Agronomy Research **19**(1), 13–27, 2021
https://doi.org/10.15159/AR.20.236

Effect of zero tillage and different weeding methods on grain yield of durum wheat in semi-arid regions

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Received: September 28th, 2020; Accepted: December 1st, 2020; Published: December 10th, 2020

Abstract. The high grain yield of wheat is limited by the dominance of weeds, particularly wild oat. Therefore, to improve wheat yield under these conditions, a field experiment was carried out in Maru Agricultural Research Station, Jordan during 2015–2016 and 2016–2017 to investigate yield response of two wheat varieties (*Triticum durum* L.) to different tillage and weeding treatments. The experimental design used was a split-split arrangement in a randomized complete block design with three replicates. Two-tillage treatments (conventional vs. zero tillage) were applied to the main plot, two wheat varieties to sub-plot, and five weeding methods (hand weeding, broadleaf + narrow leaf herbicide, broadleaf herbicide, narrow leaf herbicide, and controls) as a sub-sub-plot. The variety 'Umqais' had higher plant height, biological, grain, and straw yield than the variety 'Sham'. Hand weeding slightly increased grain yield compared with mixed herbicides (the 2,4-D plus Antelope Clodinatop- propagyl). Furthermore, mixed herbicides presented a higher grain yield than using either single herbicide. The interaction between tillage systems and weeding methods was significant in both years. The highest ($P < 0.05$) straw yield (5,990 kg ha^{-1}) was obtained by hand weeding under conventional tillage in the first season while the highest grain yield (2,005 kg ha^{-1}) was obtained by hand weeding under zero tillage in the second season. Under all weed control treatments, the variety 'Umqais' had higher biological, grain, and straw yields than the variety 'Sham' in the second season indicating that variety 'Umqais' performed better under dry conditions. Our results confirmed the superior of zero tillage for increasing the grain yield of the variety 'Umqais', and for increasing the biological and straw yields of the variety 'Sham' under semi-arid rainfed conditions of Jordan.

Key words: biological yield, broadleaf herbicide, conventional tillage, hand weeding, variety x tillage interaction.

INTRODUCTION

Wheat (*Triticum durum*) is the most important field crop grown under rainfed conditions in Jordan and considered essential for food security at the national and the global level. With the increase in world population, there is an increasing demand for wheat. At the global level, the production of wheat has improved intensely from

218.5 million tons in 1961 to 728.4 million tons in 2019 (FAO, 2019a). In 2018, the average area planted with wheat in Jordan was 20 thousand hectares, producing about 25 thousand tons of grains. Jordan imported about 900 thousand tons of wheat (FAO, 2019b).

The primary limitation for the high grain yield of wheat is the low soil moisture and the prevalence of weeds as the main obstacles under rainfed conditions in Jordan. Weeds strongly compete with wheat plants for light, nutrients, and moisture which negatively reduce grain productivity of wheat (Shah et al., 2018). Both broadleaf and narrow leaf weeds result in a decrease in soil moisture and consequently the crop grain yield (Tawaha et al., 2002). Both narrow (grassy) and broad-leaved weeds infest wheat. Among grassy weeds, wild oat (*Avena fatua*) and among broadleaf weeds, fennel (*Foeniculum vulgare*), chicory (*Cichorium spp*.), common groundsel (*Senecio vulgaris*) are of major concern in wheat friel grown rainfed in Jordan. Specifically, wild oat (*Avena spp*.) is a serious problem in wheat fields, particularly in the northern part of Jordan (Turk & Tawaha, 2002).

Hand weeding is a mechanical method used for weed control and management. This weed control method was more effective than herbicide application in suppressing the growth of weed and increasing yield (Tawaha et al., 2002; Sultana et al., 2012; Shah et al., 2018). Usually, the assessment has been done for annual weeds which are propagated by rhizomes and effectively controlled by frequent plowing. However, in wheat-based areas, the most common weeds are annual weeds of the Compositae family and Poaceae family. Nevertheless, hand weeding is not economical nowadays because of the high labor cost and wages. Therefore, chemical control of weeds became potential and caused better weed control and crop yield with the advent of herbicides (Turk & Tawaha, 2003). Several researchers have confirmed the efficiency of herbicides for weed control and increasing grain yield of wheat (Bibi et al., 2008, Mandal et al., 2014).

Many researchers have reported the impact of tillage systems on the grain yield of wheat in recent years (Yang et al., 2018; Xue et al., 2019). In Jordan, conventional tillage (CT) and zero tillage (ZT) systems are being used as described by Al-Issa & Samarah (2006). However, the effect of ZT on crop yield is controversial. Some researchers showed similar yields (Büchi et al., 2017) or yield reductions (Pittelkow et al., 2015) in ZT systems compared to the CT systems. The ZT system may have a positive impact over the CT system with specific soil, climate, and management conditions (Martínez et al., 2008; Taner et al., 2015). The ZT can improve soil structure and reduce the risk of soil erosion, leading to better water infiltration and water-use efficiency (Honsdorf et al., 2020).

The impact of tillage systems and weed control management on the yield of wheat and other crops have been studied previously (Chhokar et al., 2007; Usman et al., 2010; Kumar et al., 2013; Upasani et al., 2014; Ali et al., 2016; Susha et al., 2018; Hofmeijer et al., 2019). Winter wheat under ZT had a higher yield than that under CT when wheat was grown after either pea or spring wheat at intermediate or extensive weed control management (Young et al., 1994). Ali et al. (2016) found that a one tillage practice in a fallow year using moldboard plow resulted in the highest plant height, biological and grain yield, and harvest index of wheat. However, tillage followed by a two-time application of herbicides resulted in a maximum 1,000- grain weight of wheat (Ali et al., 2016). The best chemical method to control grasses and broadleaf weeds and to achieve a higher grain yield of wheat was using affinity herbicides in combination with zero

tillage (Usman et al., 2010). Mixed herbicides were the best treatment for controlling weeds and improving wheat yield in ZT (Chhokar et al., 2007).

A few studies have been done in Jordan to identify the best weed control method under different tillage systems. Therefore, two-field experiments were carried out in northern Jordan to study the interaction effect of tillage systems and weeding methods on the growth and grain yield of two-wheat varieties grown under rainfed conditions of Jordan.

MATERIALS AND METHODS

Study site and soil

Field experiments were carried out at Maru Agricultural Research Station (MARS) which belongs to National Agricultural Research Center (NARC), Jordan during the growing years of 2015–2016 and 2016–2017 under dryland farming conditions. MARS is located in Maru, Irbid at 32° 33′N latitude, 35° 51′ E longitude, and 589 m above sea level (Al-Ghzawi et al., 2018). Maru is characterized by hot and dry summer and mild winter with 380 mm annual precipitation and represents an intermediate drought region. Before sowing, samples of soil were collected and analyzed for chemical characteristics from the experimental site (Table 1). The soil at the experimental site is Red Mediterranean Soil (RMS) type. The soil is classified as Cambisol Vertisol (Vertic, Calcic, Chromic, Luvic, Haplic, Cambic) according to World Reference Base (WRB). Soil Texture: clay (Clay 56.2%, Silt 33.8%, Sand 10.00%).

Table 1. Soil characteristic of the experimental site

Parameters	Unit	Value
pH	-	7.75
EC	(ds/m)	0.42
P	(ppm)	0.79
K	(ppm)	194
$CaCO_3$	(%)	1.90
N	(%)	0.097
Clay	(%)	56.2
Silt	(%)	33.8
Sand	(%)	9.95
Organic matter	(%)	0.76
Texture	-	Clay

Weather data at the experimental site in both seasons were shown in Table 2. The total annual precipitation in both growing seasons, 2015–2016 and 2016–2017 was 410.8 and 309.2 mm, respectively.

Table 2. Weather data during the growing seasons of 2015–2016 and 2016–2017

Growing season 2015–2016				Growing season 2016–2017			
Year	Month	T (°C)	Rainfall (mm)	Year	Month	T (°C)	Rainfall (mm)
2015	Oct.	21.73	16	2016	Oct.	21.94	2
	Nov.	15.27	31.5		Nov.	13.70	0.8
	Dec.	9.43	22.9		Dec.	8.58	190
2016	Jan.	8.21	222	2017	Jan.	7.78	63.6
	Feb.	10.19	53.4		Feb.	8.70	23.2
	Mar.	13.77	54		Mar.	12.71	19.2
	Apr.	19.41	11		Apr.	17.53	9.8
	May	21.23	0		May	21.85	0.6
	June	26.3	0		June	26.7	0
Total		-	410.8	Total		-	309.2
Mean		16.2		Mean		15.5	

Treatments

Two tillage systems were applied to the field in the two field experiments: 1) Conventional tillage (CT) using chisel plow (duck-foot) (Italian producer) at a depth of 10–15 cm, and 2) Zero tillage (ZT). Two spring wheat (*Triticum durum*) varieties (Umqais and Sham) were sown in both growing seasons. Five weed control treatments were practiced: 1) Hand weeding (T1), 2) Broadleaf + narrow leaf herbicide (T2), 3) Broadleaf herbicide (T3), 4) Narrow leaf herbicide (T4), and 5) Control (no weeding) (T5). The hand weeding treatment was done two times in each growing season; one time at wheat growth stage of Zadoks 13 and the second time at Zadoks 25 (Zadoks et al., 1974). In the first time, the hand weeding targeted narrow leaf weeds (mainly wild oat) which emerged at the same time of wheat. In the second time, the hand weeding targeted broadleaf (commonly weeds belonging to Compositae family) which must be controlled at the late tillering stage. Therefore, the hand weeding treatment was done to target the two broadleaf and narrow leaf weeds similar to the herbicide treatment. In the herbicide treatment, the broadleaf and narrow leaf weeds were controlled by using 2,4-D [2,4-Dichlorophenoxyacetic acid; 62% (w/v) of 2,4-D Isoocytyle-ester) (Esterdefore, VAPCO, Jordan)) and Antelope [100 g of Clodinafop-propargyl and 25 g of Cloquintocet-methyl (w/v)] herbicides, respectively. The narrow leaf herbicide was applied at a rate of 2.5 mL L^{-1} of water while broadleaf herbicide at a rate of 5 mL L^{-1} water. The herbicide was sprayed at a rate of 20 mL m^{-2}. The herbicides were applied by using a mounted sprayer equipped with a fan-type nozzle. The 2,4 D and Antelope were applied according to the herbicide label at wheat growth stages of Zadoks 24, and 13 (Zadoks et al., 1974), respectively. The most common weed species that present at the experimental site were wild oat (*Avena fatua*)(), wild barley (*Hordeum bulbosum*), wild mustard (*Sinapis arvensis*), and star-thistle (*Centaurea spp*).

Crop management

The main plot size was 2.5 m × 40 m. The size of each sub-sub plot was 2.5 m × 8 m with 2 m apart. Wheat seeds were sown at a rate of 12 g m^{-2} by mechanical planter at 17.5 cm row spacing at a depth of 7–10 cm. Seeds of the two wheat varieties were planted on 30 December, 2015 and 8 January, 2017 during the two growing seasons of 2015–2016 and 2016–2017, respectively. The grains were harvested on 30 June in both growing seasons. In both seasons, wheat was planted after a legume crop. The crop received 10 g m^{-2} of diammonium phosphate (18% N and 46% P_2O_5) at the time of seeding and 5 g m^{-2} of urea $(NH_2)_2CO$ (45% N) at the tillering stage of growth.

Measurements of plant growth and grain yield

In both growing seasons, days to 50% heading (DH) and days to 50% maturity (DM) were recorded. Days to heading (HD) were determined visually by calculating the number of days from seeding to the day when the main spike had emerged from the sheath of the flag leaf. Days to physiological maturity (MD) were determined visually by calculating the number of days from seeding to the day when the plants had reached the physiological maturity stage (the plant spikes turned yellow). Plant height (PH) was measured from the soil surface to the upper part of the spike without the awns. A square quadrate (1 m^2) was placed randomly at the central rows for each treatment to measure biological, grain yield, and straw yield. The wheat moisture content at harvest was 12%.

Experimental design and statistical analysis

A split-split plot arrangement in a completely randomized block design was used for data analysis with three replicates for each treatment. The tillage treatments were considered as the main plot, while wheat varieties as a sub-plot, and weeding treatments as a sub-sub-plot. Data were analyzed using JUMP software. Analysis of variance (ANOVA) was calculated for both main and interaction effects. The differences among means were calculated according to student's t-test at a P value less than 0.05%.

RESULTS

Days to heading, days to maturity, and plant height

Analysis of variance for tillage system, variety, and weeding methods and their interaction effects on several wheat growth and yield parameters was shown for the growing season of 2015–2016 (Table 3) and the growing season of 2016–2017 (Table 4). In the first growing season, the tillage system (T) had no significant effect on days to heading (DH), days to maturity (DM), and plant height (PH) (Table 3). There were significant differences in PH among varieties (V) and weeding methods (W) without interaction among different factors. There was a significant difference in DH among varieties (V). In the second growing season, the tillage system (T) and the variety (V) significantly affected PH of wheat with some interactions among different factors (Table 4).

Table 3. Analysis of variance (F probability values) showing the effect of tillage system, varieties, and weeding methods on days to heading (DH), days to maturity (DM), plant height (PH), biological yield (BY), grain yield (GY), straw yield (SY) and 1,000-grain weight for wheat plants during the growing season of 2015–2016

Source of variation	DF	F probability values						
		DH	DM	PH	BY	GY	SY	1,000-GW
Tillage (T)	1	NS	NS	NS	NS	NS	NS	NS
Block	2	0.0001	0.0001	0.0001	0.0016	0.012	0.0013	0.0001
Error (a)	-	-	-	-	-	-	-	-
Variety (V)	1	0.0096	NS	0.014	NS	NS	NS	0.007
T × V	1	NS	NS	NS	NS	NS	NS	NS
Error (b)	-	-	-	-	-	-	-	-
Weed (W)	4	NS	NS	0.0056	0.0001	0.0001	0.0001	NS
TxW	4	NS	NS	NS	NS	NS	0.035	NS
VxW	4	NS	NS	NS	0.019	NS	0.008	NS
TxVxW	4	NS	NS	NS	NS	NS	NS	NS

NS: Not significant.

The main means of tillage systems and weeding methods for DH, DM, and PH of the two varieties of wheat were shown in both growing seasons (Table 5). There was no significant difference between conventional (CT) and zero tillage (ZT) systems for the three parameters, except for the second season where PH of wheat in ZT (71.5 cm) was higher than those for CT (69.1 cm). Both DH and PH of wheat were significantly affected by the wheat variety in both growing seasons (Table 5). At the first growing season, the variety 'Sham' had significantly earlier DH (79.2) than those for 'Umqais' (81.9). In contrast, the variety 'Sham' showed significantly later DH when compared with

'Umqais' in the second growing season. The PH of the variety 'Sham' was significantly shorter than those for 'Umqais'. For weed control methods, the only significant effect was for PH in the first growing season. All weeding methods resulted in significantly longer PH than that of the narrow leaf herbicide treatment (T4).

Table 4. Analysis of variance (F probability values) showing the effect of tillage system, varieties, and weeding methods on days to heading (DH), days to maturity (DM), plant height (PH), biological yield (BY), grain yield (GY), straw yield (SY) and 1,000-grain weight for wheat plants during the growing season of 2016–2017

Source of variation	DF	F probability values						
		DH	DM	PH	BY	GY	SY	1,000-GW
Tillage (T)	1	NS	NS	0.028	NS	0.034	NS	NS
Block	2	0.0001	NS	NS	0.0001	0.0001	0.004	NS
Error (a)	-	-	-	-	-	-	-	-
Variety (V)	1	0.001	NS	0.0001	0.0001	0.0001	0.0005	0.0014
TxV	1	0.043	NS	NS	NS	0.03	0.018	NS
Error (b)	-	-	-	-	-	-	-	-
Weed (W)	4	NS	NS	NS	0.0001	0.0001	0.001	0.0002
TxW	4	NS	0.0005	0.008	0.0002	0.0001	0.035	NS
VxW	4	0.038	0.05	NS	0.024	0.0001	NS	0.026
TxVxW	4	NS	0.021	0.01	0.0015	0.0001	0.049	0.0002

NS: Not significant.

Table 5. Main means for days to heading (DH), days to maturity (DM), and plant height (PH) for two varieties of wheat grown under two tillage systems and five weeding methods during the growing seasons of 2015–2016 and 2016–2017

Main Effect	2015–2016			2016–2017		
	DH	DM	PH	DH	DM	PH
	day		cm	day		cm
Tillage system						
Conventional	81a	112a	68.1a	79a	112a	69.1b
Zero	80a	112a	65.9a	79a	111a	71.5a
$LSD_{(0.05)}$	1.9	1.6	7.1	0.81	2.2	1.7
Variety						
Umqais	82a	113a	71.9a	78b	111a	75.6a
Sham	79b	111a	62.2b	81a	111a	65.1b
$LSD_{(0.05)}$	1.6	1.6	6.4	0.78	0.59	1.8
Weeding methods						
T1	80a	112a	70.9a	79a	112a	71.1a
T2	81a	112a	66.9a	79a	111a	70.8a
T3	80a	112a	67.1a	80a	112a	69.3a
T4	81a	112a	61.8b	80a	111a	70.3a
T5	80a	112a	68.3a	79a	111a	70.1a
$LSD_{(0.05)}$	0.79	0.81	4.5	0.43	0.60	1.5

T1: Hand weeding; T2: Broadleaf and narrow leaf herbicide; T3: Broadleaf herbicide; T4: Narrow leaves herbicide; T5: Control. *LSD*: Least significantly difference at $P < 0.05$. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

Effects on biological yield (BY), grain yield (GY), straw yield (SY) and 1,000-grain weight

In the first growing season (2015–2016), the weeding methods (W) had a significant effect on biological yield (BY), grain yield (GY), and straw yield (SY) (Table 3). However, the weeding methods (W), variety (V) and the W × V × T interaction effect had a significant effect on BY in the second growing season (Table 4).

In the first growing season, BY, GY, and SY were not significantly affected by either tillage system or variety (Table 6). However, the variety 'Sham' had significantly higher 1,000-grain weight ($P < 0.01$) than the variety 'Umqais'. For weeding methods, both hand weeding (T1) and Broadleaf + narrow leaf herbicide (T2) gave significantly the highest BY (7,883 and 7,671 kg ha^{-1}, respectively) while the control (T5) gave the lowest BY (5,731 kg ha^{-1}). Grain yield (GY) was not significantly affected by T1, T2, and T4 weeding methods. However, both T1 and T2 had significantly higher SY than other weeding methods (Table 6). The 1,000-grain weight was not significantly affected by weeding methods.

Table 6. Main means for biological yield (BY), grain yield (GY), straw yield (SY), and 1,000-grain weight (1,000-GW) for two varieties of wheat grown under two tillage systems and five weeding methods

Main Effect	2015–2016				2016–2017			
	BY	GY	SY	1,000-GW	BY	GY	SY	1,000-GW
	kg ha^{-1}			g	kg ha^{-1}			g
Tillage system								
Conventional	7,383a	2,184a	5,199a	31.4a	5,051a	1,503b	3,549a	32.3a
Zero	6,486a	2,003a	4,483a	31.8a	5,317a	1,592a	3,725a	31.7a
$LSD_{(0.05)}$	1,516	226	1,303	4.2	309	726	236	1.6
Variety								
Umqais	6,854a	2,136a	4,718a	35.0a	5,744a	1,778a	3,966a	33.6a
Sham	7,015a	2,052a	4,964a	28.2b	4,625b	1,317b	3,308b	30.4b
$LSD_{(0.05)}$	801	219	584	3.7	207	847	173	1.1
Weeding methods								
T1	7,883a	2,435a	5,448a	31.4a	5,542a	1,794a	3,748b	33.1ab
T2	7,671a	2,422a	5,249a	31.6a	5,247a	1,701a	3,546bc	33.6a
T3	6,538b	1,929b	4,609b	31.7a	5,432a	1,408bc	4,024a	31.0c
T4	6,849b	2,244a	4,604b	31.0a	4,842b	1,497b	3,346c	31.8bc
T5	5,731c	1,439c	4,292b	32.4a	4,859b	1,338c	3,521bc	30.5c
LSD(0.05)	659	202	487	1.9	322	105	255	1.4

T1: Hand weeding; T2: Broad and narrow leaf herbicide; T3: Broad leaves herbicide; T4: Narrow leaves herbicides; T5: control. *LSD*, least significant difference at $P < 0.05$. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

In the second growing season, ZT had significantly more GY (1,592 kg ha^{-1}) than that of CT (1,503 kg ha^{-1}), but other yield parameters were not affected by tillage systems (Table 6). On the other hand, the variety 'Umqais' had significantly higher BY, GY, SY, and 1,000-grain weight than the variety 'Sham'. Yield components were significantly different among weeding methods (Table 6). Both T1 and T2 had significantly higher BY and GY than the control (T5). The highest and lowest SY were significantly observed in T3 and T4, respectively.

Effect of treatments interaction on wheat yield

In the first growing season (2015–2016), tillage x weeding interaction was significantly ($P < 0.01$) affected by SY (Fig. 1). The CT resulted in a higher straw yield than ZT for the weeding methods of T1, T2, and T5. In both tillage systems, the SY of the T1 and T2 weeding methods was significantly higher than those of T5 weeding treatment (Fig. 1).

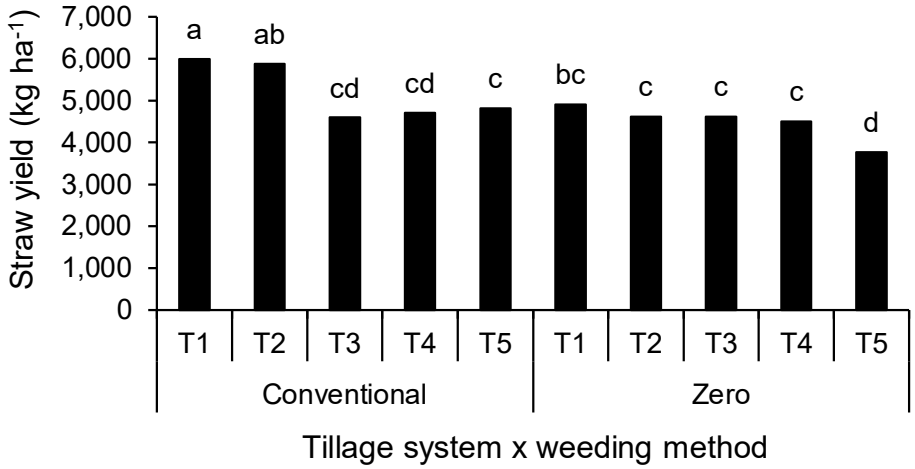

Figure 1. The tillage system x weeding method interaction effect on straw yield (SY) for wheat grown during the growing season 2015–2016. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

The effect of variety x weeding interaction on BY and SY was also significant (Fig. 2). For the weeding method T1, the variety 'Umqais' had a higher BY than that the variety 'Sham', while the SY was not different between the two varieties. In contrast, the variety 'Umqais' had lower BY and SY than the variety 'Sham' for the T2 weeding method. For the two varieties, the T1 and T2 weeding methods resulted in the highest BY and SY. The T5 weeding method resulted in the lowest BY and SY.

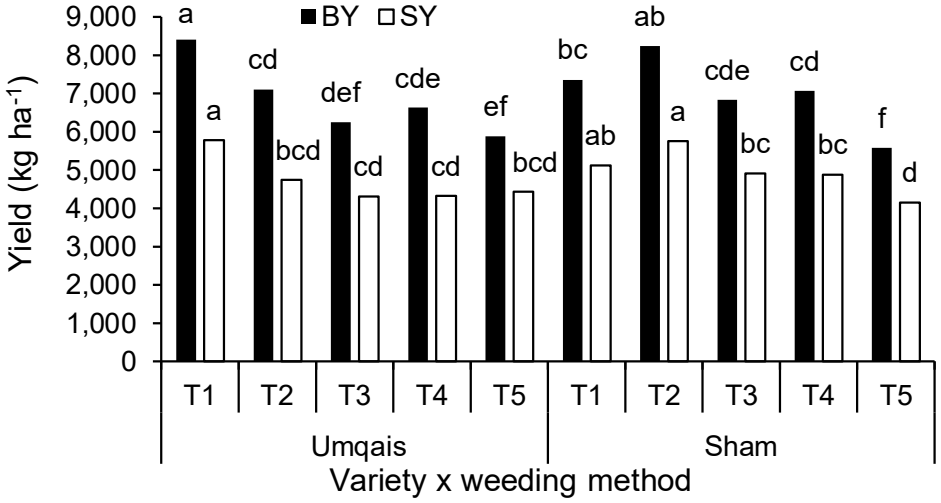

Figure 2. The variety x weeding method interaction effect on biological (BY) and straw yield (SY) for wheat grown during the growing season 2015–2016. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

For the second growing season, the tillage system x variety (Fig. 3), the tillage system x weeding method (Fig. 4), and the variety x weeding method (Fig. 5) interactions effect on BY, GY, and SY were significant. For the tillage x variety interaction (Fig. 3), ZT resulted in higher BY and SY than CT for the variety 'Sham' and higher GY for the variety 'Umqais'. For both tillage systems, the variety 'Umqais' gave significantly higher BY, GY, and SY than the variety 'Sham'.

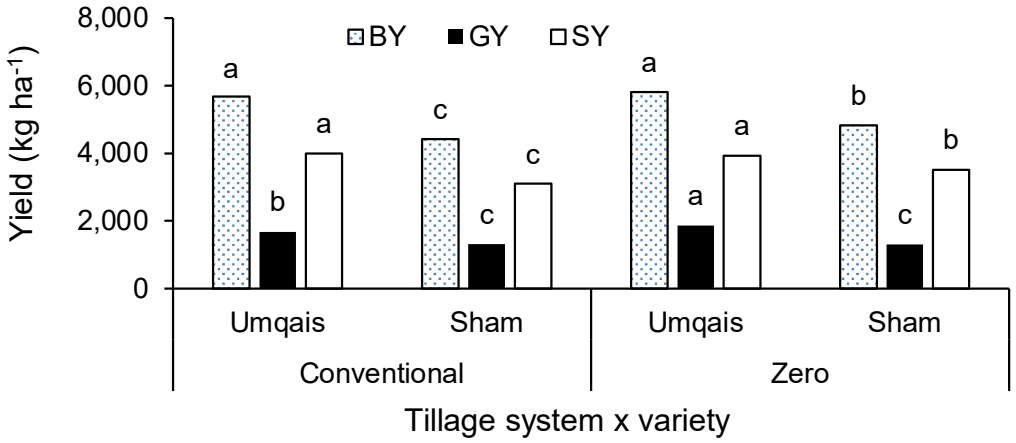

Figure 3. The tillage system x variety interaction effect on biological yield (BY), grain yield (GY), and straw yield (SY) for wheat grown during the growing season 2016–2017. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

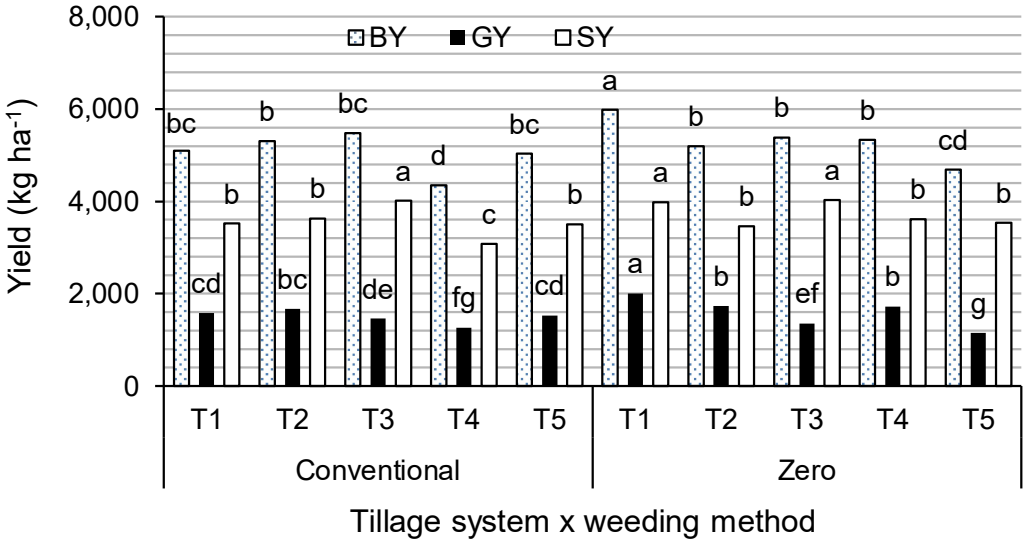

Figure 4. The tillage system x weeding method interaction effect on biological yield (BY), grain yield (GY), and straw yield (SY) for wheat grown during the growing season 2016–2017. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

The tillage system x weeding method interaction effect on BY, GY, and SY was shown in Fig. 4. Hand weeding method (T1) and narrow leaf herbicides (T4) resulted in significantly higher BY, GY, and SY in ZT compared with those in CT (Fig. 4). However, the control (T5) gave significantly higher GY in CT system (1,529.8 kg ha^{-1}) than those in ZT (1,146.3 kg ha^{-1}). In CT, T4 weeding treatment gave significantly the

lowest yield components. In ZT, the BY and GY were the highest for T1 weeding treatment while SY was the highest in broadleaf herbicide (T3) but the difference was not significant from the T1 weeding treatment (Fig. 4).

For all weeding methods, the variety 'Umqais' had significantly higher BY, GY, and SY than the variety 'Sham' in the second growing season (Fig. 5). For the variety 'Umqais', the effect of broadleaf herbicide (T3) on BY and SY was the greatest (6191.6 and 4,372.5 kg ha^{-1}, respectively), followed by hand weeding (T1) while the control (T5) had the lowest BY (5,275 kg ha^{-1}). For the variety 'Sham', the T1 weeding treatment showed the highest BY and GY. However, the T3 treatment gave the highest SY and lowest GY (Fig. 5).

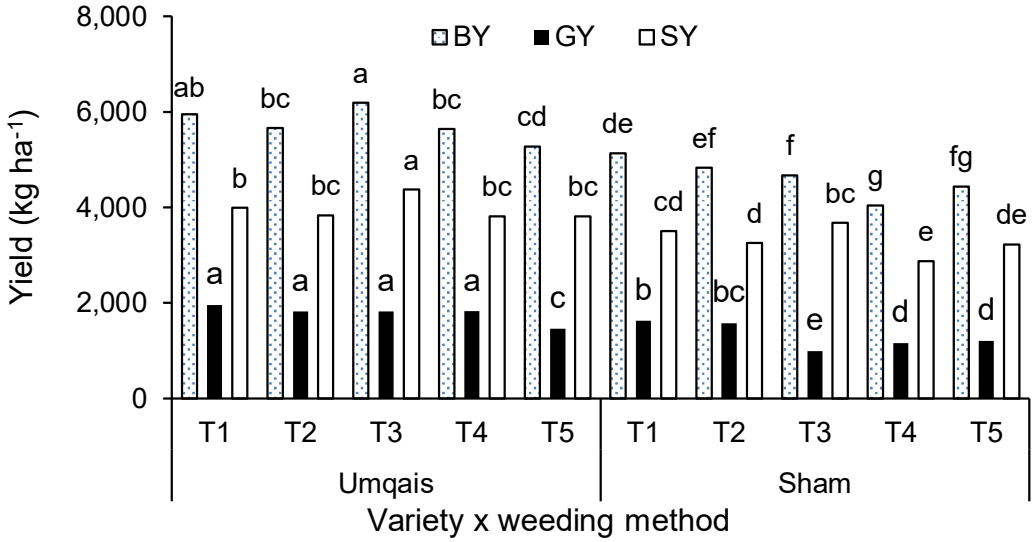

Figure 5. The variety x weeding method interaction on biological yield (BY), grain yield (GY), and straw yield (SY) for wheat grown during the growing season 2016–2017. Means followed by the same letters are not significantly different according to Student's t-test at *P* value of 0.05%.

DISCUSSION

Main effect of tillage system

This study showed no differences between the conventional (CT) and zero (ZT) tillage systems on yield parameters of wheat except for in the second growing season where plant height and wheat grain yield were significantly greater in ZT treatment. Such results were similar to the outcomes of Al-Issa and Samarah (2006) and Vita et al. (2007). The response of grain yield to tillage systems varied depending upon soil type, crop species, rainfall, and location (Khaledian et al., 2013; Liu et al., 2020).

Wheat yield was not affected by tillage systems in the first growing season which might be due to the higher rainfall in the first season than that in the second season (Table 2). The yield of wheat was lower in the second season than that in the first season. Therefore, the reduction in yield components in the second season might be due to the lower rainfall in the second season. A strong correlation was observed by Vita et al. (2007) between wheat yield and total precipitation throughout the growing season. They found that ZT performed better under limited rainfall as a result of less evaporation of soil water, and thus more water availability to plants (Vita et al., 2007). In addition, water

use efficiency (WUE) in ZT has been described to be higher in soils than those in CT (Li et al., 2005; Bryant et al., 2020). In the present study, there was no significant correlation ($r^2 = 0.15$) between plant height and grain yield of wheat (data not shown) for both experiments.

Main effect of wheat variety

Our results showed that the variety 'Umqais' had higher plant height than the variety 'Sham'. This could be associated with larger root systems of the variety 'Umqais'. Moreover, the variety 'Umqais' took slightly longer days to heading (81.9 days) than the variety 'Sham' (79.2 days) in the first growing season and vice versa for the second growing season. The variation in DH among varieties in response to the growing seasons might be due to the variation in rainfall between seasons. Thus, early heading of the variety 'Umqais' in the second season could be associated with lower rainfall because this variety is highly drought-tolerant compared with the variety 'Sham'. However, wheat yield was affected by the variety in the second season only. A higher biological, grain and straw yields for the variety 'Umqais' than those for the variety 'Sham' indicating that the variety 'Umqais' performed better under dry conditions. Other studies have revealed that early heading was positively associated with grain yield under severe drought (Van Oosterom & Acevedo, 1992). In the present study, no correlation between days to heading (DH) and grain yield was found (data not shown) under semi-arid circumstances. A similar result was obtained by van den Boogaard et al. (1996). The variety 'Umqais' was confirmed to be more efficient variety than the variety 'Haurani' due to higher yield under improved growing conditions (Al-Rjoub & Al-Samarrai, 2006).

Main effect of weed control methods

The weeding method had no effect on plant height, days to heading, and days to maturity for the two wheat varieties except for in the first season when PH of wheat was the shortest with the application of narrow leaf herbicide (Table 5). This may be due to a greater broadleaf weeds competition with the phytotoxic effect of this herbicide on wheat crops. However, Tawaha et al. (2002) found the shortest PH in barley were measured with the application of 2,4-D while the longest PH with hand weeding method. Qasem (2007) found the longest PH was under controls (no weeding).

In the present study, weeding methods had a significant effect on yield parameters of durum wheat varieties under tillage systems, although the outcomes were more realistic in the first growing season than in the second season. In both years, hand weeding revealed superior wheat yield when compared with mixed herbicides but the difference was not significant. The increase in grain yield (3%) for both years achieved with hand weed control was primarily due to the efficient control of weeds by a decrease of weed density. Similar results were supported by Turk & Tawaha (2003) and Qasem (2007) who found hand weeding method had the highest wheat grain yield.

In general, mixed herbicides presented a higher efficacy for increasing crop yield than using either single herbicide. However, narrow leaf herbicide treatment had a significantly similar effect on grain yield as mixed herbicides in the first growing season, while broadleaf herbicide had a significantly similar impact on biological yield in the second growing season. Thus, using a single herbicide under certain circumstances had proved efficiency for yield similar to mixed herbicides. For straw yield, the best result

in the second year was achieved by 2,4-D herbicide indicating the high performance of this herbicide under lower soil moisture. Results of Qasem (2007) indicated that the maximum straw yield was obtained by 'imazamethabenz-methyl' herbicide and the highest biological yield was with imazamethabenz-methyl and weed-free control.

Control or no weeding method reduced grain yield by 41% and 25% in the first and second growing season, respectively in comparison with those for hand weeding (Table 6). The reduction in grain yield was greater in the first season than the second which might be related to higher weed competition under higher soil moisture conditions in the first season. Yield losses of wheat caused by weeds may range between 30% and 80% in Jordan (Turk & Tawaha, 2003).

Tillage system x weed control method interaction

In the present study, wheat yields were significantly affected by the interaction between the tillage system and weeding methods in both seasons. Our results indicated that hand weeding was the best weeding control method under tillage systems. Hand weeding, mixed herbicides and controls (no weeding) methods showed higher straw yield in CT compared with those in ZT at first growing season (Fig. 1). Hand weeding gave the highest straw yield under CT while controls gave the lowest yield under ZT. The increase in straw yield under CT may be due to reduced weed infestation. Similarly, Upasani et al. (2014) found that continuous CT in rice and wheat sequences with application of isoproturon + 2,4- D post-emergence herbicide in wheat, was the most useful practice in direct-seeded rice–wheat system. However, hand weeding and narrow leaf herbicide showed higher biological, grain, and straw yields in ZT than those in CT for the second season (Fig. 4), which could be due to reduced weed competition. The highest and lowest grain yield were obtained from hand weeding and control, respectively under ZT. The observed increase in grain yield of wheat with the use of ZT and herbicides was similar with results of Chhokar et al. (2007). Effective weed control in ZT was based on the use of herbicides (Calado et al., 2010). Conversely, alternative strategies for nonchemical weed control are required to decrease the dependency on herbicides under ZT systems (Kumar et al., 2013).

Wheat variety x weed control method interaction

A significant interaction effect between variety and weeding methods was found on yield parameters of wheat in both years. In the first growing season, hand weeding was the best weed control method for increasing biological and straw yields for the variety 'Umqais' while mixed- herbicide method was the best for the variety 'Sham' (Fig. 2). Hence, wheat varieties responded differently to weed control methods. In the second season, the variety 'Umqais' had higher biological, grain, and straw yields than the variety 'Sham' under all weed control methods. Although the maximum grain yield was attained by planting the variety 'Umqais' and by using hand weeding treatment. The lowest grain yield was reported for the variety 'Sham' using a 2,4-D herbicide treatment (Fig. 5). Sultana et al. (2012) found that weed free treatment resulted in the highest grain yield of the variety 'Prodip' while no weeding treatment resulted in the lowest grain yield of the variety 'Shatabdi'.

CONCLUSIONS

Grain yield of wheat was improved by growing 'Umqais' variety under zero tillage and by controlling weeds either by hands or a combination of broadleaf + narrow leaf herbicide, especially in the drier season. Zero tillage resulted in an increase in grain yield of 'Umqais'variety, and biological and straw yield of 'Sham' variety in comparison with conventional tillage in the second growing season (drier season). The grain yield was significantly reduced by 25–41% when weeds were not controlled with greater grain loss in the wetter growing season than the drier one.

ACKNOWLEDGMENTS. This study is a part of the 'Enhancing food security in Arabic countries' Project. The authors gratefully thank International Center for Agricultural Research in the Dry Areas (ICARDA) which financially supported these experiments.

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