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Effect of weed control and proline treatment on wheat productivity and weed nutrient removal under water stress conditions

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Abstract : Field evaluation of the efficiency of four weed-control treatments (Tribenuron-methyl, Thifensulfuron, hand weeding and unweeded check), three proline levels (0, 100 and 200 mg/L) and their interactive effects on wheat yield and determine the macronutrient loss occurred by broadleaved weeds under three water requirements (100, 75 and 50%) trials on wheat were performed in two successive seasons at the agricultural experimental station of the National Research Centre, Nubaria, Egypt. The data show that the reduction in water applied to wheat significantly reduced number and weight of broadleaved weeds. Macronutrient removal by broadleaved weeds was significantly greater for N, P and K when wheat was irrigated with the full recommended water duty than the other water stress treatments. Weed control treatments in wheat significantly reduced number and weight of broadleaved weeds. Macronutrient loss by broadleaved weeds was significantly reduced for N, P and K under weed control treatments. The data show that spraying wheat plants with proline at 100 or 200 mg/L under 50% irrigation requirement could effectively produce similar grain yield to that achieved when the recommended treatment was applied (100%). The results indicate that WUE increased as water stress increased and gradual_increases in WUE were reported when water requirement reduced from 100% to 75% and 50%. Moreover, spraying wheat plants with proline at 200 mg/L under 50% water stress treatment doubled the ability of wheat plants to produce grain yield per irrigation water unit consumed.
Keywords: Wheat, weeds control, water requirements, macronutrient removal, yield.

Introduction

The horizontal expansion in the reclaimed desert land in Egypt is an essential part in farmland and agricultural production plan, Application of the proper agronomic practices on wheat in such soils may reduce the gap of wheat production and consumption.

Weeds is one of the most important problems in wheat production, it compete with the crop for all growth factors such as, nutrients, water, light and carbon dioxide[1]. Weed infestation especially the broadleaved ones share in substantial loss of macronutrients through up taking of N, P and K[2]. [3]reported that wheat grain yield losses due to weed interference accounted by 27.5 %. Controlling weeds by herbicidal treatments increased grain yield by about 40.3 and 13.6% compared with unweeded and hand weeding treatments, respectively[4]. Most available herbicides used in wheat are assigned for controlling particular weeds, unlike little (e.g. Florasulom+Flumetsulom and Thifensulfuron) that controls broad spectrum of weeds. Application of Florasulom+Flumetsulom and Thifensulfuron herbicides provided substantial efficacy of chemical weed control in the old lands[5].

Desert lands management pay great attention to water as it is one of the most important factors in crop production. Effective irrigation management is essential for maximizing the productivity from each unit of applied water[6]. Water scarcity and low soil fertility are the main constrains facing wheat production in the new land in Egypt. Therefore, irrigation should be adjusted to maximize crop production per unit of applied water. Water shortage causes a depression in wheat growth and yield. Therefore, exogenous application of compatible osmolytes such as proline had gained considerable attention in mitigating the effect of stress. Under stress condition, exogenous proline application improved tolerance of stressed plants[7]. Proline has been proposed to act as a compatible solute that adjusts the osmotic potential in the cytoplasm, it is considered to play an important role in defence mechanisms of stressed cells[8].

Therefore, the objectives of this research were to study the efficiency of four weed-control treatments combined with three proline level) and their interactive effects on wheat yield and associated weeds under different water requirements in Nubaria region, Egypt.

Materials and Methods

Experimental procedures:

Two field experiments were conducted during the two successive seasons (2012/13 and 2013/14) at the experimental farm of National Research Centre, Nubaria region, Egypt (latitude 30.8667 N and longitude 31.1667 E and mean altitude 21 m above sea level). The experimental area was classified as arid region with cool winters and hot dry summers prevailing in the experimental area. Table (1) illustrates the monthly mean weather data for the two growing seasons 2012/13 and 2013/14, for the experimental site in Nubaria, as obtained from the Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation. There was no rainfall that can be taken into consideration throughout the two growing seasons. The soil of experimental site is classified as sandy soil. Some physical and chemical properties of the experimental soil are shown in Tables (2a) and (2b). Irrigation water was obtained from an irrigation channel passing through the experimental area with pH 7.35, and electrical conductivity (EC) of 0.41 dS/m. The experiment was established with a split-split plot design having four replicates. The main plots included three irrigation water requirement treatments (100%, 75% and 50% water requirement throughout the season). Sub-plots were assigned to four weed-control treatments 1) Tribenuron-methyl (1-Methyl 2[[{N-(4-methoxy-6-methyl-1,3,5 triazin 2-yl) methyl amino}carbonyl] amino] sulfonyl] benzoate) known commercially as Granstar 75% DF sprayed after 25 days from sowing at the rate of 20 gm ha^{-1}, 2) Harmony extra (Methyl 3-£¨4-methoxy-6-methyl-1£¬3£¬5-Triazine-2-yl) amino |carbonyl |amino |sulonyl|-2-thiophencarboxylate) known commercially as Thifensulfuron sprayed after 25 days from sowing at the rate of 60 gm ha^{-1}, 3) Two hand weeding 30 and 50 days from sowing, and 4) Unweeded check. Sub-sub plots were devoted to the three levels of proline ($C_5H_9NO_2$) 0, 100 and 200 mg/L (P_0, P_1 and P_2). The proline treatments were foliar applied, after adding "Tween 20" (0.05 %) as a wetting agent, using hand atomizer after 28 and 35 days from sowing. All treatments under investigation were sprayed by Clodinafop-propargyl to control the associated weed grasses of wheat. The water resource for irrigation came from an irrigation channel under rotational irrigation where water existed in the channel just for 3 days every week and the channel was empty for the remaining 4 days. The experimental field was deep ploughed before planting. First disc harrow, was used for further preparation of the field for planting. A combined driller that facilitated concurrent application of fertilizer and grains was used. Wheat variety (Gimeza 9) was planted in the last week of November in both studied seasons. The driller setting was such that it applied 167 kg of seed per ha, at 5 cm soil depth with 13.5 cm row spacing. Fertilizers application was based on Minstry of Agriculture recommendations. All treatment plots received the same amount of total fertilizer. A compound fertilizer was applied as follow: 285 kg N/ha as ammonium nitrate, applied before each irrigation in six portions till before heading stage, 70 kg P_2O_5/ha as single superphosphate applied to the soil before planting and 60 kg K_2O/ha as potassium sulphate applied once after one month from sowing.

Table 1. Monthly and growing season climatic data of the experimental site.

Month	Growing season	Solar radiation [W/m²]	Precipitation [mm]	Wind speed [m/sec]	Air temperature [°C]			Relative humidity [%]
				Average	Average	Min.	Max.	Average
December	2012/13	49.4	0.2	1.8	15.6	8.9	22.2	63.3
January		49.7	0.0	2.3	14.9	8.3	21.4	61.0
February		67.5	0.1	2.1	16.9	9.3	24.5	57.7
March		93.5	3.6	2.2	18.6	11.0	26.2	60.0
April		111.0	0.0	2.3	20.8	12.8	28.8	52.3
May		130.0	0.0	1.4	20.2	12.7	27.6	49.0
December	2013/14	49.5	0.0	2.0	15.8	9.1	22.6	63.4
January		50.0	1.2	2.5	15.7	7.3	24.1	66.0
February		68.0	2.6	2.3	16.8	7.2	26.4	56.0
March		95.0	0.0	2.5	18.2	8.2	28.3	56.0
April		113.0	0.0	2.4	20.7	10.9	30.6	50.0
May		135.0	0.0	1.6	24.0	14.3	33.8	47.0

Table 2a. Soil physical characteristics of experimental site.

Soil depth [cm]	Particle size distribution [%]			Texture class	Soil moisture constants		
	Coarse sand	Fine sand	Clay + Silt		SP [%]	FC [%]	WP [%]
20	47.76	49.75	2.49	Sandy	21.0	10.1	4.7
40	56.72	39.56	3.72	Sandy	19.0	13.5	5.6
60	59.40	59.40	3.84	Sandy	22.0	12.5	4.6

SP - saturation percentage; FC - field capacity; WP - wilting point

Table 2b. Soil chemical properties of experimental site.

Soil depth [cm]	OM [%]	pH (1:2.5)	EC [dS/m]	$CaCO_3$ [%]
20	0.65	8.7	0.35	7.02
40	0.40	8.8	0.32	2.34
60	0.25	9.3	0.44	4.68

OM- Organic matter; pH- acidity or alkalinity in soils; EC- electrical conductivity

Measurements.

Weeds of broadleaved were hand pulled from one square metre of each experimental unit at 80 days after sowing (DAS). The number of weeds were recorded, then the collected weeds were first air-dried in the sun and then in an electric oven for 72 hours maintaining a constant temperature of 70°C. Consequently, the dry weights were recorded. At 90 DAS, flag-leaf area, SPAD value and plant height were measured. Flag-leaf area [cm^2] was measured on 10 tillers chosen randomly from each plot. The chlorophyll content (SPAD value) of flag leaf was determined by chlorophyll meter (SPAD-502 plus) according to soil plant analysis department section, Minolta Camera Co., Osaka, Japan as reported by[9]. Harvesting dates were in the first week in May in both seasons, where plants of 1 square meter per each experimental plot were collected to estimate spikes number m^{-2}, grain and straw yields ha^{-1}. Afterward, 10 tillers were chosen randomly from each plot, and the following traits were measured: spike length, number of spikelet/spike, grain weight and grains number/spike and spike weight. Total nitrogen (TN) was measured using Kjeldahl's method, and total crude protein (TCP) was determined by multiplying TN-content in grains by 5.75 according to[10]. The phenol-sulfuric acid method was used for determination of total carbohydrates (TC)[11]. The percentage of soil moisture content (θv) was measured by profile-probe apparatus in sandy soils.

For determination of the crop water requirements (CWR), crop evapotranspiration was calculated under standard conditions (ETc) as follows:

$ET_c = ET_o \times K_c$ (Equation 1)
where:
ET_c = Crop evapotranspiration [mm/day]
ET_o = Reference crop evapotranspiration [mm/day]
K_c = Crop coefficient

The values of ET_c and CWR are identical, whereby ET_c refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. ET_c calculated from climatic data by directly integrating the effect of crop characteristics into ET_o. The Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith method is now the sole recommended as the sole standard method for calculating ET_o. The Penman-Monteith equation is given by the following equation[12].

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\left(1 + 0.34 u_2\right)} \quad \text{(Equation 2)}$$

where:
ET_o = Reference evapotranspiration [mm/day]
R_n = Net radiation at the crop surface ([MJ/m^2] per day)
G = Soil heat flux density ([MJ/m^2] per day)
T = Mean daily air temperature at 2 m height [°C]
u_2 = Wind speed at 2 m height [m/sec]
e_s = Saturation vapour pressure [kPa]
e_a = Actual vapour pressure [kPa]
$e_s - e_a$ = Saturation vapour pressure deficit [kPa]
Δ = Slope of saturation vapour pressure curve at temperature T [kPa/°C]
γ = Psychrometric constant [kPa/°C]

The equation used the standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed for daily calculations. Amount of irrigation water was calculated according to the following equation for the sprinkler irrigation systems:

$$AW = \frac{ET_c}{E_a \times (1 - LR)} \quad \text{(Equation 3)}$$

where:
AW = applied irrigation water depth [mm/day]
E_a = application efficiency equals 75% for sprinkler irrigation system
LR = leaching requirements equals 10% for sprinkler irrigation system.
Irrigation time (IT) for solid sprinkler system was calculated according to equation as follows:

$$\text{Irrigation time in hours (IT)} = \frac{\text{Applied irrigation water depth}}{\text{Application rate for sprinkler}} \quad \text{(Equation 4)}$$

where:
AR = Application rate for sprinkler in [mm/hour]

$$AR = \frac{\text{Sprinkler discharge} \times 1000}{\text{Strip area}} \quad \text{(Equation 5)}$$

where:
Sprinkler discharge in [m3/hour]
Strip area in [m^2]

The seasonal irrigation water applied [m^3/ha/season] for 2012/13 and 2013/14, respectively are shown in Table (3).

Table 3. The seasonal irrigation water applied [m3/ha/season] for seasons 2012/13 and 2013/14.

Treatment	Growing season	
	2012/13 [m^3/ha]	2013/14 [m^3/ha]
100%	4284	4382
75%	3213	3287
50%	2142	2191

Irrigation water use efficiency (kg m^{-3}).

Irrigation water use efficiency "WUE" is an indicator of effectiveness use of irrigation unit for increasing crop yield. Irrigation water use efficiency of wheat yield was calculated according to [13] as follows:

IWUE wheat (kg m^{-3}) =Total yield (ton ha^{-1}) / Total applied irrigation water (m^3 ha^{-1}).

Statistical analyses.

The combined analysis of variance for the data of the two seasons was performed after testing the error homogeneity and Fisher's Least Significant Difference (LSD) test at 0.05 level obtained data from each season were subjected to the proper statistical analysis of variance of significance was used for the comparison between means according to[14].

Results and Discussion

Weeds:

The major weed species, which were found in the wheat fields, were annual broadleaved weeds, i.e. *Chenopodium album* L.; *Beta vulgaris* L.; *Melilotus indicus* L. and *Ammi majus* L.

Effect of water requirement:

Data presented in Table (4) clearly show that the reduction in water applied to wheat significantly reduced number and weight of broadleaves. Macronutrient removal by broadleaved weeds was significantly greater for N, P and K when wheat was irrigated with the full recommended water duty. As expected wheat irrigation with the full recommended water requirement resulted in the greatest loss of N, P and K than the other water stress treatments. Such loss may be due to the greater opportunity of broadleaved weeds to increase in number and weight which means greater loss of macronutrients applied to wheat crop. Irrigation water reduction by 25% caused 17.9, 16 and 25 kg/ha loss by broadleaved weeds for N, P and K, which represented 85, 82 and 82% respectively, compared to the wheat irrigated with the full recommended water requirement .While the corresponding values were 15.9, 15.1 and 22.3 kg/ha loss by broadleaved weeds for N, P and K, which represented 63, 78 and 74%, respectively when the plants were irrigated with 50% of with the full recommended water requirements. These results are in good agreement with those reported by[15,16].

Effect of weed control.

Data presented in Table (4) show that weed control treatments in wheat significantly reduced number and weight of broadleaved weeds. Macronutrient removal by broadleaved weeds was significantly reduced for N, P and K under weed control treatments compared to the unweeded control. Chemical weed control treatments significantly surpassed the hand weeding treatment either in number or in weight of weeds m^{-2}. It is worthy to note that neglecting weed control in wheat caused loss in macronutrient applied to wheat by 52.5, 45 and 71 kg ha^{-1} of N, P and K applied to wheat. Controlling weeds using Tribenuron-methyl caused 3.8, 3.5 and 5.3 kg ha^{-1} loss by broadleaved weeds for N, P and K, which represented 7.1, 7.7 and 7.5%, respectively compared to the unweeded control. While using Thifensulfuron caused 4.3, 3.8 and 6 kg ha^{-1} loss by broadleaved weeds for N, P and K, which represented 8.1, 8.3 and 8.5%, respectively compared to the unweeded control. The corresponding loss by broad leaved weeds using hand weeding treatment were 15.1, 13.5 and 21.1 for N, P and K , which represented 28.5, 29.7 and 15.4 %, respectively compared to the unweeded control (100%). The reduction of weed dry weight may be due to the inhibition effect of herbicide treatments on growth and development of weeds. The positive effect of weeded practices on weed wheat have been confirmed by[2].

Table 4: Effect of water regime, weed control and proline on number and dry weight of wheat broadleaved weeds and macronutrient removal by broadleaved weeds kg/ha (average of two seasons 2012/13 and 2013/14).

Characters / Treatment	Broadleaved weed (g m^{-2})		Removal by broadleaved weeds kg/ha		
	Number	Weight	N	P	K
Water regime					
100%	34.33	57.15	23.2 (100)*	19.3 (100)	30.2 (100)
75%	27.39	47.37	17.9 (77)	16.0 (82)	25.0 (82)
50%	24.80	42.17	15.9 (67)	15.1 (78)	22.3 (74)
LSD 0.05	2.24	2.59	0.17	0.023	17.0
Weed control					
Unweeded	79.47	134.20	52.8 (100%)**	45.4 (100)	71.0 (100)
Thifensulfuron	6.47	11.30	4.3 (8.1)	3.8 (8.3)	6.0 (8.5)
Hand weeding	23.97	39.98	15.1(28.6)	13.5 (29.7)	21.1(29.7)
LSD 0.05	1.11	1.18	0.14	0.045	0.25
Proline levels					
P_0	28.40	47.76	18.0 (100)***	16.1 (100)	25.2 (100)
P_1	28.89	49.27	18.6 (103)	17.1 (106)	26.0 (103)
P_2	29.24	49.66	20.4 (113)	16.9 (105)	26.2 (104)
LSD 0.05	ns	ns	0.16	ns	ns

* Refers to % of the recommended irrigation treatment.
** Refers to % of the unweeded control.
*** Refers to % of the 0% proline treatment.

According to results in Table (4) number and dry weight of broadleaved weeds after 80 days from sowing as well as nutrients uptake by weeds were insignificantly affected by proline spraying levels.

Interaction effect.

Remarkable impact of the interaction between weed management and water requirement treatments on number and dry weight of broadleaved weeds as well as NPK uptake by weeds as presented in Table (5). In this regard, spraying by Tribenuron-methyl in plots of 50% water requirement achieved the highest decreases in number and dry weight of broadleaved weeds as well as NPK uptake by weeds. On the other hand, the highest in number and dry weight of broadleaved weeds as well as NPK uptake by weeds was produced at 100% of water requirement treatment in unweeded plots. The similar conclusion was mentioned by[16].

Table 5: Effect of the first order interactions (water requirements x weed control) on number and dry weight of broad leaved weeds and macronutrient removal by broadleaved weeds kg/ha (average of two seasons 2012/13 and 2013/14).

Treatment	Characters	Broad leaved weeds ($g\ m^{-2}$)		Macronutrient Removal by broad leaved (weeds kg/ha)		
		Number	Weight	N	P	K
100%	Tribenuron-methyl	6.47	11.02	4.2	3.7	5.8
	Thifensulfuron	7.79	13.57	5.2	4.6	7.2
	Hand weeding	31.19	52.24	19.7	17.7	27.5
	Unweeded	91.88	151.76	63.8	51.3	80.1
75%	Tribenuron-methyl	5.56	11.42	4.3	3.8	6.0
	Thifensulfuron	6.89	11.73	4.4	4.0	6.2
	Hand weeding	23.84	36.45	13.7	13.6	19.3
	Unweeded	75.60	129.87	49	43.9	68.6
50%	Tribenuron-methyl	4.35	7.83	2.9	2.8	4.1
	Thifensulfuron	4.72	8.59	3.3	2.9	4.5
	Hand weeding	19.18	31.26	11.8	10.6	16.5
	Unweeded	70.93	120.99	45.6	40.9	63.9
LSD at 0.05		3.66	4.26	0.18	0.028	0.31

Wheat growth and yield attributes:

Effect of water requirement.

Water requirement had a significant effect on SPAD value, flag leaf area, plant height, spike length, no. of spikelets/spike, grain number/spike and grain weight/spike on wheat as shown in Table (6). In this connection, irrigation with 100% of water requirement significantly increased wheat characters SPAD value, growth and spike characters). In contrast, irrigation with 50% of water requirement produced the lowest values of aforementioned characteristics. Irrigation with 100% of water requirement increased available nutrients, caused increase in both the growth and the area of leaves as well as improving pigments and photosynthetic process. These findings confirmed previous results obtained by[17].

Effect of weed control.

Wheat characters: SPAD value, flag leaf area, plant height, spike length, no. of spikelets spike^{-1}, grain number spike^{-1} and grain weight spike^{-1} were significantly responded to weed management treatments, as shown in Table (6). Herein, Tribenuron-methyl was superior treatment for increasing flag leaf area and plant height. Moreover, Thifensulfuron treatment resulted in the highest values of SPAD value, spike length, no. of spikelets spike^{-1}, grain number spike^{-1} and grain weight/spike. Such enhancements due to weeded treatments might be attributed to their high efficiency in elimination of weeds (Table, 4) and consequently, decreased their competition with wheat plants on resources. The positive effect of weeded practices on wheat growth and yield components have been confirmed by[5].

Effect of proline levels.

Data presented in Table (6) show significant increases of all the studied traits with increasing proline levels from 0 to 100 and 200 mg/L. Application of 200 mg proline/L led to significant increase in SPAD value, flag leaf area, plant height, spike length, no. of spikelets spike^{-1}, grain number spike^{-1} and grain weight spike^{-1}. On the other hand, the lowest of aforementioned characters was obtained by untreated plots. The increase in wheat growth with increasing proline levels might be due to simulative effect of the vegetative growth which promotes tillering in cereals and encourages photosynthetic rate, spikes number/plant, number of spikelets/spike, spike length and grains number/spike. Similar results were reported by[18].

Table 6: Effect of water requirements, weed control and proline on growth and spike characters of wheat (average of two seasons 2012/13 and 2013/14).

Characters / Treatment	SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spike length (cm)	Spikelets number $spike^{-1}$	Grains number $spike^{-1}$	Grains weight $spike^{-1}$(g)
Water regime							
100%	34.33	25.37	88.00	10.37	16.55	42.56	1.58
75%	31.96	24.73	84.42	9.40	15.65	41.68	1.56
50%	30.30	22.50	69.92	8.91	14.48	34.91	1.37
LSD at 0.05	1.27	1.63	3.56	0.42	0.75	3.17	0.13
Weed control							
Tribenuron-methyl	33.35	25.31	86.78	9.97	16.40	41.87	1.57
Thifensulfuron	34.66	24.68	84.22	10.28	16.43	42.90	1.63
Hand weeding	33.44	23.73	79.00	9.19	15.10	37.67	1.45
Unweeded	32.15	23.08	73.11	8.80	14.30	36.02	1.37
LSD at 0.05	NS	0.54	2.13	0.31	0.23	1.15	0.07
Proline levels							
P_0	31.38	22.65	77.42	9.03	14.39	36.13	1.40
P_1	33.68	24.12	81.58	9.63	15.62	40.34	1.50
P_2	35.67	25.83	83.33	10.01	16.66	42.38	1.62
LSD at 0.05	1.14	1.12	1.94	0.22	0.27	2.17	0.08

Interaction effect:

Water requirements x Weed control.

Irrigation with 100% of water requirement produced the highest SPAD value, spike length, no. of spikelets $spike^{-1}$, grain number $spike^{-1}$ and grain weight $spike^{-1}$ when Thifensulfuron treatments was used Table (7). Also, irrigation with 100% of water requirement produced the highest flag leaf area and plant height when Tribenuron-methyl treatment was sprayed. Moreover, the minimal values of all obvious characters were obtained with irrigation of 50% water requirement and unweeded treatments. These are in general agreement with those recorded by[16].

Table7: Effect of the interaction (water requirements x weed control on, growth and spike characters of wheat (average of two seasons 2012/13 and 2013/14).

Treatment \ Characters		SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spike length (cm)	Spikelets number $spike^{-1}$	Grains number $spike^{-1}$	Grains weight $Spike^{-1}$ (g)
100%	Tribenuron-methyl	35.05	28.83	97.67	11.20	17.73	45.70	1.67
	Thifensulfuron	37.21	26.27	95.33	11.47	18.00	46.56	1.73
	Hand weeding	35.57	24.53	86.00	9.67	15.67	39.63	1.49
	Unweeded	34.07	23.83	73.00	9.13	14.80	37.13	1.41
75%	Tribenuron-methyl	34.52	25.47	91.33	9.50	16.77	43.83	1.60
	Thifensulfuron	36.83	25.00	84.67	10.00	16.10	45.83	1.67
	Hand weeding	34.87	24.57	81.67	9.23	15.27	39.53	1.55
	Unweeded	33.61	23.90	80.00	8.87	14.27	37.50	1.43
50%	Tribenuron-methyl	30.47	23.63	71.33	9.20	14.70	36.06	1.42
	Thifensulfuron	32.09	22.77	72.67	9.37	15.20	36.30	1.48
	Hand weeding	29.87	22.10	69.33	8.67	14.16	33.83	1.30
	Unweeded	28.76	21.50	66.33	8.40	13.83	33.43	1.28
LSD at 0.05		1.31	1.98	3.71	0.49	1.03	4.11	0.19

Table 8: Effect of the interaction (weed control x proline) on growth and spike characters of wheat (average of two seasons 2012/13 and 2013/14).

Treatment \ Characters		SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spike length (cm)	Spikelets number $spike^{-1}$	Grains number $spike^{-1}$	Grains weight $Spike^{-1}$ (g)
Tribenuron-methyl	P_0	30.67	23.50	80.67	9.30	14.93	1.42	37.37
	P_1	33.31	25.10	88.67	10.00	16.57	1.56	43.00
	P_2	36.05	27.33	91.00	10.60	17.70	1.72	45.23
Thifensulfuron	P_0	32.26	22.97	80.33	9.33	15.30	1.51	38.43
	P_1	35.78	24.60	85.00	10.57	16.43	1.63	44.23
	P_2	38.09	26.47	86.67	10.93	17.57	1.75	46.03
Hand weeding	P_0	31.79	22.40	76.33	8.93	14.00	1.35	35.13
	P_1	33.31	23.80	80.00	9.13	15.23	1.43	37.97
	P_2	35.20	25.00	81.00	9.50	16.07	1.56	39.90
Unweeded	P_0	30.81	21.73	71.00	8.53	13.30	1.32	33.57
	P_1	32.31	22.97	73.00	8.77	14.23	1.37	36.17
	P_2	33.32	24.53	74.67	9.03	14.33	1.43	38.33
LSD at 0.05		1.40	2.13	3.80	0.47	0.96	0.11	4.13

Weed control x Proline levels.

Data presented in Table (8) illustrate that application of 200 mg proline/L with either Thifensulfuron (for SPAD value, spike length, grain number $spike^{-1}$ and grain weight $spike^{-1}$) or Tribenuron-methyl (for flag leaf area, plant height and no. of spikelets $spike^{-1}$) produced the maximum values. In contrast, the lowest values of these characters were obtained with unweeded treatment under untreated plots with praline.

Water requirements x Proline levels.

Results indicate that irrigation 100% of water requirement with 200 mg proline/L gave the highest SPAD value content, spike length, no. of spikelets spike^{-1}, grain number spike^{-1} and grain weight spike^{-1} Table (9). Also, irrigation of 50% water requirement without proline produced the lowest values all aforementioned characteristics. These results are in good harmony with those obtained by[18].

Table 9: Effect of the interaction (water requirements x proline), growth and spike characters of wheat (average of two seasons 2012/13 and 2013/14).

Characters / Treatment		SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spike length (cm)	Spikelets number spike^{-1}	Grains number spike^{-1}	Grains weight Spike^{-1} (g)
100%	P_0	30.98	23.90	83.50	9.70	15.48	37.63	1.48
	P_1	35.44	25.45	89.00	10.58	16.63	43.78	1.58
	P_2	37.51	26.75	91.50	10.83	17.55	45.38	1.68
75%	P_0	32.68	22.88	80.50	8.75	14.03	36.88	1.43
	P_1	35.15	24.93	85.75	9.50	15.93	42.55	1.54
	P_2	37.05	26.40	87.00	9.95	17.00	45.60	1.73
50%	P_0	28.25	21.18	68.25	8.63	13.68	33.88	1.29
	P_1	30.20	21.98	70.00	8.83	14.30	34.70	1.38
	P_2	32.45	24.35	71.50	9.28	15.45	36.15	1.45
LSD at 0.05		1.35	1.95	4.11	0.39	0.93	2.96	0.14

Wheat yield and chemical composition:

Effect of water requirements.

Significant effects of water requirement treatments were found on spikes number m^{-2}, grain yield, straw yield, crude protein % and carbohydrates % Table (10). Irrigation with 100% of water requirement produced the maximum values of spikes number m^{-2}, grain yield, straw yield, crude protein % and carbohydrates %. On contrast, irrigation of 50% water requirement recoded the minimum values of the previous characters. Results also indicated that no significant differences between irrigation of 75% and 100% on yield of wheat plants. So, sufficient watering regime of 100% of water requirement might help the plant to absorb greater amount of water and nutrients led to an increase in yield and its components. These results confirmed previous results obtained by[16,19].

Effect of weed control.

Wheat yield and chemical composition of grains were significantly affected by weed management treatments, as shown in Table (10). The highest values of spikes number m^{-2}, grain yield, straw yield, crude protein % and carbohydrates % were obtained from Thifensulfuron followed Tribenuron-methyl and hand weeding treatments. While, the highest values of straw yield was obtained by Tribenuron-methyl followed by Thifensulfuron treatment. Whereas, the lowest values of the previous characters was obtained from the unweeded check. Thifensulfuron followed Tribenuron-methyl and hand weeding treatments gave higher values of grain yield/ha. These treatments significantly increased grain yield /ha over the unweeded check by 51.0, 46.8 and 23.7% respectively. Such superiority of weeded treatments minimized weed-crop competition (Table, 4) which in turn increased growth characters and positively reflected on biological, grain and straw yields ha^{-1}. Similar findings were reported by[16].

Effect of proline levels.

Data presented in Table (10) show significant increases of all the studied traits with increasing proline levels from 100 to 200 mg proline/L. Application of 200 mg proline/L led to significant increase in spikes number m^{-2}, grain yield, straw yield, crude protein % and carbohydrates%. On the other hand, the lowest values of aforementioned characters were obtained by untreated plots. The increase in wheat yield with increasing proline might be due to increase in proline accumulation, which increasing the capacity of wheat plant to tolerate stress[20].

Table10: Effect of water requirements, weed control and proline on wheat yield, protein and Carbohydrates percentage (average of two seasons 2012/13 and 2013/14).

Characters / Treatment	Spikes number m^{-2}	Grain yield ha^{-1} (ton)	Straw yield ha^{-1} (ton)	Crude protein (%)	Carbohydrates (%)
Water regime					
100%	289.42	3.69	7.22	10.54	76.29
75%	277.67	3.63	6.95	10.24	75.78
50%	239.67	3.07	6.03	9.96	74.11
LSD at 0.05	11.20	0.24	0.101	0.47	0.69
Weed control					
Tribenuron-methyl	279.89	3.90	6.99	10.37	76.11
Thifensulfuron	288.67	4.02	6.45	10.39	76.34
Hand weeding	264.89	3.29	6.22	9.98	75.19
Unweeded	242.22	2.66	4.88	9.88	73.92
LSD at 0.05	9.16	0.190	0.078	0.39	0.73
Proline levels					
P_0	255.17	3.16	5.95	9.69	75.10
P_1	271.67	3.55	6.96	9.92	75.46
P_2	279.92	3.68	7.30	10.13	75.62
LSD at 0.05	7.14	0.16	0.086	0.24	0.51

Interaction effect.

Water requirements x Weed control.

Data in Table (11) showed that there were significant effect due to the interaction between water requirements and weed control on spikes number m^{-2}, grain yield, crude protein % and carbohydrates %. Irrigation with 100% of water requirement significantly increased previous characters when Thifensulfuron treatment was applied. Results also indicated that irrigation with 100% of water requirement and Tribenuron-methyl treatments gave the maximum values of straw yield. While, the minimum values of the previous characters was recorded with unweeded treatment with irrigation of 50% water requirement. Similar results were obtained by[16].

Weed control x Proline levels.

Analysis of data revealed that the combined effect of weed control treatments and Proline levels significantly affected of spikes number m^{-2}, grain yield, crude protein % and carbohydrates %. Maximum values a previous characters Table (12) were obtained with combined Thifensulfuron treatment with application of 200 mg proline/L. While, Tribenuron-methyl treatments gave the maximum values of straw yield when 200 mg proline/L was applied. On the other hand, unweeded plots of weed control without proline application gave the lowest values of yield and chemical composition of wheat.

Table11: Effect of the interaction (water requirements x weed control) on wheat yield, protein and Carbohydrates percentage (average of two seasons 2012/13 and 2013/14).

Treatment \ Characters		Spikes number(m^{-2})	Grain yield ha^{-1} (ton)	Straw yield ha^{-1} ton)	Crude protein %	Carbohydrates %
100%	Tribenuron-methyl	304.67	4.20	7.99	11.23	77.61
	Thifensulfuron	314.33	4.35	7.56	11.43	77.81
	Hand weeding	282.67	3.49	6.79	10.55	76.36
	Unweeded	256.00	2.74	6.53	10.15	73.38
75%	Tribenuron-methyl	288.00	4.15	7.56	10.36	76.32
	Thifensulfuron	297.67	4.29	7.27	10.87	76.72
	Hand weeding	276.67	3.43	6.62	10.05	75.30
	Unweeded	248.33	2.66	6.82	10.17	74.76
50%	Tribenuron-methyl	247.00	3.36	6.29	9.98	74.40
	Thifensulfuron	254.00	3.40	6.12	10.07	74.50
	Hand weeding	235.33	2.95	6.58	9.93	73.92
	Unweeded	222.33	2.58	5.81	9.83	73.63
LSD at 0.05		15.13	0.26	0.091	0.36	0.27

Table12: Effect of the interaction (weed control x praline levels) on wheat yield, protein and Carbohydrates percentage (average of two seasons 2012/13 and 2013/14).

Treatment \ Characters		Spikes number m^2	Grain yield ha^{-1}(ton)	Straw yield ha^{-1}(ton)	Crude protein %	Carbohydrates %
Tribenuron-methyl	P_0	264.00	3.55	6.36	10.04	75.76
	P_1	283.67	4.01	7.54	10.39	76.21
	P_2	292.00	4.14	7.94	10.67	76.37
Thifensulfuron	P_0	270.00	3.64	6.12	10.19	76.02
	P_1	292.67	4.11	7.18	10.46	76.41
	P_2	303.00	4.30	7.66	10.72	76.61
Hand weeding	P_0	252.00	3.00	5.78	9.57	74.98
	P_1	266.67	3.40	6.65	9.70	75.23
	P_2	276.00	3.48	6.94	9.85	75.37
Unweeded	P_0	234.33	2.46	5.57	9.20	73.67
	P_1	243.67	2.69	6.43	9.13	73.99
	P_2	248.67	2.82	6.65	9.26	74.11
LSD at 0.05		16.00	0.23	0.87	0.31	0.35

Water requirements x Proline levels.

The interactive effects between water requirements and proline levels significantly affected spikes number m^{-2}, grain yield, straw yield, crude protein % and carbohydrates % Table (13). Plots that received 50% water requirement and proline spraying treatments produced the lowest values of aforementioned characters. Meanwhile, the maximum values of the previous characters were reported by irrigation with 100% of water requirement treatment and foliar application of 200 mg proline/L treatment. From the same table the data emphasized the role of proline as a protecting component preventing water loss and increased the assimilation capacity of wheat under water stress. The data show that spraying wheat plants with proline at 100 or 200 mg/L under 75% irrigation requirement could effectively produce similar grain yield to that achieved when the recommended treatment was applied (100%). These results confirm the beneficial role of proline under water stress conditions and help in reducing water requirements for wheat production under similar water stress conditions. These results are in good harmony with those obtained by[21].

Table13: Effect of the interaction (water requirements x proline levels) on wheat yield, protein and Carbohydrates percentage (average of two seasons 2012/13 and 2013/14).

Treatment \ Characters		Spikes number (m^{-2})	Grain yield ha^{-1}(ton)	Water use efficiency (WUE) kg/m^3	Straw yield ha^{-1}(ton)	Crude protein %	Carbohydrates %
100%	Control	271.50	3.38	0.78	6.62	10.24	75.90
	Conc.1	293.75	3.80	0.87	7.39	10.53	76.39
	Conc.2	303.00	3.91	0.90	7.66	10.76	76.59
75%	Control	261.25	3.33	1.02	6.22	10.03	75.51
	Conc.1	280.50	3.70	1.06	7.15	10.28	75.84
	Conc.2	291.25	3.87	1.14	7.51	10.41	75.98
50%	Control	232.75	2.78	1.21	5.04	9.81	73.90
	Conc.1	240.75	3.17	1.38	6.34	9.96	74.16
	Conc.2	245.50	3.27	1.42	6.72	9.78	74.28
LSD at 0.05		19.10	0.25	0.33	0.78	0.29	0.41

Water Use Efficiency (WUE) (kg grains m^{-3} water).

Data presented in Table (13) show water use efficiency expressed as kg grains m^{-3} water consumed. The results indicate that WUE increased as water stress increased. Gradual increases in WUE were reported when water requirement reduced from 100% to 75% and 50%. Proline spraying at wheat plants resulted in obvious efficiency of wheat plants in using water unit compared to the unsprayed plants. Moreover, spraying wheat plants with proline at 200 mg/L under 50% water stress treatment doubled the ability of wheat plants to produce grain yield per irrigation water unit consumed. These results explain the abovementioned results that proline application at 100 or 200 mg/L under 50% irrigation requirement could effectively produce similar grain yield to that achieved when the recommended treatment was applied (100%).

Eventually, it could be concluded that applying 100% or 75% water requirements and post-emergence application Thifensulfuron for wheat plants when addition of 200 mg proline/L was the best combination for enhancing yield and its attributes. Results also indicated that proline works to increase the wheat plants ability to withstand water shortages.

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