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Management strategies for optimizing barley yield through row spacing under variable weed competition duration

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Knowledge of crop-weed competition dynamics is necessary for implementation of cost-effective weed eradication strategy. To quantify yield loss and estimate critical competition period of weeds in barley (*Hordeum vulgare* L.) crop, two-year field study was executed at research area, Department of Agronomy, College of Agriculture, University of Sargodha, Pakistan during winter seasons (2016-17 and 2017-18). Treatments comprised of three row spacings viz., S_1 = 15 cm, S_2 = 20 cm and S_3 = 25 cm and twelve crop-weed competition periods viz., weedy until 14, 28, 42, 56, 70 days and till harvesting and weed free until 14, 28, 42, 56, 70 days and till harvesting. Data indicated significant increases in plant height (5%), number of productive tillers count m^{-2} (2%), grain count per spike (7%), 1000-grain weight (9%), biological yield (7%) and grain yield (15%) of barley in 15 cm row spacing over the other row spacings. On the other hand, significant reduction in weed dry weight (4%) was recorded in 15 cm row spacing followed by 20 cm and 25 cm row spacings. Means data of both years showed that weed free until harvest had a significant improvement in plant height (20%), productive tiller m^{-2} (13%), grains per spike (57%), 1000-grain weight (67%), biological yield (27%) and grain yield (50%) compared to weedy until harvest. The logistic model supported the field study results and suggested that critical weed free period (CWFP) and critical time for weed removal (CTWR) for barley to avoid 10% yield losses were 73-74 days and 16-18 days after crop emergence (DAE). The model also predicted that wider crop row spacing resulted an extension of 1 day in in CTWR and CWFP for getting better crop yield while maintaining higher farmers' earning. To our cognizance, we are the first who established facts regarding the weed competition period under different row spacing's in barley crop in Pakistan other scientists could avail to develop efficacious weed management plans in other areas of the country.
Keywords: Row spacing; weed competition; weed interference; grain yield; barley.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a very important cereal crop and used as feed and fodder crop usually in dry region (Ghanbari *et al*., 2012). In Pakistan, barley is grown as a grain crop and mostly cultivated on saline soils and arid region. Its average yield in the country is comparatively lower than other barley producers of world due to low soil fertility status (Govt. of Pakistan, 2012). The area and production of barley in the country is 55 thousand hectares and 55 thousand tons respectively (Govt. of Pakistan, 2019). In the world, it is cultivated for manufacturing different food products for human, poultry and animals and also used in medicine industry (FAO, 2011).

Weeds have ability to compete with crop plants for nutrients, soil moisture, light interception and space (Wright *et al*., 2001). During crop-weed competition, yield reduction depends on weeds persistence, total foliage production and population density (Blackshaw *et al*., 2002). Moreover, variations exist among competition durations and crop families like wheat-weeds competition remained usually between period of 12 and 24 days after crop emergence

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(Agostinetto *et al*., 2008). However, weed competition for longer period and at higher population density have ability to cause crop yield losses from 35 to 83% (Usman *et al*. 2001). Similarly, in wheat crop-weed competition, weeds should be eradicated within two to five weeks after emergence to get better crop harvest (Rehman *et al*., 2019). But effective weed management strategies for a specific crop are not economically possible without having sufficient knowledge of weed competition duration (Martin *et al*., 2001). Weed control at proper timing and crop growth stages facilitated the significant improvement in crop production (Knezevic *et al*., 2002). The critical timing for weed removal (CTWR provides the information to reduce the yield losses for a specific crop (Knezevic *et al*., 2002). Recently, climate changing pattern forced the scientists to remain area specific for publishing recommendations to weed control. Moreover, proper control of weeds is considered necessary having knowledge of CTWR, weed type and intensity, and crop growth stage (Rajcan and Swanton, 2001; Knezevic *et al*., 2002).

The greater the infestation the larger will be the impact of competition on barley yield. Barley production was 14 to 22% reduced due to the interference of wild oat (*Avena fatua* L.) (Scursoni and Satorre, 2005). The major weeds prevalent in barley and wheat fields in multiple cropping system of Pakistan are little seed canary grass (*Phalaris minor* Retz.), burclover (*Madicago denticulata* L.), white sweet clover (*Mellilotus alba* Medik.), wild oat (*Avena fatua* L.), rye grass (*Lolium temulentum* L.), creeping thistle (*Cirsium arvense* L.), common lambsquarters (*Chenopodium album* L.), blessed milkthistle (*Silybum marianum* L.), malcolm stock (*Malcolmia africana* L.), field bindweed (*Convolvulus arvensis* L.), catch weed bedstraw (*Galium aparine* L.), scarlet pimpernel (*Anagallis arvensis* L.) common vetch (*Vicia sativa* L.), and fumitory (*Fumaria indica* L.) (Marwat *et al*., 2006). Appropriate weed control methods, timely weed control and curtailed crop-weeds competition periods help to gain the crop yields (Khaliq *et al*., 2013). Weed growth is regulated by row spacing through which higher yield can be obtained (Marwat, 2002; Bakht *et al*., 2007). High seed rate of crop with narrower row spacing enhanced the crop production (Chauhan, 2012) while the decreased seed rate and wider row spacing hampered crop production (Bakht *et al*., 2007). Narrow row spacing is considered as a tool to control weeds (Fahad *et al*., 2014). Closely spaced plant rows can support the crop to suppress the weeds through space and shade which gives low weed strength (Khaliq *et al*., 2014). In wheat, closely spaced crop enhanced the crop yield up to 29% (Shah and Nazir, 2005). Furthermore, narrow row spacing in crop plants allows them to exploit diverse growth factors which are restricted i.e. macro and micro nutrients, light and space, more proficiently as compared to weeds (Ashraf *et al*., 2014). For concrete weed management strategy, information regarding weed threshold level and critical weed–crop competition duration is essential and supportive in making decision regarding weed control timing (Martin *et al*., 2001). Due to sudden variations in climatic conditions, area specific weed control strategy must take care of CTWR and weed species strength into consideration (Knezevic *et al*., 2002; Rajcan and Swanton, 2001).

Up till now, there is little knowledge about the CTWR and CWFP about barley crop. Moreover, little information is known about weed dynamics response to narrow as well as wider crop row spacing in barley crop. Study was therefore had been planned to estimate the CTWR and CWFP in barley crop at different crop row spacing. So that barley growers can apply cost-effective and proper weed management practices by using specific tools under agro-ecological conditions of Punjab, Pakistan.

MATERIALS AND METHODS

***Experimental site and climate*:** The current study was conducted under agro-climatological conditions of Sargodha, at the Agronomic Research Area, College of Agriculture, University of Sargodha, Pakistan during winter season 2016-17 and 2017-18. The study site (Research farm of Agronomy) is located at 32.08ºN, 72.67ºE at an altitude of 193 m. The climate is subtropical semi-arid. (Source: Agro-Metrological Lab, University of Sargodha).

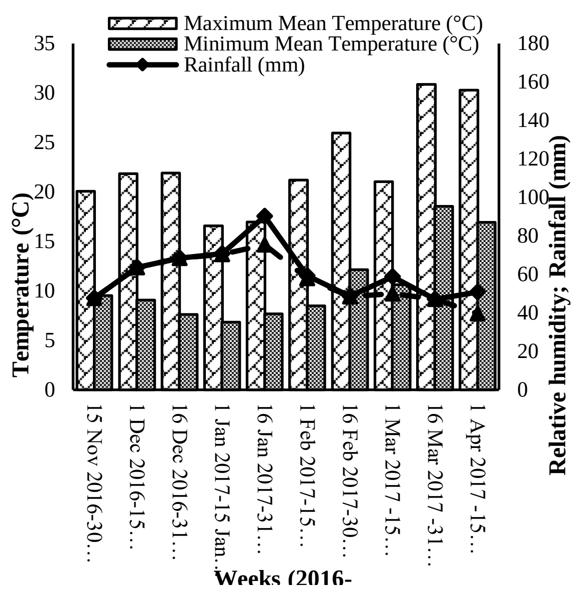

Figure 1. Meteorological data recorded at College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan during 2016-17.

The summarised weather situation prevailing during crop growth period in year 2016-17 and 2017-18 has been shown in Fig. 1 and 2. The soil of experimental site belongs to Hafizabad series that is clay loam (Khan 1986). The pre-sowing physio-chemical characteristics of the soil recorded were EC 2.19±0.3 dS m^{-1} (Conductivity bridge from 1:2:5 soil water ratio), pH 7.8±0.1 (Beckman’s Glass electrode pH meter by Jackson 1973), organic matter 0.72% (Walkyey and Black method by Piper 1966), total N 600 ppm (Modified Kjeldahl Method by Piper 1966), available P 60 ppm (Olsen's Method by Jackson, 1973) and exchangeable K 80 ppm (Flame photometric by Jackson, 1973).

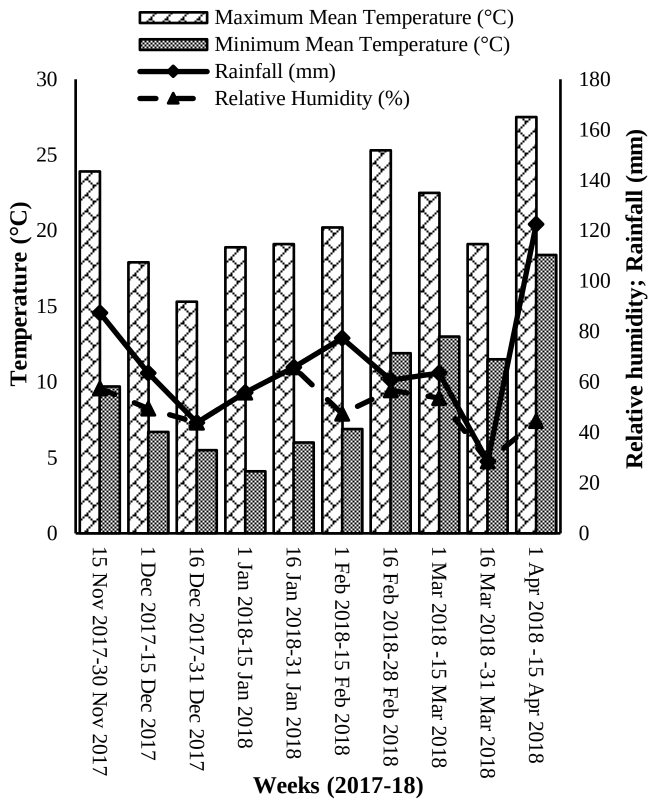

Figure 2. Meteorological data recorded at College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan during 2017-18.

***Crop husbandry and experimental design*:** The experimental units were arranged according to randomized complete block design under split plot arrangement with three replications and plot size of 7 m × 3 m with 20, 15 and 12 barley lines in respective treatment. Barley (*Hordeum vulgare* L. CV. *Rakhshan-10*) was sown on November 26, 2016 and November 26, 2017 using a hand drill with seed rate of 90 kg ha^{-1}. Recommended fertilizer rate was applied to barley crop i.e. 100:50:50 kg ha^{-1} N:P:K in the form of urea (N 46%), diammonium phosphate (N 18%, P 46%) and muriate of potash (K_2O 60%) as fertilizer sources. Recommended dose of phosphorus and potash and 1/3rd dose of nitrogen was applied at sowing time. Remaining two equal splits of nitrogen were applied at stem elongation and booting stage of barley crop. Barley experimental plots were irrigated four times; at the crown root initiation, stem elongation, heading, and at grain-filling stages. Experimental treatments included crop row spacing in main plots viz., S_1=15 cm, S_2=20 cm, S_3=25 cm and weed competition duration in sub plots viz., weedy until days after sowing and weed free up to 14, 28, 42, 56, 70 DAS and till harvesting. The crop was harvested at full maturity on 15th of April during both years. All weeds were naturally grown and removed according to treatment.

***Data collection*:** To take data of weed dry weight, a quadrat of 1 m^2 was placed at two different places which were randomly selected in each plot at different time durations. All weeds were cut manually, dried under shade and then oven-dried, thereafter their average was worked out. At maturity, height of plants was measured by using meter rod. Number of fertile tillers was counted in four adjacent lines to one m length. Grains per spike were counted when head reached near maturity and then their average was calculated. From each experimental unit, a sub-sample of 1000 grains of barley was taken and weighed by an analytical balance (Model Number: HC2204). After oven-drying at 70°C for the period of 24 hours, until a constant weight was obtained. At physiological maturity, barley crop was harvested from each experimental unit, tied up in bundles and tagged accordingly. To determine biological yield of each experimental unit, these bundles were weighed by using bench scale (Model Number: TCS-602). All bundles were threshed separately and grain yield was taken and converted into Mg (mega gram) ha^{-1}.

***Statistical analysis*:** The data regarding all the variables were statistically analyzed by Fisher's analysis of variance technique, and the variation among the treatment averages was compared using HSD at 5% probability (Steel *et al*., 1997). For analysis of two-years data (2016-17 and 2017-18), MSTAT-C statistical package (Freed *et al*., 1991) was used. As the differences among means of two years for all parameters were found to be non-significant, the data of both years were pooled and means are shown in table for plant spacing and weed competition duration in weedy and weed free treatments. Weed free plots were maintained through manual weeding. To measure the effect of weed free and weedy periods on relative grain yield of barley, a three-parameter logistic equation was used. By the repetitious use of the NLIN procedure in SAS (SAS Institute, 2008), in line with the Knezevic *et al*. (2002), parameters of nonlinear regression were as follows:

$$Y = ((1 / (EXP(K * (T - x)) + F)) + ((F - 1) / F)) * 100$$

where Y is the relative barley grain yield (percent season-long weedy and weed-free control) and T is time in days after emergence (DAE), while K and F are constants, and X is the point of inflection (DAE) (Knezevic *et al*., 2002).

RESULTS

Averages across years showed that crop row spacing as well as weed competition duration both affected ($P<0.05$) weed dry biomass (Table 1). A 4% increase in weed dry weight occurred by increasing crop row spacing from 15 to 25 cm. The maximum weed dry biomass in the broader row spacing might be attributed to availability of greater space and less inference of weed with crop plants resulting in vigorous weed growth. Among weed competition treatments, highest dry weight of weeds (62.3 g m^{-2}) was observed in weedy until harvesting (D_6) while minimum (6.61 g m^{-2}) weed biomass was recorded in weed free until 70 DAS (D_{11}) and 56 DAS (D_{10}) compared to other treatments.

Weed competition duration and crop row spacing affected ($P<0.05$) barely plant height (Table 2). Two years' means

Table 1. Influence of plant spacing on weed dry weight of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Weed dry weight (m^{-2}) (2016-17)				Weed dry weight (m^{-2}) (2017-18)				Weed dry weight (m^{-2}) combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	6	7	10	9 J	8	9	10	10 J	7	8	10	8 I
D_2 = (28WD)	9	11	13	11 I	11	13	14	13 I	10	12	13	11 H
D_3 = (42WD)	16	17	17	17 G	17	17	19	18 G	16	17	18	17 F
D_4 = (56WD)	18	19	20	20 F	18	20	22	22 F	18	19	21	19 F
D_5 = (70WD)	57	58	60	59 B	60	58	60	60 B	58	58	60	59 B
D_6 = (HarWD)	60	62	64	62 A	63	62	64	64 A	61	62	64	62 A
Weed free until days after sowing												
D_7 = (14WF)	40	42	42	41 C	43	42	44	44 C	41	42	43	42 C
D_8 = (28WF)	31	33	33	33 D	34	33	35	35 D	32	33	34	33 D
D_9 = (42WF)	33	24	23	26 E	33	24	25	28 E	33	24	24	27 E
D_{10} = (56WF)	12	14	14	14 H	14	15	16	15 H	13	14	15	14 G
D_{11} = (70WF)	5	7	8	7 J	5	7	9	7 J	5	7	8	7 I
D_{12} = (HarWF)	0	0	0	0 K	0	0	0	0 K	0	0	0	0 J
Means	24 B	25 A	25 A		24 C	25 B	26 A		25 B	25 B	26 A	
HSD values	Plant spacing (S) = 0.801, Weed competition (D) = 2.29 & S×D=2.783				Plant spacing (S) = 0.803, Weed competition (D) = 2.27 & S×D=2.781				Plant spacing (S) = 0.804, Weed competition (D) = 2.32 & S×D=2.785			

Means separated by letter in each column are not significantly different among weed competition duration at P ≤ 0.05.
Means separated by in each rows are not significantly different among plant spacing at P ≤ 0.05.

Table 2. Influence of plant spacing on plant height (cm) of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Plant height (cm) (2016-17)				Plant height (cm) (2017-18)				Plant height (cm) combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	107	104	103	105 C	109	106	104	106 C	108	105	104	106 C
D_2 = (28WD)	106	103	101	103 D	108	103	103	105 D	107	103	102	104 D
D_3 = (42WD)	101	96	94	97 G	102	98	96	98 G	101	97	95	97 G
D_4 = (56WD)	95	93	90	93 I	97	93	90	93 I	96	93	90	93 I
D_5 = (70WD)	93	90	87	90 J	95	92	89	92 J	94	91	88	91 J
D_6 = (HarWD)	88	87	82	86 L	90	89	84	87 L	89	88	83	86 L
Weed free until days after sowing												
D_7 = (14WF)	91	86	85	87 K	94	88	85	89 K	92	87	85	88 K
D_8 = (28WF)	97	93	92	94 H	99	95	91	95 H	98	94	92	95 H
D_9 = (42WF)	103	100	98	100 F	105	102	98	102 F	104	101	98	101 F
D_{10} = (56WF)	105	100	100	102 E	107	100	100	102 E	106	100	100	102 E
D_{11} = (70WF)	108	104	104	105 B	110	108	104	107 B	109	107	104	108 B
D_{12} = (HarWF)	109	107	105	108 A	111	109	108	109 A	110	108	107	108 A
Means	100 A	97 B	95 C		102 A	99 B	96 C		101 A	98 B	96 C	
HSD values	Plant spacing (S) = 0.561, Weed competition (D)=0.105 & S×D=0.233				Plant spacing (S) = 0.563, Weed competition (D)=0.104 & S×D=0.232				Plant spacing (S) = 0.566, Weed competition (D)= 0.107 & S×D=0.235			

Means separated by letter in each column are not significantly different among weed competition duration at P ≤ 0.05. Means separated by in each rows are not significantly different among plant spacing at P ≤ 0.05.

showed that barley plant height reduced by 3% and 5% by increasing crop spacing from 15 cm to 25 cm, respectively. The maximum plant height (101 cm) of barley (*Hordeum vulgare* L.) was observed in the narrowest (15 cm) crop spacing which might be attributed to very little space left for weeds resulting in poor weed competition with crop, resulting in better availability of water and nutrients thus enhancing crop growth. Among the weed competition duration treatments, the tallest plants (108 cm) of barley were observed in plots kept weed free until harvest (D_{12}) which were followed by those kept weed free up to 70 DAS (D_{11}). Smallest plant height (86 cm) was recorded in weedy until harvest (D_6) treatment.

Crop yield is directly influenced by productive tillers count m^{-2} at harvesting time which is influenced by crop-weed competition at early growth period, available resources and

Table 3. Influence of plant spacing on number of productive tillers (m^{-2}) of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Number of productive tillers m^{-2} (2016-17)				Number of productive tillers m^{-2} (2017-18)				Number of productive tillers m^{-2} combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	269	267	265	267 C	271	269	267	269 C	270	268	266	268 C
D_2 = (28WD)	269	264	262	265 D	269	266	264	266 D	269	265	263	265 D
D_3 = (42WD)	262	258	254	258 G	266	260	258	261 F	264	259	256	259 G
D_4 = (56WD)	251	246	245	247 I	253	250	247	250 H	252	248	246	248 I
D_5 = (70WD)	247	242	239	243 J	251	244	241	245 I	249	243	240	244 J
D_6 = (HarWD)	238	233	235	235 L	240	236	237	238 K	239	235	236	236 L
Weed free until days after sowing												
D_7 = (14WF)	239	237	234	237 K	241	239	238	239 J	240	238	236	238 K
D_8 = (28WF)	259	253	247	253 H	263	255	251	256 G	261	254	249	254 H
D_9 = (42WF)	265	259	259	261 F	267	263	261	264 E	266	261	260	262 F
D_{10} = (56WF)	265	263	261	263 E	269	265	263	266 D	267	264	262	264 E
D_{11} = (70WF)	271	269	268	269 B	273	272	270	272 B	272	271	269	270 B
D_{12} = (HarWF)	274	270	268	271 A	276	272	272	273 A	275	271	270	272 A
Means	259 A	255 B	253 C		261 A	257 B	255 C		260 A	256 B	254 C	
HSD values	Plant spacing (S) = 0.92, Weed competition (D) = 1.43 & S×D=2.94				Plant spacing (S) = 0.93, Weed competition (D) = 1.41 & S×D=2.95				Plant spacing (S) = 0.95, Weed competition (D) = 1.45 & S×D=2.98			

Means separated by letter in each column are not significantly different among weed competition duration at $P \leq 0.05$. Means separated by in each rows are not significantly different among plant spacing at $P \leq 0.05$.

Table 4. Influence of plant spacing on grains per spike of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Grain per spike (2016-17)				Grain per spike (2017-18)				Grain per spike combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	50	47	44	47 C	52	48	50	50 C	51	48	47	48 C
D_2 = (28WD)	48	45	45	46 D	52	46	45	48 D	50	46	45	47 D
D_3 = (42WD)	37	36	35	36 G	39	37	38	38 G	38	37	36	37 G
D_4 = (56WD)	31	31	29	30 I	33	31	31	32 I	32	31	30	31 I
D_5 = (70WD)	29	27	26	27 J	29	29	28	29 J	29	28	27	28 J
D_6 = (HarWD)	21	22	25	23 L	25	22	25	24 L	23	22	25	23 L
Weed free until days after sowing												
D_7 = (14WF)	25	24	22	24 K	27	26	25	26 K	26	25	24	25 K
D_8 = (28WF)	34	33	32	33 H	36	35	33	35 H	35	34	33	34 H
D_9 = (42WF)	40	39	38	39 F	42	41	39	41 F	41	40	39	40 F
D_{10} = (56WF)	43	43	42	43 E	45	43	42	43 E	44	43	42	43 E
D_{11} = (70WF)	50	48	49	49 B	54	52	49	52 B	52	50	49	50 B
D_{12} = (HarWF)	54	50	49	51 A	56	56	53	55 A	55	53	51	53 A
Means	39 A	37 B	36 C		41 A	39 B	38 C		40 A	38 B	37 C	
HSD values	Plant spacing (S) = 0.106, Weed competition (D) = 1.079 & S×D=0.62				Plant spacing (S) = 0.107, Weed competition (D) = 1.080 & S×D=0.63				Plant spacing (S) = 0.109, Weed competition (D) = 1.081 & S×D=0.64			

Means separated by letter in each column are not significantly different among weed competition duration at $P \leq 0.05$. Means separated by in each rows are not significantly different among plant spacing at $P \leq 0.05$.

environmental conditions. Mean data of both years related to productive tillers count m^{-2} of barley (Table 3) exhibited that productive tillers count m^{-2} differed with alteration in row spacing and period of crop-weed competition ($P<0.05$). Productive tillers count m^{-2} decreased as row spacing in barley crop was increased. Hence, the highest number of productive tillers count m^{-2} (260) of barley was attained in narrow row spacing (15 cm) which was significantly reduced by widening it to 20 cm and 25 cm. In case of competition duration, the highest number of productive tillers m^{-2} (272) was attained in weed free until harvest (D_{12}) followed by weed free until 70 DAS. Similarly, the lowest number of productive tillers m^{-2} (236) was found in weedy until harvest (D_6) treatment.

Crop row spacing and competition duration affected ($P<0.05$) grains count per spike of barley (Table 4). Average across the years, a reduction in grains count per spike was resulted in

Table 5. Influence of plant spacing on 1000-grain weight (g) of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	1000 grain weight (g) 2016-17				1000 grain weight (g) 2017-18				1000 grain weight (g) combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	45	45	43	43 C	46	45	43	45 C	45	44	43	44 C
D_2 = (28WD)	38	38	37	37 E	40	38	38	38 E	39	38	37	38 E
D_3 = (42WD)	32	32	30	30 G	33	32	32	32 G	32	31	31	31 G
D_4 = (56WD)	26	27	24	26 I	27	27	26	26 I	27	26	25	26 I
D_5 = (70WD)	23	23	21	23 J	24	23	23	23 J	24	23	22	23 J
D_6 = (HarWD)	18	18	16	16 L	18	18	17	17 L	18	17	16	17 L
Weed free until days after sowing												
D_7 = (14WF)	21	21	19	20 K	21	21	20	20 K	21	20	19	20 K
D_8 = (28WF)	30	30	28	29 H	30	30	28	30 H	30	29	28	29 H
D_9 = (42WF)	36	34.6	32	34 F	36	35	34	35 F	36	35	33	35 F
D_{10} = (56WF)	42	40.2	41	41 D	42	41	42	41 D	42	41	40	41 D
D_{11} = (70WF)	47	46.7	46	46 B	49	47	47	48 B	48	47	46	47 B
D_{12} = (HarWF)	51	50	49	50 A	53	52	51	52 A	52	51	50	51 A
Means	34 A	33 B	32 C		35 A	34 B	33 C		35 A	33 B	32 C	
HSD values	Plant spacing (S) = 0.046, Weed competition (D)=0.762 & S×D=1.568				Plant spacing (S) = 0.048, Weed competition (D)=0.765 & S×D=1.571				Plant spacing (S) = 0.049, Weed competition (D) = 0.769 & S×D=1.579			

Means separated by letter in each column are not significantly different among weed competition duration at $P \leq 0.05$. Means separated by in each rows are not significantly different among plant spacing at $P \leq 0.05$.

Table 6. Influence of plant spacing on grain yield (Mg ha^{-1}) of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Grain yield (Mg ha^{-1}) (2016-17)				Grain yield (Mg ha^{-1}) (2017-18)				Grain yield (Mg ha^{-1}) combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	1.5	1.5	1.3	1.4 C	1.7	1.5	1.5	1.6 C	1.6	1.5	1.4	1.5 C
D_2 = (28WD)	1.5	1.3	1.2	1.3 D	1.5	1.5	1.4	1.5 D	1.5	1.4	1.3	1.4 D
D_3 = (42WD)	1.1	1.1	0.9	1.0 G	1.3	1.3	1.1	1.2 F	1.2	1.2	1.0	1.1 G
D_4 = (56WD)	1.0	1.0	0.9	1.0 H	1.2	1.0	0.9	1.0 J	1.1	1.0	0.9	1.0 I
D_5 = (70WD)	1.1	0.8	0.7	0.9 I	1.1	1.0	1.1	1.1 I	1.1	0.9	0.9	1.0 J
D_6 = (HarWD)	0.8	0.7	0.8	0.8 J	1.0	0.9	0.8	0.9 L	0.9	0.8	0.8	0.8 L
Weed free until days after sowing												
D_7 = (14WF)	1.0	0.9	0.7	0.9 I	1.0	1.1	0.7	1.0 K	1.0	1.0	0.8	0.9 K
D_8 = (28WF)	1.1	1.0	1.0	1.0 G	1.3	1.2	1.0	1.2 H	1.2	1.1	1.0	1.1 H
D_9 = (42WF)	1.2	1.2	1.2	1.2 F	1.4	1.2	1.0	1.2 G	1.3	1.2	1.1	1.2 F
D_{10} = (56WF)	1.4	1.2	1.1	1.2 E	1.4	1.4	1.3	1.4 E	1.4	1.3	1.2	1.3 E
D_{11} = (70WF)	1.6	1.5	1.4	1.5 B	1.8	1.7	1.4	1.6 B	1.7	1.6	1.4	1.6 B
D_{12} = (HarWF)	1.7	1.6	1.4	1.6 A	1.9	1.6	1.6	1.7 A	1.8	1.6	1.5	1.6 A
Means	1.3 A	1.2 B	1.1 C		1.4 A	1.3 B	1.2 C		1.3 A	1.2 B	1.1 C	
HSD values	Plant spacing (S) = .011, Weed competition (D) = .023 & S×D=.004				Plant spacing (S) = .012, Weed competition (D) = .022 & S×D=.004				Plant spacing (S) = .013, Weed competition (D) = .024 & S×D=.005			

Means separated by letter in each column are not significantly different among weed competition duration at $P \leq 0.05$. Means separated by in each rows are not significantly different among plant spacing at $P \leq 0.05$.

response to increase in crop row spacing. Barley gained the greatest grain count per spike (40) in narrow spacing which was 5% and 7% greater than 20 cm and 25 cm respectively. In weed competition duration treatments, the highest grain count per spike (53) were observed in weed free until harvest (D_{12}) followed by weed free up to 70 DAS (D_{11}). Minimum grains count per spike (23) was recorded in weedy until harvest (D_6).

Among yield contributing characters, final grain yield of a cereal crop depends on 1000-grain weight. Any variation in the 1000-grain weight will influence the grain yield. Average across the year, 1000-grain weight decreased (P<0.05) as the crop row spacing increased (Table 5). The higher 1000-grain weight (35 g) of barley was recorded from 15 cm row spacing in comparison to 20 cm and 25 cm. In weed competition duration, 1000-grain weight was reduced as the weeds remained in competition with crop for longer duration. Weedy until harvest reduced the 1000-grain weight by 67% from that produced under weed free until harvest.

Row spacing and competition duration imposed a significant (P<0.05) influence on the grain yield of the barley (*Hordeum vulgare* L.) (Table 6). Years' means showed that 15 cm crop row spacing attained the highest grain yield (1.3 Mg ha^{-1}) which was 8% and 15% higher than those recorded with 20 cm and 25 cm spacings, respectively. The outcomes of the present study are of greater significance in adjusting row spacing as weed management tool. Among competition duration treatments, the highest barley grain yield loss (50%) was resulted due to weed competition duration imposed through whole crop duration (D_6).

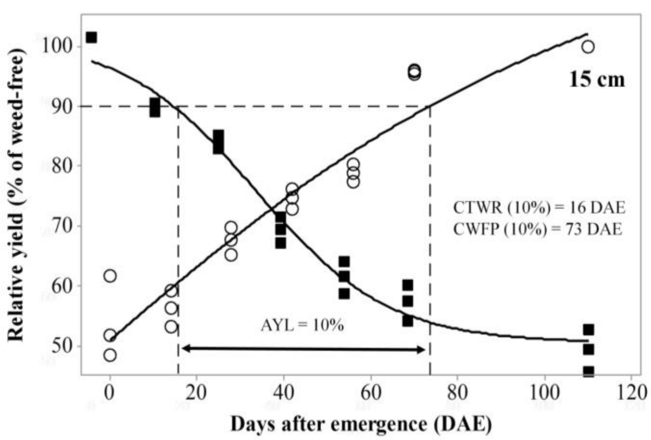

Figure 3. Logistic model showing relative grain yield of barley at different weed competition durations during at plant spacing 15 cm. The critical time for weed removal (CTWR) and critical weed free period (CWFP) to achieve 10% of acceptable yield loss (AYL) are provided. (combined over 2016-17 and 2017-18 growing seasons).

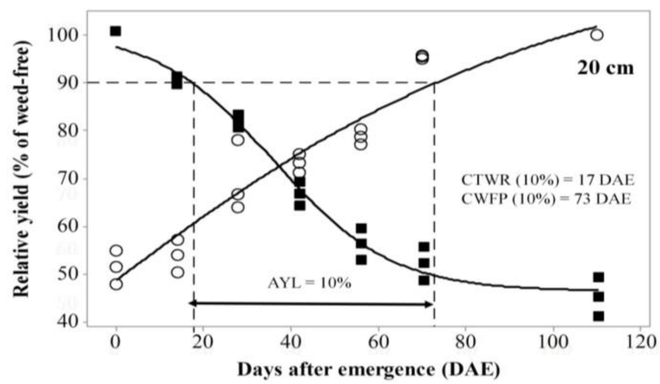

Figure 4. Logistic model showing relative grain yield of barley at different weed competition durations during at plant spacing 20 cm. The critical time for weed removal (CTWR) and critical weed free period (CWFP) to achieve 10% of acceptable yield loss (AYL) are provided. (combined over 2016-17 and 2017-18 growing seasons).

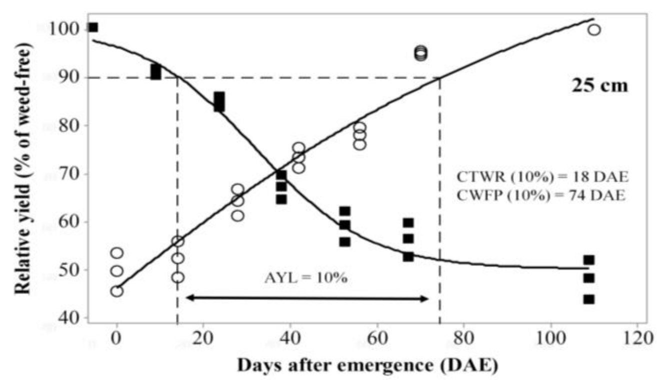

Figure 5. Logistic model showing relative grain yield of barley at different weed competition durations during at plant spacing 25 cm. The critical time for weed removal (CTWR) and critical weed free period (CWFP) to achieve 10% of acceptable yield loss (AYL) are provided. (combined over 2016-17 and 2017-18 growing seasons).

The logistic model indicated that barley's relative grain yield tended to fit the best pertaining to all types of weed competition periods on averages of both years (Fig. 3 to 5), which proved significant effect of weedy and weed free periods on barley's grain yield. Tables 7 and 8 showed coefficients for three parameters used for fitting the logistic model. The model illustrated the critical time for weed removal (CTWR) and critical weed free period (CWFP) of weeds in barley (*Hordeum vulgare* L.) to avoid 10% losses in its grain yield to be 16 and 73 DAE in 15 cm, 17 and 73 DAE in 20 cm and 18 and 74 DAE in 25 cm crop row spacing.

Table 7. Coefficients estimates used to determine the CTWR on relative barley yield using a logistic model. (combined over 2016-17 and 2017-18 growing seasons).

Spacing	Coefficients		
(cm)	K	X	F
15 cm	0.0681 (0.0066)	25.32(1.912)	2.117(0.070)
20 cm	0.0752(0.0067)	26.12(1.584)	2.097(0.059)
25 cm	0.0794 (0.0086)	27.04 (1.817)	2.065 (0.069)

[a]Data fit to equation, where x is the point of inflection (DAT), K and F are constants.

Table 8. Coefficients estimates used to determine the CWFP on relative barley yield using a logistic model. (combined over 2016-17 and 2017-18 growing seasons).

Spacing	Coefficients		
(cm)	K	B	A
15 cm	0.0140 (0.0039)	0.887(0.104)	123.5(14.76)
20 cm	0.0159 (0.0040)	0.895(0.089)	118.9(12.16)
25 cm	0.0157 (0.0035)	0.967 (0.082)	121.5 (11.51)

[a]Data fit to equation, where x is the point of inflection (DAT), K and F are constants.

Data averaged across years told that biological yield was influenced by row spacing and competition duration (Table 9). Significant ($P<0.05$) increase in biological yield showed with decrease in row spacing. Row spacing 25 cm co-existence decreased the barley yield by 7%. Among weed competition durations, weed free treatment throughout crop growing season (D_{12}) produced the maximum biological yield (6.4 Mg ha^{-1}) which was followed by weed free until 70 DAS (D_{11}) (6.3 Mg ha^{-1}). The lowest biological yield (4.7 Mg ha^{-1}) could be achieved by imposing weed competition duration across the crop growing period (D_6) compared to all other treatments.

DISCUSSION

This might be due to continuous weed eradication for most of the crop growth period that resulted in better crop growth that imposed shading effect on weeds. Our results support the observations of Rehman *et al*. (2019) who described that prolonged competition periods facilitated the weeds to flourish rapidly than crop and resulted in their maximum accumulation of dry biomass. Safdar *et al*. (2016) stated that weed dry biomass increased by increasing the crop row spacing resulting in wheat yield. Reduction in barley plant height in response to extended weed competition period might be due to more increase in severity of weed competition for nutrients, space, light and water. Significantly shorter height of barley in response to wider row spacing and long weed competition period enhanced the severity of weed stress as expressed by higher weed biomass. Our findings are similar with the observations of Chauhan (2012), who stated that plant height of rice was increased in narrow row spacing. There might be effective precipitation and lesser mean maximum and minimum temperatures in the months of January and February during growing seasons of both years that played a significant role in increasing plant height. Total

Table 9. Influence of plant spacing on biological yield (Mg ha^{-1}) of barley under different weed competition durations (combined over 2016-17 and 2017-18 growing seasons).

Weed competition (D) (DAS)	Biological yield (Mg ha^{-1}) (2016-17)				Biological yield (Mg ha^{-1}) (2017-18)				Biological yield (Mg ha^{-1}) combined over 2016-17 and 2017-18 growing seasons			
	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means	15 (cm)	20 (cm)	25 (cm)	Means
Weedy until days after sowing												
D_1 = (14WD)	6.0	6.0	6.0	6.0 C	6.6	6.4	6.0	6.3 C	6.3	6.2	6.0	6.2 C
D_2 = (28WD)	5.9	5.8	5.7	5.8 D	6.3	6.0	5.9	6.1 D	6.1	5.9	5.8	5.9 D
D_3 = (42WD)	5.6	5.3	5.2	5.4 G	5.8	5.7	5.4	5.6 F	5.7	5.5	5.3	5.5 G
D_4 = (56WD)	5.3	5.1	5.0	5.1 I	5.5	5.3	5.0	5.3 H	5.4	5.2	5.0	5.2 I
D_5 = (70WD)	5.0	5.0	4.6	4.9 J	5.8	5.0	5.0	5.3 H	5.2	5.0	4.8	5.0 J
D_6 = (HarWD)	5.2	4.5	4.6	4.8 K	5.2	4.9	4.8	5.0 I	4.8	4.7	4.7	4.7 L
Weed free until days after sowing												
D_7 = (14WF)	4.6	4.7	4.5	4.6 L	4.9	5.1	4.7	4.9 J	5.0	4.9	4.6	4.8 K
D_8 = (28WF)	5.4	5.2	5.0	5.2 H	5.8	5.6	5.2	5.5 G	5.6	5.4	5.1	5.4 H
D_9 = (42WF)	5.6	5.5	5.3	5.5 F	6.0	5.7	5.5	5.7 E	5.8	5.6	5.4	5.6 F
D_{10} = (56WF)	5.7	5.7	5.6	5.7 E	6.3	5.9	6.0	6.1 D	6.0	5.8	5.8	5.9 E
D_{11} = (70WF)	6.4	6.2	5.9	6.2 B	6.6	6.4	6.3	6.4 B	6.5	6.3	6.1	6.3 B
D_{12} = (HarWF)	6.6	6.3	6.0	6.3 A	6.8	6.5	6.4	6.6 A	6.7	6.4	6.2	6.4 A
Means	5.60 A	5.44 B	5.28 C		5.96 A	5.70 B	5.51 C		5.8 A	5.6 B	5.4 C	
HSD values	Plant spacing (S) = .018, Weed competition (D) = .036 & S×D=.074				Plant spacing (S) = .017, Weed competition (D) = .035 & S×D=.075				Plant spacing (S) = .019, Weed competition (D) = .038 & S×D=.078			

Means separated by letter in each column are not significantly different among weed competition duration at $P \leq 0.05$. Means separated by in each rows are not significantly different among plant spacing at $P \leq 0.05$.

number of productive tiller of barley were increased with reducing the weed competition duration supports the fact that prolonged weed competition deprives the crop from nutrients and water during early growth phases of crop resulting in poor tillering (Irshad, 2000). Our findings support the results of Coleman and Gill (2005) who stated that extending competition duration caused 15-20% lower productive tillers count m^{-2}. Decrease in grain count per spike due to prolonged weed competition duration might be the resultant of suppressed plant growth at initial stages that produced weak spike growth and ultimately less grain number per spike. The similar conclusions were also drawn by Khan and Hassan (2006) in wheat crop. Bajwa *et al*. (2015) concluded that wider row spacing and prolonged weed competition duration produced fewer grains per spike in oat. Consistent favorable environmental conditions (temperatures + rainfall + relative humidity) along with weed management strategy might have suited the fertilization process and spike length during both years (Fig. 1 to 5). The declining trend in 1000-grain weight with extension in competition duration might be due to increased severity in weed competition for nutrients, water, light etc. Khan *et al*. (2007) demonstrated the same results that prolong weed durations had inhibitory effect on 1000-grain weight of wheat. Suitable environmental conditions (2016-17 and 2017-18) were not improved the grain weight in those treatments where weeds interfered with barley for a longer period. Study results substantiate the findings of Kumar and Sundari (2002) who noted a linear drop in grain yield of maize by extending weed competition duration and payable to reduction in yield contributing traits. Rehman *et al*. (2019) also reported that weed control should be applied at early growth periods to avoid drastic reduction in grain yield of maize. Similarly, Chauhan and Johnson (2011) recorded that by decreasing crop row spacing and competition duration in rice, its grain yield was enhanced. Rehman *et al*. (2019) studied CTWR on blessed milkthistle (*Silybum marianum* L.) in wheat and Safdar *et al*. (2016) studied CTWR on ragweed parthenium (*Parthenium hysterophorus* L.) in autumn-sown maize by using logistic models. They concluded that CTWR enabled us to estimate the exact yield losses at exact growth stage of the crops. Our results are in line to the observations of Rehman *et al*. (2019), who documented that increase in weed competition duration had substantial yield reduction. Favorable meteorological conditions (Figure 1 and 2) and effective rainfall dropped the mean maximum temperature at early stages of crop, which resulted in better crop growth and development.

Conclusion: The consolidated means results of both years' research data showed that narrow row spacing of barley (*Hordeum vulgare* L.) crop restricted the horizontal and vertical growth of weeds and improved its grain yield by 15%. While competition duration of weeds could reduce its grain yield up to 50%. The logistic model at different plant spacings (15, 20 and 25 cm) prescribed a period of 16 to 18 DAE to be the CTWR and 73 to 74 DAE to be the CWFP of weeds in barley to avoid 10% losses in grain yield of barley showing that barley producers should keep the crop free from weeds during this period.

***Conflict of Interest*:** The Authors declare that there is no conflict of interest

***Authors' Contribution Statements*:** MES and MAA executed the field research, MES, RQ, MAN, TA, MN and MSH data curation and formal analysis, RM logistic model analysis, whereas MES, RQ and HHA conceived the idea and supervised the work.

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REFERENCES

Agostinetto, D., R. P. Rigoli, C. E. Schaedler, S. P. Tironi and L. S. Santos. 2008. Critical period for weed competition with wheat. Planta Daninha. 26:271-278.

Ashraf, U., S. A. Anjum, I. Khan and M. Tanveer. 2014. Planting geometry-induced alteration in weed infestation, growth and yield of puddled rice. Pakistan Journal of Weed Science Research. 20:77-89.

Bajwa, A. A., G. Mahajan and B. S. Chauhan. 2015. Nonconventional weed management strategies for modern agriculture. Weed Science. 63:723-747.

Bakht, J., Z. Qamer, M. Shafi, H. Akber, N. Ahmad and M. J. Khan. 2007. Response of different wheat varieties to various row spacing. Sarhad Journal of Agriculture. 23:839-846.

Blackshaw, R. E., D. Lemerle, R. Mailer and K. R. Young. 2002. Influence of wild radish on yield and quality of canola. Weed Science. 50:344-349.

Chauhan, B. S. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technology. 26:1-13.

Chauhan, B. S. and D. E. Johnson. 2011. Row spacing and weed control timing affect yield of aerobic rice. Field Crops Research. 121:226-231.

Coleman, R. and G. Gill. 2005. Trends in yielding ability and weed competitiveness of Australian wheat cultivars. Proceedings of the Australian Agronomy Conference, Australian Society of Agronomy.

Fahad, S., S. Hussain, S. Saud, S. Hassan, H. Muhammad, D. Shan and A. Jan. 2014. Consequences of narrow crop row spacing and delayed *Echinochloa colona* and *Trianthema portulacastrum* emergence for weed growth and crop yield loss in maize. Weed Research. 54:475-483.

FAO. 2011. Production Year Book. Food and Agriculture Organization of the United Nations, Rome. No. 57.

Freed, R., S. P. Eisensmith, S. Goetz, D. Reicosky, V. W. Smail and P. Wolberg. 1991. Users Guide to MSTAT-C: a software program for the design, management, and analysis of agronomic research experiments. Michigan State University, East Lansing, MI.

Ghanbari, A., M. Babaeian, Y. Esmaeilian, A. Tavassoli and A. Asgharzade. 2012. The effect of cattle manure and chemical fertilizer on yield and yield component of barley (*Hordeum vulgare*). African Journal of Agricultural Research. 7:504-508.

Govt. of Pakistan. 2012. Pakistan Economic Survey 2011-12. Finance Division, Economic Advisor's Wing, Islamabad, pp.12.

Govt. of Pakistan. 2019. Pakistan Economic Survey 2018-19. Economic Adviser's Wing, Finance Division, Islamabad, pp.19.

Irshad, A. 2000. Interference of barnyard grass (*Echinochola crus–galli*) and strategy of its control in fine rice (*Oryza sativa* L.). Ph.D. Thesis. Dept. Agron. Univ. of Agric. Faisalabad, Pakistan.

Jackson, M. L. 1973. Soil Chemical Analysis. Prentice Hall of India. Pvt. Ltd. New Delhi. p. 498.

Khaliq, A., A. Matloob and B. S. Chauhan. 2014. Weed management in dry-seeded fine rice under varying row spacing in the rice-wheat system of Punjab, Pakistan. Plant Production Science. 17:321-332.

Khaliq, A., A. Matloob, M. Z. Ihsan, N. A. Rana, Z. Aslam and F. Rasool. 2013. Supplementing herbicides with manual weeding improves weed control efficiency, growth and yield of direct seeded rice. International Journal Agriculture and Biology. 15:191-199.

Khan, G. S. 1986. Need for international crosschecking and correlation in soil analysis for international classification systems in: proceedings of the twelfth international forum on soil taxonomy and agro-technology transfer: soil survey of Pakistan, volume 1, soil survey of Pakistan, Lahore. 276-293 p.

Khan, I. J., G. Hassan, Ihsaullah and I. A. Khatak. 2007. Effect of wild oats (*Avena fatua* L.) densities and proportions on yield and yield components of wheat. Journal of Agricultural and Biological Sciences. 2:26-31.

Khan, I. A. and G. Hassan. 2006. Effect of wild oats (*Avena fatua*) densities and proportions on yield and yield components of wheat. Pakistan Journal of Weed Science Research. 12:67-77.

Knezevic, S. Z., S. P. Evans, E. E. Blankenship, R. C. Van Acker and J. L. Lindquist. 2002. Critical period for weed control: the concept and data analysis. Weed Science. 50:773-786.

Kumar, S. M. S. and A. Sundari. 2002. Studies on the effect of major nutrients and crop-weed competition period in maize. Indian Journal of Weed Science. 34:309-310.

Martin, S. G., R. C. Van Acker and L. F. Friesen. 2001. Critical period of weed control in spring canola. Weed Science. 49:326-333.

Marwat, I. M. 2002. Effect of weed management practices on different traits of wheat. On Line Journal Biological Science. 2:719-721.

Marwat, K. B., H. Zahid, G. Bakhtiar and S. Muhammad. 2006. Survey on weed problems in wheat crop in district Mardan. Pakistan Journal of Weed Science Research. 12:353-358.

Mekki, B. B., F. A. A. Sharara and K. G. El-Rokiek. 2010. Effect of weed control treatments on yield and seed quality of some canola cultivars and associated weeds in newly reclaimed sandy soils. Ammerican Eurasian Journal Agriculture and Environmental Science. 7:202-209.

Piper, C.S. 1966. Soil and plant analysis. Hans Publisher, Bombay.

Rehman, A., R. Qamar, M. E. Safdar, A-ur. Rehman, H. M. R. Javeed, M. Shoaib, R. Maqbool and T. Abbas. 2019. Influence of competitive duration of blessed milkthistle with wheat. Weed Technology. 33:280-286.

Rajcan, I. and C. J. Swanton. 2001. Understanding maize–weed competition: resource competition, light quality and the whole plant. Field Crops Research. 71:139-150.

Safdar, M. E., A. Tanveer, A. Khaliq and R. Maqbool. 2016. Critical competition period of parthenium weed (*Parthenium hysterophorus* L.) in maize. Crop Protection. 80:101-107.

SAS Institute. 2008. SAS/STAT 9.1 User's Guide the Reg Procedure: (Book Excerpt). SAS Institute.

Steel, R. G. D., J. H. Torrie and D. A. Dicky. 1997. Principles and Procedures of Statistics a biometrical approach. Third edition. McGraw-Hill Publishing Company, New York, USA. Pp 178-198.

Scursoni, J. A. and E. H. Satorre. 2005. Barley (*Hordeum vulgare*) and wild oat (*Avena fatua*) competition is affected by crop and weed density. Weed Technology. 19:790-795.

Shah, N. H. and A. Nazir. 2005. Effect of different methods of weed control on the yield and yield components of wheat. Pakistan Journal of Weed Science Research. 11:97-101.

Usman, A., K. A. Elemo, A. Bala and A. Umar. 2001. Effect of weed interference and nitrogen on yields of a maize/rice intercrop. International Journal of Pest Management. 47:241-246.

Wright, A., S. Egan, J. Westrup and A. Grodecki. 2001. Weed management for successful plant establishment. Produced by community education and extension support. NRM facts, vegetation series V. 48. Department of natural resources and mines, The State of Queensland.