

## Article

# Competition of Weeds Dominated by Wild Oat (*Avena sterilis* L.) in Wheat (*Triticum durum* Desf.) in Jordan

Jamal R. Qasem

Plant Protection Department, Faculty of Agriculture, University of Jordan, Amman 11942, Jordan; jrqaem@ju.edu.jo; Tel.: +962-6-5355000 (ext. 22515)

**Abstract:** Wheat is the main field crop grown in Jordan. Productivity is low due to different factors, including erratic rainfall, poor soil fertility and weed competition. A field experiment was carried out at the University of Jordan Research Station for two growing seasons to determine the effect of weed competition on growth and yield of wheat (*Triticum durum* Cv. “Hourani”). Treatments consisted of either allowing weeds to infest the crop or maintaining the crop weed-free for increasing durations after emergence. Results showed that, the longer the periods of weed competition, the greater the loss in crop growth and yield. Average reductions in grain and straw yields were 41% and 37%, respectively. The highest grain yield obtained was from weed-free, and the lowest was in weed-infested plots for the entire growing season. Average grain yield was not significantly different at 14 to 49 days of weed-infested periods, while none of the weed-free periods produced a yield similar to that of the weed-free control. However, maintaining a weed-free crop for three weeks after emergence significantly increased grain yield compared with the weed-infested control. High rainfall in the first season almost doubled weed growth and greatly reduced wheat growth and yield compared with the second season. To determine the critical period of weed competition and the influence of weed infestation on wheat grain yield, Gompertz and logistic equations were fitted to data representing increasing duration of weed-free and weed-infested periods, respectively. Based upon an arbitrary 5% level of average grain yield loss in the two years, the critical period of weed competition occurred at 0–49 days after wheat emergence, which corresponded with the rapid increase in weed biomass.

**Keywords:** weed-free periods; weed-infested periods; wheat yield loss; weed-interference



**Citation:** Qasem, J.R. Competition of Weeds Dominated by Wild Oat (*Avena sterilis* L.) in Wheat (*Triticum durum* Desf.) in Jordan. *Agronomy* **2021**, *11*, 1816. <https://doi.org/10.3390/agronomy11091816>

Academic Editors: Jeffrey Weidenhamer, Sajid Latif and Leslie A. Weston

Received: 29 July 2021

Accepted: 30 August 2021

Published: 9 September 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Wheat is the main field crop grown under rainfed conditions in Jordan. The country has not been able to meet its basic food requirements in recent years. Productivity is generally low and has not been exceeding 1200 kg ha<sup>−1</sup> in recent years [1–3]. Although the area planted by this crop is becoming more restricted to the marginal land of low annual rainfall, it remains the largest in terms of land cultivated. A total of 60,000 ha are planted with wheat every year; the country's wheat production meets its needs for only 10 days [4]. Though Jordan wheat production fluctuated substantially in recent years, it tended to decrease through the 1970–2019 period, ending at 25,000 tons in 2019 [5]. The area grown by this crop, however, is also decreasing over time. In 1980, for example, wheat occupied about 133,000 ha, and the total yield was 134,000 t [6]. At present, Jordan imports more than 96% of its wheat needs [7].

Erratic and fluctuated rainfall distribution, poor soil fertility, primitive seed bed preparation practices, use of low yielding varieties with little response to fertilizers and the lack of use of fertilizers and suitable weed control methods (mainly herbicides) early after crop and/or weed emergence are among factors responsible on wheat yield reduction [1]. The lack of use of selective grass killer herbicides in cereals and absence of crop rotation lead to a wild oat (*A. sterilis*) dominance in wheat. *Avena sterilis* L. is the greatest nuisance

in different locations and mainly in the northern part of the country that relatively receives high rainfall and mainly grown by cereals. The weed is difficult to control because of morphological and physiological similarities to crop plants, while untimed hand-weeding is still widely practiced but hardly effective because of difficulty in differentiating between weed and wheat seedlings by untrained labors at early growth stages. Herbicides used in cereal crops are very limited in number and mainly applied for broadleaf weed control, but the use of selective herbicides against narrow-leaved weeds is almost absent.

Wild oat (*Avena sterilis* L.) is a persistent and dominant weed in cereals in different parts of the world including the Mediterranean [1,8,9]. It competes with wheat for different growth factors [10,11] and causes great grain yield losses [8,9] ranged between 17 and 62% at a density of 146–162 plants  $\text{m}^{-2}$  depending on the cultivar [11,12] and up to 75% in certain parts of the world [13]. Economic threshold for *A. sterilis* subsp. *ludoviciana* was found at weed density between 7 and 12 plants  $\text{m}^{-2}$  [14], and a high negative significant linear regression was obtained between crop yield and weed density [15,16]. Gonzalez and Hernando [17] reported greatest wheat yield reduction at two wild oat plants per six plants of wheat, and a significant wheat yield reduction at 30 to 60 plants  $\text{m}^{-2}$  was reported by Dordio et al. [18].

Singh and Bajpai [19] found that 4 weeks of hand-weeding at 25 to 70 days after sowing resulted in the best weed control, lowest weed dry weight and highest wheat yield compared to the weedy control. The longer the wheat and *A. sterilis* competition, the shorter the time that the crop remains each stage of its tillers. Gonzalez and Correa [20] reported little weed competition effect when weeds were removed before crop tillering stage, but after that wheat growth and yield were significantly affected.

The critical period of weed competition was defined as the time from seeding or emergence when weed competition does reduce crop yield and the time after which weed competition will no longer reduce yield [21,22]. It is also known as the critical period of weed control [23] and defined as the duration of the crop life cycle in which it must be kept weed-free to prevent yield loss from weed interference. This period has been determined for many crop species, including wheat and found different between crops [24–29]. In competition of wheat (*Triticum* spp.) with ryegrass, Terefe et al. [30] reported maximum wheat number of tillers and spike length and number recorded were at 15–45 days after sowing, while minimum values for the same growth parameters were at 45–75 days after sowing. These authors suggested the removal of ryegrass before the critical weed/crop competition period, which most probably occurs at 15–45 days after sowing, at which the crop should be kept weed free. Agostinetto et al. [31] reported that wheat yield components were not affected by weed competition, and effective control measures should be taken between 12 and 24 days after emergence. Chaudhary et al. [32] determined the critical period of weed competition in wheat and found that it occurred at 30–50 days after crop sowing. Refsell [23] reported that winter wheat should be kept weed-free approximately 30 to 45 days after planting to prevent significant yield loss. Ali et al. [33] found that weed control after 20 days of crop emergence suppressed weed density and dry weight by 76% and 95%, respectively, and increased grain yield by 34% over the weed-infested control. The highest grain yield obtained was from plots where weeds were removed after 30 days from sowing. However, the critical period of weed competition was determined to be between 30 and 50 days after sowing of wheat. In a more recent study, Silva et al. [34] found that the number of reproductive tillers per plant and spikelets per spike, spike length, plant height and wheat crop yield were significantly affected by coexistence with prevailing infestation of wild radish (*Raphanus raphanistrum* L.), and the critical period of interference was determined at 16 to 24 days after crop emergence.

In general, a limited number of studies was reported on *A. sterilis* competition in wheat. The literature on the determination of the critical period of weed competition including *A. sterilis* in this crop is lacking under local conditions. Therefore, the present work was conducted to study the competition effect of weeds dominated by wild oat (*A. sterilis*) on growth and yield of wheat and to determine the critical period of weed competition based

on weed-infested and weed-free treatments after crop emergence. Information on this period could be used by local farmers to decide suitable weed control methods at a time that will have maximum benefit to the crop growth and productivity.

## 2. Materials and Methods

### 2.1. Field Experiments

A field experiment was conducted to study the effect of weed competition on wheat (*Triticum durum* Desf. cv. “Hourani”) for two years. The “Hourani” cultivar was chosen because it is usually preferred and grown by local farmers, since it is very well adapted to the low rainfall and poor soil fertility conditions prevailing in most areas that grown by cereals in the country. In both growing seasons, the experiment was carried out at the University of Jordan Research Station at the campus, Al-Jubeiha, located at an elevation of 980 m above sea level, with an average annual precipitation of about 450 mm. The soil is clay loam and contained 62.3% clay, 36.7% silt, 1.1% sand and 0.7 organic matter; it had a pH of approximately 7.6. The soil of the experimental site mostly represented the soil type used to grow wheat in the country.

The soil was tilled twice, one by chisel to a depth of 20 to 25 cm, followed by a rotary cultivator. The soil land was leveled, and rows were made-opened by using a small hand hoe. Plot size was  $3 \times 1.05 \text{ m}^2$  and consisted of three rows. Planting distance was 35 cm between rows, and 40 cm was left between plots. Total number of plots per block was 14, giving a total number of 56 plots in the experimental site each year. Wheat seeds of the previous year harvest were sown at a rate of  $100 \text{ kg ha}^{-1}$  on November each year. During both growing seasons, NPK fertilizer (18:10:16) was added a month after sowing at  $250 \text{ kg ha}^{-1}$ , and then another application was applied two months later, using the same rate. Wheat plants were left growing under rainfed conditions. Information on prevailing climatic conditions at the experimental site during both growing seasons is shown in Table 1.

**Table 1.** Metrological conditions in the experimental site in both growing seasons.

Climatic Factor	First Growing Season	Second Growing Season
Total rainfall (mm) for October to June	1076.1 mm	542.4 mm
Highest amount of rain water received	919.9 mm (December–February)	366 mm (November–December)
Minimum air temperature	1.74 °C	3.1 °C
Maximum air temperature	6.6 °C	10.5 °C

In both experiments, weeds were allowed to compete with wheat plants for 0, 14, 21, 28, 35, 42 and 49 days after crop emergence; they were then removed, and plots were kept weed-free thereafter. In other plots, weeds were continuously hand-weeded and kept weed-free for similar periods after wheat emergence. Then weeds were left to grow until harvest. Weed-removal treatments (zero time) were started on 9 and 31 December in both years, respectively.

Plants were harvested at 5 cm from the above soil level on early July each year. Data on wheat grain and straw yields, plant height, and weight of 1000 kernels were recorded. Weeds in the experimental area were also harvested and separated into broadleaf and wild oat; all species were identified and their densities determined. Panicle number of wild oat plant was also recorded in the second growing season. Weeds were oven-dried at 70 °C for 72 h, and their dry weight was determined.

### 2.2. Statistical Analysis

Treatments in both experiments were laid out in a randomized complete block design with four replicates. Data of each experiment were first subjected to the analysis of variance

(ANOVA), using SAS software SAS (r) version 9.1 [35]. Treatments means were separated and compared by using the least significant difference test (LSD) at 5% level of probability.

Data on wheat growth and grain yield and that on weed-shoot dry weight in the two experiments were combined together and averaged. All wheat data were expressed as a percentage of the weed-free plots (0 time of weed-infested treatment), while weed-shoot dry weight was presented as a percentage of their dry weight in the weed-infested plants (0 time of weed-free treatment). To determine the effects of weed duration on wheat, a nonlinear regression line [36] was compared for average wheat grain and straw yield and weed competition or free periods. Similar comparisons were also performed between these treatments and weed-shoot dry weight. The Gompertz equation [37] was used to describe the increasing duration of weed-free on wheat grain and straw yield:

$$Y = A \exp(-B \exp(-kT)) \quad (1)$$

where Y is the yield (% of season-long weed-free wheat), A is the yield asymptote (% of season-long weed-free wheat), B and k are constants, and T is the time from emergence (days). The logistic equation [38,39] was used to describe the effect of increasing duration of weed infestation on grain and straw yields:

$$Y = ((1/(D \exp(K(T - X))) + F) + (\frac{F - 1}{F})) \times 100\% \quad (2)$$

where Y is the yield (% of season-long weed-free wheat), T is the time from emergence (days), X is the point of inflection (days), and D and F are constants. Time (T) was expressed as days after wheat emergence date so the critical period of weed competition could be compared. Using a 5% level of accepted yield loss, we determined the beginning and end of the critical period by using the Gompertz and logistic equations. Grain yield data were also regressed against weed dry weight for weed-free and weed-infested treatments.

### 3. Results

#### 3.1. Weed Population

The naturally occurring weed species in the experimental site and their average densities are presented in Table 2. Wild oat (*Avena sterilis* L.) was the dominant in the two years, with an average density of 128 plants m<sup>-2</sup>, followed by forked mouse-ear chickweed (*Cerastium dichotomum* L.) at 45 plants m<sup>-2</sup>.

#### 3.2. Experiment 1 (First Growing Season)

##### 3.2.1. Wheat Growth

Weed infestation for different periods after wheat emergence reduced crop grain and straw yields compared with weed-free control for the entire growing period (Table 3).

Differences in grain yield were not significant when weeds competed for up to 3 weeks after crop emergence. Longer weed competition periods significantly reduced wheat grain yield, with the lowest yield being obtained when weeds competed with crop plants for the entire growing season. Reduction in wheat grain yield of weed-infested plots for the whole growing season was by 62.2% of the weed-free control. Weed infestation for only 4 weeks after crop emergence resulted in 36% grain yield loss compared with weed-free control, and yield was not significantly changed at longer competition periods until harvest. On the other hand, for the weed-free period up to 4 weeks after crop emergence, although the grain yield increased compared with weed-infested control, the differences were not significant (Table 3). Crop plants kept weed-free for 5 weeks onward resulted in a grain yield not significantly different from that of the weed-free control for the entire growing season.

**Table 2.** Weed species found in the experimental site and their average densities in the two seasons.

WEEDS				
Scientific Name	Common Name	Family Name	Density (Plant m <sup>-2</sup> )	
			First Growing Season	Second Growing Season
<i>Avena sterilis</i> L.	Wild oat	Gramineae	90	166
<i>Cerastium dichotomum</i> L.	Forked mouse-ear chickweed	Caryophyllaceae	38	51
<i>Anthemis arvensis</i> L.	Mayweed	Compositae	11	10
<i>Silene conoidea</i> L.	Large sand catchfly	Caryophyllaceae	6	-
<i>Convolvulus arvensis</i> L.	Field bindweed	Convolvulaceae	3	51
<i>Hypericum triquetrifolium</i> Turra	St. John's wort	Hypericaceae	3	3
<i>Lens culinaris</i> Medik. (volunteer)	Lentil	Leguminosae	2	-
<i>Convolvulus althaeoides</i> L.	Mallow-leaved bindweed	Convolvulaceae	1	-
<i>Launaea nudicaulis</i> (L.) Hook. f.	Naked launaea	Compositae	1	-
<i>Moluccella laevis</i> L.	Bells of Ireland	Labiatae	1	-
<i>Papaver rhoeas</i> L.	Field poppy	Papaveraceae	1	-
<i>Polygonum aviculare</i> L.	Knotgrass	Polygonaceae	1	-
<i>Sinapis arvensis</i> L.	Wild mustard	Cruciferae	1	1
<i>Vicia</i> sp.	Vetch	Leguminosae	1	-
<i>Sonchus oleraceus</i> L.	Common sow thistle	Compositae	-	1
<i>Cardaria draba</i> L.	White top	Cruciferae	-	1
<i>Mercurialis annua</i> L.	Annual mercury	Euphorbiaceae	-	1

Almost similar trend in the effect of weeds on wheat straw yield was also obtained (Table 3). None of the weed-free periods gave straw yield similar to that of the weed-free control for the entire growing season (Table 3). Straw yield reduced more with longer weed competition periods. Generally, a long weed-free period increased straw yield, but the highest significant values obtained were when the crop was kept weed-free for 6 weeks or longer after emergence. The highest total wheat yield (grain and straw) obtained was when weeds competed with the crop not longer than 3 weeks after crop emergence and when kept weed-free for at least 6 weeks after emergence. Total wheat yield in these treatments was similar to that of the weed-free control (data not presented).

The effect of weed competition on weight of 1000 kernels showed no significant difference between the weed-free control, weed-infested crop up to 3 weeks after emergence and weed-free wheat for 7 weeks after emergence (Table 3).

Although crop height was almost similar in all weed-free treatments but was generally lower than that in weed-infested treatments, the differences were not significant (Table 3).

### 3.2.2. Weed Growth

Total weed-shoot dry weight increased at long competition periods with the highest weight obtained from weed-infested plots for the entire growing season (Table 3). However, the weed-shoot dry weight was not significantly changed at periods from 5 to 7 weeks after crop emergence. At harvest, none of the weed-free periods gave weed growth (in terms of shoot dry weight) similar to that of the weed-infested control. However, crop left weed-free for short periods (2 to 3 weeks after emergence) resulted highest weed growth among the weed-free periods.

The weed-shoot dry weight produced in response to both weed-infested and weed-free periods calculated as a percentage of weed-infested control is shown in Table 3. Weed growth was greater in weed-infested than in weed-free treatments.

**Table 3.** Effect of weed competition at different periods on wheat at Al-Jubeiha during the first year growing season.

Period after Emergence (Days)	Wheat				Weeds			
	Grain (kg ha <sup>-1</sup> )	% of the Weed Free Control	Straw (kg ha <sup>-1</sup> )	Plant Height (cm)	Weight of 1000 Seeds (g)	Broadleaf Dry Weight (kg ha <sup>-1</sup> )	Total Weed Dry Weight (kg ha <sup>-1</sup> )	% of Weed-Infested Control
Weed-Infested								
0	1163.5 ab*	100.00	4460.3 a	64.0 b-d	47.1 a	0.0	0.0 g	0.00
14	1000.0 a-c	85.95	3127.0 b	70.0 a-d	46.0 a	123.8	271.9 fg	9.97
21	1228.6 a	97.00	3365.1 b	71.0 a-c	45.3 b	67.5	342.4 e-g	12.55
28	680.4 c-e	58.48	2460.3 cd	74.0 a	42.0 c	266.3	711.8 d-g	26.09
35	746.0 c-e	64.12	2021.6 d-f	61.3 d	45.0 b	487.5	1606.1 bc	58.87
42	454.0 e	39.02	2158.7 d-f	66.0 a-d	44.5 bc	337.5	1313.6 b-d	48.15
49	588.3 de	50.56	2211.1 d-f	72.0 ab	42.9 bc	48.8	2047.5 ab	75.05
Weed-Free								
0	412.7 e	35.47	1825.4 e-g	71.0 a-c	43.0 bc	270.0	2728.1 a	100.00
14	666.7 c-e	57.30	1396.8 g	66.0 a-d	44.5 bc	206.3	1153.1 c-e	42.27
21	763.5 b-e	65.62	1640.6 fg	64.0 b-d	48.5 a	255.0	1640.6 bc	60.14
28	746.0 c-e	64.12	2253.9 de	66.0 a-d	44.0 bc	90.0	1628.1 bc	59.68
35	898.4 a-d	77.22	2454.9 cd	68.0 a-d	43.0 bc	105.0	1134.4 c-f	41.58
42	1031.7 a-c	88.67	3000.0 bc	62.0 cd	45.0 b	210.0	604.9 d-g	22.17
49	1174.6 a	100.95	3148.6 b	64.0 b-d	44.3 bc	168.8	609.4 d-g	22.33
LSD (p = 0.05)	399.9	-	573.3	9.0	2.9	-	869.4	-

\* Mean values in the same column followed by the same lower-case letter are not significantly different according to Fisher's LSD at  $p = 0.05$ .

### 3.3. Experiment 2 (Second Growing Season)

#### 3.3.1. Wheat Growth

Both wheat grain and straw yields were reduced with weed competition. Reduction in grain yield was by 24.6% and in straw yield by 20.7% of the wheat-free control (Table 4).

The grain yield was more reduced with weed-infested periods than straw yield. Weed infestation for 6 weeks after wheat emergence produced a grain yield that was not significantly different from that of the weed-free control for the entire growing season. A weed-free period for 4 weeks after crop emergence was enough to produce a grain yield similar to that of the weed-free control (Table 4). The grain yield of weed-free crop up to 3 weeks after emergence was not significantly different from that of the weed-infested control.

The effect of weed competition on wheat straw yield showed an almost-similar trend to that of grain yield, but with lower responses. Only weed infestation for the entire growing season significantly reduced straw yield. However, the weed-free period for 7 weeks after crop emergence increased straw yield by 40.08% compared with the weed-infested control, and by 11.04% over that of the weed-free control (Table 4).



**Table 4.** Effect of weed competition at different periods on wheat at Al-Jubeiha during the second-year growing season.

Period after Emergence (Days)	Grain (kg ha <sup>-1</sup> )	% of Weed-Free Control	Straw (kg ha <sup>-1</sup> )	Plant Height (cm)	Weight of 1000 Seeds (g)	Broadleaf Dry Weight (kg ha <sup>-1</sup> )	Total Weed Dry Weight (kg ha <sup>-1</sup> )	% of Weed Infested Control	Wild Oat Panicle No. m <sup>-2</sup>
WEED-INFESTED									
0	1632.5 <sup>ab*</sup>	100.00	4921.1 <sup>ab</sup>	94 <sup>b-d</sup>	44.2 <sup>a</sup>	0.0	0.0 <sup>g</sup>	0.00	0 <sup>c</sup>
14	1669.8 <sup>ab</sup>	102.28	4573.5 <sup>a-c</sup>	91 <sup>d</sup>	44.6 <sup>a</sup>	52.3	115.1 <sup>fg</sup>	10.25	9 <sup>bc</sup>
21	1858.4 <sup>a</sup>	113.84	5059.5 <sup>ab</sup>	98 <sup>ab</sup>	42.3 <sup>a</sup>	28.5	144.9 <sup>e-g</sup>	12.98	12 <sup>bc</sup>
28	1866.7 <sup>a</sup>	114.35	4789.7 <sup>a-c</sup>	93 <sup>cd</sup>	43.1 <sup>a</sup>	112.7	301.3 <sup>d-g</sup>	26.83	10 <sup>bc</sup>
35	1701.3 <sup>ab</sup>	104.21	4765.1 <sup>a-c</sup>	98 <sup>a</sup>	42.9 <sup>a</sup>	205.3	679.8 <sup>bc</sup>	60.53	9 <sup>bc</sup>
42	1766.3 <sup>ab</sup>	108.19	4658.7 <sup>a-c</sup>	98 <sup>ab</sup>	42.1 <sup>a</sup>	142.8	556.0 <sup>b-d</sup>	49.51	10 <sup>bc</sup>
49	1492.9 <sup>bc</sup>	91.45	4436.5 <sup>bc</sup>	98 <sup>ab</sup>	42.1 <sup>a</sup>	20.6	866.7 <sup>ab</sup>	77.18	11 <sup>bc</sup>
WEED-FREE									
0	1230.2 <sup>c</sup>	75.34	3900.8 <sup>c</sup>	97 <sup>bc</sup>	42.8 <sup>a</sup>	114.3	1123.0 <sup>a</sup>	100.00	53 <sup>a</sup>
14	1478.3 <sup>a-c</sup>	90.54	4988.1 <sup>ab</sup>	97 <sup>bc</sup>	41.7 <sup>a</sup>	87.3	488.1 <sup>c-e</sup>	43.46	21 <sup>a-c</sup>
21	1529.4 <sup>a-c</sup>	93.67	4746.0 <sup>a-c</sup>	96 <sup>bc</sup>	44.3 <sup>a</sup>	107.9	694.4 <sup>bc</sup>	61.83	43 <sup>ab</sup>
28	1642.9 <sup>ab</sup>	100.62	5097.3 <sup>ab</sup>	97 <sup>bc</sup>	42.5 <sup>a</sup>	38.1	265.9 <sup>d-g</sup>	23.68	26 <sup>a-c</sup>
35	1604.8 <sup>ab</sup>	98.29	4690.5 <sup>a-c</sup>	95 <sup>b-d</sup>	42.7 <sup>a</sup>	44.4	480.2 <sup>c-f</sup>	42.76	13 <sup>bc</sup>
42	1706.3 <sup>ab</sup>	104.50	4069.5 <sup>bc</sup>	102 <sup>a</sup>	43.3 <sup>a</sup>	88.9	256.0 <sup>d-g</sup>	22.80	9 <sup>bc</sup>
49	1598.3 <sup>ab</sup>	97.89	5464.3 <sup>a</sup>	94 <sup>b-d</sup>	41.7 <sup>a</sup>	71.4	256.3 <sup>d-g</sup>	22.82	7 <sup>c</sup>
LSD ( $p = 0.05$ )	347.6	-	966.0	4	3.4	-	368.0	-	35

\* Mean values in the same column followed by the same lower-case letter are not significantly different according to Fisher's LSD at  $p = 0.05$ .

The total (grain and straw) wheat yield was not significantly changed between weed-free control and weed-infested periods up to 7 weeks after emergence and between these and weed-free periods for 7 weeks after wheat emergence (data not presented).

Kernel weight was not significantly changed at any weed-infested or weed-free periods from that of the weed free-control, and the same was for crop height; however, wheat plants were higher in the second growing season (Table 4).

### 3.3.2. Weed Growth

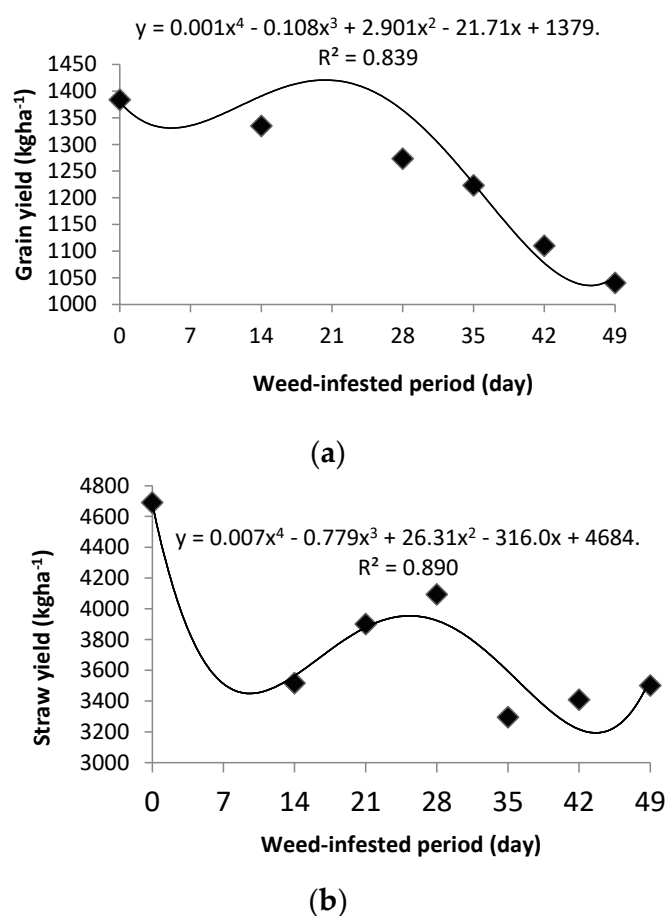
The weed-shoot dry weight increased with weed-infested periods (Table 4), but it did not significantly change at periods from 2 to 4 and 5 to 7 weeks after crop emergence. The highest weed growth was when weeds competed with crop plants until harvest. Differences however, in weed dry weight were not significant between weed-infested control and weeds competed for 7 weeks after crop emergence. On the other hand, weed dry weight was reduced with weed-free periods with the highest weight at 2 to 3 weeks weed-free periods after crop emergence (Table 4). The lowest weed growth obtained was at the longest weed-free periods (6 and 7 weeks after emergence).

Considering the weed-shoot dry weight calculated as a percentage of weed-infested control, weed response to weed-infested and weed-free periods is shown in Table 4. The weed-free period from 14 to 21 days after crop emergence was the period at which weeds exerted maximum effects on crop plants and weeds attained the highest growth and shoot dry weight among weed-free treatments.

### 3.4. Effect of Weeds on Average Wheat Growth and Yield in the Two Growing Seasons

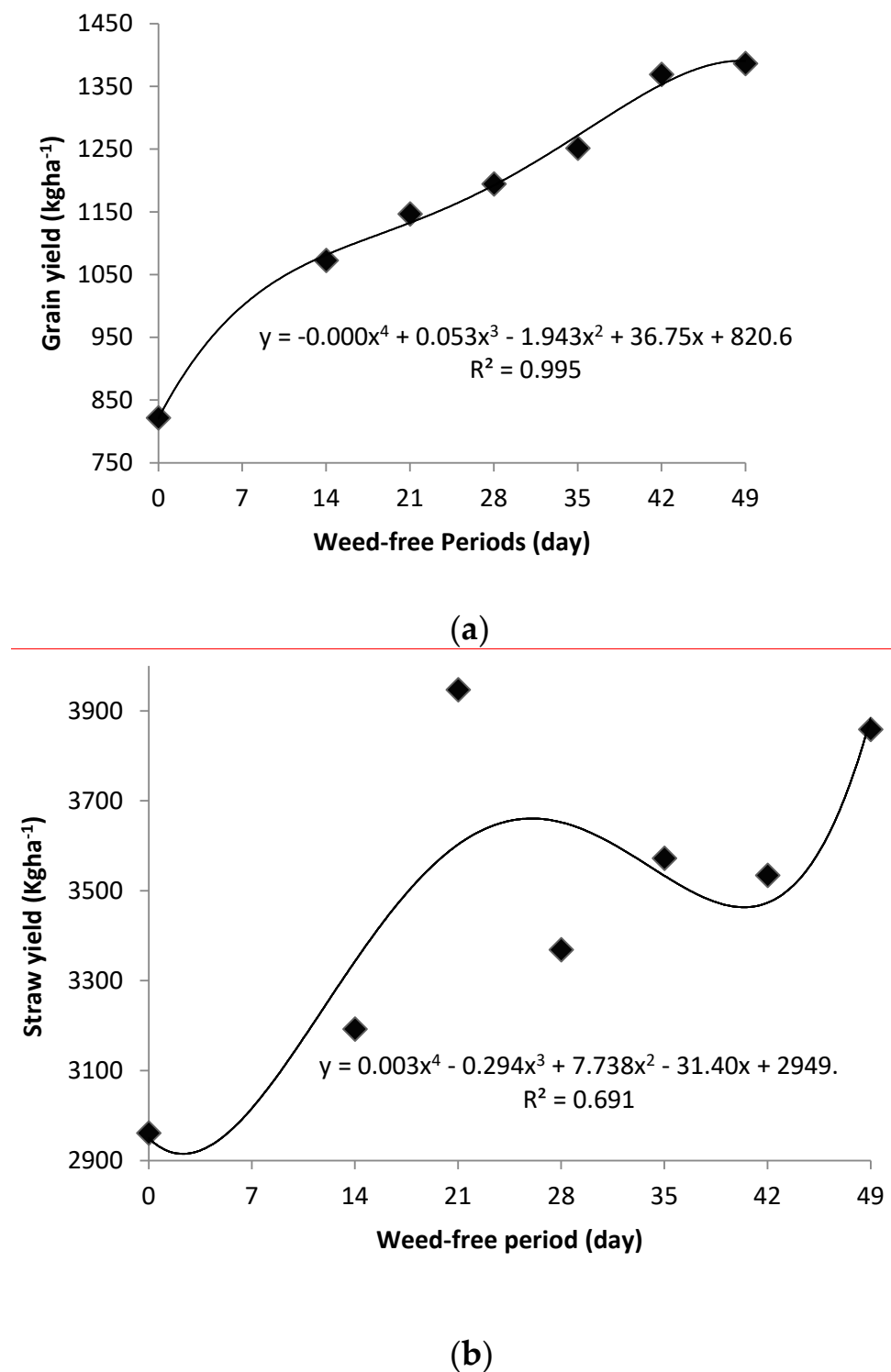
#### 3.4.1. Effect of Weed-Infested or Weed-Free Periods on Average Grain and Straw Yields of Both Growing Seasons

Weed competition for the entire growing season reduced average grain and straw yields by 41% and 37%, respectively (Figure 1a,b). The grain yield was reduced by 9.51% when plots were kept weed-infested for 28 days after crop emergence. Meanwhile, plots kept weed-free for a similar period provided 55.56% higher grain yield than that of the weed-infested control (Figure 2a). Both wheat grain and straw yields were dramatically decreased with weed competition for 14 days or longer periods after emergence (Figure 1a,b). A strong correlation coefficient ( $R^2 = 0.839$ ) was found between weed-infested periods and grain yield and between these and straw yield ( $R^2 = 0.89$ ). In contrast, the grain-yield line showed slight increases (not significantly changed) at weed-free periods from 14 to 28 days after emergence, and the straw yield showed almost a similar trend (Figure 2b) at periods from 28 to 42 days after emergence. However, weed-free treatment for any period increased both parameters compared with the weed-infested control. A stronger correlation coefficient ( $R^2 = 0.995$ ) between weed-free duration and average wheat grain yield was found than with straw yield ( $R^2 = 0.691$ ). Regression analysis of average grain yield against weed-shoot dry weight at different weed-free and weed-infested periods resulted in a linear decrease in crop yield with competition period, with coefficient of duration  $R^2 = 0.978$  ( $Y = 0.008 \times 4 - 0.878 \times 3 + 29.79 \times 2 - 347.4 \times 1925$ ) and a linear increase with weed-free period. Wheat grain yield decreased, and weed biomass increased in weed-infested treatments, and the opposite was true in the weed-free treatments.



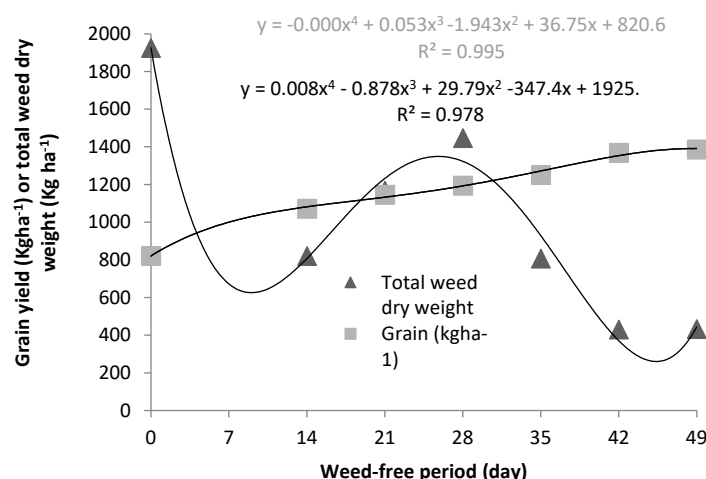
**Figure 1.** Effect of weed-infested periods on (a) average grain yield and (b) straw yield of the two growing seasons.





**Figure 2.** Effect of weed-free periods on average grain (a) and straw (b) yields of the two growing seasons.

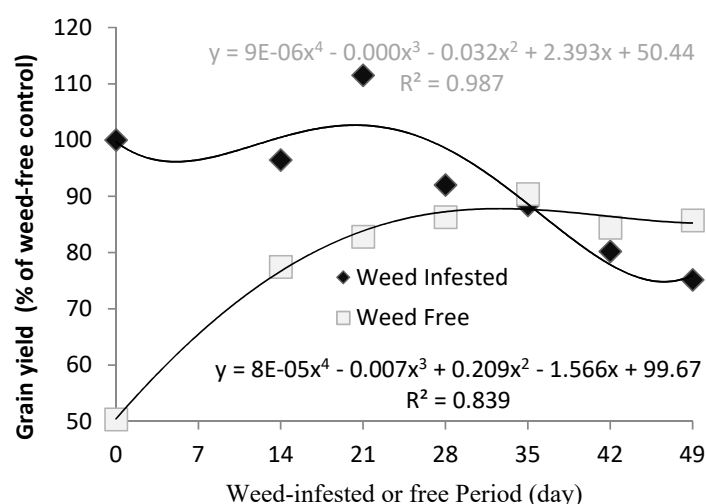
Grain yield losses decreased as the weed-free period increased and weed dry weight decreased, with the least weed growth (<22.2% of weed-infested control) at 36 days into the weed-free period (Figure 3). At this point, wheat grain yield was maximum. Late weed competition did not affect wheat grain yield as that at early competition.



**Figure 3.** Effect of weed-free periods on average grain yield or total weed dry weight for two growing seasons.

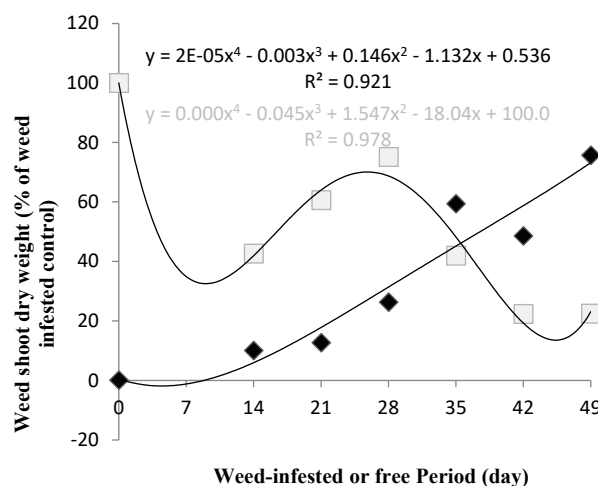
### 3.4.2. Effect of Weed-Infested and Weed-Free Periods on Average Grain Yield of Both Seasons

The average grain yield of wheat in weed-infested and weed-free treatments is shown in Figure 4. Trends in wheat yields and weed growth at different periods of weed-infested and weed-free treatments were similar to those shown for the effect in each season separately. Generally, average wheat grain yield was strongly and negatively correlated with weed-infested period ( $R^2 = 0.978$ ) and increased with weed-free periods ( $R^2 = 0.995$ ). The highest yield obtained was from crop kept weed-free for the whole growing season and the lowest from weed-infested plots for the entire growing season. However, drastic reduction in grain yield was obtained with weed-infested periods, while the response of wheat yield increases was slow in the weed-free treatments. The  $R^2$  for the nonlinear relationship between wheat grain yield and the period of competition was 0.839. Based on the arbitrary 5% level of grain yield loss, the critical period of weed competition occurred between 0 and 49 days after wheat emergence (Figure 4).



**Figure 4.** Wheat grain yield as affected by increasing durations after emergence of the crop maintained as either weed free (□) or weed-infested (◆). The critical period of weed competition (CPC) is the interval between time after emergence for which weed emergence reduced yields by 5% and time after emergence at which crop had to be maintained weed-free to prevent a 5% yield loss. Curves based on average combined data of two years.

Results showed that yield loss was progressively greater with a longer duration of weed competition. However, substantial amounts of weed dry weight were produced, particularly at longer competition periods or shorter weed-free periods (Figure 5).



**Figure 5.** Weed dry weight as affected by increasing durations of weed-free (□) or weed-infested (◆). Weed dry weights were measured at the various times of weed removal for plots initially infested with weeds and at harvest for the treatments kept weed-free until a specified period. Data are average of two years.

### 3.4.3. The Critical Period of Weed Competition

Parameters for equations depicting the critical time of weed removal and the critical weed-free period in wheat are summarized in Table 5. The  $R^2$  for nonlinear relationship between wheat grain yield and the period of competition equals 0.511 for the logistic equation and 0.745 for the Gompertz equation.

**Table 5.** Parameter estimates and correlation coefficient for logistic equation used to fit grain-yield data for increasing weed-infested period (from time of emergence) and parameter estimates for the Gompertz equation used to fit yield data for increasing weed-free period (after emergence).

Logistic Parameters					Gompertz Parameters			
F	D	K	X	$R^2$	A	B	K	$R^2$
542.96	0.0043	0.1234	−0.039	0.511	0.00049	3,210,052	14.92	0.745

In this study, the beginning of the critical period was defined as the time after crop emergence by which weed competition reduced yields by 5%. Similarly, the end of the critical period was defined as the period at which the crop must remain free of weeds to prevent grain yield loss from exceeding 5%. Based on average grain yield loss in the two growing seasons, the critical period of weed competition occurred between 0 and 49 days after wheat emergence (Table 6).

**Table 6.** The onset and the end of the critical period of weed competition for three levels of grain yield loss in wheat from the logistic and Gompertz equations.

Logistic			Gompertz		
Time of Indicated %Yield Loss			Time of Indicated %Yield Loss		
2.5%	5%	10%	2.5%	5%	10%
0	0	0	49	49	49

Results showed that yield loss was progressively greater with a longer duration of weed competition. Meanwhile, the onset of competition did not vary at a 2.5–10% level of grain yield losses, and the end was the same (49 days) after wheat emergence.

#### 4. Discussion

Wheat suffers most from weed competition that can severely reduce yield quantity and quality [1]. Different weed species are usually associated with wheat [40], but narrow-leaved weeds and mainly grasses represent a real threat to crop growth and productivity. Wild-oat morphological and physiological similarities and growth requirements to wheat plants increased their dominance in absence of selective and effective herbicides, crop rotation, and difficulty in differentiating the weed from crop plants by untrained labors early in growth.

Weed competition for the entire growing season reduced average grain yield by 41% and straw yield by 37% compared with the weed-free control. Other workers reported 16–75% wheat yield reduction and low quality due to wild-oat competition [11–13]. However, the longer the weed competition period, the more there are negative effects of the weed on wheat grain and straw yields (Tables 3 and 4).

The critical period of weed competition in wheat is rarely determined based on weed competition duration, but general weed-competition studies based on emergence time of competing species, weed and crop densities, or weed/crop density ratios are varied [14–16]. Reduction in grain yield was comparable to that reported by other workers at similar weed densities [11,12]. In the present work, the dramatic grain yield reduction in weed-infested treatments and the slow response of the crop to weed-free periods indicate the strong competition effect that the weed exerted on crop plants. Higher wheat plants in weed-infested plots than in weed-free plots (Table 3) indicate a strong competition for light. In dense weed population, phenotypic plasticity is an important character that allows crop plants to elongate and trap light.

Considering the average data of two years of experiments, it is clearly demonstrated that weed competition for any period after crop emergence seriously reduced wheat grain and straw yield (Figure 1a,b), while weed-free periods longer than 14 days after emergence increased crop grain yield (Figure 2a). In most cases, early weed competition is irreversible and cannot be compensated by adding more resources or late weed control [41]. Weed removal failed to overcome competition effects after certain periods, and the crop did not recover from weed competition. Moreover, keeping the crop weed-free for certain periods did not eliminate the competition effects of the late emerged weeds (Figure 2a,b) except at the longest period or when weed infestation was only for a short time.

Weed shoot dry weight was almost doubled at each increment increase in weed competition period (Figure 5) but greatly reduced after each weed-free period and not substantially changed at periods longer than 28 days after crop emergence. This indicates that wheat plants suffer from weed competition shortly after emergence but can effectively suppress weeds when maintained weed-free for even 14 days after emergence. These results were compatible with the findings of other workers emphasized the importance of weed removal early in the season [42]. Wheat has been mentioned as one of the good competing crops when establish free from weeds for a relatively short period after emergence [43]. However, results showed that delay in weed removal for 14 days after crop emergence resulted average grain yield loss by 42% (Figure 4), while crop grain yield loss was reduced with weed-free period. It seems that weeds could not tolerate the shading effects offered by wheat plants to effectively compete when the crop had an initial start. This was demonstrated from the high reduction (>58% of the weed-infested control) in weed dry weight obtained as a result of delay in weed emergence for 14 days after crop emerged. Total biomass of weeds emerged thereafter was less than 12% that of the weed-infested control (Figure 5). The critical period of weed competition coincides with the beginning of duration increase in weed dry weight. However, this period may last longer for lower levels of grain yield loss (Table 4). The determined period, however, occurred before the

crop-tillering stage, which in turn supports data obtained on crop growth and yield. At a longer weed-free period than 42 days after crop emergence, it was possible to maintain a crop yield comparable to that of the weed-free control, since competition for moisture and nutrients was lessened early in crop growth. Wheat plants after this period enter into a full tiller resting stage, with good growth and resource accumulation allowing regrowth, active cell division, and stem elongation. However, any wild oat plants left during or after the crop tillering stage were greatly influenced, and the number of panicle-shedding seeds for re-infestation was reduced and can be easily and selectively removed, using other methods of weed control, including herbicides. However, the timing of weed removal is influenced by wheat cultivar, planting density, agricultural practices, dominant weed species (wild oat) and its density, prevailing environmental conditions, and weed population composition. Wheat cultivars were found different in competition with weeds (including *A. sterilis*) [12,44,45] and in responses to growth factors [45]. The “Hourani” wheat cultivar used in this study is not among the strong competing cultivars grown in Jordan and thus might have greatly suffered from weed competition [46]. Hucl [47] stated that the tillering capacity of wheat cultivars is extremely important in the competition against weeds. Certainly, the flush of weeds emerging after the occurrence of the critical period of weed competition would need to be controlled in order to prevent re-infestation. Wheat suppressed development of the late-emerging weeds; hence, the weed dry weight at harvest was greatly reduced by 87% when wheat was kept weed-free until 21 days after emergence. It is obviously shown that wheat can withstand late weed competition better than at early competition, but when plots were initially kept weed-free, the grain yield loss was greatly reduced, indicating that weeds that emerged after the initial weed-free period had a very low effect on crop yield. These results agreed with those of Dimson [48]. Weed-shoot dry weight proved to be a good indicator of weed competition. The differences in weed-shoot dry weight between the two lines in Figure 5 represent the suppressing effect of wheat upon the weeds. The long critical period of weed competition indicates a greater yield loss due to weed-competition durations. However, this period is likely conservative and may be extended with less competitive weed species and a more competitive crop cultivar, or with different agricultural practices.

Results indicated that weed competition for a short period early in the season is serious and causes significant yield loss, and thus it leaves no alternative to complete weed removal to avoid crop growth and yield reductions. These results agreed with the findings of Singh and Bajpai [19], who reported that 4 weeks of hand-weeding at 25–70 days after sowing resulted in the best weed control and highest wheat yield. All weed-infested and weed-free treatments failed to give straw yield similar to that of the weed-free control in the first growing season (Table 3), but generally weed-free periods in the second season gave similar or more straw yield than the weed-free control (Table 4). These results may be due to the fact that the average annual rainfall in the first growing season was almost doubled, better distributed, and conserved compared with that of the second season. High rainfall in the first season aggravated weed-competition effects on crop growth and grain yield, as compared with the second season. Total weed-shoot dry weight in the second season was only 41.2% that of the first growing season. This, however, resulted in more wheat growth suppression and yield reductions and doubled weeds’ dry-matter production. It has been reported that wild oat affected grain yield more than straw weight and wheat development, productivity, and total accumulation of N and P all effected, whereas, in the weed, the competition offered by crop plants affected straw yield more than grain yield [49]. Results of the present study may confirm the high level of water needed for the high growth and competitiveness of wild oat.

The tendency of crop plants to give high growth or yield shortly after the start of weed infestation results from the fact that crop plants tend to expand resource capture or conversion efficiency in response to early or short weed-competition periods or to low weed density. However, this crop competitive advantage is rapidly dissipated at longer competition periods or at higher weed densities.

Torner et al. [50] reported that, as the density of *A. sterilis* increased, barley yield decreased exponentially. This relationship between weeds and crop plants occasionally occurs, since weeds have more chances to exhaust crop growth by removing more resources and exert more smothering effects on crop plants. However, most annual and effective weed species, including wild oat, tend to complete their life cycle earlier than crop plants, shedding seeds and thus ensuring their existence in the environment. Therefore, low shoot dry weight of weeds in weed-infested control or at long weed competition periods was found since weeds matured, dried and wind-blown before harvested. This was well demonstrated in the first growing season, which received a high average rainfall.

## 5. Conclusions

Early weed competition harmed wheat and lowered crop grain and straw yield. Wheat must be kept weed-free for at least 42 days after emergence in order to prevent significant grain yield loss. High rainfall in the first growing season doubled wild oat growth and, thus, its competition effects. Considering average grain yield of the two growing seasons, the critical period of weed (dominated by wild oat) competition occurred at 0–49 days after crop emergence. In both growing seasons, weeds emerged after weed-free periods attained low growth in general, and their competition effects on crop plants appeared lower than the weed-infested crop early in the season. These results confirm the importance of weed control early in the season in order to avoid crop yield reduction. Future research work may test the competitive abilities of different wheat cultivars in the country and possible introduction of certain plant species, including segetal weeds, that keep pathogens away from crop plants, favor pollination of cereals and propose specific actions for the introduction/reintroduction of the other disappeared or rare segetal species at field level [51]. This approach is becoming more important, considering possible future scenarios when intensive farming is possibly changed to an extensive and organic farming with a lower environmental impact [52,53]. These crop or weed species can effectively compete with *A. Sterilis* and reduce its impact on wheat crop. This however, may be also achieved by following an effective crop rotation or intercropping system.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The author thanks Abeer Brash and Madi Al-Abaddi for their technical assistance.

**Conflicts of Interest:** The author declares no conflict of interest.

## References

1. Qasem, J.R. Chemical control of wild-oat (*Avena sterilis* L.) and other weeds in wheat (*Triticum durum* Desf.) in Jordan. *Crop Prot.* **2007**, *26*, 1315–1324. [CrossRef]
2. Khoury, H.Y.; Jordan: Grain and Feed Annual; GAIN Report Number: JO4004; USDA Foreign Agricultural Service. Grain Report, Global Agriculture Information Network, Required Report Public Distribution: 6 October 2004. US Embassy. Available online: <http://www.fas.usda.gov/graifiles/200411/146117914.doc> (accessed on 13 December 2004).
3. Available online: [http://www.dos.gov.jo/owa-user/owa/FOCAL\\_AGR.agr\\_kk?LANG=Eanddis=2](http://www.dos.gov.jo/owa-user/owa/FOCAL_AGR.agr_kk?LANG=Eanddis=2) (accessed on 30 June 2021).
4. Available online: <https://www.jordantimes.com/news/local/wheat-production-expected-increase-twofold-> (accessed on 25 July 2021).
5. Jordan—Wheat Production Quantity. Available online: <https://knoema.com/atlas/Jordan/topics/Agriculture/Crops-Production-Quantity-tonnes/Wheat-production> (accessed on 29 June 2021).
6. Department of Statistics (DoS). *Agricultural Statistical Year Book, and Agriculture Sample Survey*; Department of Statistics (DoS): Amman, Jordan, 1980.
7. Wheat Reserves Boosted by New Silos—Ministry. Available online: <http://www.jordantimes.com/news/local/wheat-reserves-boosted-new-silos-%E2%80%94-ministry> (accessed on 10 July 2021).
8. Fernandez-Quintanilla, C.; Navarrete, L.; Torner, C.; Sanchez del Arco, M.J. *Avena sterilis* en cultivos de cereales. In *Biología De Las Malas Hierbas De Espana*; Sanz, F.X., Fernandez-Quintanilla, C., Eds.; Phytoma Espana: Valencia, Spain, 1997; pp. 11–23.



9. Barroso, J.; Fernandez-Quintanilla, C.; Ruiz, D.; Hemaize, P.; Rew, L.J. Spatial stability of *Avena sterilis* ssp. *Ludoviciana* populations under annual applications of low rates of imazamethabenz. *Weed Res.* **2004**, *44*, 178–186. [\[CrossRef\]](#)
10. Gonzalez Ponce, R. Competition for nitrogen and phosphorus between wheat and wild oat (*Avena sterilis* L.) according to the proximity of their time of emergence. *Plant Soil* **1987**, *102*, 133–136. [\[CrossRef\]](#)
11. Dhima, K.V.; Eleftherohorinos, I.G. Influence of nitrogen on competition between winter cereals and sterile oat. *Weed Sci.* **2001**, *49*, 77–82. [\[CrossRef\]](#)
12. Balyan, R.S.; Malik, R.K.; Panwar, R.S.; Singh, S. Competitive ability of winter wheat cultivars with wild-oat (*Avena ludoviciana*). *Weed Sci.* **1991**, *39*, 154–158. [\[CrossRef\]](#)
13. Wilson, B.J. Post-emergence control of wild-oats in Queensland with difenzoquat, flamprop-methyl, diclofop-methyl and barban. *Aust. J. Exp. Agric.* **1979**, *19*, 108–117. [\[CrossRef\]](#)
14. Zanin, G.; Berti, A.; Toniolo, L. Estimation of economic thresholds for weed control in winter wheat. *Weed Res.* **1993**, *33*, 459–467. [\[CrossRef\]](#)
15. Hoesle, U.M. Studies on the Weed Competition in Moroccan Wheat Crops with Particular Regard to the Water Factor. Ph.D. Thesis, Universitat Hohenheim, Stuttgart, Germany, 1981; pp. 117–123.
16. Saavedra, M.M.; Jimenez-Hidalgo, M.J.; Gacia-Torres, L. Wild oats (*Avena sterilis* subsp. *sterilis*) and wheat (*Triticum aestivum* L.) competition in southern Spain: A methodological approach. In Proceedings of the EWRS Symposium Integrated Weed Management in Cereals, Helsinki, Finland, 4–6 June 1990; European Weed Research Society: Wageningen, The Netherlands, 1990; pp. 231–238.
17. Gonzalez Ponce, R.; Hernando, V. Wild oat competition in wheat at different levels of infestation and different stage of development of both species. In *Escarda Quimica en Cultivos Herbaceos Extensivos: VIII Jornada de Estudio de la Association Interprofesional Para el Desarrollo Agrario*, 1976; Inst. De Edafologia y Biologia Veg: Saragossa, Spain, 1977.
18. Dordio, U.; Dordio, M.F.; Madeira, J.M. Wild oats—A weed of wheat fields levels of infestation. In Proceedings of the Congresso Portugues de Fitiatría e de Fito farmacologia e III Simposio Nacional de Herbologie, Lisboa, Portugal; 1981; Volume 1, pp. 223–236.
19. Singh, V.K.; Bajpai, R.P. Crop-weed competition in dwarf wheat under hill zone of Chhattisgarh-MP. *Curr. Res.-Univ. Agric. Sci.* **1992**, *21*, 43–44.
20. Gonzalez; Ponce, R.; Correa, M. Effect of *Avena sterilis* in *Triticum vulgare*. In Proceedings of the Compte Rendu de la 10 Conference du Columa, Paris, France, 1979; pp. 401–406.
21. Nieto, J.H.; Brondo, M.A.; Gronzalez, J.T. Critical period of the crop growth cycle for competition from weeds. *Pest Artic. News Summ. Sect. C* **1968**, *14*, 159–166. [\[CrossRef\]](#)
22. Zimdahl, R.L. *The Concept and Application of the Critical Weed-Free Period*; CRC Press Inc.: Boca Raton, FL, USA, 1988; pp. 145–155. ISBN 08-493-68162.
23. Refsell, D.E. Integrated Weed Management in Kansas Winter Wheat. Ph.D. Thesis, Department of Agronomy, College of Agriculture, Kansas State University, anhattan, KS, USA, 2013; p. 88.
24. Weaver, S.E. Critical period of weed competition in three vegetable crops. *Weed Res.* **1984**, *24*, 317–325. [\[CrossRef\]](#)
25. Crook, T.M.; Renner, K.A. Common lambsquarters (*Chenopodium album*) competition and time of removal in soybeans (*Glycine max*). *Weed Sci.* **1990**, *38*, 358–364. [\[CrossRef\]](#)
26. Qasem, J.R. Pigweed (*Amaranthus* spp.) interference in transplanted tomato (*Lycopersicon esculentum*). *J. Hort. Sci.* **1992**, *67*, 421–427. [\[CrossRef\]](#)
27. Gantoli, G.; Ayala, V.R.; Gerhards, R. Determination of the critical period for weed control in corn. *Weed Technol.* **2013**, *27*, 63–71. [\[CrossRef\]](#)
28. Odero, D.C.; Wright, A.L. Critical period of weed control in snap bean on organic soils in South Florida. *HortScience* **2018**, *53*, 1129–1132. [\[CrossRef\]](#)
29. Merino, J.; Pedreros, A.; Fischer, S.; López, M.D. Critical period of weed interference on total polyphenol content in quinoa. *Chil. J. Agric. Res.* **2019**, *79*, 405–414. [\[CrossRef\]](#)
30. Terefe, H.; Denberu, E.; Woldeesenbet, A. Effects of different weeding time of ryegrass on growth and yield components of wheat (*Triticum* spp.) in Jimma Are, South West Ethiopia. *Int. J. Res.-Granthaalayah* **2016**, *4*, 111–117. [\[CrossRef\]](#)
31. Agostinetto, D.; Rigoli, R.P.; Schaedler, C.E.; Tironi SP e Santos, L.S. Período crítico de competição de plantas daninhas com a cultura do trigo1. *Planta Daninha Viçosa-MG* **2008**, *26*, 271–278. [\[CrossRef\]](#)
32. Chaudhary, S.U.; Hussain, M.; Ali, M.A.; Iqbal, J. Effect of weed competition period on yield and yield components of wheat. *J. Agric. Res.* **2008**, *46*, 47–53.
33. Ali, H.; Tahir, M.; Nadeem, M.A. Determining critical period of weed competition in wheat under different tillage systems. *Pak. J. Life Soc. Sci. (PJLSS)* **2014**, *12*, 74–79.
34. Silva, A.A.P.; Oliveira NETO, A.M.; Naiara, G.; Karpinski, R.A.K.; Maciel, C.D.G. Weed interference periods in early wheat in the Midwest of Parana. *Planta Daninha Viçosa-MG* **2016**, *34*, 291–298. [\[CrossRef\]](#)
35. SAS Institute Inc. *SAS/STAT®9.1 User's Guide; Ver. 9.1*; SAS Institute Inc.: Cary, NC, USA, 2004.
36. Hall, M.R.; Swanton, C.J.; Anderson, G.W. The critical period of weed control in grain corn (*Zea mays*). *Weed Sci.* **1992**, *40*, 441–447. [\[CrossRef\]](#)
37. Cousens, R. Misinterpretation of results in weed research through inappropriate use of statistics. *Weed Res.* **1988**, *28*, 281–289. [\[CrossRef\]](#)

38. Knezevic, S.Z.; Evans, S.P.; Blankenship, E.E.; Van Acker, R.C.; Lindquist, J.L. Critical period for weed control: The concept and data analysis. *Weed Sci.* **2002**, *50*, 773–786. [CrossRef]
39. Ratkowsky, D.D. *Handbook of Nonlinear Regression Models*; Dekker: New York, NY, USA, 1990.
40. Qasem, J.R. Weed Management in wheat. In *Wheat: Genetics, Crops and Food Production. Agriculture Issues and Policies*; Maria, T.M., Ed.; Nova Science Publishers: New York, NY, USA, 2011; pp. 1–79. ISBN 978-1-61209-307-9.
41. Qasem, J.R. *Weeds and Their Control*; University of Jordan Publications: Amman, Jordan, 2003; p. 628.
42. Zimdahl, R.L. *Weed-Crop Competition. A Review*; International Plant Protection Center, Oregon State University: Corvallis, OR, USA, 1980; 196p.
43. Anonymous. IPM Series No. 15. 2000. Available online: <http://ag.arizona.edu/pubs/crops/az1197.pdf> (accessed on 10 July 2020).
44. Ponce, R.G.; Lamela, A.; Salas, M.L. Effect of nitrogen and herbicide on grain yield and protein content of a tall and semi-dwarf wheat (*Triticum aestivum*) cultivar in semi-arid conditions. *Dev. Plant Soil Sci.* **1990**, *41*, 565–568.
45. Ponce, R.; Santin, I. Competitive ability of wheat cultivars with wild oats de-pending on nitrogen fertilization. *Agronomie* **2001**, *21*, 119–125. [CrossRef]
46. Qasem, J.R.; Tell, A.M. Response of some wheat cultivars to weeding and fertilizer treatments. *Dirasat* **1993**, *20B*, 63–74.
47. Hucl, P. Response to weed control by four spring wheat genotypes differing in competitive ability. *Can. J. Plant Sci.* **1997**, *78*, 171–173. [CrossRef]
48. Dimson, E.V. Cauliflower Production in Arizona, Weeds. 2001. Available online: <http://pestdata.ncsu.edu/cropprofiles/docs/azcauliflower.html> (accessed on 20 March 2009).
49. Gonzalez Ponce, R.; Fernandez, H. Effect of time of sowing *Triticum vulgare* L. and level of *Avena sterilis* L. infestation in competition between the two species. *An. Edafol. Y Agrobiol.* **1978**, *37*, 839–852.
50. Torner, C.; Gonzalez Andujar, J.L.; Fernandez-Quintanilla, C. Wild oat (*Avena sterilis* L.) competition with winter barley: Plant density effects. *Weed Res.* **1991**, *31*, 301–307. [CrossRef]
51. Perrino, E.V.; Calabrese, G. Endangered segetal species in southern Italy: Distribution, conservation status, trends, actions and ethnobotanical notes. *Resour. Crop. Evol.* **2018**, *65*, 2107–2134. [CrossRef]
52. WWW International. Risk and Resilience in a New Era. In *Living Planet Report 2016*; WWW International: Gland, Switzerland, 2016.
53. Food and Agriculture Organization of The United Nations (FAO). *The Future of Food and Agriculture–018-0678-6 Trends and Challenges*; FAO: Rome, Italy, 2017.