Yield and Essential Oil Response in Coriander to Water Stress and Phosphorus Fertilizer Application

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***Abstract*. Coriander (*Coriandrum sativum* L.) contains essential oil, and various extracts from the seeds possess anti-bacterial, antioxidant, anti-diabetic, anti-cancerous and anti-mutagenic activities. Field experiments were carried out to study the effect of phosphorus (P) fertilization (0, 12 and 24 kg·ha^{-2} P) on the seed yield, and volatile oil of Egyptian cultivar of coriander under water stress conditions. The oil was obtained by hydrodistillation extraction method using Clevenger apparatus. Chemical analysis of the oil was done by using gas chromatography and mass spectrometry (GC/MS). Increasing water amounts and P fertilization rates increased plant height, number of branches, number of umbels and seed yield. Essential oil yields increased significantly with increasing water regimes from 50% to 100% of ET crop. Irrigation applied at 100% of crop water need, combined with 24 kg·ha^{-2} P, gave the best seed and oil yields results. Coriander plants have high water use efficiency (WUE) at 50% ET crop, and 24 kg·ha^{-2} P whilst irrigation at 100% ET crop without any phosphorus application gave the lowest WUE. Concerning essential oil constituents, linalool was the major compound in coriander fruits.**

Coriandrum sativum is an annual herb belonging to the *Apiaceae* family. It is native to Mediterranean regions and cultivated for the fresh green herb and the fruits as well as for production of essential oils. The dried fruits are used for different purposes, such as food ingredients, cosmetics, perfumery and drugs. As a medicinal plant, coriander has been recommended for dyspeptic complaints, loss of appetite, convulsion, insomnia, anxiety, hypolipidemic, indigestion, carminative, diuretic, tonic, stomachic, and against worms and rheumatism [1, 2]. Moreover, the essential oil and various extracts from coriander fruits possess anti-bacterial [3-7], antioxidant [8, 9], anti-diabetic [10], anti-cancerous and anti-mutagenic activities [11]. It can also act as a sedative or for relief of nervousness [12].

Water stress in plants may lead to physiological disorders, such as a reduction in photosynthesis and transpiration [13]. In the case of aromatic plants, this insufficiency may cause significant changes in the yield and composition of essential oils. Water stress decreased the oil yield of rosemary [14], anise [15], and essential oil yield of dragonhead [16]. By contrast, water stress caused a significant increase in oil yield of citronella grass expressed on the basis of plant fresh mass [17]. The severity of water stress response can further vary with cultivar and plant density in parsley [18].

Phosphorus is an essential nutrient for crop growth and quality. In this respect, increasing phosphorus levels increased each of growth characters and oil yield on groundnut [19]. Application of phosphorus fertilizer had a positive effect on essential oil content and yield of cumin plant [20], whilst fresh herb and oil yields of dragonhead increased significantly with an increase in P application [16]. In as much as P application has been found to increase yields in coriander [21], research on influence of water shortage on P uptake and ultimately seed and essential oil content is lacking.

Therefore the aim of this study was to determine the effects of phosphorus fertilization on the seed yield, volatile oil and chemical composition of coriander under water stress conditions.

Materials and Methods

Study site

Two field experiments were carried out over two successive seasons of 2010/2011 and 2011/2012 at the National Research Centre Experimental Farm in El-Nubaria district, El-Buheira Governorate, Egypt. The 2010/2011 and 2011/2012 rainfall amounts and temperatures were recorded (Table 1). The sandy soil on the experimental site and irrigation water were analyzed [22]. The field capacity (FC) and wilting point (WP) were determined according to the pressure membrane methods. The field capacity, permanent wilting point, available soil moisture (ASM) and bulk density (BD), as means over the two seasons were 34.5, 16.0, 18.5% and 1.36 g cm^{-3}, respectively.

Planting treatments and experimental design

The experiment was laid out as a randomized complete block design with a factorial arrangement. Treatments consisted of 3 water regimes (control, i.e. 100% of the evapotranspiration (ET crop)), 75% and 50% of the control (drought treatments)) and three P rates (0, 12 and 24 $kg·ha^{-2}$). There were 9 plots in one replication which were repeated in four blocks. The sizes of the plots were 9.6 m^2 consisting of 4 rows of 0.60 m width and 4 m length. All P treatments were applied at planting as calcium super phosphate (15.5% P_2O_5). A surface drip (GR 4 $L·h^{-1}$) irrigation system was applied every 3 days. This supplied 6586, 4940 and 3293 $m^3·ha^{-1}$ per season, respectively for 100% of the ET crop (control water regime treatment for coriander calculated from the metrological data in the region), 75% and 50% of the control (drought treatments). Egyptian cultivar of coriander seeds (*Coriandrum sativum* var. *microcarpum*) were obtained from Medicinal and Aromatic Dep., National Research Centre, Egypt and sown in mounds, 20 cm apart in November 2010 and 2011. Thinning was done to two plants per mound at 30 days after planting (DAP). Each plot received 40 kg ha^{-1} of nitrogen and potassium as basic fertilizer at planting and 20 kg ha^{-1} nitrogen fertilization at 5 months after planting. All other recommended cultural practices were uniformly applied during the period of the experiments.

Data collection and analysis

At harvest, plant growth characters i.e. plant height (cm), number of branches; number of umbels per plant and seed yield was measured. At the end of the growing season, water use efficiency (WUE) was calculated for coriander seed and oil yields; $g \cdot m^{-3}$, and $ml \cdot m^{-3}$ respectively, in both growing seasons to indicate the productivity of irrigation water unit.

$$WUE = \frac{\text{Seed yield } (g \cdot m^{-2}) \text{ or oil yield } (ml \cdot m^{-2})}{\text{Applied irrigation water } (m^{3} \cdot m^{-2})}$$

The significance differences between the main and interaction effects of treatments were determined using ANOVA. When significant differences were present, treatment means were separated using Fischer's protected $LSD_{0.05}$.

Harvested coriander seeds were air-dried for 10 days and stored at ambient temperature ($25 \pm 2^{o}C$) without exposure to direct sunlight. Ground samples were subjected to hydrodistillation for 2.5 hours using a Clevenger-type apparatus [23] and expressed as ($ml \cdot 100\ g^{-1}$ air dry seed), while essential oil yield per plant was expressed as $ml \cdot plant^{-1}$.

Gas chromatography coupled to mass spectrometry (GC/MS) analysis of essential oil was done with a Hewlett Packard model 5890 comprising of Gas chromatograph equipped with 5 series Mass selective detector 9144 (HP). The column used was SE-54 (30 m x 0.25 mm i.d.). The oven temperature was maintained at 60°C for 2minutes, after injection, and then programmed at 5°C per minute, to 270°C. The injector temperature was 270°C and MS condition was kept at 280°C. Compounds were identified by matching their mass spectra with those recorded in the MS library and further confirmed by comparison.

Results and Discussion

Physical and chemical properties of the soil

The sandy soil used for the experiment was chemically analyzed [22] and showed low Electrical conductivity (EC) (Table 2), typical of soils in most droughty areas. This makes the sandy soils ideal for the experiment as it has a lower water holding capacity coupled with low nutrient contents, as compared to the amounts required for optimum growth and yield of coriander.

Analysis of irrigation water used in the experiment

Water used for coriander irrigation had a pH of 7.5 (H_2O), with EC of 0.50 (dSm-1). Soluble cations were 2.50, 0.20, 1.50 and 0.60 for Na, K, Ca and Mg respectively, whilst anions were 2.80 and 0.80 for Cl and sulphates respectively (Table 3). The low electrical conductivities in the water (0.50 dSm^{-1}) makes it ideal for use in evaluating effects of nutrient fertilization on coriander growth and development under water stress conditions.

Effect of water shortage and superphosphate fertilizer treatments on the growth parameters, yield and yield components of coriander

Data presented in Table 4 indicated that irrigation regimes and/or phosphorus fertilization affected plant height, number of branches, and number of umbels and weight of seeds plant^{-1} or m^{-2} of both seasons. Increasing water amounts increased all these plant yield components. The highest mean values due to irrigation treatments were recorded with plants that received the highest amounts of water (100% of the ET crop). The pronounced effect of increased irrigation on plant height, number of branches, number of umbels and coriander seed yield may be attributed to the availability of sufficient moisture around the root concentrated and thus a greater proliferation of root biomass resulting in the higher absorption of nutrients and water leading to production of higher vegetative biomass [24]. It was found that increasing levels of water stress reduce growth and yield due to reduction in photosynthesis and plant biomass. Under increasing water stress levels photosynthesis was limited by low CO_2 availability due to reduced stomatal and mesophyll conductance. Drought stress is associated with stomatal closure and thereby with decreased CO_2 fixation. Coriander shows superiority at the uppermost rate of irrigation treatments in producing the highest plant height, number of branches, number of umbels, and seed yield [25- 33].

Application of P fertilizer at 12 and 24 kg·ha^{-2} significantly increased plant height, number of branches, number of umbels and seed yield over that of no fertilizer. The highest mean values of plant height, number of branches, number of umbels and weight of seeds was obtained at application of 24 kg·ha^{-2} P. Means comparison (Table 4) showed that non application of phosphorus fertilizer (control) led to the least seed weight, plant height, number of branches and number of umbels. Application of phosphate fertilizer increased absorption of phosphorus and its effect on the recovery rate of photosynthesis and plant growth of coriander [21, 26, 27].The use of phosphorus fertilizer, leads to increased production of photosynthetic material, reducing the loss of flowers, and consequently an increase in yield components in coriander plants.

Improved phosphorus nutrition appears to stimulate processes which reduce plant water stress. Physiological studies under well watered conditions showed suboptimal phosphorus levels reduce root hydraulic conductivity causing low plant water potential and stomatal conductance. Furthermore, phosphorus fertilized plants had lower stomatal conductance and net photosynthesis rate [34].

Oil yields per plant increased significantly with increasing water regimes from 50% to 100% of the crop water need. Higher mean values of essential oil and oil yield in coriander seeds were obtained by higher water regimes (100% of ET crop).

Water quantities and phosphorus application and their interaction affected the percentage and yield of essential oils in coriander (Table 4). The mean values of essential oils percentage and yield due to P treatments showed that increasing P fertilizer significant increased the percentage and yield of essential oils. The same results were found in previous studies on coriander [21, 28] and also on dragonhead [16].

There was a significant difference in most of interaction treatments between irrigation and P levels. Increases in both moisture and P levels enhanced the plant height, number of branches, number of umbels, seeds yield and essential oil yield. The irrigation applied at 100% of ET crop, combined with P fertilizer at 24 $kg \cdot ha^{-2}$, gave the best results.

Chemical composition of seed oil of coriander detected using GC- MS

In the coriander at fruiting stages (fruits), 20 chemical constituents, representing more than 94% of the total chemical composition of the essential oil, were identified in the samples (Table 5). Linalool, nerol and α-terpineol constituents were present in amount more than 10%. Linalool ranged from 35.13 to 65.58%, nerol ranged from 3.52 to 22.36%, and α-terpineol ranged from 7.17 to 16.68%. Other constituents present were α-pinene (0.0 to 1.23%), α-terpinene (0.65 to 3.74%), limonene (0.59 to 2.32%), γ-terpinene (0.56 to 1.860), anethole (0.46 to 8.20%), geranial (1.37 to 4.56%), geraniol (1.13 to 2.06%), decanal (0.0 to 1.43), camphor (0.73 to 3.54%) and borneol (0.78 to 3.12%). Other constituents were present in amount less the 1% (Table 5).

The maximum percent of linalool (65.58%) was obtained from 50% of ET crop fertilized with 24 $kg{\cdot}ha^{-2}$ P. While, plants receiving 100% of crop water needs without P fertilizer gave the lowest linalool percent (35.13%). On the contrary, it was found that irrigation with 100% of ET crop with 24 $kg{\cdot}ha^{-2}$ P, gave the highest percent of nerol, α-terpineol, anethole and α-pinene, and the lowest percent of linalool, camphor and carvacrol. Also as clearly shown in Table 5, irrigation at 50% of the crop water needs with 12 $kg{\cdot}ha^{-2}$ P, gave the lowest percent of limonene, γ-terpinene, borneol, and geranial and the highest percent of α-terpinene, P-cymene and geraniol.

Irrigation of coriander plants at 50% of ET crop led to increased concentration of linalool and borneol, while irrigation at 100% of ET crop contributed to higher percentages of α-terpineol, anethol and nerol. Maximum concentrations of limonene and γ-terpinene and less concentration of α-pinen were found when irrigation was applied at 75% of coriander water needs.

At fruiting stage, linalool content in the coriander seed oil has been reported to be 40% [35]; 55% [36]; 57-59% [37] 63% [38]; 70-75% [39]; 72-83% [40, 41] and 87.54% [42]. It seems that different metabolic pathways closely related to genetic information were elicited in coriander secondary metabolism, generating the great variability of the essential oil composition [43]. Overall, the results reported on the chemical composition of the coriander plants during different stages of maturity revealed great differences occurring during maturation process. It may be suggested that these differences were concomitant with modification in secondary metabolism [40, 44].

Water use efficiency

The highest values of field water use efficiency (WUE) calculated from water applied were 102.62, and 102.97 g of coriander seed per cubic m of irrigated applied water ($g \cdot m^{-3}$) at 50% ET crop, and 24 $kg \cdot ha^{-2}$ P, in the first and the second growing seasons, respectively. The same trends were shown when coriander oil yields were used to evaluate irrigation water productivity. In the contrary, irrigation at 100% ET crop without any phosphorus application gave the lowest WUE values of 52.81 and 52.29 $g \cdot m^{-3}$ for the two seasons respectively.

Irrigated coriander plants (at 100% ET crop) fertilised with superphosphate (24 $kg \cdot ha^{-2}$ P) resulted in high yield components and essential oil content than water stressed plants without any P applied. Lowest values of WUE for coriander oil yield were obtained when no phosphate fertiliser was added under the three water regimes. This study clearly shows the effectiveness of addition of super phosphate under sufficient water needs in improving seed as well as oil production in coriander. It is worthy to further investigate irrigation needs in soils with a higher water holding capacity.

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Tables

Table 1. Meteorological data at National Research Centre Experimental Farm in El-Nubaria district (Egypt) during the two growing seasons.

	2010/2011					2011/2012				
Months	T (°C)		Solar radiation Dgt [W/m²]	RH (%)	ETo (mm d^{-1})	T (°C)		Solar radiation Dgt [W/m²]	RH (%)	ETo (mm d^{-1})
	Max.	Min.				Max.	Min.			
November	4.3	29.5	209	72.9	3.5	4.3	29.5	209	72.9	3.5
December	2.3	27.4	183	75.1	2.9	6.3	34.2	189	78.8	2.9
January	10.4	34	204	72.9	3.9	17.1	39.6	239	73.8	4
February	4.2	35.4	233	68.8	4	13.9	41.3	247	73.1	4.8
March	6.3	37.4	266	62.4	4.8	16.8	35.6	291	75.2	4.9
April	17.5	37.9	287	73.8	5.8	13.9	42.8	294	76	5.9
May	14.2	43.6	300	66.7	6.4	14.3	43.5	309	67.9	6.5

Monthly average: T – temperature, RH – relative humidity, ETp – potential evapotranspiration.

Table 2. Soil physical and chemical analysis.

Soil depth	Soil texture	pH 1:2.5	EC dSm $^{-1}$ 1:5	Soluble cations (meq˙100 g soil)				Soluble anions (meq˙100 g soil)		
				Na^+	K^+	Ca^{++}	Mg^{++}	HCO^{-3}	Cl^-	SO^{-4}
0-15	Sandy	8.22	0.20	0.90	0.20	0.60	0.50	0.60	0.75	0.85
15-30	Sandy	7.94	0.20	0.80	0.10	0.50	0.30	0.40	0.70	0.60
30-45	Sandy	8.00	0.15	0.60	0.01	0.20	0.20	0.20	0.60	0.21

Method according to Black et al. (1982)

Table 3. Analysis of irrigation water used in the experiment.

pH	EC	Soluble cations (meq˙l^-)				Soluble anions (meq˙l^-)		
1:2.5	dSm^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	HCO^{-3}	Cl^-	SO^{-4}
7.55	0.50	2.50	0.20	1.50	0.60	1.20	2.80	0.80

Method according to Black et al. (1982)

Table 4. Effect of water deficit and superphosphate fertilizer treatments on the growth parameters, yield and its attributes of coriander plants.

Water regimes	Super-phosphate application (kg·ha^{-2})	Plant height (cm)	Number of branches per plant	Number of umbels per plant	Seed weight (g• plant^{-1})	Seed yield (g• m^{-2})	Oil % of seed	Oil yield of seed (ml• m^{-2})
3293 m^{3}• ha^{-1} (50% of the ETcrop)	Without (control)	40.535	2.78	3.895	1.9715	22.5145	0.41	0.046
	12	43.675	2.935	4.56	2.815	32.171	0.466	0.075
	24	46.415	3.73	5.475	2.9635	33.8475	0.476	0.0805
Mean		43.545	3.15	4.645	2.5785	29.5105	0.451	0.067
4940 m^{3}• ha^{-1} (75% of the ETcrop)	Without (control)	48.685	3.42	6.045	2.285	26.1145	0.486	0.0635
	12	51.59	4.285	6.18	2.8535	32.5905	0.5	0.0815
	24	55.435	4.23	6.48	3.0085	34.4	0.51	0.0875
Mean		51.905	3.93	6.24	2.717	31.0345	0.499	0.0775
6586 m^{3}• ha^{-1} (100% of the ETcrop)	Without (control)	56.29	5.165	6.925	3.0265	34.643	0.524	0.091
	12	57.915	5.655	8.21	3.09	35.3145	0.59	0.104
	24	59.84	6.175	8.97	3.6635	41.8475	0.61	0.1275
Mean		58.015	5.665	8.035	3.2525	37.3275	0.575	0.1075
Mean values as affected by superphosphate application	Without (control)	48.505	3.79	5.625	2.426	27.7465	0.474	0.067
	12	51.06	4.24	6.32	2.918	33.3595	0.519	0.0865
	24	53.895	4.71	6.97	3.2135	36.6985	0.532	0.099
Response	W	*	*	*	*	*	**	***
	P	*	*	*	*	*	**	***
	I x P	NS	NS	NS	NS	NS	**	***

W= water regimes, P= Superphosphate application rates, W x P = Interaction. *, **, ***denote significance at P≤0.05, P≤0.01, P≤0.001 respectively and NS denotes non significance at P≤0.05.

Table 5. The relative percentage of the chemical constituents detected with GC-MS in the seeds volatile oil of coriander plant.

	Water regimes treatments											
	3293 $m^{3} \cdot ha^{-1}$ (50% of the ETcrop)			4940 $m^{3} \cdot ha^{-1}$ (75% of the ETcrop)			6586 $m^{3} \cdot ha^{-1}$ (100% of the ETcrop)					
	Super phosphate application treatments									Response		
	0 $kg \cdot ha^{-2}$	12 $kg \cdot ha^{-2}$	24 $kg \cdot ha^{-2}$	0 $kg \cdot ha^{-2}$	12 $kg \cdot ha^{-2}$	24 $kg \cdot ha^{-2}$	0 $kg \cdot ha^{-2}$	12 $kg \cdot ha^{-2}$	24 $kg \cdot ha^{-2}$			
Components	Relative percentage (%)									W	P	I x P
α-pinene	1.17	1.16	0.07	-	-	0.77	0.93	0.48	1.23	*	**	NS
B-pinene	-	0.26	0.60	0.29	0.39	-	-	-	0.47	*	**	NS
α-terpinene	2.35	3.74	0.65	1.19	2.31	1.77	2.88	1.69	2.00	*	**	NS
P-cymene	-	0.78	0.71	-	-	0.63	-	0.21	0.39	*	**	NS
limonene	1.18	0.59	1.49	2.32	2.26	1.80	1.86	0.89	1.56	*	***	NS
γ -terpinene	0.15	0.56	1.19	1.86	1.80	1.32	1.56	0.68	0.87	*	**	NS
linalool	55.27	64.83	65.58	57.86	58.86	52.37	45.15*	56.88	35.13	**	*	*
camphor	3.54	1.60	1.18	1.70	1.78	1.50	1.49	3.25	0.73	*	**	NS
borneol	3.03	0.78	3.12	1.03	1.16	0.95	0.94	1.33	0.80	*	*	NS
α-terpineol	8.54	7.99	8.41	7.17	7.48	8.52	11.38	11.11	16.68	**	*	NS
decanal	1.43	0.42	1.35	-	-	1.27	1.08	1.31	0.95	**	*	*
nerol	8.10	7.26	3.52	13.31	13.96	11.53	22.36	9.76	21.93	*	**	*
geranial	3.11	1.37	3.17	1.89	1.73	4.56	2.00	1.93	2.16	*	**	NS
geraniol	1.46	2.06	1.13	1.44	1.40	1.14	1.15	1.80	1.30	*	*	NS
anethol	1.66	1.61	1.24	2.35	2.05	0.46	2.54	1.54	8.20	*	*	NS
carvacrol	1.69	0.37	1.50	0.16	0.36	2.18	0.49	0.25	-	*	*	NS
thymol	1.46	0.74	1.95	0.45	0.35	1.04	0.84	0.36	0.40	*	**	NS
undecanal	-	0.49	-	0.62	0.69	0.91	0.98	0.26	0.56	*	NS	NS
neryl acetate	0.28	0.41	0.39	-	-	1.07	-	-	-	NS	NS	NS
identified compounds	96.51	98.84	99.15	96.10	98.99	94.73	98.58	98.922	97.95			

W= water regimes, P= Superphosphate application rates, W x P = Interaction. *, **, ***denote significance at P≤0.05, P≤0.01, P≤0.001 respectively and NS denotes non significance at P≤0.05.

Figures

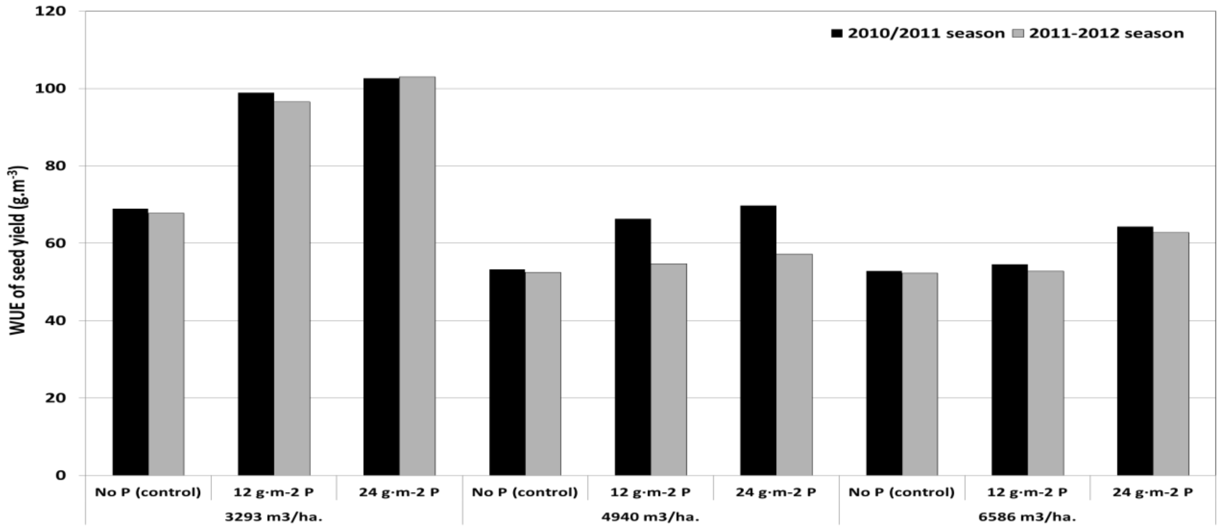

Fig. 1. Effect of the interacting between water deficit and superphosphate fertilizer treatments on Water Use Efficiency (WUE) of coriander seed yield (g·m^{-3}) in the two growing seasons.

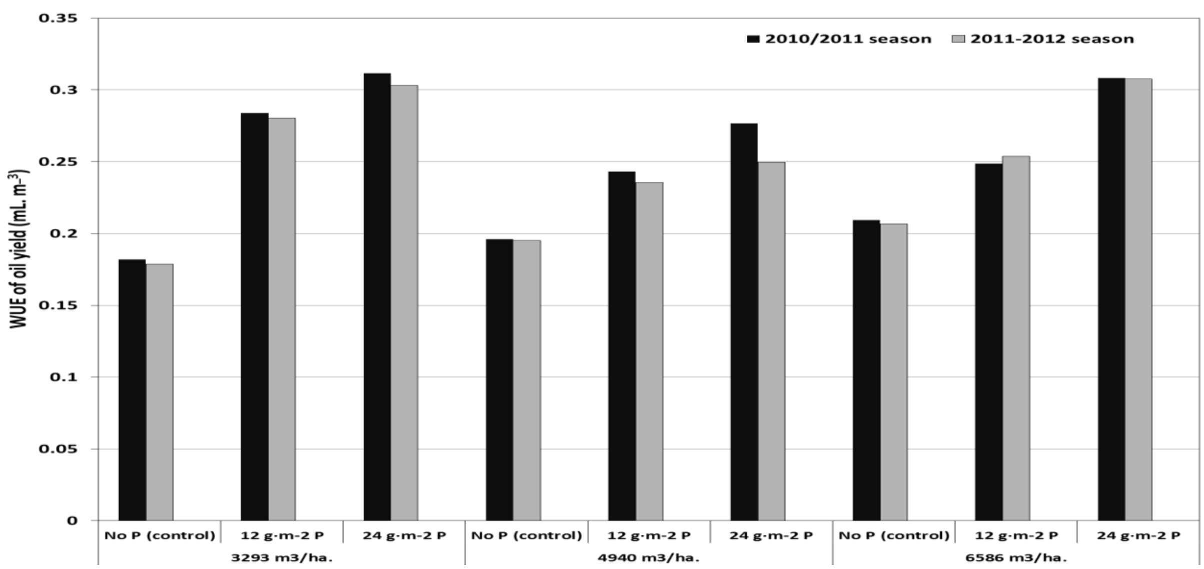

Fig. 2. Effect of the interacting between water deficit and superphosphate fertilizer treatments on Water Use Efficiency (WUE) of coriander oil yield (mL·m^{-3}) in the two growing seasons.