result of wider row spacing and tillage operations. These results are in line with those of Basic *et al*. (2004).

Conclusion

Based on results obtained from this study, it is concluded that among tillage practices, one time Cultivator + one time Rotavator performed better in terms of wheat yield and suppressing weeds number and biomass. Considering row spacing, 30 cm row to row distance boosted yield and yield attributes in wheat crop. Tillage practice comprising of one time Cultivator + one time Rotavator and 30 cm row spacing is recommended for enhancing wheat yield in the study area.

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Novelty Statement

The study is novel for crop growers/ farmers to grow wheat with high yield by efficiently managing tillage practices and row to row spacing in fields under the agro climatic condition of Peshawar, KP-Pakistan.

Author's Contribution

Conceptualization, Methodology, Formal analysis, Writing-Original draft: Wakeel Ahmad. Data Curation and Validation: Arsalan Zahid. Supervision, Writing-Review and Editing: Shazma Anwar.

Generative AI and AI-assisted technology statement

During the preparation of this work, no generative artificial intelligence (AI) or AI-assisted technologies were used in the writing, editing, data analysis, or figure generation. All content was produced entirely by the authors.

Conflict of interest

The authors have declared no conflict of interest.

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