INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)

ISSN: 2223-7054 (Print) 2225-3610 (Online)

http://www.innspub.net

Vol. 23, No. 6, p. 21-36, 2023

RESEARCH PAPER

OPEN ACCESS

Evaluation the most important factors affecting yield and yield components of durum wheat (*Triticum durum* Desf.) grown using full package production practices in a Semiarid Mediterranean environment

Yahya Bani Khalaf[1], Khaldoun O. Al Sane*[1], Osama Migdadi[1], Iyad Musallam[1], Abdul Latief Al-Ghzawi[2]

[1]*National Agricultural Research Center (NARC), Baq'a, Jordan*

[2]*Department of Biology and Biotechnology, School of Science, The Hashemite University, Zarqa, Jordan*

Article published on December 13, 2023

Key words: Full-package, Grain yield, Rainfed, Technology-transfer

Abstract

Cultivating the most important staple food crops in Jordan, both bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.), faces critical problems regarding food security anxiety. In addition, climate change and global warming have affected wheat production in Jordan. An innovative, practical technology that comprises new management practices, equipment, fertilizers, herbicides, and improved varieties has been introduced as a step on the right track towards facing food security challenges. In this study, two varieties of *Triticum* durum the improved variety (MARU1) and the local cultivar (HOURANI) were examined, under field conditions at Maru Agricultural Station in northern Jordan during the 2016–2017 and 2017–2018 growing seasons. Treatments applied were fertilization (four different combinations) and weed control method (three combinations). In both growing seasons, both grain yield (GYLD) and biological yield (BYLD) were significantly increased when planting the new variety (MARU1) and combined Urea+DAP (F1) and also 2,4-D+Antilope (W3). Using the full-package technology was proven to be crucial for improving wheat yield potential in the rainfed dry land of Jordan. Implementing technology transfer and adopting an improved variety and proper crop management techniques have significantly enhanced farmer livelihood, increased profits, and mitigated food security anxiety.

* **Corresponding Author:** Khaldoun O. Al Sane ✉ Khaldoun_mk@yahoo.com

Introduction

Many critical problems facing the production of Jordanian bread (*Triticum aestivum* L.) and hard wheat (*Triticum durum* Desf.) such as climate change and the old production package.(Al-Ghzawi *et al.*, 2019; Choudhary *et al.,* 2018). Jordan is a Mediterranean country which is considered as one of the driest countries in the region and has the lowest levels of water supply resources (Ismael *et al.*, 2018). The adverse conditions of climate change and rainfall fluctuations with poor distribution would negatively affect wheat productivity and the whole rainfed agricultural systems in Jordan (Shakhatreh *et al.*, 2013; Al-Ghzawi *et al.*, 2018, 2019; Anbar *et al.*, 2020). Actually, Jordan is severely affected by climate change and global warming associated conditions by which it would be predicted, according to Jordanian Ministry of Environment Records (2009), to have decreasing trends for precipitation (8-20%) and increasing trends for temperature (1.0-2.8°C), especially in the northern and western parts of the country (Al-Ghzawi *et al.*, 2018). The low level and instability of Jordanian wheat yield reflected these problems (ICARDA, 2010). In fact, Jordan production package is very old and needs an urgent modification to address the problem of low yield and associated challenges of climate change (FAO, 2018). Production package has to be implemented, and this must take place in a step-wise linear manner and is meant to emulate the shifts in technology.

To solve the above-mentioned problems, there is a need to update the production package into the farmer's fields in Jordan. This can be applied via using improved stress tolerant wheat varieties, adding fertilizer, and using herbicides for weed control (Awada, 2012; Shakhatreh *et al.*, 2013). Actually, our recommended package should be developed in a way that a new cultivars are being released which are tolerant to climatic change associated conditions in Jordan (ICARDA, 2010; Ajlouni *et al.*, 2011). Indeed, breeders in Jordan work along with farmers in a participatory approach starting from initial breeding nurseries in which the selection is conducted within a large number of genetic materials and resulted in developing varieties of general superiority and wide adaptability to a wide range of climatic conditions via targeting morpho-physiological, agronomical, and qualitative traits of durum and bread wheat. (Abdel-Ghani, 2008; Ajlouni *et al.*, 2011; Al Hiary *et al.,* 2015; Joudi, 2017).

Updating this package should be coupled with new and proper fertilization protocol. Actually, Soils of Jordan are characterized by its poor fertility due to being cultivated many centuries ago. This has been accompanied with low organic matter content, high pH and carbonates (El Zuraiqi *et al.*, 2004) which make most of the indigenous nutrients in the soil low in content and restricted in their availability. Practically, the farmers, in rainfed agricultural systems, have been applying mainly organic fertilizer, while in irrigated areas usually have been applying chemical fertilizers along with organic fertilizer more than needed by crops (El Zuraiqi *et al.*, 2004). They have indicated that yields of field crops grown in the rainfed areas could be significantly enhanced by using proper fertilization. In a study testing a well-adapted wheat germplasms conducted in four Mediterranean countries including Jordan, Savin *et al.* (2022) reported significant variation in grain yield among tested germplasms in the 16 experiments. They have found that yields for the fertilized rainfed crops were much higher compared to the unfertilized control crops.

Critical weed management and control practices must be updated in wheat production areas in Jordan (Turk and Tawaha, 2003; Chhokar *et al.* 2019; Qasem, 2021). It is well known that weeds negatively affected wheat production. Weed compete with wheat crops for soil moisture content, nutrients, light, and space, reducing wheat vigor, tillering capacity, head size, and other yield components (Yasin *et al.,* 2010; Kaur *et al.,* 2018). Weeds also provide shelter for harmful insects and pests, causing considerable yield reductions (Kaur *et al.,* 2018). In addition, weeds lower the grain quality and the product's market value and increase the cost of harvesting, threshing, and cleaning (Yasin *et al.,* 2010; Kaur *et al.,* 2018). Herbicide combinations have often been applied to control a broad spectrum of weed flora in wheat fields, including narrow- and broad-leaved weeds (Kaur *et al.,* 2018; Chhokar *et al.,* 2019).

Despite that many researchers shows that the full package (improved cultivar, fertilizer, using mechanical drilling, and using broad- and narrow-leaf herbicide) gave the highest yield, but in some cases, the farmer cannot have the ability to apply all components of the full package. Therefore, this study aimed to find the most important components of the full package, in order to help the Jordanian farmers who cannot apply all the components of the full package, to choose and give priority for the most important component of the full package that will have highly significant results on their yield and production.

Materials and methods

Experimental conditions

Wheat seeds were sown under field conditions at Maru Agricultural Station in Irbid governorate in northern Jordan (32°33ʹ N latitude, 35°51ʹ E longitude, and 589 m above sea level; Al-Ghzawi *et al.*, 2019). Maru has typical Mediterranean climate conditions with hot and dry summer and average annual precipitation of about 380 mm. The soil of the experimental field was classified as silty clay with a pH of 7.8 (Table 1).

Table 1. Soil chemical and physical analysis results for the experimental site at Maru Agricultural Station, Irbid, Jordan

Chemical and physical properties	
P%	1.16
K%	1.94
$CaCO_3$%	1.90
N%	0.10
PH	7.75
E.C ($ds.m^{-1}$)	0.42
Clay	56.20
Silt	33.80
Sand	10.00

Experimental layout

Experimental plots were managed following the National Agricultural Research Center (NARC) management practices but with modifications, through which an old production package was much improved as an urgent modification has to be implemented by this research work including; an improved variety of wheat, fertilization treatments and weed control treatments in order to try to minimize the yield gap effect, and hinder the problem of low yielding and associated challenges of climate change (ICARDA, 2010; FAO, 2018). The experiments were performed from December to June 2016–2017 and 2017–2018 growing seasons (Fig. 1).

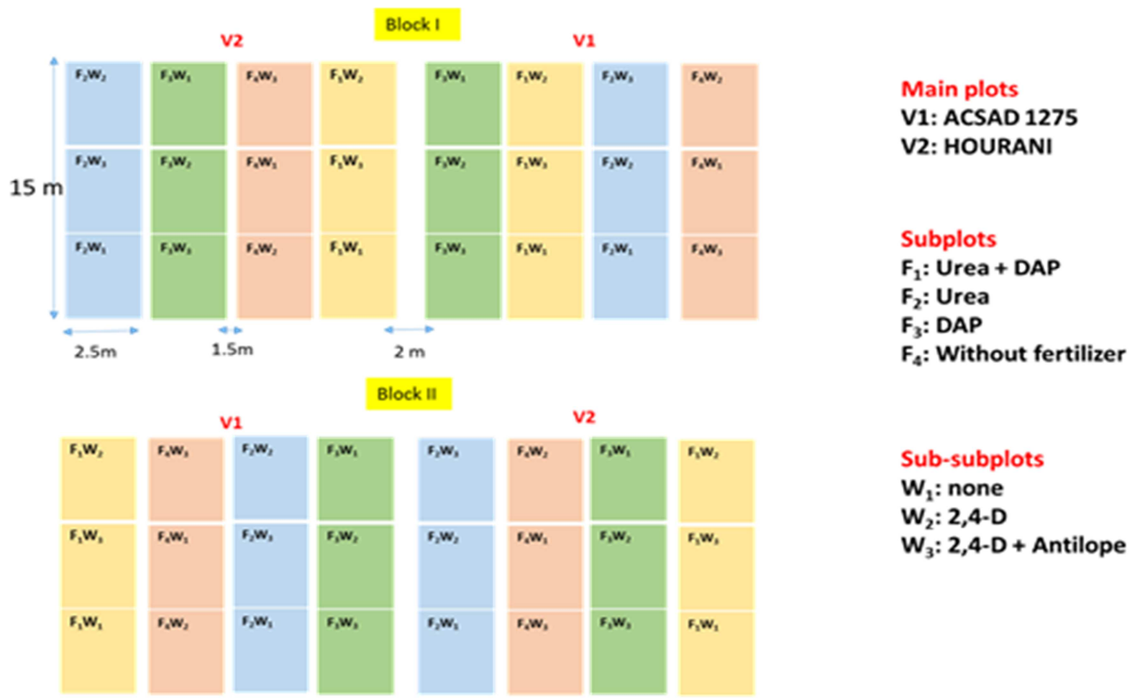

Fig. 1. The experimental layout in which treatments were assigned to the main plot, subplots and sub-subplots.

Plant material

The varieties tested were; MARU1 is a new registered variety of hard wheat (Triticum durum Desf.), because of scientific cooperation between the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and NARC in Jordan and it is labeled under "MARU1" after the registration. Field and laboratory experiments showed that this variety has high productivity; the average yield of MARU1 reached 3.5 tons/hectare compared to 1.4837 and 1.5044 tons/ha (in 2016/2017 and 2017/2018 growing seasons; respectively) (FAO, 2018). MARU1 is characterized by an excellent grain quality (the protein content reached 14%, making it excellent for the pasta and bread industry) and suitability to be cultivated in dry areas. Interestingly, MARU1 has shown its superiority in resistance to diseases, especially rust, besides high technological traits and the high generic weight of the grains. It is also distinguishable by early maturity, among other varieties evaluated. HOURANI is another investigated variety that was used as the local check. HOURANI is a local variety of drought-tolerant durum wheat suitable for rainfed cultivation in dry regions.

Two wheat varieties were evaluated: the improved variety (MARU1) and the local check (HOURANI). The drilling machine was used as the best wheat sowing method (an even distribution of seeds in the field, a uniform stand of wheat populations, and enough contact with the soil) to ensure even and proper germination (Noor *et al.,* 2018). Treatments applied were: fertilization (four different levels: a. Urea + DAP; b. Urea alone; c. DAP alone and e. without fertilization) and weed control method (three levels: a. without weed control; b. the herbicide (2,4-D) alone; c. the herbicides (2,4-D with Antilope).

Treatments applied

Two varieties of wheat; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2) where treated as follows: Four fertilization treatments; Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4), three weed control treatments; without weed control (W1), 2,4-D alone (W2) and 2,4-D+Antilope (W3), besides their combinations.

Traits tested

Grain yield (GYLD) ($g.m^{-2}$) and biological yield (BYLD) ($g.m^{-2}$) of the two wheat varieties tested.

Experimental design and statistical analysis

The experiment was arranged split-split plot in a randomized complete block design and replicated three times. The wheat varieties were randomly assigned to the whole plot treatments, the fertilizer treatments to the subplots, and the herbicides treatments to the sub-subplots.

All data were statistically analyzed using the Statistical Analysis System STATISTICA 7.0 (StatSoft Inc., USA). A standard analysis of variance procedure for this design in randomized blocks was used to calculate treatment means, standard errors, and significant differences between treatments. Univariate analysis of significance for grain yield (GYLD) and biological yield (BYLD) was performed. A comparison of means was conducted using the least significant difference test (LSD at P (0.05).

Results

The presence of some critical variables, such as the annual rainfall (amount and distribution), number of rainy days and air temperature has insignificant effects on the prediction of wheat output (Table 2). During both growing seasons, univariate analysis of significance for both grain yield (GYLD) and biological yield (BYLD), and LSD tests have shown that all treatments applied were significant during both 2016–2017 and 2017–2018 growing seasons, including the wheat varieties tested (Table 4), weed control method (Table 5) and fertilization treatment (Table 6).

Conventional, old practices for cereals management in Jordan were followed. This research is suggesting a new, improved high-tech. production package for managing durum wheat (*Triticum durum* desf.) through optimization of fertilizers, weed management and adoption of an improved variety in Jordan which represents the rain-fed agricultural systems.

Regarding wheat variety, significant differences were presented between the two varieties in terms of GY and BY, where Maru1 produced more yield and have a higher BY as well (Table 4). The improved variety (MARU1) (V1) has shown much better performance and a significant effect compared to the local check (HOURANI) (V2) in both growing seasons, especially during the 2017–2018 growing season where the grain yield was (264.09 g.m^{-2}) for the improved variety compared to (165.01 g.m^{-2}) for the local check with about 60% increase (Table 4). It was also shown that the biological yield followed the same trend where it was more significant for the improved variety (515.63 and 1209.84 g.m^{-2}) compared to the local check (470.04 and 796.02 g.m^{-2}) during 2016–2017 and 2017-2018 growing seasons; respectively (Table 4).

Applying both 2,4-D and Antilope to control weeds (for both broad-leaved and narrow-leaved weeds; respectively) has resulted in the highest grain yield during both 2016–2017 and 2017–2018 growing seasons irrespective of the variety and fertilization method (Table 5) During the 2016–2017 growing season, GYLD was 173.53 g.m^{-2} when applying 2,4-D and Antilope together (W3), followed by 155.46 g.m^{-2} in case of applying 2,4-D alone (W2). This surpassed 130.21 g.m$^{-2,}$ which resulted from leaving the plot without weed control at all (W1) (Table 5), showing that the weed control method has a significant effect; where the application of both herbicides together (W3) has resulted in an increase of 11.62% in grain yield compared to the application of broadleaf herbicide alone (W2) and 33.26% increase compared to the grain yield if no weeding was practiced (W1). Similar results were obtained during the next growing season (2017-2018), in which a grain yield of 267.71 g.m^{-2} when applying 2,4-D and Antilope together (W3) was obtained. The no weed control treatment (W1) reported the lowest value, 171.79 g.m^{-2} (Table 5). Indeed, the application of both herbicides together (W3) has resulted in an increase of 31.14% in grain yield compared to the application of broadleaf herbicide alone (W2) and a 55.83% increase compared to no weeding treatment (W1) (Table 5). Similarly, the biological yield followed the same scenario during both growing seasons. During the 2016–2017 growing season, when applying 2,4-D and Antilope together (W3), we have obtained a biological yield of 540.25 g.m-2 and the lowest value (441.13 g.m-2) had resulted when no weed control (W1) was practiced (Table 5). As expected, similar results were obtained during the 2017–2018 growing season.

Table 2. Amount of rainfall and distribution (mm), minimum, maximum and mean air temperature (°C) in Quasbat Irbid, during 2016-2017 and 2017/2018 growing seasons.

Month	2016-2017				2017-2018			
	Amount of rainfall	Air temperature			Amount of rainfall	Air temperature		
		Min.	Max.	Avg.		Min.	Max.	Avg.
October	2	14.73	30.11	21.94	7.6	5.1	21.6	12.4
November	0.8	4.36	23.05	8.58	46	2.4	25.4	12.3
December	190	4.36	13.72	8.58	159.2	1.3	19.7	9.6
January	63.6	2.78	13.90	7.78	122.4	1.3	24.7	12.4
February	23.2	2.39	15.86	8.70	19	7.3	19.0	12.5
March	19.2	7.10	19.35	12.71	77.2	9.3	26.6	17.5
April	9.8	9.28	26.46	17.53	12	15.6	32.3	24.1
May	0.6	13.21	30.63	21.85	7	16.9	31.2	23.5
Total	309.2				450.4			
Long-term annual average	400				400			
% of long-term average	77.3				112.6			

Applying Urea and DAP together (F1) has resulted in a greater grain yield and biological yield during the 2016-2017 growing season compared to the other fertilization treatments applied (Table 6), but the effect was not significant compared to applying the Urea alone (F2); 162.09 g.m^{-2} and 155.70 g.m^{-2} for the grain yield and 544.92 g.m^{-2} and 510.08 g.m^{-2} for the biological yield; respectively. However, a significant effect has resulted when compared with the remaining fertilization treatments; DAP alone (F3), which resulted in 147.98 g.m^{-2} grain yield and 462.42 g.m^{-2} biological yields, and with (F4) treatment in which no fertilizer was applied, and resulted in 146.49 $g.m^{-2}$ grain yield and 453.92 $g.m^{-2}$ biological yields (Table 6). No significant effect was observed between the last three fertilization treatments regarding grain yield and the last two treatments regarding biological yield (Table 6). In comparison, the 2016-2017 growing season has shown similar results regarding the effect of applying Urea and DAP together (F1) and the superiority of this treatment over other fertilization treatments for both grain and biological yields (Table 6). It has resulted in a 10.65% and 20.04% increase compared to no fertilization (F4) during the 2016-2017 growing season and 69.26% and 35.75% increase during the 2017-2018 growing season regarding grain and biological yields; respectively (Table 6).

Table 3. A comparison between conventional old practices followed by farmers and the improved high-tech. production package experimented

Old practices followed by Farmers	Improved high-tech. production package
1. Use of deep (mould board) Plowing and without harrowing 2. The used variety are not certified and are not sterilized(commonly use of unsterilized seeds subject crop to smuts) 3. Planting date usually late (they wait for the first effective rain fall to control the emerged weeds by plowing and there planting so they miss part of limited soil moisture 4. seed drillers are not common and if used are not calibrated for right planting depth (instead of 8cm they plant at 15cm depth so most of seeds are lost .most farmers broadcasting the seeds 5. Seeding rate up to 20kg. 6. use of DAP fertilizers at planting not common 7. use of Urea is miss Practiced ,quantity and date are not in the optimum 8. weed control it is commonly not use chemical control and if it is used not in the proper stage of weed and crop grass type weeds are not controlled 9. Harvesting : many miss-practices are common: a. use of rented combines that pass from barley to wheat and from variety to variety, from infected to non-infected resulting in bad seed crop b. the cutter of the combine put close to the soil surface (to maximize straw yield) leading to polluting the crop with stones ,soil and broken seeds) c. Increasing the thresher speed (to ground the straw) leading to high proportion of broken seed d. harvesting at improper time when at early morning leading to lost in crop (many spike have dew) e. use of old bags that could be polluted with other crops (Barley) or other wheat varieties	1. Use of chisel plow and harrowing. 2. Use of certified clean and sterilized (use of sterilized seeds help crop to avoid smuts) 3. Committed to the proper planting date, so take use of the first effective rains and allow crop to take fall crop cycle 4. Use of seed drillers at the right planting depth 5. Seeding rate 12 kg/ha 6. Use of DAP with planting 7. Urea fertilizer are applied in the optimum date and optimum quantity 8. Monitoring weed population and applying both broad -leaf and narrow-leaf herbicide in the right time and rate 9. Use of the proper protocol of the harvesting machine: cleaning before harvesting new field ,harvesting at the proper height, 10. Harvesting at proper time of the day, use of new bags. 11. The speed of machines is calibrated properly to prevent break down.

In addition, the combined effect of the three factors, wheat variety, weed control method, and fertilizer treatment, on both grain and biological yields was also assessed (Tables 7 and 8; Figs. 2, 3 a and b). During the 2016-2017 growing season, the interaction among these factors was only significant for the biological yield (Table 7; Fig. 2).

Table 4. Grain yield (GYLD) (g.m-2) and Biological yield (BYLD) (g.m-2) of two wheat varieties; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2) during 2016–2017 and 2017–2018 growing seasons irrespective of weed control and fertilization method*

Variety	2016–2017 growing season		2017–2018 growing season	
	Grain yield (GYLD) (t ha-1)	Biological yield (BYLD) (t ha-1)	Grain yield (GYLD)	Biological yield (BYLD) (t ha-1)
MARU1 (V1)	1.62 a	5.16 a	2.64 a	1.21 a
HOURANI (V2)	1.45 b	4.70 b	1.65 b	7.96 b

*Means followed by different letters within the same category and column are significantly different at P (0.05 using least significant difference (LSD) test.

Table 5. Grain yield (GYLD) (t ha-1) and Biological yield (BYLD) (t ha-1) of two wheat varieties for three weed control treatments; 2,4-D+Antilope(W3),2,4-D alone (W2) and without weed control (W1) during 2016–2017 and 2017–2018 growing seasons irrespective of the variety and fertilization method*

Weed control treatment	2016–2017 growing season		2017–2018 growing season	
	Grain yield (GYLD) (t ha-1)	Biological yield (BYLD) (t ha-1)	Grain yield (GYLD) (t ha-1)	Biological yield (BYLD) (t ha-1)
2,4-D+Antilope (W3)	1.74 a	5.40a	2.68a	1.29a
2,4-D alone (W2)	1.55 b	4.97 b	2.04 b	8.99 b
without weed control (W1)	1.30 c	4.41 c	1.72 c	8.23 c

* Means followed by different letters within the same category and column are significantly different at P (0.05 using least significant difference (LSD) test.

Table 6. Grain yield (GYLD)(t ha-1) and Biological yield (BYLD) (t ha-1) of two wheat varieties for four fertilizer treatments; Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4) during 2016–2017 and 2017–2018 growing seasons irrespective of the variety and weed control method*

Fertilization treatment	2016–2017 growing season		2017–2018 growing season	
	Grain yield (GYLD) (t ha-1)	Biological yield (BYLD) (t ha-1)	Grain yield (GYLD) (t ha-1)	Biological yield (BYLD) (t ha-1)
Urea and DAP together (F1)	1.62 a	5.45 a	2.75 a	11.17 a
Urea alone (F2)	1.56 ab	5.10 a	2.34 b	10.89 a
DAP alone (F3)	1.48 b	4.62 b	1.87 c	9.83 b
without fertilizer (F4)	1.46 b	4.54 b	1.62 d	8.23 c

*Means followed by different letters within the same category and column are significantly different at P (0.05 using least significant difference (LSD) test.

The best treatment that yielded the highest value for the biological yield (635.00 g.m-2) was obtained using the improved variety (MARU1) (V1), fertilized with Urea and DAP together (F1), and sprayed with the two herbicides 2,4-D with Antilope together (W3); (V1F1W3) and the lowest biological yield was obtained)323.50 g.m-2) when the local check (HOURANI) (V2) was planted, and neither fertilization (F4) nor weed control (W1) were applied (V2F4W1) (Table 7; Fig. 2).

During the 2017-2018 growing season, the interactions among these factors were significant for both grain and biological yields (Table 8; Fig. 3a&b).

The best treatment that yielded the highest value for the grain yield (414.25 g.m-2) was obtained using the improved variety (MARU1) (V1), fertilized with Urea and DAP together (F1), and sprayed with the two herbicides 2,4-D with Antilope together (W3). The lowest value for grain yield was obtained (103.80 g.m-2) when the local check (HOURANI) was planted, and neither fertilization (F4) nor weed control (W1) or 2,4-D alone (W2) were applied (V2F4W1 or V2F4W2) (Table 8; Fig. 3a) since there was no significant variation between these two treatments. The biological yield was almost affected in the same way as the grain yield with the highest value (1919.73 g.m-2) obtained when using the improved variety (MARU1) (V1), but with different combinations of herbicides and fertilization treatments; DAP alone (F3) together with the herbicides 2,4-D and Antilope (W3).

Table 7. Biological yield (BYLD) ($g.m^{-2}$) of two wheat varieties tested* as affected by four fertilization treatments** and three weed control treatments*** during 2016–2017 growing season under rainfed conditions.

Combinations of treatments	Biological yield (BYLD) ($t\ ha^{-1}$)
V1F1W3	6.35 a
V1F1W2	5.88 b
V1F2W3	5.80 b
V1F3W3	5.58 bc
V1F2W2	5.30 cd
V2F1W3	5.23 cde
V1F1W1	5.15 cdef
V1F2W1	5.15 cdef
V1F4W3	5.13 defg
V2F2W3	5.13 defg
V1F3W2	5.07 defg
V2F1W2	5.03 defgh
V2F3W3	5.03 defgh
V2F4W3	5.01 defgh
V1F3W1	4.84 efghi
V1F4W2	4.75 fghi
V1F4W1	4.70 ghi
V2F2W2	4.63 hij
V2F1W1	4.60 hij
V2F2W1	4.45 ijk
V2F3W2	4.24 jk
V2F3W1	4.03 k
V2F4W2	4.03 k
V2F4W1	3.24 l

*Two varieties of wheat; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2).

**Four fertilization treatments: Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4).

***Three weed control treatments; 2,4-D+Antilope (W3), 2,4-D alone (W2) and without weed control (W1).

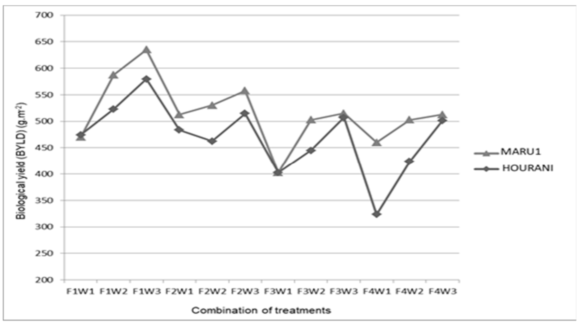

Fig. 2. Performance of two wheat varieties; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2) during 2016–2017 growing season in terms of biological yield (BYLD) ($g.m^{-2}$) as affected by different combinations of fertilization method (F) and weed control method (W); where Four fertilization treatments were applied: Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4) together with three weed control treatments; 2,4-D+Antilope (W3), 2,4-D alone (W2) and without weed control (W1).

Besides, the lowest value for biological yield was obtained (538.06 g.m-2) when the local check (HOURANI) was planted, and neither fertilization (F4) nor weed control (W1) or 2,4-D alone (W2) were applied (V2F4W1 or V2F4W2) (Table 8; Fig. 3b). As illustrated, other combinations have varying effects on both grain and biological yields.

Indeed, a comparison between the old practices and the new technological package has been illustrated in (Table 3) below.

Table 8. Grain yield (GYLD) ($t\ ha^{-1}$) and Biological yield (BYLD) ($t\ ha^{-1}$) of two wheat varieties tested*as affected by four fertilization treatments** and three weed control treatments*** during 2017–2018 growing season under rainfed conditions.

Combinations of treatments	Grain yield GYLD ($t\ ha^{-1}$)	Biological yield (BYLD) ($t\ ha^{-1}$)
V1F1W3	4.14 a	1.53 b
V1F1W2	3.70 b	1.51 b
V1F2W3	3.39 c	1.33 cd
V1F3W3	2.87 d	1.92 a
V1F2W2	2.82 d	1.06 ef
V2F1W3	2.62 e	9.70 fgh
V1F1W1	2.53 ef	10.33 fg
V1F2W1	2.49 f	11.05 ef
V1F4W3	2.30 g	12.17 de
V2F2W3	2.30 g	10.70ef
V1F3W2	2.10 h	9.80 fgh
V2F1W2	1.95 i	7.84 ijk
V2F3W3	1.92 i	14.01 bc
V2F4W3	1.88 i	8.53 hij
V1F3W1	1.87 ij	10.44 fg
V1F4W2	1.79 j	8.95 ghi
V1F4W1	1.69 k	8.89 ghi
V2F2W2	1.63 kl	7.09 jki
V2F1W1	1.55 l	7.04 jklm
V2F2W1	1.40 m	6.20 lmn
V2F3W2	1.29 n	7.16jkl
V2F3W1	1.19 o	6.42klmn
V2F4W2	1.05 p	5.38 n
V2F4W1	1.04 p	5.46 mn

*Two varieties of wheat; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2).

** Four fertilization treatments: Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4).

*** Three weed control treatments; 2,4-D+Antilope (W3), 2,4-D alone (W2) and without weed control (W1).

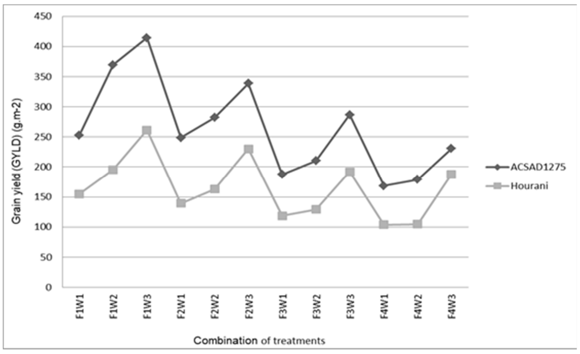

Fig. 3a. Performance of two wheat varieties; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2) during 2017–2018 growing season in terms of grain yield (GYLD) (g.m^{-2}) as affected by different combinations of fertilization method (F) and weed control method (W); where Four fertilization treatments were applied: Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4) together with three weed control treatments; 2,4-D+Antilope (W3), 2,4-D alone (W2) and without weed control (W1).

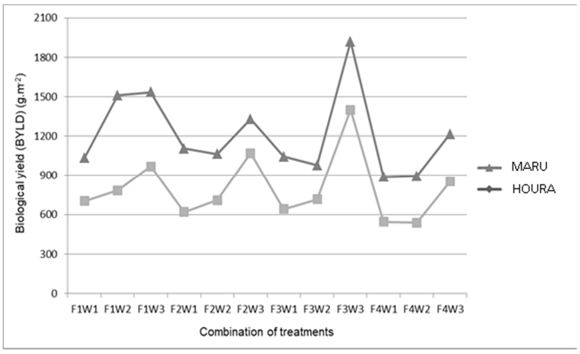

Fig. 3b. Performance of two wheat varieties; the improved variety (MARU1) (V1) and the local check (HOURANI) (V2) during 2017–2018 growing season in terms of biological yield (BYLD) (g.m^{-2}) as affected by different combinations of fertilization method (F) and weed control method (W); where Four fertilization treatments were applied: Urea and DAP together (F1), Urea alone (F2), DAP alone (F3) and without fertilizer (F4) together with three weed control treatments; 2,4-D+Antilope (W3), 2,4-D alone (W2) and without weed control (W1).

Discussion

Our investigation showed that the improved variety (MARU1) was an outstanding wheat variety with much better performance and a significant effect than the local check (HOURANI) in both growing seasons studied. The novelty of the current research comes from the excellent and competitive wheat variety available to farmers in rain-fed agricultural systems. The interaction of genotype and environment describes how each variety of wheat will respond to different growing environments and conditions (Barkley *et al.,* 2010). In Jordan, domestic wheat production has very high variability. Improved wheat varieties raised yields by 10-12 percent, generating produce worth about 207,000 USD and 164,000 USD in 2012/2013 and 2013/2014 growing seasons, respectively (ICARDA Communication Team, 2016). According to their assessment, several wheat lines developed by the initiative's Egyptian program have adapted well to rain-fed conditions in Jordan, and some have exceeded the grain yield of the local landraces, such as the local check (HOURANI) by up to 25 percent and certified varieties as well. The current investigation confirmed these findings.

The portfolio theory of finding the best wheat variety with high yielding potential and risk-minimizing characteristics was adopted in Kansas, USA (Barkley *et al.,* 2010). In the same context, the grain yield advantage offered by a new batch of wheat varieties, compared to the most popular ones in Pakistan, has been examined (Joshi *et al.,* 2017). They have found that the participatory varietal selection (PVS) trials showed that nearly 50% of the newly released wheat varieties (CIMMYT germplasm collection) offered an average of 5–17% more grain and biological yields over the old check varieties. Our results had shown that the grain yield reduction was caused by replacing one or more of the levels of each factor tested. Indeed, a "blend" of seeds of different wheat varieties has been cultivated by wheat producers in their attempt to stabilize yields (Bowden *et al.,* 2001). Carranza-Gallego and co-workers (2018) showed that old cereal varieties could be a promising climate change mitigation strategy in Mediterranean rainfed cereal cropping systems. In fact, using certified clean and sterilized seeds help crop to avoid smuts.

It was essential to practice weed control in our experimental plots, as weed infestation has been a significant limitation in achieving the optimal wheat yields. The weed control method applied has significantly affected both grain and biological yields in the current study. As shown in Table 5, the highest grain and biological yields were obtained during both 2016–2017 and 2017–2018 growing seasons using 2,4-D and Antilope to control both broad-leaved and narrow-leaved weeds, respectively. Similarly, integrating hand weeding with herbicide at a low dose compared to the weedy check has been examined on weed control, yield, and yield components of rainfed wheat cultivated in central highlands of Ethiopia (Amare *et al.,* 2016). They have also shown that post-emergence herbicide (2, 4-D) or hand weeding could further reduce the harmful effects of weeds on wheat crops. Indeed, using of the proper protocol of applying both broad -leaf and narrow-leaf herbicide in the right time and rate and monitoring weed population are essential in the effective management.

In the same context, the results obtained by Zahan and co-workers (2016) suggest that both wheat grain and biological yields could be enhanced by applying a combination of both pre-and post-emergence herbicides.

The broadleaf herbicide (2,4-D) has been widely applied as an essential herbicide for weed control in wheat production systems (Peterson *et al.,* 2016). It is a member of the chlorophenoxy chemical family. The chemistry, physiology, mode of action, toxicology, environmental behavior, and effect on ecosystem services have been thoroughly studied and published. Interestingly, particular focus has been given recently to the mechanisms of 2,4-D action at the molecular level to understand better its mode of action in controlling the broad-leaved weeds (Peterson *et al.* 2016). However, there is a considerable shift in weed flora in wheat production systems worldwide (Chhokar *et al.,* 2019). Farmers of Jordan are continuously using 2,4-D alone, which only controls broadleaf weeds. Under such a situation, the need to supplement these herbicides with other herbicide options for controlling narrow-leaf weeds has become urgently required. Antilope, a newly manufactured herbicide, effectively controls many narrow-leaved weeds, including the most harmful weed, wild oat (*Avena fatua* L.), characterized by being widespread annual and difficult to eradicate grass of the family Poaceae in wheat fields. Indeed, the successive use of the 2,4-D herbicide has enabled the wild oat to dominate and adversely affect wheat productivity. Therefore, a combination of 2,4-D and Antilope could be an alternative to control diverse weed flora in wheat, which was executed during our study.

Similarly, effective and broad-spectrum weed control in wheat was done using a combination of sulfosulfuron and pyroxsulam (Chhokar *et al.,* 2019). In the same context, a study was conducted by Kaur and co-workers (2018) in which they have monitored and evaluated several herbicides and their combinations and revealed that Pendimethalin 2.5 L. ha^{-1} together with Atlantis 400 g. ha^{-1} was found to be the most effective in controlling the weed population, producing the highest number of grains per ear, and promoting wheat grain yield up to 62.30% over the weedy check. Interestingly, they have pointed out that the development of herbicide resistance can be delayed by rotating those herbicide treatments. However, Kailkhura and colleagues (2015) have pointed out that combinations of pre-emergence application followed by post-emergence application of herbicides were most effective in controlling weed infestation. No weed control treatment during the wheat growing in a study conducted by Amare and co-workers (2016) could cause a yield reduction of 72% and 72.7% in wheat yield during the 2014 and 2015 cropping seasons, respectively.

In the current study, planting the improved variety (MARU1) (V1) and fertilization with Urea+DAP together (F1) but changing the weed control method from V1F1W3 (best treatment) to V1F1W2 or V1F1W1 (using broadleaf herbicide alone or no weed control; respectively) attained a reduction in grain yield of 12% and 63.7%; respectively. These results were confirmed from an economic point of view; planting the improved variety (MARU1) (V1) and fertilization with Urea+DAP together (F1) along with applying 2,4-D + Antilope (W3) resulted in 2058 USD/ha in comparison with 470 USD/ha if we used the combination of the (V2F4W1) treatment; where the local check (HOURANI) was planted and neither fertilization (F4) nor weed control (W1) were applied (Al Hiary *et al.* 2015). Actually, fertilizers applied at the optimum date and optimum quantity is an important component of our high-tech. production package.

The influence of planting the improved variety (MARU1) (V1) was practically proven in the field over the local check (HOURANI); planting the local check even with the best fertilization and best weed management practice (V2F1W3) resulted only in 1251 USD/ha compared to 2058 USD/ha when planting the improved variety, as mentioned earlier. Indeed, the improvement of wheat varieties is based on the genetic variety of plants and the selection of outstanding individuals (Bhering *et al.,* 2015).

Breeders perform germplasm exploration and collection. They can get these genetic resources from gene banks and exchange them with other breeders. Such breeding materials are involved in successive breeding programs towards developing superior genotypes or varieties with favorable traits (Purugganan and Fuller, 2009; Kidane *et al.,* 2017). In our investigation, the improved variety planted (MARU1) has shown, upon advanced field trials, higher and more stable yields and higher tolerance to diseases and insect pests, heat stress, and drought. Thus, it was used throughout our research. As expected, fertilization treatment in our study significantly affected the grain yield; were changing from V1F1W3 to V1F2W3, V1F3W3, or V1F4W3 (i.e., replacing the Urea+DAP together with Urea only, DAP only, or no fertilization) has reduced the grain yield by 22.10%, 43.00% or 80.10%; respectively.

Nitrogen fertilization significantly influenced grain and biological yields and components (Patanita *et al.,* 2019). Besides, the highest grain yield values were obtained in treatments with conventional nitrogen fertilizers (Patanita *et al.,* 2019). In agreement with our findings, applying nitrogen (120 kg), P2O5 (60 Kg), and K2O (40 kg) as a basal dose beside the foliar application of NPK with one spray of the micronutrient (Zn) at the grain filling stage are the best practice in wheat cultivation (Kumar *et al.,* 2018). Similarly, the response of wheat productivity to different nitrogen levels under rainfed conditions of Pakistan was reported, and maximum grain yield (2396.99 kg. ha^{-1}) was got at N (120 kg. ha^{-1}) among other levels tested (Ibrahim *et alo.,* 2019). In the same context, Choudhary and colleagues (2018) colleagues have found that the treatment of Thiourea (at 500 ppm) gave significantly higher values in terms of plant height, effective tillers, grain weight, and grain yield (1524 kg. ha^{-1}) compared to the control (1173 kg. ha^{-1}). In our study and during the 2017-2018 growing season, the combined application of Urea and DAP has surpassed the grain and biological yields than those resulting from applying Urea alone by 17.59% and by 46.61% resulting from applying DAP alone, showing the necessity of applying nitrogen fertilizers in mid-season to improve the grain and biological yields further.

Overall, the weakness of wheat production is because of the lack of farmer awareness, especially about the wheat technical package (Elgilany *et al.,* 2011). Al-Hiary (2015) showed that around 50% of farmers had finished high school, whereas 34% had high education. Indeed, NARC, together with wheat breeders in Jordan, have been building capacity, raising awareness, and encouraging farmers to cultivate the improved varieties, including (MARU1), and they planted these varieties as they realize the significance of these varieties in producing high yields of both seeds and hay. Field schools and feedback results from wheat farmers significantly contribute to wheat breeding programs in order to develop higher-yielding new wheat varieties with disease resistance characteristics to replace the old varieties as a step towards mitigating food security anxiety (De Vita *et al.,* 2007; ICARDA, 2010; Dreisigacker *et al.,* 2019; Fradgley *et al.,* 2019). Still, wheat yield results in most developing countries of the CWANA region, including Jordan, show a considerable yield gap. Recent yield gap analysis at a global level showed that the difference between potential yield and farm yield in most countries, although narrowing, ranges between 26 and 69%, with an average of 48% (Fischer *et al.,* 2014).This gap analysis included data on experimental yields obtained upon adopting improved agronomic management practices (potential yields) and yields from traditional farmers' fields (Pala *et al.,* 2011). The results of Al-Karablieh and co-workers (2002) concluded that it is possible to organize wheat production in the Irbid region using only rainfall and area data available in the early months of the growing season, therefore giving the policy and decision-maker enough time for economic arrangements.

In addition, it has been necessary to conduct precise experiments to determine the best cultivation methods and treatments required by wheat varieties in different growing conditions to make suitable agronomic recommendations (FAO, 2018). Gratefully, farmers were motivated by our improved practices applied in the field trials, and they would like to adopt these technologies of full-package approach in the next coming growing seasons for increased income, sustainable production, and better livelihood.

Conclusion

This study highlighted the great importance of the full package of practices for wheat cultivation, which comprises using the improved variety and proper fertilization using DAP and Urea together and including the narrow-leaf with broadleaf herbicides. Using the full-package technology was crucial for improving wheat's yield potential in Jordan's rainfed dry land. Reduction in potential grain and biological yields occurred because of the missing of these practices, and reductions in yield were further exacerbated when two or more of these elements were not applied. Agricultural research centers must rapidly transfer efficient procedures to farmers to reduce the yield gap and achieve food security.

Declaration of competing interest

The authors declare that they have no competing interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

Authors would like to thank the International Center for Agricultural Research in the Dry Areas (ICARDA) for supporting this Project entitled. Enhancing Food Security in Arab Countries. Project # 1227.

References

Abdulla F. 2020. 21st century climate change projections of precipitation and temperature in Jordan. Procedia Manufacturing **44**, 197-204.

Achilli AL, Roncallo PF, Echenique V. 2022. Genetic Gains in Grain Yield and Agronomic Traits of Argentinian Durum Wheat from 1934 to 2015. Agronomy **12**, 2151. https://doi.org/10.3390/ agronomy12092151.

Al-Bakri JT. 2008. Soils of Jordan. In: Zdruli, P. & Trisorio Liuzzi, G. (Eds.) Status of Mediterranean Soil Resources: Actions Needed to Support Their Sustainable Use. Mediterranean Conference Proceedings, Tunis, Tunisia 26-31 May 2007, Medcoastland Publication, IAM Bari, Italy.

Al-Bakri J, Suleiman A, Abdulla F, Ayad J. 2011. Potential impact of climate change on rainfed agriculture of a semi-arid basin in Jordan. Phys. Chem. Earth. **36**, 125-134. https://doi.org/10.1016/j.pce.2010.06.001.

Al-Ghzawi AA, Bani Khalaf Y, Al-Ajlouni ZI, AL-Quraan NA, Musallam I, Bani Hani N. 2018. The effect of supplemental irrigation on canopy temperature depression, chlorophyll content, and water use efficiency in three wheat (*Triticum aestivum* L. and *T. durum* Desf.) varieties grown in dry regions of Jordan. Agric. **8** (5), 67.

Al-Ghzawi AA. 2011. Bread Wheat (*Triticum aestivum* L.) Productivity and Profitability as Affected by Method of Sowing and Seeding Rate Under Qena Environment. Asian Journal of Crop Science **3**, 188-196. DOI: 10.3923/ajcs.2011.188.196.

Al-Ghzawi A, Al-Ajlouni Z, Al Sane K, Bsoul Y, Musallam I,Bani Khalaf Y, Al-Hajaj N, Al Tawaha A, Aldwairi Y, Al-Saqqar H. 2019. Yield stability and adaptation of four springbarley (*Hordeum vulgare* L.) cultivars under rainfed conditions.Res Crops **20**(1), 10-18.

Hiary A, Masnat, Shakhatreh Y, Khalaf YB, Ababneh M. 2015. Characterization of the Socioeconomic Conditions, Full Package and Adoption of New Technologies of Wheat Crop at Irbid Governorate, Jordan. Asian Journal of Agricultural Extension, Economics & Sociology **3** (6), 605-618. DOI: 10.9734/AJAEES/2014/9880.

Al-Karablieh E, Salman A, Fisher FM. 2002. Forecasting wheat production: The case of the Irbid region of Jordan. Quarterly Journal of International Agriculture **41**, 191-206.

Al Naber M. 2018. Groundwater-Based Agriculture in Arid Land: The case of Azraq Basin, Jordan. 208 pages. Joint PhD thesis, Montpellier SupAgro, France, and Wageningen University, Wageningen, The Netherlands. ISBN: 978-94-6343-739-4 DOI: https://doi.org/10-18174/431556

Amare T, Raghavaiah CV, Zeki T. 2016. Productivity, Yield Attributes and Weed Control in Wheat (*Triticum aestivum* L.) as Influenced by Integrated Weed Management in Central High Lands of Ethiopia, East Africa. Adv Crop Sci Tech **4**, 206. DOI: 10.4172/2329-8863.1000206

Barkley A., Peterson HH, Shroyer J. 2010. Wheat Variety Selection to Maximize Returns and Minimize Risk: An Application of Portfolio Theory. Journal of Agricultural and Applied Economics **42** (1), 39–55

Bhering LL, Junqueira VS, Peixoto LA, Cruz CD, Laviola BG. 2015. Comparison of methods used to identify superior individuals in genomic selection in plant breeding. Genet Mol Res **14** (3), 10888-96. DOI: 10.4238/2015. PMID: 26400316.

Bowden R, Shroyer J, Roozeboom K, Claassen M, Evans P, Gordon B, Heer B, Janssen K, Long J, Martin J, ASchlegel R, Sears, Witt M. 2001. Performance of Wheat Variety Blends in Kansas. Keeping Up with Research No. 128. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Carranza-Gallego G, Guzmán GI, García-Ruíz R, González de Molina M, Aguilera E. 2018. Contribution of old wheat varieties to climate change mitigation under contrasting managements and rainfed Mediterranean conditions. Journal of Cleaner Production **195**, 111-121. DOI: 10.1016/j.jclepro.2018.05.188.

Chhokar RS, Sharma RK, Gill SC, Singh RK. 2019. Broad spectrum weed control in wheat with pyroxsulam and its tank mix combination with sulfosulfuron. Journal of Research **11** (1), 23-36. DOI: 10.25174/2249- 4065/2019/85871

Choudhary RN, Patel NJ, Suthar KJ. 2018. Effect of PGRs and chemicals on yield and yield attributes of durum wheat under conserved soil moisture condition of Bhal region of Gujarat. In: Upadhyay, P.K., Rajanna, G.A., Sepat, S., Bana, R.S., Choudhary, A.K., Singh, T., Singh, R.K., Rathore, S.S., Kumar, D., Nath, C.P., Shiva Dhar, Ghosh, P.K. and Yadav, R.L. (Eds.). Doubling farmers' income through agronomic interventions under changing scenario: extended summaries of XXI Biennial National Symposium. Indian Society of Agronomy, IARI, New Delhi, p. **652**.

Dadarwal RS, Jat MK, Balbir S. 2018. Effect of water stress mitigating strategies on growth and productivity of wheat under semi-arid conditions of south-western Haryana. In: Upadhyay, P.K., Rajanna, G.A., Sepat, S., Bana, R.S., Choudhary, A.K., Singh, T., Singh, R.K., Rathore, S.S., Kumar, D., Nath, C.P., Shiva Dhar, Ghosh, P.K. and Yadav, R.L. (Eds.). Doubling farmers' income through agronomic interventions under changing scenario: extended summaries of XXI Biennial National Symposium. Indian Society of Agronomy, IARI, New Delhi, p. **652**.

Deng Y, Teng W, Tong Y-P, Chen X-P, Zou C-Q. 2018. Phosphorus Efficiency Mechanisms of Two Wheat Cultivars as Affected by a Range of Phosphorus Levels in the Field. Frontiers in Plant Science **9**. DOI: 10.3389/fpls.2018.01614

De Vita P, Nicosia OLD, Nigro F, Platani C, Di Fonzo ND, Reifolo C, Cattivelli L. 2007. Breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars released in Italy during the 20th century. Eur. J. Agron. **26**, 39-53.
DOI: 664 10.1016/j.eja.2006.08.009

FAO. 2018. The future of food and agriculture: Alternative pathways to 2050. Rome, Italy.

Fischer RA, Byerlee D, Edmeades GO. 2014. Crop Yields and Global Food Security: Will Yield Increase Continue to Feed the World. ACIAR Monograph No. 158. Canberra: Australian Centre for International Agricultural Research, pp. xxii, 634.

Fradgley N, Gardner KA, Cockram J, Elderfield J, Hickey JM, Howell P, Mackay IJ. 2019. A large-scale pedigree resource of wheat reveals evidence for adaptation and selection by breeders. PLOS Biology **17** (2), e3000071.
DOI: 10.1371/journal.pbio.3000071

Ghosh A, Singh RK, Singh VK. 2018. Strategic development of water saving wheat cultivation under different tillage and crop residue management for optimum crop and water productivity. In: Upadhyay, P.K., Rajanna, G.A., Sepat, S., Bana, R.S., Choudhary, A.K., Singh, T., Singh, R.K., Rathore, S.S., Kumar, D., Nath, C.P., Shiva Dhar, Ghosh, P.K. and Yadav, R.L. (Eds.). Doubling farmers' income through agronomic interventions under changing scenario: extended summaries of XXI Biennial National Symposium. Indian Society of Agronomy, IARI, New Delhi, p. **652**.

Hochman Z, Horan H. 2018. Causes of wheat yield gaps and opportunities to advance the water-limited yield frontier in Australia. Field Crops Research **228**, 20–30. DOI: 10.1016/j.fcr.2018.08.023

Hussain M, Cheema A, Abbas Q, Ashraf F, Shahzad M, Farooq M, Jabran K. 2018. Choice of nitrogen fertilizer affects grain yield and agronomic nitrogen use efficiency of wheat cultivars. Journal of Plant Nutrition **41** (18), 2330–2343.
https://doi.org/10.1080/01904167.2018.1509998

Ibrahim M, Ali J, Raza MA, Inayat-ur-Rahman, Khan IA, Khan SA, Khan J, Rehman A, Attaullah. 2019. Wheat productivity in response to ridge sowing and nitrogen application on rainfed condition. Pure Appl. Biol. **8** (1), 523-529. http://dx.doi.org/10.19045/bspab.2018.700212

The International Center for Agricultural Research in the Dry Areas (ICARDA). 2010. Conference on Food Security And Climate Change In Dry Areas. 1-4 FEBRUARY 2010, AMMAN, JORDAN.

Ismael M, Srouji F, Boutabba MA. 2018. Agricultural technologies and carbon emissions: evidence from Jordanian economy. Environ Sci Pollut Res **25**, 10867–10877

Khan A. 2 0 1 6. Performance of different bread wheat varieties for yield and yield attributes under diallel Combinations. Annals of Agrarian Science **14**(2). DOI: 10.1016/j.aasci.2016.03.001

Kidane YG, Mancini C, Mengistu DK, Frascaroli E, Fadda C, Pè ME, Dell'Acqua M. 2017. Genome Wide Association Study to Identify the Genetic Base of Smallholder Farmer Preferences of Durum Wheat Traits. Frontiers in Plant Science **8**. DOI: 10.3389/fpls.2017.01230

Kosina P, Reynolds M, Dixon J, Joshi A. 2007. Stakeholder perception of wheat production constraints, capacity building needs, and research partnerships in developing countries. Euphytica **157**, 475-483.

Kumar P, Pal Y, Kumar V, Singh S, Rathi S. 2018. Performance of foliar applied fertilizer on wheat in tarai and bhabar area of Uttarakhand. In: Upadhyay, P.K., Rajanna, G.A., Sepat, S., Bana, R.S., Choudhary, A.K., Singh, T., Singh, R.K., Rathore, S.S., Kumar, D., Nath, C.P., Shiva Dhar, Ghosh, P.K. and Yadav, R.L. (Eds.). Doubling farmers' income through agronomic interventions under changing scenario: extended summaries of XXI Biennial National Symposium. Indian Society of Agronomy, IARI, New Delhi, p. **652**.

Lantican MA, Braun HJ, Payne TS, Singh R, Sonder K, Baum M, Ginkel MV, Erenstien O. 2016. Impact of international wheat improvement research 1994-2014. Mexico, DF: International Maize and Wheat Improvement Program.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, Washington, DC.

Pala M, Oweis T, Benli B, De Pauw E, El Mourid M, Karrou M, Jamal M, Zencirci N. 2011. Assessment of wheat yield gap in the Mediterranean: Case studies from Morocco, Syria and Turkey. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. 36 pp.

Palm C. 2013. Conservation agriculture and ecosystem services: An overview. Agric. Ecosyst. Environ. **187**, 87-105. http://dx.doi.org/10.1016/j.agee.2013.10.010

Patanita M, Tomaz A, Oliveira P, Boteta L, Dôres J. 2109. Water Regime and Nitrogen Management to Cope with Wheat Yield Variability under the Mediterranean Conditions of Southern Portugal. Plants **8**, 429. DOI: 10.3390/plants8100429.

Patrignani A, Lollato RP, Ochsner TE, Godsey CB, Edwards JT. 2014. Yield Gap and Production Gap of Rainfed Winter Wheat in the Southern Great Plains. Agronomy Journal **106** (4), 1329. DOI: 10.2134/agronj14.0011

Peterson M, McMaster S, Riechers D, Skelton J, Stahlman P. 2016. 2, 4-D Past, Present, and Future: A Review. Weed Technology **30** (2), 303-345. DOI: 10.1614/WT-D-15-00131.1

Purugganan MD, Fuller DQ. 2009. The nature of selection during plant domestication. Nature **457**, 843–848. DOI: 10.1038/nature.07895.

Qasem, Jamal R. 2021. Competition of Weeds Dominated by Wild Oat (*Avena sterilis* L.) in Wheat (*Triticum durum* Desf.) in Jordan. Agronomy **11(**9), 1816. https://doi.org/10.3390/agronomy11091816

Rong L, Gong K, Duan F, Li S, Zhao M, He J, Zhou W, Yu Q. 2021. Yield gap and resource utilization efficiency of three major food crops in the world- A review. Journal of Integrative Agriculture **20** (2), 349-362. DOI: 10.1016/s2095-3119 (20)63555-9

Royo C, Ammar K, Villegas D, Soriano JM. 2021. Agronomic, Physiological and Genetic Changes Associated With Evolution, Migration and Modern Breeding in Durum Wheat. Front. Plant Sci. **12,** 674470. DOI: 10.3389/fpls.2021.674470

Savin R, Cossani M, Dahan R, Ayad JY, Albrizio R, Todorovic M, Karrou M, Slafer GA. 2022. Intensifying cereal management in dryland Mediterranean agriculture: Rainfed wheat and barley responses to nitrogen fertilization. European Journal of Agronomy **137**, 126-518. https://doi.org/10.1016/j.eja.2022.126518

Shakhatreh Y, Carvalho P, Foulkes M, Musallam I, Ismail F, Khalaf Y. 2013. Improving wheat agricultural practices to cope with climate change effects in Jordan. In Conference: 1st CIGR Inter-Regional Conference on Land and Water Challenges (Water,environment and agriculture: challenges for sustainable development), Bari (Italy)

Tadesse W, Amri A, Sanchez-Garcia M, El Bouhssini M, Oweis T, Karrou M, Patil S, Bassi F, Baum M. 2016. Improving wheat production in the CWANA region, in "Achieving sustainable cultivation of wheat. Volume 2: Cultivation techniques. Cambridge, United Kingdom: Burleigh Dodds Science Publishing

Turk MA, Tawaha AM. 2003. Weed control in cereals in Jordan, Crop Protection **22**(2), 239-246, https://doi.org/10.1016/S0261-2194(02)00182-5.

Van Ittersum MK, Cassman KG, Grassini P, Wolf J, Tittonell P, Hochman Z. 2013. Yield gap analysis with local to global relevance- A review. Field CropsRes. **143**, 4–17, http://dx.doi.org/10.1016/j.fcr.2012.09.009.

Verhulst N, Govaerts B, Verachtert E, Castellanos-Navarrete A, Mezzalama M, Wall P, Deckers J, Sayre, KD. 2010. Conservation Agriculture, Improving Soil Quality for Sustainable Production Systems. In: Lal, R., Stewart, B.A. (Eds.), Advances in Soil Science: Food Security and Soil Quality. CRC Press, Boca Raton, FL, USA, pp. **137–208**.

Yasin M, Tanveer A, Iqbal Z, Ali A. 2010. Effect of Herbicides on Narrow Leaved Weeds and Yield of Wheat (*Triticum aestivum* L.). World Academy of Science, Engineering and Technology **68** 1280-1282.

Zahm S, Weisenburger D, Babbitt P, Saal R, Vaught J, Cantor K, Blair A. 1990. A Case-Control Study of Non-Hodgkin's Lymphoma and the Herbicide 2,4-Dichlorophenoxyacetic Acid (2,4-D) in Eastern Nebraska. Epidemiology **1** (5), 349-356.