Italian Journal of Agrometeorology
Rivista Italiana di Agrometeorologia

Firenze University Press
www.fupress.com/ijam

Citation: Ibrahim Mohamed El-Metwally, Nadia Gad (2019) Wheat productivity and water use efficiency responses to irrigation, cobalt and weed management. *Italian Journal of Agrometeorology* (1): 13-24. doi: 10.13128/ijam-287

Received: May 23, 2018

Accepted: January 08, 2019

Published: June 04, 2019

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Wheat productivity and water use efficiency responses to irrigation, cobalt and weed management

Produttività del frumento e efficienza di utilizzo dell'acqua a diverse gestioni del livello di irrigazione, cobalto e gestione delle infestanti

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Abstract. The effect of three irrigation levels (100%, 75% and 50% of crop water requirement), five weed control treatments (pyroxsulam, mesosulfuron-methyl, isoproturon+diflufenican, hand weeding and unweeded check control treatment), five cobalt concentrations (0, 5, 10, 15 and 20 ppm) and their interaction on wheat productivity, weed growth and water use efficiency, were examined in two field experiments in sandy soil at the Agricultural Experimental Station of the National Research Centre, Egypt. The results indicated that pyroxsulam recorded the greatest weed control efficiency. Application of 100% of crop water requirement showed the largest values of flag-leaf area, chlorophyll content, plant height, spikes number/m^2, grains number/spike, 1,000 grain weight, straw and grain yield of wheat plants, compared with all other irrigation treatments. Isoproturon+diflufenican followed by pyroxsulam and mesosulfuron-methyl treatments gave the largest grain yield. Application of cobalt resulted in recovery from the negative effects of insufficient water on wheat yield in low fertility soils and using cobalt at a rate of 15 ppm resulted in increased wheat grain yield. The maximum grain yield with largest protein and carbohydrates percentages in grains was obtained by application of 100% of crop water requirement with pyroxsulam and using 15 ppm cobalt, followed by 75% of crop water requirement combined with isoproturon+diflufenican treatment, with insignificant difference between both two interaction treatments.

Keywords. Wheat, herbicides, water requirement, weeds, cobalt, yield.

Abstract. L'effetto di 3 livelli d'irrigazione (100%, 75% e 50% del fabbisogno idrico della coltura), 5 trattamenti di controllo delle infestanti (pyroxsulam, mesosulfuron-methyl, isoproturon+diflufenican, diserbo manuale e un trattamento di controllo non diserbato), 5 concentrazioni di cobalto (0, 5, 10, 15 and 20 ppm) e la loro influenza sulla produttività del frumento, sulla crescita delle infestanti e sull'efficienza d'utilizzo dell'acqua, sono stati esaminati in due campi sperimentali su suolo sabbioso nella Stazione Sperimentale Agricola del Centro di Ricerca Nazionale, Egitto. I risultati hanno indicato che pyroxsulam ha riportato la migliore efficienza per il controllo delle infestanti. L'applicazione del 100% del fabbisogno idrico ha avuto come effetto maggiori valori di superficie fogliare, contenuto di clorofilla, altezza della pianta, numero di spighe per m^2, numero di semi per spiga, peso di 1000 semi, resa di granella e paglia per le piante di frumento, in confronto agli altri trattamenti di irrigazione. Isoproturon+diflufenican seguito dai trattamenti con pyroxsulam e mesosulfuron-methyl hanno dato i migliori risultati in termini di resa in granella. L'aggiunta di cobalto è risultata in un recupero dall'effetto negativo dovuto all'insufficienza idrica sulla resa del frumento nei suoli a bassa fertilità e usando cobalto con una dose di 15 ppm è risultato un aumento di resa della granella. La massima resa in granella è stata ottenuta dall'applicazione di 100% del fabbisogno idrico con pyroxsulam e usando cobalto a 15 ppm, seguito da 75% di fabbisogno idrico combinato con il trattamento di isoproturon+diflufenican, con una differenza non significativa per le interazioni tra entrambi i trattamenti.

Parole chiave. Frumento, Erbicidi, Fabbisogno idrico, Infestanti, Cobalto, Resa.

INTRODUCTION

Increasing wheat production under biotic (weeds, etc.) and abiotic (drought, salinity, etc.) stress conditions has become an important focus over the last decades in the world and particularly in Egypt, with the aim of decreasing the gap between production and consumption. Increasing wheat yield could be achieved by maximizing the production through vertical and horizontal expansion by desert reclamation (Mahgoub and Sayed, 2001). Growing wheat in the typical desert sandy soils would require different specific cultural practices to those applied in the old cultivated fertile soils.

Irrigation water and weed control are the most limiting factors for wheat production in the newly reclaimed desert areas. Water deficit is the major obstacle for crop production, especially in arid and semi-arid regions (Hussain *et al.*, 2004). Decreasing the irrigation requirements from 100% to 50% significantly decreased most growth characteristics such as yield, yield attributes and protein content while water use efficiency increased significantly (Abdelraouf *et al.*, 2013).

Weeds limit wheat yield potential in arid regions because they increase evapotranspiration and compete with wheat plants for limited soil moisture, nutrients and light resulting in reported grain yield reductions of 41% (Abouziena *et al.*, 2008), 92% (Tiwari and Parihar, 1997) and in serious cases, leading to complete crop failure (Abdul-Khaliq and Imran, 2003). Weeds may inhibit wheat growth through the release of allelopathic chemicals that are toxic to wheat plants (Ortega *et al.*, 2002). Using chemical weed management significantly decreased the weed population and increased wheat grain yield over weedy check control plots (El-Metwally *et al.*, 2015a; Abd Elsalam *et al.*, 2016).

Cobalt (Co) could promote growth, especially under abiotic stress, as it plays an important role in the drought tolerance of plants and may be essential for some plants (Pilon-Smits *et al.*, 2009). Cobalt plays a major role in the water balance of plants cultivated under water deficit conditions and is an essential element for the synthesis of vitamin B_{12} which is required for human and animal nutrition (Smith, 1991). Application of cobalt at 12.5 ppm significantly increased growth, yield and yield parameters as well as nutritional status of the wheat grain (Gad and El-Metwally, 2015). Therefore, the objective of this investigation was to study the effects of irrigation requirements, weed management and Co concentration on wheat productivity.

MATERIALS AND METHODS

Experimental procedures

A two-year field experiment was conducted during two successive seasons (2012/13 and 2013/14) at the Agricultural Experimental Station of the National Research Centre, Nubaria, Beheira Governorate, Egypt. The site is classified as arid with cool winters and hot dry summers. Tab. 1 illustrates the monthly mean weather data for the two growing seasons studied, as obtained from the Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt. Little rainfall was observed during the two growing seasons. The soil texture of the experimental site is sandy.

Most relevant physical and chemical properties of the experimental soil are shown in Tab. 2. Irrigation water had pH 7.35, and EC was 0.41 dS/m. The experiment was established as a split-spilt plot design with four replicates.

The main plots included three irrigation water requirements (100%, 75% and 50% of the crop water requirements, CWR) while the sub-plots comprised weed management treatments including: three herbicides each of them applied 25 days after sowing (DAS), (1) Pyroxsulam, Pallas 4.5% OD, at the rate of 400 ml ha^{-1};(2) Isoproturon+diflufenican, Panther 55% SC, at the rate of

Tab. 1. Monthly weather data of the experimental site.
Tab. 1. Dati meteo mensili del sito sperimentale.

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

Tab. 2. Physical and chemical properties and water status of experimental soil.
Tab. 2. Proprietà fisiche e chimiche e condizioni idriche del suolo nel sito sperimentale.

Soil depth [cm]	Particle size distribution [%]				Chemical properties				Moisture status [%]	
	Coarse sand	Fine sand	Clay + Silt	Texture class	OM [%]	pH	EC [dS/m]	$CaCO_3$ [%]	FC	WP
20	47.76	49.75	2.49	Sandy	0.65	8.7	0.35	7.02	10.1	4.7
40	56.72	39.56	3.72	Sandy	0.40	8.8	0.32	2.34	13.5	5.6
60	59.40	59.40	3.84	Sandy	0.25	9.3	0.44	4.68	12.5	4.6

FC: field capacity; WP: wilting point, OM: Organic matter; pH: acidity or alkalinity in soils; EC: electrical conductivity.

1500 ml ha^{-1} and (3) Mesosulfuron-methyl, Atlantis 1.2 % OD, at the rate of 1500 ml ha^{-1} in addition to hand weeding twice at 30 and 50 DAS, and unweeded check (control). Five Co levels (0, 5, 10, 15 and 20 ppm in the form of cobalt sulphate) were distributed in the sub-sub plots and sprayed once at the third true leaf seedling stage (22 DAS). The experimental unit size was 10.5 m^2.

Based on weather data recorded from an adjacent weather station, reference evapotranspiration (ET_0) was calculated using the Penman-Monteith equation given by Allen *et al.* (1998). Crop evapotranspiration (ET_c) was then calculated as follows:

$$ET_c = ET_o \times K_c \quad (1)$$

where:
ET_c = Crop evapotranspiration [mm/day]
ET_o = Reference crop evapotranspiration [mm/day]
K_c = Crop coefficient

The amount of irrigation water was computed according to the following equation for the sprinkler irrigation systems:

$$AW = \frac{Etc}{Ea \text{ x } (1 - LR)} \quad (2)$$

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.

The seasonal irrigation water applied [m^3/ha] for each irrigation treatment in 2012/13 and 2013/14, respectively, are shown in Tab. 3.

Tab. 3. Seasonal irrigation water applied [m^3/ha] under different irrigation levels for 2012/1 and 2013/14 seasons.
Tab 3. Volumi di acqua stagionale applicati [m^3/ha] con differenti livelli di irrigazione per le stagioni 2012/1 e 2013/14.

Irrigation level	Growing season	
	2012/13	2013/14
100%	4284	4382
75%	3213	3287
50%	2142	2191

Grains of wheat variety Shaka 93 were planted at a rate of 167 kg/ha at 5-cm soil depth with 13.5-cm row spacing in the last week of November in both seasons.

All experimental units received the same fertilization rates. Ammonium nitrate was applied at 285 kg N/ha to the soil before planting and at tillering (10%), while the remaining was divided in six equal applications before each irrigation until the heading stage. Single super-phosphate was applied at a rate of 70 kg P_2O_5/ha to the soil in two equal rates before planting and at tillering stage. Potassium sulphate was applied once at 30 DAS at a rate of 60 kg K_2O/ha.

Measurements

Weeds

Weeds were hand pulled from one square meter of each experimental unit at 80 DAS, identified and classified into broadleaved and narrow-leaved weed groups. The collected weed biomass was first air-dried in the sun, then in an electric oven for 72 hours at a constant temperature of 70 °C before the dry weight was recorded. Macronutrients (N, P and K) in the weeds were determined according to Cottenie *et al.* (1982).

Wheat

Growth traits

At 90 DAS, flag-leaf area, SPAD chlorophyll values and plant heights were measured. Flag-leaf area was measured on 10 tillers chosen randomly from each plot. The chlorophyll content of the 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 (Minolta Camera Co., 1989).

Yield and yield attributes

Harvesting was done in the first week of May in both seasons. Plant samples were collected from one square meter per plot to estimate the number of spikes. Subsequently, 10 tillers were chosen randomly to measure spike length, number of spikelet/spike, grains number/spike, grain weight/spike and 1000-grain weight. The whole plot was harvested to estimate the grain and straw yields per hectare.

Grain chemical analysis

Following to AOAC (1990) methods of analysis, samples of wheat grains were taken to estimate total carbohydrates, total soluble sugars percentage, fats % by extraction using Soxhlet Apparatus with hexane as an organic solvent. In addition, total nitrogen was determined by Kjeldahl method and total crude proteins calculated by multiplying total nitrogen by 5.8. Additionally, Co in wheat grains was determined as described by Cottenie *et al.* (1982).

Irrigation water use efficiency

Irrigation water use efficiency "IWUE" is an indicator of effectiveness use of irrigation to increase crop yield. IWUE of wheat yield was calculated according to James (1988) as follows:

IWUE wheat (kg m^{-3}) =Total yield (kg 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. The data were then subjected to analysis of variance (ANOVA) according to Gomez and Gomez (1984). The differences among means were compared using Fisher's Least Significant Difference (LSD) test at 0.05 probability level.

RESULTS AND DISCUSSION

Weeds growth

The most commonly surveyed weeds in the experimental field through the two growing seasons were: grasses comprising wild oat (*Avena fatua* L.), green foxtail (*Setaria viridis* L) and ryegrass (*Lolium temulentum*

Tab. 4. Effect of water requirement, weed control and Co concentration on dry weight of wheat weeds and macronutrient uptake by weeds (combined analysis of two seasons).
Tab. 4. Effetto del trattamento irriguo, controllo delle infestanti e concentrazione di Co sul peso secco delle infestanti del grano e capacità di assunzione di macronutrienti da parte delle infestanti (analisi combinate di 2 stagioni).

Treatments	Dry weight of weeds (g/m^2)			Uptake of nutrients by weeds (g/m^2)		
	Broadleaved	Grasses	Total	N	P	K
Water requirement						
100%	49.63	26.31	75.94	1.34	0.121	2.18
75%	42.82	20.52	63.34	1.12	0.101	1.82
50%	33.38	13.33	46.71	0.82	0.075	1.34
LSD 0.05	3.17	2.23	4.82	0.14	0.17	0.24
Weed control						
Pyroxsulam	10.68	7.67	18.35	0.32	0.029	0.53
Mesosulfuron-methyl	15.15	11.55	26.70	0.47	0.042	0.77
Isoproturon+diflufenican	13.62	10.14	23.76	0.42	0.038	0.68
Hand weeding	35.86	24.16	60.02	1.06	0.096	1.72
Unweeded	134.57	46.75	181.32	3.20	0.291	5.25
LSD 0.05	5.11	4.71	9.15	0.19	0.022	0.35
Co concentration (ppm)						
0	36.33	15.73	52.06	0.92	0.083	1.49
5	40.30	18.47	58.77	1.04	0.094	1.69
10	43.35	20.88	64.23	1.13	0.103	1.84
15	44.77	22.19	66.96	1.18	0.107	1.92
20	45.12	22.29	67.41	1.19	0.108	1.93
LSD 0.05	2.07	1.39	3.17	0.11	0.013	0.24

L.) and broadleaved weeds comprising wild beet (*Beta vulgaris* L.), lambsquarters (*Chenopodium album* L.) and greater ammi (*Ammi majus* L.) .

The response of weed growth to irrigation levels differed among weed groups as reducing irrigation levels from 100% to 75% or 75% to 50% led to decreases in the dry weight of broadleaved, grasses and total weeds by 15.9 to 28.3%, 28.2 to 35.0%, and 19.9 to 35.6%, respectively (Tab. 4). Moreover, supplying wheat plants with 50% of crop water requirement caused decreases in N, P and K concentrations in weeds. In contrast, the application of 100% of crop water requirements gave the highest values of N, P and K. These results are in harmony with those obtained by Bhat *et al.* (2006); Chaudhary *et al.* (2011); El- Hag (2015).

All weed treatments reduced the dry weight of broadleaved, grasses and total weeds as well as nutrient uptake by weeds compared with weedy check control treatment (Tab. 4). Pyroxsulam was the most effective herbicide and reducing nutrient uptake by weeds, while isoproturon+diflufenican was the second most effective herbicide treatment. Pyroxsulam, isoproturon+diflufenican, mesosulfuron-methyl and hand weeding recorded the greatest efficiency and reduced the dry weight of weeds by 89.9, 86.9, 85.3 and 66.9%, respectively, compared with the unweeded control. The differences between the three herbicides tested were not statistically significant at the P=0.05 level.

The mode of action of the herbicides in this study differ. Isoproturon interferes with the photosynthetic process and diflufenican inhibits carotenoid synthesis in plants. The primary biochemical target site of mesosulfuron-methyl is the enzyme acetohydroxy acid synthase which acts via foliage and soil, to inhibit the development of new leaves. Pyroxsulam inhibits acetolactate synthase (metosulam), the key plant enzyme that inhibits the branched chain amino acids leucine, isoleucine and valine.

These results are in general agreement with those recorded by Shaban *et al.* (2009); Neijad *et al.* (2013); El-Metwally *et al.* (2015b); Abd Elsalam *et al.* (2016).

The results in Tab. 4 clearly indicate that Co levels caused a significant effect on weed growth as the application of 20 ppm Co markedly increased the dry weight and nutrient uptake of weeds after 80 DAS. The lowest values were the no Co treatment and there were insignificant differences between the 15 and 20 ppm Co treatments.

Sethi and Kaur (2016) reported that application of cobalt chloride at concentrations ≥ 0.1 mM caused significant reduction in the germination (%) and germination index and increased the mean germination time of littleseed canarygrass (Phalaris minor); whereas cobalt chloride at greater concentrations significantly reduced the seedling growth of littleseed canarygrass and wheat with a more pronounced effect on root length as compared to shoot length.

Significant interactions were found between irrigation levels and weed management on the dry weight of total weeds (Tab. 5). The application of 50% of crop water requirement resulted in the lowest values of weed dry weight when pyroxsulam herbicide was used. Similar trends were noticed by Chaudhary *et al.* (2011); Abd Elsalam *et al.* (2016).

With regard to the interactive effects between irrigation level and Co treatments on weeds, the data in Tab. 6 show that the plots which received 50% of crop water requirement and Co treatment produced the smallest dry weight of weeds. The maximum values were found with 100% irrigation level and Co applied at 15 ppm; this confirms the results cited by Gad and El-Metwally (2015) in corn. Moreover, Tab. 7 indicates that the maximum values of dry weight of total weeds were recorded with unweeded and spraying of 15 ppm Co. In contrast, the lowest value of dry weight of total weeds was obtained by pyroxsulam application without Co addition.

Wheat

Growth traits

The results in Tab. 8 reveal significant impacts of irrigation level on flag leaf area, flag leaf chlorophyll content (SPAD value) and plant height. Irrigation with 100% of crop water requirement significantly increased these growth traits compared with the 75 or 50% levels. No significant differences between 100 and 75% of crop water requirement were found. Accordingly, supplying wheat plants with adequate water requirement might help the plant to absorb greater amount of water and nutrients, enhancing internodes elongation, since nutrients encourage cell division and enlargement and meristematic activity. Besides, the beneficial effect of water for improving pigments and photosynthetic process. These results are in harmony with those obtained by El-Sherif *et al.* (2007); Ramadan and Awaad (2008); Abd Elsalam *et al.* (2016).

Pyroxsulam was the most effective treatment resulting in increasing wheat flag leaf area, flag leaf chlorophyll content and plant height (Tab. 8). Moreover,

Tab. 5 Effect of the interactions (weed control x water requirement) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 5. Effetto delle interazioni (controllo delle infestanti X fabbisogno idrico) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinate di 2 stagioni).

Weed control	Irrigation level		
	100%	75%	50%
Pyroxsulam	24.06	18.16	12.80
Mesosulfuron-methyl	32.94	24.04	23.14
Isoproturon+diflufenican	29.60	23.38	18.30
Hand weeding	77.60	61.20	39.26
Unweeded	216.00	187.92	138.02
LSD 0.05		9.82	

Tab. 6 Effect of the interactions (Co concentration x water requirement) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 6. Effetto delle interazioni (concentrazione di Co X fabbisogno idrico) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinato di due stagioni).

Irrigation level	Co concentration (ppm)				
	0	5	10	15	20
100%	62.60	71.30	78.92	82.80	84.58
75%	51.60	59.70	64.04	69.10	70.26
50%	42.00	45.28	47.74	49.00	49.50
LSD 0.05			4.34		

Tab. 7 Effect of the interactions (weed control x Co concentration) on total dry weight of weeds (g/m^2) in wheat (combined analysis of two seasons).
Tab. 7. Effetto delle interazioni (controllo delle infestanti X concentrazione di Co) sul peso secco totale delle infestanti (g/ m^2) nel frumento (analisi combinato di due stagioni).

Weed control	Co concentration (ppm)				
	0	5	10	15	20
Pyroxsulam	14.33	16.63	19.27	20.43	21.03
Mesosulfuron-methyl	21.33	23.83	28.23	29.80	30.33
Isoproturon+diflufenican	17.67	21.67	25.17	26.77	27.53
Hand weeding	46.67	54.00	59.33	67.33	69.43
Unweeded	160.33	177.67	185.83	190.50	192.23
LSD 0.05			10.12		

Tab. 8. Effect of water regime, weed control and Co concentration on growth and yield attributes of wheat (combined analysis of two seasons).
Tab. 8. Effetto del regime idrico, controllo delle infestanti e concentrazione di Co sulla crescita e resa del frumento (analisi combinate di 2 stagioni).

Treatments	Growth traits			Yield attributes					
	SPAD value	Flag leaf area (cm^2)	Plant height (cm)	Spikes number/ m^{-2}	Spike length (cm)	Spikelets number $spike^{-1}$	Grains number $spike^{-1}$	Grains weight $spike^{-1}$ (g)	1000- grain weight (g)
Irrigation level									
100%	46.02	44.40	93.9	408.8	12.46	18.70	58.22	2.45	37.18
75%	45.42	42.82	90.6	390.6	11.76	18.67	56.16	2.29	36.00
50%	42.96	38.01	78.8	312.8	9.88	16.96	46.66	1.61	31.43
LSD 0.05	2.03	2.11	4.2	20.2	1.53	0.93	2.51	0.29	2.01
Weed control									
Pyroxsulam	46.67	43.90	91.8	421.3	12.27	19.72	58.77	2.45	37.00
Mesosulfuron-methyl	46.00	42.61	87.7	380.3	11.60	18.33	56.27	2.34	35.97
Isoproturon+diflufenican	45.90	43.67	88.7	400.7	11.85	18.78	56.97	2.32	36.25
Hand weeding	44.27	40.22	85.8	337.3	10.70	17.55	52.53	1.89	34.10
Unweeded	41.17	38.42	84.9	314.0	10.20	16.30	47.20	1.57	31.11
LSD 0.05	1.21	2.13	3.2	23.1	0.78	0.93	3.25	0.18	2.11
Co concentration (ppm)									
0	40.70	37.73	83.7	328.0	9.87	16.60	50.50	1.70	30.90
5	43.47	39.62	87.9	353.1	10.66	18.00	52.60	2.00	33.20
10	45.80	42.95	89.8	386.5	11.99	18.90	55.50	2.31	36.50
15	47.40	44.40	88.9	396.3	12.16	18.60	56.70	2.40	37.15
20	46.23	43.84	88.5	389.4	12.10	18.40	55.90	2.17	36.60
LSD 0.05	1.53	1.77	3.2	19.2	1.21	NS	1.14	0.24	1.77

isoproturon+diflufenican treatment was statistically at par with pyroxsulam for improving these wheat growth characters. The enhancement of wheat growth in the weeded plots might be attributed to the efficiency in weed elimination (Table, 4) and the reduction of weed competition. Similar findings confirming these results were reported by (Chaudhary *et al.*, 2011; Neijad *et al.*, 2013; Singh *et al.*, 2013).

The results in Tab. 8 indicate that increasing Co up to 15 ppm gave the highest values of flag leaf area, flag leaf chlorophyll content and plant height. While increasing the Co level more than 15 ppm reduced these effects.

These observations are consistent with previous reports obtained by Gad and El-Metwally (2015) who reported that smaller doses of Co resulted in maximum growth and yield of corn plants as compared with the larger doses. They added that responses associated with low Co levels may be attributed to reduced catalase and peroxidase activities at smaller levels of Co (5, 10 and 15). These enzymes are known to induce plant respiration, increasing the consumption of products of photosynthesis reducing plant growth. Wheat seedlings treated with cobalt chloride at concentrations ≥0.1 mM exhibited significant increase in total soluble sugars (TSS) content with concomitant decrease in protein content (Sethi and Kaur (2016).

Moreover, smaller Co levels have positive effects due to several induced effects on hormonal synthesis and metabolic activity, while greater Co levels were found to increase the activity of some enzymes such as peroxidase and catalase in plant, thus increasing catabolism rather than anabolism. The same conclusion was mentioned by Gad *et al.* (2011); Korayem *et al.* (2014) and Gad and El-Metwally (2015).

Yield and yield attributes

Data presented in Tab. 8 and 9 reveal that the application of 100% of crop water requirements led to the maximum values of number of spikes/m^2, spike length, number of spikelets/spike, number of grain/spike grain, grain weight/spike, 1000- grain weight as well as grain and straw yields.

Tab. 9. Effect of water requirement, weed control and Co concentration on yield and chemical composition of grains wheat (combined analysis of two seasons).

Tab. 9. Effetto del fabbisogno idrico, controllo delle infestanti e concentrazione di Co sulla resa e composizione chimica della granella (analisi combinate di 2 stagioni).

Treatments	Yield		Chemical composition of grain					Water Use Efficiency
	Straw ton/ha	Grain ton/ha	Total carbohydrates %	Total soluble sugars %	Protein %	Fate %	Co ppm	
Irrigation level								
100%	9.42	4.30	70.74	4.95	11.60	2.64	5.30	0.92
75%	8.17	4.00	68.51	4.70	10.54	2.06	4.25	1.23
50%	6.84	2.81	65.60	3.60	9.62	1.71	3.97	1.30
LSD 0.05	0.71	0.53	2.11	0.49	0.51	0.33	0.27	0.12
Weed control								
Pyroxsulam	9.45	4.36	69.37	5.00	11.17	2.30	4.88	1.34
Mesosulfuron-methyl	8.13	3.73	68.86	4.70	10.95	2.18	4.72	1.15
Isoproturon+diflufenican	8.60	4.07	69.28	4.82	11.10	2.21	4.83	1.25
Hand weeding	7.67	3.35	67.24	4.10	10.00	1.94	4.16	1.03
Unweeded	6.87	3.00	66.65	3.55	9.64	1.75	3.89	0.92
LSD 0.05	0.82	0.42	1.14	0.63	0.42	0.28	0.30	0.11
Co concentration (ppm)								
0	7.20	3.12	67.20	3.80	10.11	1.70	3.31	0.96
5	7.85	3.52	67.80	4.00	10.50	2.02	4.56	1.08
10	8.50	3.89	68.50	4.80	10.77	2.20	4.83	1.20
15	8.90	4.08	69.30	4.85	10.99	2.31	5.02	1.25
20	8.20	3.92	68.60	4.70	10.60	2.13	4.75	1.21
LSD 0.05	0.47	0.34	0.72	0.35	NS	0.17	0.21	0.09

There was no significant difference between the addition of 100% and 75% watering requirement on most of the growth and yield traits. In contrast, using 50% of crop water requirements gave smaller values of these crop characters. Drought increases respiration which decreases assimilates for grain filling and investigator reported that drought stress reduces photosynthesis and translocation rates, decreasing grain yield (Mahgoub and Sayed, 2001; Badawi *et al.*, 2008). Thus, sufficient water of 100% or 75% of crop water requirement will help the plant to absorb greater amount of water and nutrients encouraging cell division and enlargement and meristematic activity (Fageria *et al.*, 2010). Besides, the beneficial effect of water for improving pigments and photosynthetic process and accumulation of metabolites lead to increases in yield and its components (El-Hag, 2015; Abd Elsalam *et al.*, 2016).

Concerning the effect of weeded practices on yield and its attributes, all weeded plots produced more yield over the weedy control treatment. Applying pyroxsulam resulted in increases in the number of spikes/m^2, straw and grain yields by 34.2, 37.6 and 45.3 % over the weedy control, respectively (Tab. 8 and 9). Such treatment minimized weed-crop competition (Tab. 4) and saved more of the available resources for improved crop growth (Tab. 8). Thus, this treatment increased plant height and resulted in greater straw and grain yields. The positive effect of weed control on wheat yield and its components have been confirmed by El-Metwally and El-Rokiek (2007); Tesfay (2014); Abd Elsalam *et al.* (2016) whereas weed competition causes a reduction in wheat grain yield;48.7% reduction was observed by Kamrozzaman *et al.*, (2015).

Data presented in Tab. 8 and 9 show significant increases of all the studied traits, (except protein %), with increasing Co levels from 0 to 15 ppm. Application of 15 ppm Co led to significant increase in the number of spikes/m^2, spike length, number of grains/spike, grain weight/spike, 1000- grain weight as well as grain and straw yields. On the other hand, the smallest values of these growth and yield parameters were recorded in untreated plots. Moreover, no significant differences between 15 and 20 ppm Co were found.

These data are in harmony with those obtained by Gad and El–Metwally (2015). They stated that smaller doses of Co resulted in maximum growth and yield of corn plants as compared with the larger doses. They also reported that the responses associated with small Co levels may be attributed to catalase and peroxidase activities which were found to decrease with low levels of Co and increase with the higher ones. These enzymes are known to induce plant respiration, so superior resulting in successive consumption for products of photosynthesis and consequently reduce the plant growth.

Data in Tab. 10 show that there was a significant effect due to the interaction between irrigation level and weed control on grain yield. Irrigation with 100% water requirement significantly increased grain yield when pyroxsulam was applied compared with the other treatments. Results also indicated that 100% irrigation and using Isoproturon+diflufenican was slightly less effective but not significantly so. The smallest grain yield was recorded with the unweeded treatment and irrigation of 50% of crop water requirement. These results are in harmony with those of El-Metwally *et al.* (2015b); Abd Elsalam *et al.* (2016).

There are significant interactions between irrigation level and Co addition rate on grain yield (Table 11). Irrigation with 100% crop demand recorded the largest grain yields when wheat plants were treated with 15 ppm Co.

The interaction effect of weed control treatments and Co level significantly affected grain yield as maximum values were obtained with combined treatment of pyroxsulam and 15 ppm Co (Tab. 11). The unweeded plots without Co application gave the smallest grain yield.

Tab. 10. Effect of the interactions (weed control x water requirement) on grain yield of wheat ton/ha (combined analysis of two seasons).
Tab. 10. Effetto delle interazioni (controllo delle infestanti X fabbisogno idrico) sulla resa della granella ton/ha (analisi combinate di 2 stagioni).

Weed control	Irrigation level		
	100%	75%	50%
Pyroxsulam	5.08	4.80	3.20
Mesosulfuron-methyl	4.40	4.00	2.80
Isoproturon+diflufenican	4.80	4.40	3.00
Hand weeding	3.80	3.60	2.64
Unweeded	3.40	3.20	2.40
LSD 0.05		0.43	

Tab. 11. Effect of the interactions (Co concentration x water requirement) on grain yield of wheat ton /ha (combined analysis of two seasons).
Tab. 11. Effetto dell'interazione (concentrazione di Co X fabbisogno idrico) sulla resa della granella ton/ha (effetto combinato di 2 stagioni).

Irrigation level	Co concentration (ppm)				
	0	5	10	15	20
100%	3.64	4.10	4.48	4.86	4.60
75%	3.42	3.86	4.24	4.40	4.16
50%	2.30	2.60	2.95	3.18	3.01
LSD 0.05			0.37		

Tab. 12. Effect of the interactions (weed control x Co concentration) on grain yield of wheat ton /ha (combined analysis of two seasons).
Tab. 12. Effetto delle interazioni (controllo infestanti X concentrazione di Co) sulla resa del frumento ton/ha (effetto combinato di 2 stagioni).

Weed control	Co concentration (ppm)				
	0	5	10	15	20
Pyroxsulam	3.60	4.17	4.53	4.82	4.68
Mesosulfuron-methyl	3.33	3.60	3.87	4.07	3.87
Isoproturon+diflufenican	3.43	3.90	4.30	4.47	4.27
Hand weeding	2.75	3.15	3.57	3.73	3.60
Unweeded	2.48	2.78	3.18	3.25	3.20
LSD 0.05			0.52		

Grain chemical analysis

The concentrations of total carbohydrates, total soluble sugars, protein, fats and Co were appreciably influenced by irrigation level (Tab. 9), progressively increasing up to 100% irrigation demand. A similar trend was found by other authors (El-Sherif *et al.*, 2007; Singh *et al.*, 2013; El-Metwally *et al.*, 2015b; Abd Elsalam *et al.*, 2016).

As shown in Table 9 all of the weed control treatments significantly improved the concentrations of total carbohydrates, total soluble sugars, protein, fates and Co in wheat grain. The largest values were obtained from the pyroxsulam treatment followed by isoproturon+diflufenican and mesosulfuron-methyl treatments but these were no significantly different. These results may be due to the reduced weed competition for nutrients, water and light. Similar results were obtained by Shehzad *et al.*, 2012; Tesfay, 2014; Abd Elsalam *et al.*, 2016.

The concentrations of total carbohydrates, total soluble sugars, fats and Co in wheat grain were appreciably influenced by Co levels (Tab. 9). In this respect, with each increase in Co level, there was a progressive improvement in chemical composition.

Application of Co at 15 ppm led to the largest concentrations of total carbohydrates, total soluble sugars, protein, fats percent and Co. These results are in harmony with those obtained by Gad (2012) revealed that Co addition in plant media increased protein, total soluble solids, total carbohydrates and total soluble sugars in groundnut seeds. Similar findings were reported by Korayem *et al.* (2014) in rice, and Gad and El–Metwally (2015) in corn.

Water Use Efficiency

Water use efficiency (WUE) is expressed as grain yield (kg) divided by unit of water consumed (m^3). The data in Tab. 9 indicate that WUE progressively increased as water stress increased from 100% to 75% and 50%.

These results illustrate the significant impact of weed control treatments on water use efficiency. Pyroxsulam enhanced WUE more than the other weeded practices while the unweeded control has the poorest WUE value. The differences between the three herbicides tested were insignificant.

Co addition resulted in significant improvements in water WUE of wheat plants compared with the untreated plants with the best WUE value obtained by the addition of 15 ppm Co.

CONCLUSION

It may be concluded that the best approach to enhancing the yield of wheat is to apply at least 75% of crop water requirements and to control weeds by the application of pyroxsulam herbicide and 15 ppm Co. The results also indicated that Co significantly increases the ability of wheat plants to withstand water shortages, reducing the crop water requirement by 25%.

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APPENDIX

Tab. 1. Source of variance, degree of freedom and mean square of the studied traits under irrigationlevels, weed control as well as cobalt concentrations.
Tab. 1. Fonte di varianza, grado di libertà e valore quadratic medio dei tratti studiati sotto diversi livelli di irrigazione, controllo delle infestanti e concentrazione di cobalto.

source	DF	Broad leaved	Narrow leaved	Total weeds	N-Uptake	P-Uptake	K-Uptake	SPAD value	Flag leaf area	Plant height	No. of spikes/ m^2	Spike length (cm)	Spikelets number $spike^{-1}$
Blocks	2	5.791 NS	0.2349 NS	276.15 NS	88.57 NS	0.00166 NS	0.0084 NS	148.61 NS	14.69 NS	2.40 NS	152.71 NS	0.624 NS	0.2672 NS
Irrigation	2	8476.26**	5115.36**	30179.22**	152.308**	1.051**	10.303**	64.98**	451.37**	83.52**	239788.3**	111.04*	128.383**
Main plot error	4	25.198	3.532	134.78	86.600	0.00134	0.01522	0.3741	6.5108	1.61	78.66	0.4225	1.5658
Weed	4	168427.37**	23182.62**	437782.98**	263.21*	2.007**	341.52**	275.42**	382.34**	2951**	184240.69**	73.088**	118.83**
Irr.×W.	8	2384.02**	749.02**	5407.10	94.35 NS	1.025**	5.081**	4.911 NS	1.505 NS	2.894 NS	4629.04**	1.289**	2.9116*
Sub plot Error	24	8.379	1.8849	117.74	87.44	0.0015	0.03059	3.771	5.91	2.714	172.93	0.6060	0.4083
Cobalt	4	1424.60**	725.41**	3840.70**	81.81 NS	0.0045**	0.6371**	23.44**	29.62**	30.94**	3651.41**	9.479*	21.016 NS
Irr.× Co.	8	65.879**	31.98**	188.89 NS	88.78 NS	0.00181 NS	0.01033 NS	0.4108 NS	0.2671 NS	0.328 NS	116.17 NS	0.34392 NS	0.25265 NS
W.×Co.	16	154.8984**	33.46**	436.35**	88.05 NS	0.0022 NS	0.0265*	0.5769 NS	0.2419 NS	0.6976 NS	107.08 NS	0.3548 NS	0.13967 NS
W.×. Irr×Co.	32	28.876 NS	18.334 NS	175.118 NS	88.32 NS	0.00181 NS	0.0048 NS	0.5016 NS	0.2281 NS	0.4077 NS	90.33 NS	0.36919 NS	0.10257 NS
Error	345	17.3197	6.133	126.49	89.99	0.00165	0.01348	4.292	2.996	3.387	173.11	0.48943	0.5137

Tab. 2 Source of variance, degree of freedom and mean square of the studied traits under irrigationlevels, weed control as well as cobalt concentrations.

source	DF	Grains number $spike^{-1}$	Grains weight $spike^{-1}$ (g)	1000-grain weight	Straw ton/ ha	Grain ton/ ha	Total carbohy-rates %	Total soluble sugar %	Protein %	Fate%	Cobalt ppm	Water use Efficiency
Blocks	2	14.90 NS	0.0279 NS	15.69 NS	0.3404 NS	0.0279 NS	13.98 NS	0.1201 NS	1.257 NS	1.016 NS	0.3879 NS	0.0187 NS
Irrigation	2	992.10*	6.3174**	399.17**	206.95**	6.3174**	852.10*	5.9994**	235.88**	11.664*	196.24**	4.2144**
Main plot error	4	1.0398	0.6444	5.2447	0.0761	0.6444	1.0277	0.6345	0.1446	0.837	0.0751	0.5342
Weed	4	1372.62*	14.993**	299.31**	94.366**	14.993**	128961*	13.981**	4.473**	7.842**	93.378**	11.248**
Irr.×W.	8	9.382**	0.038*	0.099 NS	5.0591**	0.038*	8.282**	0.101*	2.7699**	1.349 NS	4.0987**	0.029*
Sub plot Error	24	2.4553	0.0134	5.11	0.0878	0.0134	2.6553	0.0151	0.5865	1.297	0.0787	0.0112
Cobalt	4	41.7394**	0.5679**	28.12**	3.2476**	0.5679**	39.6292**	0.4987**	4.060 NS	1.181 NS	3.1422**	0.4214**
Irr.× Co.	8	0.5625 NS	0.0016 NS	0.2841 NS	0.0569 NS	0.0016 NS	0.6014 NS	0.0036 NS	0.035 NS	1.114 NS	0.0574 NS	0.0017 NS
W.×Co.	16	10.664 NS	0.0039 NS	0.2329 NS	0.0339 NS	0.0039 NS	11.321 NS	0.0041 NS	0.0671 NS	1.207 NS	0.0342 NS	0.0045 NS
W.×. Irr×Co.	32	0.3844 NS	0.00256 NS	0.2311 NS	0.0458 NS	0.00256 NS	0.3954 NS	0.01012 NS	0.0321 NS	1.163 NS	0.0464 NS	0.0114 NS
Error	345	2.773	0.0162	2.796	0.1494	0.0162	2.883	0.0148	0.32135	1.180	0.1399	0.0158