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Effects of Irrigation Regimes and Duration of Weed Interference on Grain Yield of Wheat (*Triticum aestivum* L.) in Middle Egypt

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TWO EXPERIMENTS were performed at Farm of Faculty of Agriculture, El-Minia University Egypt, during two consecutive winter seasons 2017-2018 and 2018-2019 to evaluate the impact of weed removal period and different irrigation regimes on weeds, critical period of weed competition and yield and its components on wheat crop. A strip-plot design with three replications was used. Four irrigation regimes were in the horizontal plots and eight treatments of weed competition (4 weed-free periods and 4 weed competition periods) were in vertical plots. Results showed that omitting two irrigation (IR_4) significantly decreased total density and dry weight of weeds, wheat traits, i.e. plant height, spike length, number of grains spike^{-1}, 1000-grain weight, number of spikes m^{-2}, grain yield and grain ability. Weed infestation for whole season significantly decreased all studied traits compared with weed removal even once after wheat sowing (DAS). Maximum yield losses of wheat due to weed infestation in whole season were 28.52 and 28.17% compared with weed-free treatment in the 1st and 2nd seasons, respectively. Cubic model was the best model for weed-free and weed competition over all treatments of the two seasons. The critical periods for weed control were 28 to 52 and 28 to 67 DAS in the two seasons, respectively.

Keywords: Critical period of weed control, Irrigation regimes, Weed infestation, Wheat.

Introduction

Wheat (*Triticum aestivum* L.) is considered the leading cereal of the world. In Egypt, the total cultivated area of wheat reached 1.314 million ha and the final production exceeded 8.8 million tons with an average of 6.7ton ha^{-1} (FAOSTAT, 2018). Agricultural land is limited in the world (World Bank Group, 2015), whereas, in the 2050 year, the global demand for food crops is expected to increase (Tilman et al., 2011). Currently, wheat production is not enough for local consumption as a result of the steady increase in the population of Egypt. For this reasons, efforts should be done toward enhancing the wheat yield, to fill this gap. Egyptian researchers focused on developing agricultural processes i.e. land preparation for cultivation, water management, weed control and other good practices.

Water management is one of the biggest challenges facing Egyptian agriculture, as it is the limited resource for crops. In Egypt, the agricultural sector consumes more than 84% of the available water resources (El-Beltagy & Abo-Hadeed, 2008). So, the country as experiencing, severe water scarcity because of recent population growth and climate change. Many investigators indicated that water deficit at any developmental stage tended to significant reductions in wheat yield and its components. Such yield reduction will be larger if water deficit occurred during the heading and ripening stages (Elhag, 2017; Seleiman & Abdel-Aal, 2018). Irrigation plays an

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essential role in terms of occurring good growth and development of wheat. Proper irrigation water of wheat is necessary as a requirement of the crop, since its productivity is directly related to the assured supply of irrigation, and the deficiency of irrigation causes the yield loss. Using irrigation at critical growth periods lead to increase grain yield of wheat (Wajid et al., 2002). In the water scarcity, it is recommended that water must be applied to a sensitive growth phase which can result in maximum grain yield and the number of grains (Leghari et al., 2017). Weeds competition for irrigation water reduced water availability, and led to crop water stress (Zimdahl, 2013). Moreover, weeds directly compete with crops for water leading to less water available for crops, where weeds are potentially responsible for 34 % of crop loss worldwide and cause water loss by seepage through root channels, transpire water, and cut water flow in irrigation ditches, leading to higher consumption by weeds and more evaporative water loss (Oerke, 2006; Zimdahl, 2013). Therefore, proper weed control raises available soil water to produce the more yield of each fed^{-1}. Abouziena et al. (2014) found that the consumptive use of water for weed (*Chenopodium album*) was estimated by 550mm against 479mm for the wheat crop. Many researchers demonstrated that the importance of irrigation treatment to maximize wheat productivity. In respect, Kassab et al. (2019) showed that irrigation of wheat plants at 35 days from sowing, led to a significant increase of yield, yield attributes, and maximization the of water productivity.

In wheat, weeds alone are one of the major constraints in the crop as they reduce productivity losses depending upon weed species, severity, and duration of weed infestation (Jat et al., 2003; Abbas et al., 2009). The critical period is defined as the period during which weeds must be controlled to prevent yield losses. Since the concept of the critical period was introduced, it has been used to determine the period during which control operation should be carried out to minimize wheat yield losses (Zimdahl, 1988). The critical period for weed control is a period in the crop growth cycle during which weeds must be controlled to prevent unacceptable yield losses (Knezevic, 2000). Controlling weeds based on the critical period of weed control (CPWC) is an integral part of the integrated weed management (IWM) system and can be considered the first step to design weed control strategy (Ramirez, 2002). The CPWC has got a beginning and an end as well. The beginning of CPWC is determined by estimating critical time for weed removal (CTWR) after which weed control must be initiated to ensure potential yield (Anwar et al., 2012). The end of CPWC, on the other hand, is determined by estimating a critical weed-free period (CWFP) required from planting to avoid irrevocable yield loss (Evans et al., 2003). Recently, weed control programs have often focused on nonchemical weed control method, i.e., safety methods, or eco-friendly. Hand weeding or hoeing is safe and very effective against annual and biennial weeds as well as the most effective means of weed control. Therefore, CPWC has been the subject of extensive research in field crops for the last few decades (Dillehay et al., 2011). The fewer yield losses happen if weeds were manually controlled at early stages (Ali et al., 2014; Riya et al., 2017). The critical period of crop weed competition in wheat between 30-60 days after sowing and crop should be kept weed-free during this period (Khan et al., 2017). Generally, the first stages of growing wheat yield, ranging from 4-10 weeks, are very effective in determining the yield ability of the wheat crop to the accompanying weeds (Hammood & Safi, 2018). Plant height, biomass, and yield significantly decreased with each increase in competition (Ka et al., 2020).

The objective of this work is to study the influences of weed removal period and the different number of irrigations on weeds, the critical period for weed control (CPWC), and yield of wheat crop under conditions of middle Egypt.

Materials and Methods

Experimental site and duration

The experiment was carried out at the Experimental Farm of Faculty of Agriculture, El-Minia University during 2017-18 and 2018-19 winter seasons to estimate the effects of weed removal period and irrigations number on weeds, the critical period of weed/wheat competition and yield of wheat (cv. Giza 168). Physical and chemical analysis of the soil of the experimental sites indicated that the soil was clay loam and containing organic matter (1.51%), total N (0.09%), and pH 8.05.

Experimental design and treatments

A strip-plot design with three replications was used. Each replicate included= 4 irrigations regimes arranged in the horizontal plots × 8 periods for weed control placed in vertical plots as follows:

1) Horizontal treatments (Irrigation regimes)

1. IR_1: Full irrigation= Five irrigations at tillering, stem elongation, booting, heading, and ripening stages.
2. IR_2: Four irrigations at tillering, stem elongation, booting, and heading stages.
3. IR_3: Three irrigation at tillering, stem elongation, and booting stages.
4. IR_4: Two irrigation at tillering and stem elongation stages.

2) Vertical treatments (4 weed-competition and 4 weed-free)

1- W_1: Weed-free for the whole season.
2- W_2: Weed-free up to 25 days after sowing [DAS].
3- W_3: Weed-free up to 50 DAS.
4- W_4: Weed-free up to 75 DAS.
5- W_5: Weed competition for the whole season.
6- W_6: Weed competition up to 25 DAS.
7- W_7: Weed competition up to 50 DAS.
8- W_8: Weed competition up to 75 DAS.

Agricultural practices

All plots were sown on 20th November in both seasons, with a seeding rate of 60kg fed^{-1} and the drilling method was used on the rows at 20cm apart on flat land. The sub-plot area was 10.5m^2 (3.5m length and 3m width) and consisted of 15 rows. Calcium superphosphate (15.5% P_2O_2) was added during seedbed preparation at the rate of 150kg P_2O_2 fed^{-1}, nitrogen fertilizer at the rate of 70kg N fed^{-1} in the form of urea (46.5% N) in three portions, 20% with seed sowing, 40% before the 1st irrigation and 40% before the 2nd irrigation. The other recommended agricultural practices of growing wheat in the region were done. No chemical method was used for weed control where accomplished by hand pulling. The preceding summer crop was soybean in both seasons.

Data for all traits recorded from each sub-plot as follows:

Weeds sampling

Different weeds were removed from the experimental site at four periods, i.e. 20, 40, 60 and 80 DAS by hand-pulling from one square meter of each sub-plot for collecting weed samples, then identified and counted by species and classified to annual broad and grassy weeds to determine the dry weight of grassy, broad-leaved and total annual weeds. Weeds were air-dried for 3 days and dried in the oven at 70°C for 24hrs. The dry weight of weeds for each group (g m^{-2}) was recorded.

Phenological traits

The following phonological, development stages were recorded :

1- The days from sowing to heading: This trait was recorded as from sowing till 50% of spikes emerge completely from the flag sheath.
2- The days from sowing to maturity: It was recorded as from sowing till 50% of peduncles turned yellow.

Yield and yield components

At harvest time, ten plants were chosen randomly taken from each sub-plot to study the yield characters, i.e. plant height (cm), spike length (cm), number of grains spike^{-1}, 1000-grain weight (g) and number of spikes m^{-2}. Grain yield fed^{-1} was calculated by harvesting plants of all plot area (10.5m^2) and weighing the resulting grain. Also, grains ability (kg day^{-1}) and relative yield losses (%) were calculated as follows :

The maximum wheat yield loss due to weed competition was calculated as :

Grain ability (kg day^{-1})= Grain yield (kg fed^{-1}) / Number of days sowing to maturity (Seleiman & Abdel-Aal, 2018).

The maximum wheat yield loss due to weed competition was calculated as:

Relative yield loss (%)= (Yield of weed free plot- Yield of treated plot)/ (Yield of weed free plot) ×100 (Aref et al., 2013)

Estimation of the critical period of wheat-weeds competition

The onset and the end of the critical period within which weed control is mandatory were estimated by the response curves of relative yield compared to all seasons weed-free. The critical period of weed control was computed by fitting the best equation according to the following equations:-

* Linear model is estimated using the formula: $Y = a + b x$

where : Y = Is the grain yield fed^{-1} in kg.
a: Is the Y intercept.
b: Is the linear coefficient of regression.
x: Is the duration of the applied weed-free or weed-Competition period.

* Quadratic polynomial model is computed using the formula: $Y = a + bx + cx^2$

where : Y = Is the grain yield fed^{-1} in kg.
a: Is the Y intercept.
b: Is the linear coefficient of regression.
c: Is the quadratic coefficient of regression.
x: Is the duration of the applied weed-free or weed-competition period.

* Cubic polynomial model is computed using the formula: $Y = a + bx + cx^2+dx^3$

where: Y = is the grain yield fed^{-1} in kg.
a: Is the Y intercept.
b: Is the linear coefficient of regression.
c: Is the quadratic coefficient of regression.
d: Is the cubic coefficient of regression.
x: Is the duration of the applied weed-free or weed-competition period.

Data analyses

Data were subjected to technique analysis of variance (ANOVA) for the strip-plot design as mentioned by Gomez & Gomez (1984) by mean of "MSTAT-C" and (SPSS Ver. 20) computer software package and Least Significant Differences (LSD) at 5% level of probability was calculated for comparison among treatments means. Data were analyzed statistically by Center Laboratory for Design and Statistical Analysis Research, Agriculture Research Center, Giza, Egypt.

Results

Effect of irrigation periods

Weed density and total dry weight of annual weeds

Medium natural weed populations were observed at the trial sites in both seasons. The weed density of the unweeded control plots was 74.4 plant m^{-2}, 95.7g m^{-2} for dry weight weeds, average in two seasons (Table 1). The major weed species associated with a wheat crop at the experimental plots, through 2017-18 and 2018-19 seasons were wild oat *(Avena* spp.) and lesser canary grass (*Phalaris* spp*.)* as annual grassy weeds, lambsquarters *(Chenopodium* sp.), sowthistle (*Sonchus oleraceus* L.), bur clover *(Medicago polymorpha* L.)*,* annual yellow sweet clover *(Melilotus indica* L.), great ammi *(Ammi majus* L.), spiny Emex (*Emex spinosus* L.)*,* and dock *(Rumex dentatus* L.) as annual broad-leaved weeds.

The density and dry weight of weeds (g m^{-2}) at different irrigation regimes have given in (Table 1). Significantly the lowest density and dry weight of weeds were recorded with the application of irrigation at IR_4 than IR_3, IR_2, and IR_1, in both seasons. While the highest one was recorded by adding five irrigations (IR_1).

Yield and yield attributes

Available data in (Table 2) indicated that irrigation regimes had a significant influence on all studied traits in the 1st and 2nd seasons. The highest mean value of such traits understudy was obtained from supplying plants with sufficient water amount as 5 irrigations (control, IR_1) at tillering, stem elongation, booting, heading and ripening stages followed by that of omitting the 5th irrigation (IR_2), omitting the 4th and 5th irrigations (IR_3) and then by omitting 3rd, 4th and 5th irrigations in both seasons.

Wheat traits, such as the number of the days from sowing to heading and maturity (days from sowing), plant height (cm), spike length (cm), number of grains $spike^{-1}$, 1000-seed weight (g), number of spikes m^{-2}, grain yield (ton fed^{-1}) and grain ability (kg fed^{-1}) were increased significantly by (6.96 and 6.36%), (4.96 and 5.76%), (13.21 and 12.95%), (16.79 and 16.40%), (24.02 and 27.30%), (13.78 and 12.75%), (17.74 and 16.42%), (141.36 and 161.62%) and (129.97 and 147.34%), respectively by applying full irrigation treatment (IR_1) as compared with (IR_4) in both seasons. Based upon the effect of irrigation regimes could be arranged in the following descending order IR_4 followed by IR_3, IR_2, and IR_1.

TABLE 1. Effect of weed infestation treatments on total weed density, dry weight of weeds, yield and its components in 2017-18 and 2018-19 seasons

Weed removal or competition periods	Total density of weeds (m^{-2})	Dry weight of Weeds (g m^{-2})	Days from sowing to heading	Days from sowing to maturity	Plant height (cm)	Spike length (cm)	No. of grains spike^{-1}	1000-seed weight (g)	No. of spikes m^{-2}	Grain yield (ton fed^{-1})	Relative yield loss (%)	Grain ability (kg day^{-1})
(Season 2017-18)												
W_1	0.00	0.00	94.82	147.74	101.41	14.23	51.05	39.34	385.97	2.707	0.0	18.23
W_2	25.27	37.54	90.54	140.92	91.71	11.48	44.09	35.84	306.59	2.274	16.00	16.06
W_3	19.02	30.37	92.03	144.83	94.51	12.23	46.23	37.14	327.41	2.439	9.90	16.75
W_4	14.86	26.17	93.30	146.03	98.84	12.95	47.89	38.30	356.35	2.618	3.29	17.85
W_5	74.73	90.52	88.77	136.88	83.55	10.34	40.74	35.82	278.57	1.935	28.52	14.07
W_6	30.58	42.62	92.24	144.11	92.59	12.24	43.58	37.33	331.48	2.592	4.25	17.87
W_7	53.65	66.6	90.44	143.52	87.70	11.60	43.04	36.46	313.46	2.448	9.57	16.99
W_8	59.79	72.61	89.28	139.46	84.58	10.82	41.72	35.38	285.91	2.253	16.77	16.09
$LSD_{0.05}$	**0.52**	**1.61**	**0.21**	**0.48**	**0.96**	**0.09**	**0.05**	**0.35**	**0.92**	**0.05**	**1.9**	**0.29**
(Season 2018-19)												
W_1	0.00	0.00	94.20	145.62	102.10	13.41	49.75	39.41	392.02	2.659	0.0	18.17
W_2	29.97	40.95	90.06	139.38	90.99	12.08	42.37	35.73	310.78	2.295	13.69	16.34
W_3	25.22	33.90	91.41	141.46	96.04	12.40	44.26	36.82	336.03	2.450	7.86	17.22
W_4	19.82	27.50	92.83	143.14	99.53	12.84	46.63	38.26	367.69	2.576	3.12	17.87
W_5	73.98	100.87	88.16	135.55	84.64	11.54	39.13	35.00	281.66	1.910	28.17	13.98
W_6	41.18	56.92	91.55	143.48	94.96	12.25	43.07	38.14	336.58	2.555	3.91	17.71
W_7	62.71	83.87	89.70	141.29	88.37	11.96	41.65	37.01	319.37	2.368	10.94	16.67
W_8	65.08	87.98	88.33	139.43	85.04	11.56	40.49	35.78	291.48	2.222	16.43	15.83
$LSD_{0.05}$	**0.74**	**1.51**	**0.16**	**0.21**	**1.92**	**0.09**	**0.06**	**0.15**	**1.17**	**0.02**	**0.91**	**0.15**

TABLE 2. Effect of irrigation regimes on total density of weeds, dry weight of weeds, phenological and some yield traits in 2017-18 and 2018-19 seasons

(IR) Irrigation regimes	Total density of weeds (m^{-2})	Dry weight of weeds (g m^{-2})	Days from sowing to heading	Days from sowing to maturity	Plant height (cm)	Spike length (cm)	No. of grains spike^{-1}	1000-seed weight (g)	No. of spikes m^{-2}	Grain yield (ton fed^{-1})	Grain ability (kg day^{-1})
(Season 2017-18)											
IR_1	40.73	53.17	94.38	146.68	97.46	12.73	48.48	39.15	344.73	3.309	22.56
IR_2	38.09	48.65	92.44	144.28	93.57	12.55	46.87	37.84	336.97	2.726	18.89
IR_3	36.12	47.24	90.65	141.04	90.29	11.76	44.73	36.42	318.40	2.227	15.79
IR_4	24.00	34.16	88.24	139.75	86.09	10.90	39.09	34.41	292.78	1.371	9.81
LSD 0.05	**0.43**	**1.7**	**0.21**	**0.50**	**1.1**	**0.04**	**0.05**	**0.11**	**1.04**	**0.02**	**0.29**
(Season 2018-19)											
IR_1	48.85	67.54	93.27	144.84	98.46	13.06	47.66	39.10	353.00	3.299	22.78
IR_2	45.46	61.86	91.84	142.90	93.59	12.67	45.54	37.79	341.54	2.717	19.01
IR_3	35.74	48.45	90.32	139.98	90.61	12.10	43.03	36.51	324.05	2.240	16.00
IR_4	28.92	38.15	87.69	136.95	87.17	11.22	37.44	34.68	303.21	1.261	9.21
LSD 0.05	**0.42**	**0.79**	**0.14**	**0.24**	**1.69**	**0.05**	**0.07**	**0.07**	**8.24**	**0.013**	**0.09**

Effect of weed-free and weed infestation periods

Total density of weeds and dry weight of annual weeds

Data pertaining in (Table 1 and Fig.1) revealed that the total annual density of weeds and dry weight of weeds were significantly increased with increased duration of weedy periods (WCP) and weeds age, and decreased with increasing duration of the weed-free periods (WFP) in the wheat field in both seasons. Weed dry weight may be more useful than density for comparing treatments because weed biomass is reflected the competition of weeds with wheat crop on nutrient, light, and water irrigation, but the number of weeds reflected to the seed bank in the soil.

Yield and its attributes

Yield components and grain yield, *i.e.* number of days from sowing to heading and maturity, plant height, spike length, No. of grains spike^{-1}, 1000-seed weight, No. of spikes m^{-2}, grain yield, and grain yield ability were significantly influenced by different competition durations in both seasons (Table 1).

All traits of wheat were increased by increasing duration of weed-free period (WFP) conditions and decreased with the increasing duration of weedy periods (WCP) conditions. Weed competition for the whole season produced the relative yield losses by (28.52 and 28.17%) under 90.52 and 100.87g m^{-2} dry weight of total weeds in the 1st and 2nd seasons, (Table 1 and Fig. 2).

Figure 3 shows that the dry weight of total annul weeds increased by increasing the duration of the early competition period due to allowing weeds grow from the beginning of crop emergence until the end of competition period, while in weed free period dry weight of total weeds decreased by increasing the duration of weed free period due to the removal of weeds in the early interval of crop growth and allowing weeds growth till the end stage of wheat crop. Increasing dry weight of total weeds than 29 to 31 and 49 to 62g m^{-2} can be reduced less than 5% from wheat grain yield production under weed free and weed competition treatments, respectively. The best period for weeds removal to produce 95% of wheat grain must be two times at 31 and 62 days after sowing.

Effect of interaction between irrigation periods and weed-free and weed infestation periods

Total weed density and dry weight of annual weeds

It is clear from (Table 3 and Fig. 4) revealed that the interaction between IR_4 treatment and weed-free up to 75 DAS (W4) gave the highest reduction of total weed density (11.08 and 12.91) and the total dry weight of weeds (21.33 and 17.33g m^{-2}), while the lowest reduction was obtained by IR_1 + W_5 (82.40 and 88.90) for total weed density and (99.57 and 122.26g m^{-2}) for a total dry weight of weeds in the 1st and 2nd seasons, respectively.

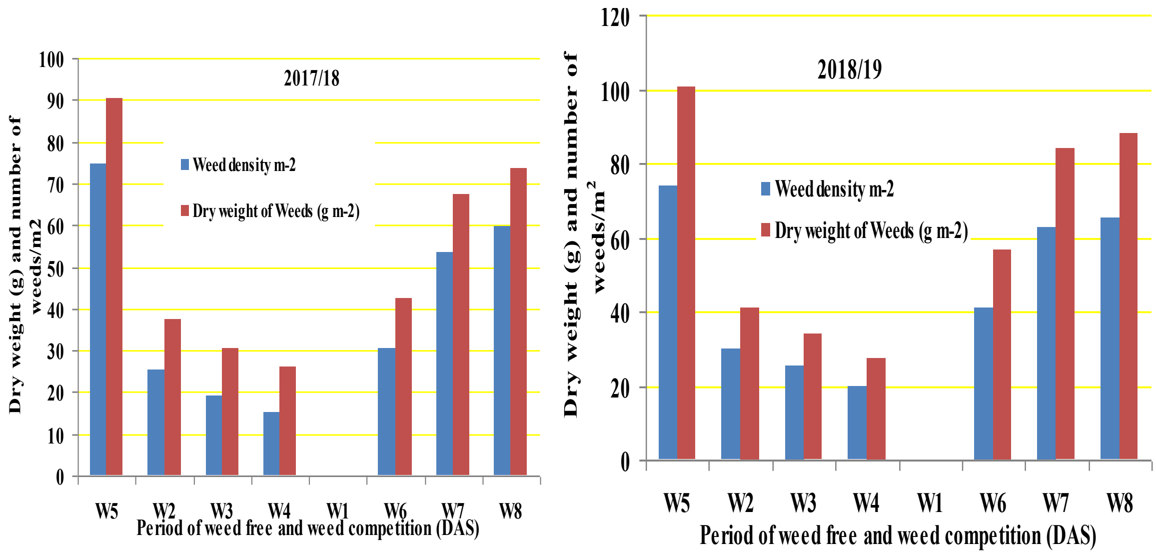

Fig. 1. The relationship between the period of weed-free, weed competition, and dry weight of total annual weeds in 2017-18 and 2018-19 seasons

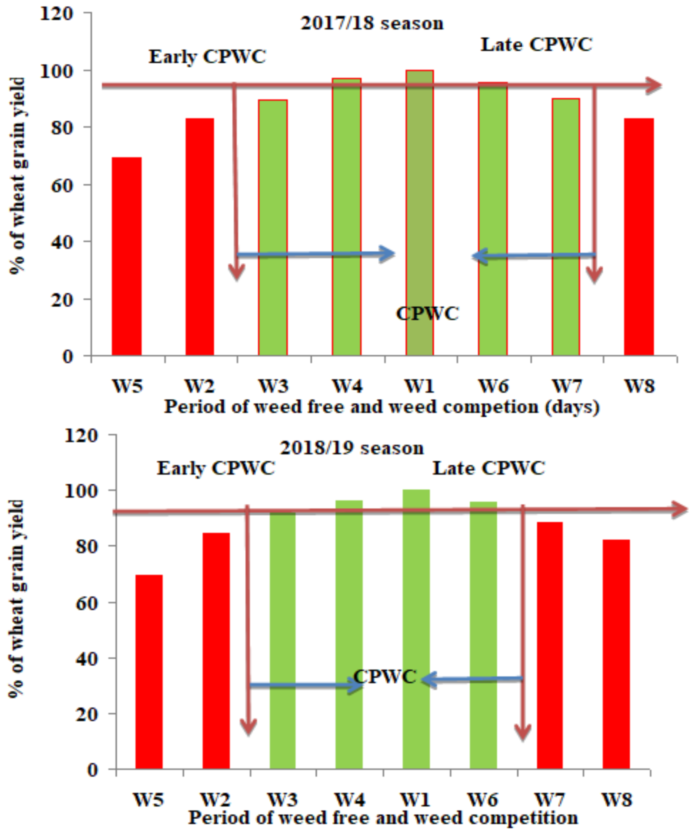

Fig. 2. The relationship between weed-free, weed competition, and % of wheat grain yield, compared to grain yield of weed-free in 2017-18 and 2018-19 seasons

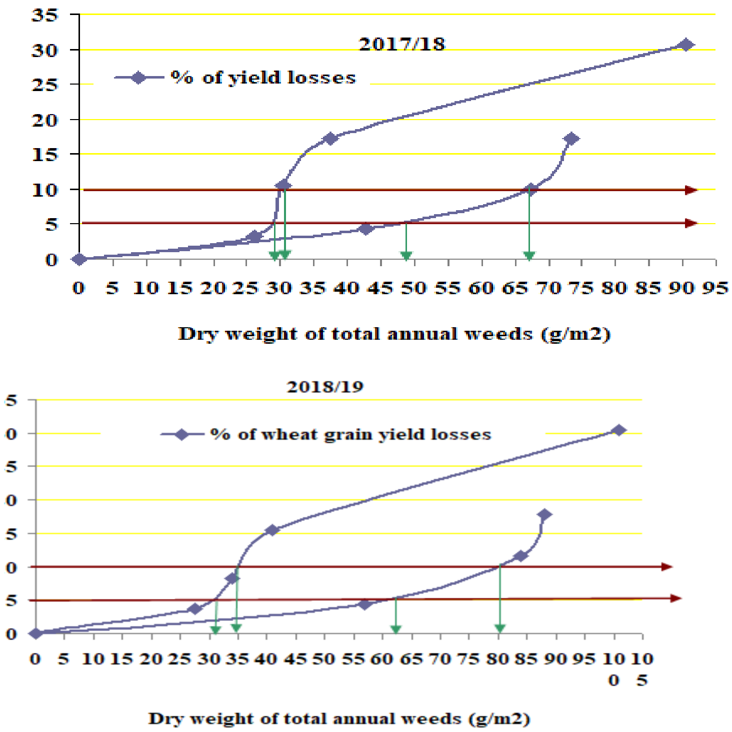

Fig. 3. The relationship between dry weight of total annual weeds and percent of wheat grain yield losses in 2017-18 and 2018-19 seasons

TABLE 3. Effect of interaction between irrigation regimes and weed infestation treatment on the total density of weeds, total dry weight of weeds and yield and its components in 2017-18 and 2018-19 seasons

Traits	Total density of weeds (m^{-2})				Total dry weight of weeds ($g\ m^{-2}$)				Days from sowing to heading				Days from sowing to maturity				Plant height (cm)			
	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4
Season 2017-18																				
W1	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	98.90	96.23	93.05	91.02	152.26	149.36	145.34	144.33	110.17	106.18	98.87	90.41
W2	30.37	28.87	24.60	17.23	42.58	42.08	36.84	28.65	92.71	91.05	90.16	88.23	144.36	142.05	139.46	138.14	98.71	94.24	90.34	83.54
W3	22.36	20.70	18.37	14.63	34.10	31.26	30.12	26.01	94.17	92.91	91.13	89.90	146.69	145.42	143.10	141.45	101.47	99.30	91.93	85.34
W4	17.42	16.17	14.77	11.08	29.91	27.34	25.68	21.33	96.48	94.21	92.22	90.30	149.77	146.35	145.01	142.64	106.00	102.69	97.02	89.54
W5	82.40	79.97	77.17	59.40	99.57	96.83	93.67	71.69	91.00	90.12	87.90	85.17	140.33	137.58	135.02	134.80	86.70	84.78	82.03	80.67
W6	35.47	34.17	32.40	20.27	48.02	46.93	44.03	31.49	95.94	93.48	91.52	88.03	149.32	146.44	143.14	139.21	96.73	94.17	93.34	92.62
W7	65.33	60.53	58.67	30.08	82.34	74.35	71.10	41.95	93.04	91.11	90.03	87.57	146.32	144.51	141.97	141.13	90.57	88.37	86.80	85.04
W8	72.45	64.33	63.03	39.33	88.83	77.08	76.16	51.72	91.84	90.40	89.16	85.72	141.34	141.54	140.02	136.28	89.34	85.39	82.03	81.56
$LSD_{0.05}$	**0.89**				**2.61**				**0.37**				**0.40**				**2.31**			
Season 2018-19																				
Traits	Total density of weeds (m^{-2})				Total dry weight of weeds ($g\ m^{-2}$)				Days from sowing to heading				Days from sowing to maturity				Plant height (cm)			
	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4
W1	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	97.87	95.28	92.99	90.65	149.01	147.24	144.30	141.93	110.18	104.83	99.64	93.75
W2	39.80	36.07	24.89	19.13	55.05	49.64	33.85	25.27	91.25	90.97	90.00	88.00	143.60	141.05	138.10	134.77	98.36	88.15	90.37	87.10
W3	33.57	30.80	20.80	15.71	45.81	41.33	27.85	20.63	93.53	92.04	91.03	89.03	144.53	143.13	140.27	137.23	103.36	99.38	92.70	88.70
W4	24.67	23.24	18.48	12.91	35.61	31.75	25.33	17.33	95.18	94.03	92.09	90.01	147.27	145.30	142.04	137.93	106.88	103.51	96.96	90.79
W5	88.90	85.60	65.67	55.73	122.26	116.11	89.53	75.59	90.42	89.69	87.79	84.73	140.13	136.13	134.01	131.93	88.84	84.36	82.07	81.97
W6	49.27	45.63	38.98	30.83	68.07	62.03	53.91	43.65	94.76	92.80	91.02	87.63	146.97	145.17	142.14	139.63	98.42	95.56	93.31	92.56
W7	74.60	68.07	57.77	50.40	102.43	92.82	77.14	63.09	92.12	90.28	89.59	86.83	144.23	143.30	140.02	137.60	92.40	88.13	86.95	85.98
W8	80.03	74.30	59.36	46.61	111.12	101.20	79.95	59.63	91.06	89.66	88.02	84.57	142.27	141.87	138.97	134.60	89.27	84.81	82.89	83.21
$LSD_{0.05}$	**0.89**				**1.99**				**0.34**				**0.21**				**3.65**			

W_1: Weed-free for the whole season W_5: Weed competition for the whole season IR1:5 irrigations at tillering, stem elongation, booting, heading, and ripening stages

W_2: Weed-free up to 25 DAS W_6: Weed competition up to 25 DAS IR2:4 irrigations at tillering, stem elongation, booting and heading (omitting 1 irrigation at ripening stage)

W_3: Weed-free up to 50 DAS W_7: Weed competition up to 50 DAS IR3: 3irrigation at tillering, stem elongation and booting(omitting 2 irrigations at each of heading and ripening stages)

W_4: Weed-free up to 75 DAS W_8: Weed competition up to 75 DAS IR4:2 irrigation at tillering and stem elongation (omitting 3 irrigations at each of booting, heading and ripening stages)

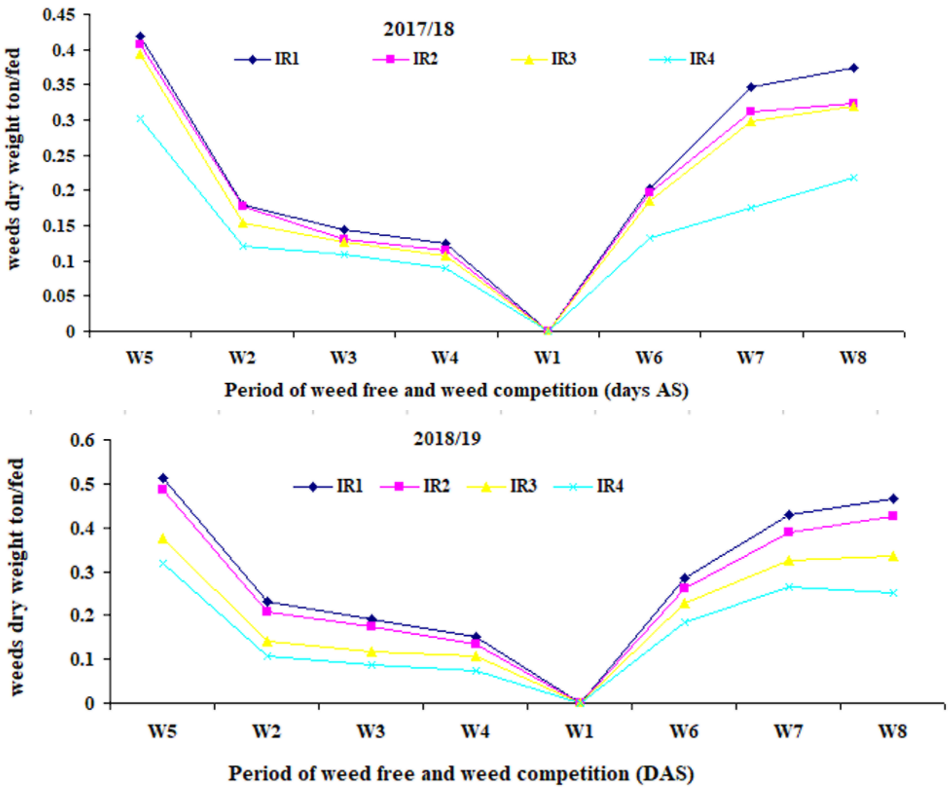

Fig. 4. The relationship between duration of weed-free, weed competition, and dry weight of total annual weeds (ton fed^{-1}) in 2017-18 and 2018-19 seasons

Yield and its attributes

The results in Tables 3 and 4 showed that the interaction effects of the two experimental factors significantly affected all the studied characters in both seasons. The best values were (98.90 and 97.87 day) for days from sowing to heading, (152.26 and 149.01 day) for days from sowing to maturity, (110.17 and 110.18cm) for plant height, (15.53 and 15.14cm) for spike length, (55.02 and 53.84) for No. of grains spike^{-1}, (42.23 and 41.94g) for 1000-grain weight, (413.42 and 420.93) for No. of spikes m^{-2} and (3.628 and 3.611ton fed^{-1}) for grain yield in the 1st and 2nd seasons, respectively due to applied weed-free for all season (W_1) and supply wheat plants with full irrigation (IR_1). While the lowest values of these traits were obtained by weed competition for whole season (W_5) with 2 irrigation treatment (IR_4).

Determination the critical period of weed-wheat competition

Classical biological approach

Figure 5 reported that the critical period of weed/wheat competition was 28 to 52 in 2017-18 and 28 to 67 DAS in the 2018-19 seasons. Its critical weed-free period (CWFP) required from sowing avoiding irrevocable yield less than 5% under the weed infestation in experimental soil. These results due to decreased weed infestation in experimental soil, which 90.52 and 100.87g m^{-2} dry weight of total annual weeds.

Mathematical models to determine the critical period of weed-wheat competition

The relationship between wheat grain yield (ton fed^{-2}) and the period of weed removal was high significant with linear, quadratic, cubic and logistic models. Table 5 shows the values coefficient of determination (R^2) and standard error of estimate (SE) of the tested models in the 2017-18 and 2018-19 seasons. The highest value of the coefficient of determination (R^2) for the cubic models which the best model is for weed-free and weed competition in the two seasons**.** The results of the coefficient of determination (R^2) being 0.111 and 0.101 for weed-free and being 0.054 and 0.049 for the weed competition over all treatments in 2017-18 and 2018-19 seasons, respectively.

TABLE 4. Effect of interaction between irrigation regimes and weed infestation treatment on yield and its components in 2017-18 and 2018-19 seasons

Traits	Spike length (cm)				Number of grains spike^{-1}				1000-grain weight (g)				Number of spikes m^{-2}				Grain yield (ton fed^{-1})			
	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4
Season 2017-18																				
W1	15.53	15.04	14.02	13.03	55.02	53.52	50.84	44.84	42.23	40.91	38.04	37.01	413.42	405.01	377.90	347.57	3.628	3.072	2.502	1.625
W2	12.62	11.93	11.73	11.06	48.85	45.88	43.26	38.36	37.66	36.78	35.44	33.50	322.01	318.86	308.23	277.27	3.144	2.601	2.150	1.200
W3	13.02	12.92	12.70	11.55	50.85	47.58	45.63	40.86	39.93	38.16	36.49	33.96	350.58	340.99	321.54	296.53	3.360	2.761	2.236	1.400
W4	14.80	14.02	13.41	12.14	51.30	50.00	47.85	42.40	41.18	39.17	37.70	35.16	390.09	373.16	349.90	312.27	3.544	2.937	2.408	1.585
W5	11.14	11.05	10.10	9.89	43.69	43.03	41.24	35.01	37.45	36.26	35.35	33.40	297.14	288.40	276.23	252.50	2.818	2.244	1.763	0.917
W6	13.65	12.90	12.22	11.19	47.64	46.30	44.40	35.97	39.09	38.17	37.02	35.02	351.54	345.20	327.63	301.56	3.540	2.884	2.404	1.540
W7	12.44	12.34	11.59	10.90	46.42	45.02	43.46	37.25	38.52	37.14	36.10	34.09	332.56	326.66	305.48	289.13	3.349	2.765	2.257	1.421
W8	11.26	11.12	11.05	10.00	44.04	43.64	41.19	38.04	37.09	36.09	35.21	33.13	300.47	297.51	280.27	265.40	3.093	2.545	2.093	1.282
LSD at 5%		**0.12**				**0.13**				**0.19**				**1.85**				**0.07**		

Season 2018-19

Traits	Spike length (cm)				Number of grains spike^{-1}				1000-grain weight (g)				Number of spikes m^{-2}				Grain yield (ton fed^{-1})			
	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4	IR1	IR2	IR3	IR4
W1	15.14	14.91	13.93	12.93	53.84	51.96	48.71	44.50	41.94	41.03	37.84	36.85	420.93	410.12	381.98	355.04	3.611	3.005	2.484	1.535
W2	11.92	11.80	11.60	10.61	47.85	44.88	41.15	35.60	37.59	36.50	35.30	33.53	329.27	318.09	311.38	283.03	3.223	2.646	2.203	1.107
W3	13.00	12.87	12.00	11.04	48.86	46.47	43.31	38.41	38.72	37.94	36.61	34.01	366.29	348.82	328.60	300.40	3.313	2.812	2.315	1.359
W4	14.31	13.93	12.13	11.42	50.57	48.85	46.02	41.09	40.86	39.13	37.51	35.51	402.00	389.04	359.01	320.72	3.513	2.909	2.472	1.409
W5	11.07	11.00	10.02	9.26	42.38	40.92	39.37	33.83	36.68	35.61	34.01	33.07	299.07	290.33	279.02	258.24	2.808	2.206	1.776	0.850
W6	13.07	12.80	12.09	11.02	48.29	45.93	44.02	34.02	40.17	38.90	37.37	36.13	359.10	349.65	330.37	307.18	3.503	2.897	2.397	1.421
W7	12.21	12.04	11.30	10.86	45.99	43.88	41.63	35.09	38.97	37.24	36.90	34.93	340.50	329.16	310.64	297.20	3.301	2.691	2.193	1.288
W8	11.17	11.05	11.03	10.03	43.51	41.43	40.05	36.96	37.16	36.03	36.52	33.34	306.87	297.10	291.38	270.57	3.121	2.570	2.080	1.118
LSD at 5%		**0.17**				**0.10**				**0.26**				**2.62**				**0.05**		

W_1: Weed-free for whole season; W_5: Weed competition for whole season; IR1:5 irrigations at tillering, stem elongation, booting, heading and ripening stages

W_2: Weed-free up to 25 DAS; W_6: Weed competition up to 25 DAS; IR2:4 irrigations at tillering, stem elongation, booting and heading (omitting 1 irrigation at ripening stage)

W_3: Weed-free up to 50 DAS; W_7: Weed competition up to 50 DAS; IR3: 3irrigation at tillering, stem elongation and booting(omitting 2 irrigations at each of heading and ripening stages)

W_4: Weed-free up to 75 DAS; W_8: Weed competition up to 75 DAS; IR4:2 irrigation at tillering and stem elongation (omitting 3 irrigations at each of booting, heading and ripening stages)

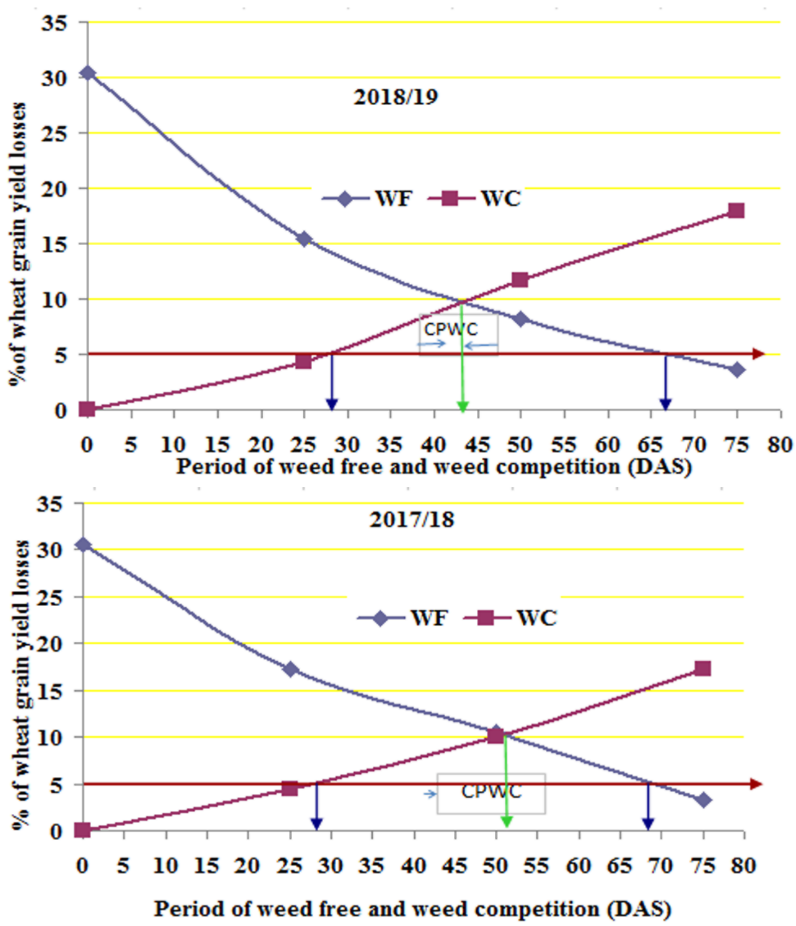

Fig. 5. Effect of weed free and weed competition period on % of wheat grain yield losses compared to grain yield of weed free for the whole season in 2017-18 and 2018-19 seasons.

TABLE 5. Estimated relationships between grain yield and irrigation regime with the weed-free and weed-competition period in 2017/18 and 2018/19 seasons

Seasons	Treatments	Regression models	R Square	SE	Prediction equation	CPWC/ week allowed losses yield (10%)
2017-18	Weed-free	Linear	0.107**	0.730	Ý=1.984+0.009x	
		Quadratic	0.110**	0.737	Ý =1.945+0.014x-6.3E-5x^2	
		Cubic	**0.111****	**0.050**	**Ý =1.935+0.019x+1.992E-6x^3**	**24.79**
	Weed competition	Linear	0.053**	0.727	Y=2.726-0.006x	
		Quadratic	**0.054****	**0.735**	**Y=2.706-0.004x-3.197E-5x^2**	**48.57**
		Cubic	0.054**	0.743	Y=2.707-0.004x-5.267E-6x^2-2.373E-7x^3	
2018-19	Weed-free	Linear	0.094**	0.765	Y=1.985+0.009x	
		Quadratic	0.100**	0.771	Y=1.920+0.016x+0.0x^2	
		Cubic	**0.101****	**0.779**	**Y=1.910+0.023x+2.138E-6x^3**	**20.62**
	Weed competition	**Linear**	**0.049****	**0.766**	**Ý =2.675-0.006x**	**46.98**
		Quadratic	0.048**	0.774	Y=2.665-0.005x-1.673E-5x^2	
		Cubic	0.048**	0.783	Y=2.659-1.3E-6x^3	

** Significante at 1%

Data cleared that the critical period of weed control over all studied agricultural practices, according to the recommended allowed yield losses value (10%) being 24.79 and 20.62 days after sowing for weed-free and being 48.57 and 46.98 days after sowing for weed-competition in the first and second seasons, respectively. These periods were determined by solving the estimated equations for both weed-free and weed-competition with yield value equal 90% of yield produced from weed free whole season treatment (i.e., 10% yield losses). These results indicated that, the critical period for weed control did not differ more than the individual irrigation regime under study. The cubic model was fit model had high R^2 and low standard error of estimated compared to other models and they had significant calculated f value in the two seasons for weed-free. Whereas the quadratic and linear models were fit models for weed-competition in the 1st and 2nd seasons respectively. So, these models were the best of the response models tested for describing the relation between wheat grain yield to weed-free and weed competition (Fig. 6).

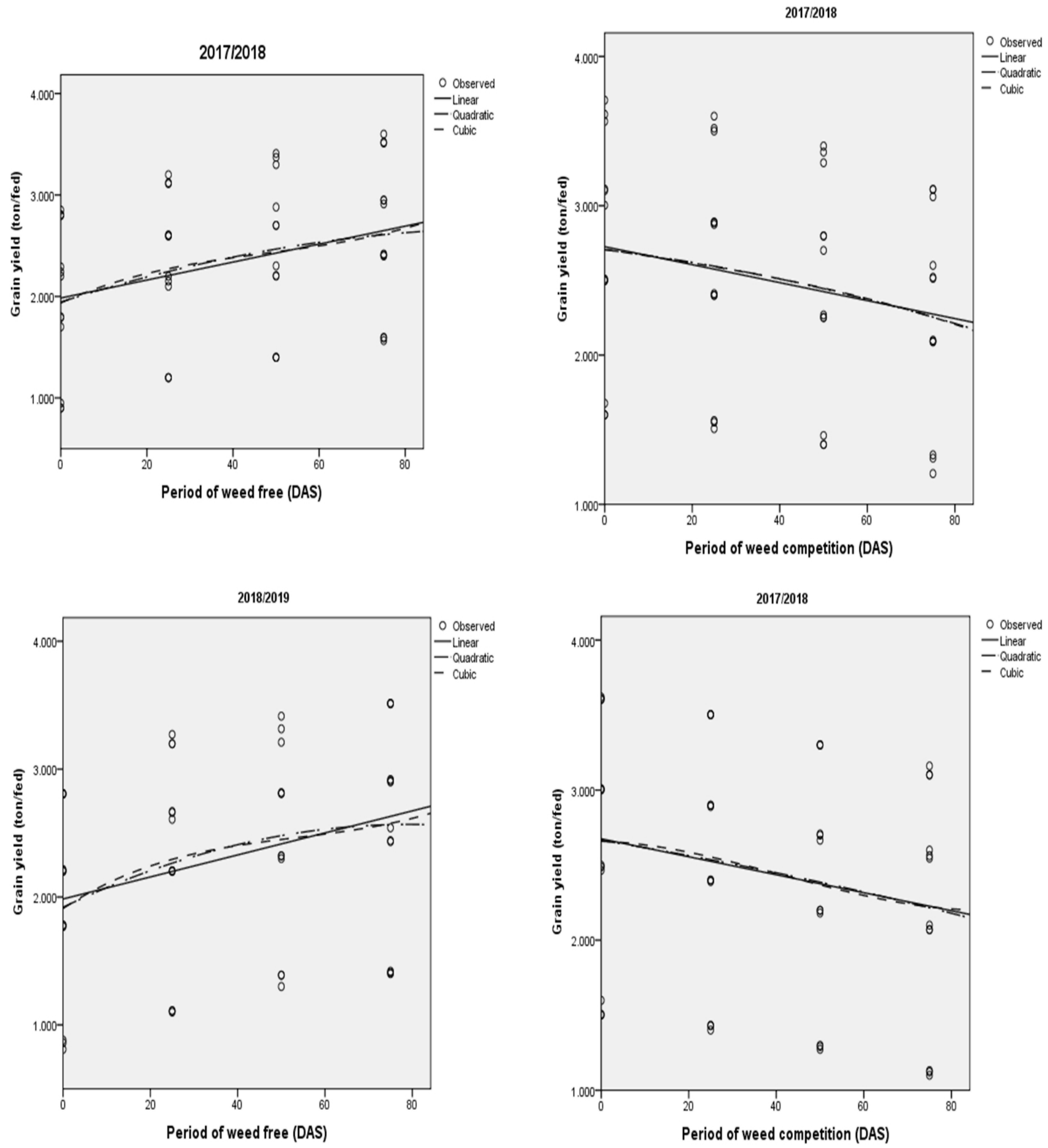

Fig. 6. The relationship between the period of weed-free (WF) or weed competition (WC) and wheat grain yield (kg fed^{-1}), linear and cubic models

Discussion

Effect of irrigation periods

Total weed density and dry weight of annual weeds

As seen in this study, the amount of irrigation water wasted by weed competition can be conserved through suitable weed control practices, to provide more water for wheat and produce more yield fed^{-1}. Data presented in Table 1 shows that the greatest reduction in total weed density (41.08 and 40.80%) and dry weight of weeds (35.75 and 43.51%) in both seasons, respectively, recorded at the lowest rate of irrigation (IR_4) due to the lowest availability of moisture, which does not provide suitable environment for weeds growing, the same results recorded by Verma et al. (2008, 2015). Under the lower rate of irrigation conditions, weeds can reduce crop yield more than 50% through moisture competition only (Abouziena et al., 2014). Moreover, (Ihsan et al., 2015) reported that the drought stress from 75% to 50% field capacity resulted reductions 29-40% of *Setaria* height, 14-27% in *Setaria* density and 11-26% in *Setaria* dry biomass, as well as severe drought stress (FC 50%), resulted in the maximum suppression in weed attributes as compared with the well-watered conditions. These results agree with the findings of Singh et al. (2009) and Nadeem et al. (2010) who reported an increase in weed population and dry weight with increasing irrigation level from 0.60 to 1.00 IW: CPE. The increase in total density and dry weight of weeds at a higher rate of irrigation resulted from the greater availability of moisture (El-Metwally *e*t al., 2015; Verma et al., 2017).

Yield and its attributes

Current results show that the studied traits of wheat plant recorded higher values by applying full irrigation (IR_1). The superiority of number days from sowing to heading, days from sowing to maturity as phenological parameters and plant height obtained at full irrigation (5 irrigations) during either vegetative growth or ripening stages. This may be due to the enough soil moisture in the root zone help the plants to absorb a greater amount of water and nutrients, which enhancing internodes elongation and cell division as well as photosynthetic process and metabolites accumulation, which consequently increases the No. of days from sowing and physiological mature. Many researchers reported that the availability of sufficient moisture for wheat plants caused increasing in plant height, No. of spikes m^{-2}, spike length, 1000-grain weight and grain yield (Leghari et al., 2017, Elhag, 2017, Seleiman & Abdel-Aal, 2018, Kassab et al., 2019; Dehghan et al., 2020), and days from sowing till heading and maturity (Elhag, 2017; Seleiman & Abdel-Aal, 2018). The main impact of irrigation on the studied traits could be written in the following ascending order $IR_4 < IR_3 < IR_2 < IR_1$ as the values of the studied traits increase by increasing the irrigation applied (from IR4 to IR1). Supplying wheat plants with 5 irrigations to more availability of plant food nutrient during grain filling duration led to achieving improvements in yield and its components and it also leads to an obvious increase in phenological development stages and consequently increase the dry matter accumulation and fertility of florets, which affect the number of spikes m^{-2} as well as the number of grains $spike^{-1}$. Many investigators found an increase in the number of each spikelets $spike^{-1}$, grains $spike^{-1}$ and 1000 grain weight as well as grain yield by normal irrigation at crown root initiation + tillering + jointing + flowering + milky + dough stages (Ahmad & Kumar, 2015). El-Gabry & Hashem (2008) stated that the application of five irrigations to wheat crop possessed maximum spikes $plant^{-1}$, spike length, grain weight $spike^{-1}$, and grain yield ton fed^{-1} as compared to skip 2nd irrigation and skip 3rd irrigation.

Effect of weed-free and weed infestation periods

Total Weed density and dry weight of annual weeds

Concerning weed removal treatments, significant increment and reduction were recorded in weed density due to increasing durations of weedy and weed-free periods, respectively, as a result of the prolonged weed growth period. This indicated that the competitive ability of a given density of weeds that emerged with the crop and their dry matter production was strongly dependent on the length of the period they remained in the field with wheat. Weed dry weight increased by increasing weed interference period (Riya et al., 2017). Similar results were recorded by Zenebech (2018) and Girma & Adare (2019) who observed that weed density and dry weight decreased with increasing duration of the weed-free period in an experiment conducted to determine the critical period for weed control in barley. Anwar et al. (2012) and Merino et al. (2019) also reported that the highest rate of weeds was in weedy check and the lowest rate was in weed-free plots in rice crops.

Yield and its attributes

According to the results, the reductions in wheat yield and its traits might be due to increasing weeds' competition with wheat plants for growth resources, particularly light, soil nutrients and place, which negatively affected vegetative growth of wheat plants, particularly dry matter accumulation as well as their photosynthesis efficiency and translocation of synthates to be stored in grain, consequently decrease the No. of grains spike^{-1}, No. of spikes m^{-2}, 1000-grain weight and grain yield ability. Ali et al. (2014) showed that weed control up to 20DAS suppresses the weed density and dry weight by 76% and 95%, respectively and increases the grain yield up to 34%. Wheat yield decreased by increasing competition period, thus weed-free treatment gave the highest grain yield 2.78ton ha^{-1} and the lowest one was found in weedy treatment 1.35ton ha^{-1} (Riya et al., 2017). The results are following the findings of (Girma & Adare, 2019) on barley and (Ka et al., 2020) on sorghum.

Effect of interaction between irrigation periods and weed-free and weed infestation periods

The results in Tables 3 and 4 showed that the interaction between $IR_1 \times W_1$ gave the highest values of all traits for wheat plants. While the interaction between $IR_4 \times W_4$ gave the lowest values of total density and dry weight of weeds. Both, drought stress (applied as different FC) and weed competition period cause significant yield loss in wheat crop and the magnitude of yield loss increases by decreasing FC and increasing weed-crop competition period, thus the productivity of wheat is largely depends on timely and effective weed control (Ihsan et al., 2015). It could be due to better soil moisture conditions during plant growth which helped in better utilization of nutrients by the plant, thus lead to production of the highest yield and nutrient uptake (Verma et al., 2017). Similar results were obtained by Singh (2007) and El-Metwally et al. (2015).

Critical of weed/wheat competition

The experimental fields in the first and second season had medium infestation by weeds 90.52 and 100.87g m^{-2} dry weight of total annual weeds. The highest values of the coefficient of determination (R^2) were for the cubic model, which the best model for weed-free and weed competition in the two seasons. The values of the coefficient of determination (R^2) being 0.111 and 0.101 for weed-free and being 0.054 and 0.049 for the weed competition over all treatments in 2017-18 and 2018-19 seasons, respectively. This agree with what Aref et al. (2013) reported. Data clarify that the critical period for weed control over all studied agricultural practices, based on recommended yield losses (10%) were 24.79 and 20.62 days after sowing for weed-free and 48.57 and 46.98 days after sowing for weed-competition in the first and second seasons, respectively. These results due to weed infestation in experimental soil were medium and in the first season the weeds presented in the late wheat-growing stage, but the second season the weeds presented in the early growing stage. These results showed that, the critical period for weed control did not affected significantly by irrigation regime under study. The cubic model recorded high R^2 and low standard error of estimated compared to other tested models and it had significant calculated values in the two seasons. So, this model was the best among the response models tested for describing the relation between wheat grain yield and either weed-free or weed competition, (Fig. 6).

Conclusion

It was concluded from this study that weed infestation is one of the major factors limiting the yield of wheat as its seedling growth is slow during the first three weeks making it a poor competitor at earlier stages of crop growth. The critical period of weed- wheat interference ranges from 28-60 DAS, during which, weeds must be controlled to keep wheat plant free from weeds.

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تأثير معاملات الري وفترات التنافس البيني للحشائش علي محصول الحبوب في القمح بمصر الوسطى

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تم عمل البحث الحالي بالمزرعة التجريبية بكلية الزراعة ، جامعة المنيا مصر ، خلال الموسمين المتتاليين 18-2017 و 19-2018 لتقييم أثر الفترة الحرجة لمنافسة الحشائش في القمح لنظم رى مختلفة على محصول القمح ومكوناته والحشائش المصاحبة له. نفذت التجربة بتصميم القطاعات كاملة العشوائية بترتيب الشرائح المنشقة فى ثلاث مكررات وذلك من خلال منهج الإنحدار وكذلك تقدير العلاقة بين المحصول وأنظمة الرى المختلفة. حيث وزعت 4 أنظمة الري فى القطع الأفقية ، بينما تم توزيع 8 معاملة منافسة الحشائش عشوائياً فى القطع الرأسية. أظهرت النتائج أن تعريض نباتات القمح لريتين يقلل بشكل كبير من الكثافة والوزن الجاف للأعشاب الضارة، والصفات الفينولوجية، وإرتفاع النبات، وطول السنبلة، وعدد الحبوب بالسنبلة، وزن 1000 حبة، عدد السنابل/م^2، محصول الحبوب والقدرة النسبية لمحصول الحبوب. وقد أدى عدم مقاومة الحشائش طوال الموسم إلى نقص معنوى في جميع الصفات المدروسة مقارنة بازالة الحشائش حتى لمرة واحدة بعد زراعة القمح. أظهرت النتائج أن الحد الأقصى للخسائر في محصول القمح بسبب الإصابة بالحشائش في الموسم بأكمله كانت 28.52 و 28.17٪ مقارنة بالمعاملة الخالية من الحشائش في الموسمين الأول والثاني على التوالي. بإستخدام طريقة الإنحدار (الخطى - التربيعى - التكعيبى . اللوجستى) تم التوصل إلى أن معادلة الإنحدار التكعيبى والتى لها أعلى R^2 تراوحت بين 0,111 و 0,101 لمعاملات خلو المحصول من الحشائش للموسمين على التوالي وكانت كل من المعادلتين التربيعية والخطية لهما أعلى R^2 حيث كان 0,054 و 0,049 لمعاملات منافسة الحشائش للموسمين الأول والثانى على التوالى، بإستخدام الطرق البيولوجية التقليدية لتحديد الفترة الحرجة لمنافسة الحشائش للقمح ، أظهرت النتائج أن الفترة الحرجة لمنافسة الحشائش للقمح بإستخدام هذه الطريقة البيلوجية كانت بعد 28 إلي 52 و28 إلى 67 يوم من الزراعة للموسم الأول والثاني على التوالي.