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RESEARCH ARTICLE

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Amelioration of drought stress on physiological performance of pearl millet (*Pennisetum americanum*) plant grown under saline condition using potassium humate and silicon source

ABSTRACT:

A field experiment was carried out during 2012 season at Ras Sudr Agricultural Experimental Station, South Sinai Governorate of Egypt, to study the response of two pearl millet cultivars namely (Shandaweel 1 and Sudan pop I) growing in saline soil to three periods of irrigation (4 day, 8 day, and 12 day) and four treatments (potassium humate, silicon (diatoms), mixture of both and control). The effect of these treatments on the growth and chemical composition of pearl millet was investigated. The increased period of irrigation reduced growth parameters, photosynthetic pigments, mineral ions content (K, Ca, Mg, and P) and increased Na^+, proline, ascorbic acid contents, total phenols and total flavonoids of both studied pearl millet cultivars. Also, all soil additives significantly increased parameters of both cultivars. However, the obtained results indicated that Sudan pop I cultivar was more drought tolerant than Shandaweel 1 cultivar. From the current study, the adverse effects of drought stress on pearl millet plants under Ras Sudr conditions can be ameliorated by using silicon and potassium humate which had a positive effect on most of the biochemical components and growth parameters.

KEY WORDS:

Pearl millet, Drought, Silicon, Potassium humate, Photosynthetic pigments, Minerals, Proline, Phenols, Flavonoids.

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INTRODUCTION:

Pearl millet [*Pennisetum americanum*] is one of the major cereal crops in semi-arid regions of Africa and Asia and it is certainly the mainstay for millions of people in the Sahel. It is grown as grain and fodder crop (Blummel *et al*., 2003). It is generally grown under rainfed conditions in arid and semi-arid regions of the world. Due to the low and erratic rainfall in these regions, the crop can face water stress at various stages of development (Manga and Yadav, 1993). In Egypt, pearl millet is not the staple food of rural populations as in the other countries of Africa, but it is used as summer fodder crop, since there is a shortage in the production of summer fodder crops. Egypt, as in most the arid regions, is classified among the countries which are threatened by dryness and salinity (Qadir *et al*., 2006). In addition, water availability is about 800 m^3 below the threshold of 1000 m^3/person/year (Paranychianakis and Chartzoulakis, 2005).

To overcome water scarcity, many countries have adopted the use of marginal water for irrigation (Oron *et al*., 2002). The salinity of those water sources typically exceeds the limit tolerated by conventional crop plants which are for the majority sensitive glycophytes (Hu *et al*., 2005). Pearl millet is one of the most drought tolerant cereals of all domesticated crops (Bidinger and Hash, 2004).

Drought is one of the major abiotic stresses influencing the agricultural production worldwide (Bhardwaj and Yadav, 2012). It is one of the principal abiotic factors that strongly limit crop production and restricts the normal growth and development of plants; hence, several chemical materials have been used to reduce its harmful effects (Babaogli *et al*., 2012; Jalal *et al*., 2012). Various planting physiological and biochemical processes are affected by drought result in the production of reactive oxygen species, which can in turn damage cell components, alter plant metabolism and retard plant growth leading to death (Gunes *et al*., 2007; Abdelkader *et al*., 2012).

Application of plant biofertilizer is one of the most important way to increase drought tolerance of plants. Treatments with potassium humate and silicon are effective in reducing the adverse effect of drought on growth, yield and chemical composition of Pearl millet plant. Humic substances, the major component of soil organic matter, are the subject of the study in various areas of agriculture such as soil chemistry, fertility, plant physiology, as well as environmental sciences because of multiply role played by these materials that can benefit plant growth (Tan, 1998). Potassium humate causes an increase in crop quality and tolerance of plant to drought, saline, cold, diseases and pests stresses (Gadimov *et al*., 2007). Silicon is the second most abundant element on the surface of the earth crust and in the soil (Epstein, 1999). Silicon alleviates many abiotic stresses including chemical stress (metal toxicity, nutrient imbalance) and physical stress (lodging, drought, salt, radiation, high temperature, freezing, UV) and many others (Ma and Takahashi, 2002; Richmond and Sussman, 2003; Ma, 2004).

Therefore, the objective of this experiment is to study the effect of drought stress on Pearl millet plant under saline condition. In addition, trails were assessed to increase the adaptation of Pearl millet to drought and saline stress by applying potassium humate and diatoms (silicon source) as soil additives. The effect of these treatments on growth, yield and chemical compositions of Pearl millet was recorded under saline soil irrigated with ground-salinized water at Ras Sudr in South Sinai.

MATERIAL AND METHODS:

Field experiment:

A field experiment was carried out during 2012 season at Agricultural Experimental Station in Ras Sudr Research Station, Desert Research Center, at South Sinai Governorate, Egypt, to study the effect of interaction between three periods of irrigation (4-day, 8-day, and 12-day) and four soil treatments (potassium humate, silicon, mixture of both and control) on the growth, yield and chemical composition of two pearl millet cultivars (Shandaweel 1 and Sudan pop I) under saline conditions. Pearl millet cultivar Sudan pop I grains were obtained from ICBA (International Center for Biosaline Agriculture) and grains of Egyptian local cultivar Shandaweel 1 were obtained from the Field Crop Institute, Agriculture Research Center, Ministry of Agricultures, Giza, Egypt. Recommended fertilization for this type of soil and other agricultural practices were applied according to Desert Research Center as recommended for the ordinary pearl millet fields in the experimental location. The chemical analysis of irrigation water and soil were presented in table 1 a & b.

Table 1. Water and soil chemical analysis

(a) Chemical analysis of soil

Depth (cm)	pH	EC (dS/m)	Saturation soluble extract (mg/100 g)							
			Cations				Anions			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	$HCO_3^{=}$	Cl^{-}	SO_4^{--}
0-30	7.7	8.69	24. 70	5.40	57. 40	0.53	0	6.00	61.70	23.90
30-60	7.9	7.40	16. 9	4.00	47.3	0.35	0	3.60	49.40	21.10

(b) Chemical analysis of irrigation water

EC dS/m	pH	Soluble anions (meq/l)				Soluble cations (meq/l)			
		CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
7.85	7.77	0.00	2.50	25.7	58.6	22.3	8.50	52.90	0.36

Cattle organic manure and calcium super phosphate fertilizers (15.5% P_2O_5) were added during soil preparation at rates of 20 m^3/fed and 200 kg/fed, respectively. Potassium sulfate (48% K_2SO_4) were added at the rate of 50 kg/fed at 20 days after sowing. Nitrogen fertilizer in the form of ammonium nitrate (33.5% N) were added at rate of 100 kg/fed in the two equal doses, the 1st dose was applied after 20 days from sowing dates and the 2nd dose was added after the first cut just before irrigation. Each experimental unit area was 10.5 m^2 (1/400 fed.) and contained four furrows (3.5 m in length and 60 cm apart).

Soil additives treatments will be carried out as (1) Potassium humate was used in a rate of 8 kg/fed, commercial name "Humic Total" consists of (Humic acid 80%- 12% K_2O – water solubility: 98% soluble –

pH: 8-9 – Bulk density: 83 g/100 ml). It is black powder produced by LEILI Agrochemistry Beijing, China and imported by TECHNOGREEN Co. (2) Silicon as Diatomes in a rate of 5 kg/fed, Diatoms consists of (SiO_2 85.70%- Al O_3 5.95% – water solubility: 98% soluble – pH: 7). It is grey powder produced by LEILI Agrochemistry Beijing, China and imported by TECHNOGREEN Co. (3) mixture of Potassium humate (4 kg/fed) + Silicon (2.5 kg/fed). (4) Control (tap water). Each treatment was applied as soil treatment after 20 days and 60 days from sowing date. Planting was carried out on May 2012, Pearl millet seeds were sown, at the above-mentioned sowing dates, in hills (about 5 seeds/hill, 20 cm apart) on the two ridges of furrows and covered with the sand and irrigation was applied after sowing directly. Two cuts were taken, the 1st cut was taken after 60 days from sowing date and the 2nd cut was taken after 50 days from the 1st cut date. At every cut, one square meter from each plot was chosen at random to estimate the following growth parameters (plant height, fresh weight and dry weight). Treatments were arranged in a split-split plot design with three replicates. Three periods of irrigation were arranged in the main plots, soil additives were allocated in the sub plots, and the cultivars were assigned in the sub-sub plots.

Chemical analysis:

1- Photosynthetic pigments: fresh leaf samples (0.5 g) were homogenized in mortar with 85% acetone according to Fadeel (1962). The optical densities were measured Spectro-photometrically using pharamisia LKB at 662, 644, and 440 nm. Photosynthetic pigments (Chlorophyll a, b and carotenoids) concentrations were calculated using wettstein's formula (Wettstein, 1957).

2- Mineral ions content: shoot samples were oven dried at 70˚C for constant weight. Dried materials were ground to a fine powder. About 0.2 g of dried ground shoots was digested in H_2SO_4: H_2O_2 (5: 1) for chemical analysis of mineral ions, Na, K, Ca, P, and Mg. Sodium, Calcium, Potassium were determined photometrically in the acid digested samples by using flame photometer (Perkin Elemer model-149) according to Brown and Lilleland (1946). Magnesium content was estimated using atomic absorption Unicam 929 AA Spectrometer by hollow cathode lamp 10 mA according to Cook (1997). Phosphorus (P) was determined colourimetry according to the method described by Murphy and Riley (1962).

3- Proline content: free proline concentration was measured colorimetrically in the extract of fresh materials according to Bates *et al*. (1973).

4- Ascorbic acid: content of ascorbic acid was calculated as described by Sadasivam and Balasubramanian (1987) and the results were expressed as mg/g dry weight.

5- Total phenols were estimated using the method of Malik and Singh (1980).

6-Total flavonoids were determined according to the colorimetric method described by Adom and Liu (2002).

Statistical Analysis:

Data were subjected to statistical analysis according to Steel and Torrie (1960).

L.S.D at 0.05 levels was used to detect significant differences.

RESULTS:

Growth parameters:

Effect of irrigation intervals:

It is evident from the present data in table 2 that the longest plant height, fresh and dry weights were obtained with 4-day irrigation interval, whereas the lowest value of these parameters were recorded at irrigation interval every 12 days during 1st cut and 2nd cut in the growing season. The analysis of variance showed that irrigation intervals had significant effect on growth parameters of pearl millet cultivars.

Table 2. Effect of irrigation intervals on growth parameters of pearl millet cultivars grown under Ras Sudr conditions in 2012 season.

Irrigation intervals treatment	Plant height (cm)	Forage yield (Ton/fed.)		Plant height (cm)	Forage yield (Ton/fed.)	
		Fresh	Dry		Fresh	Dry
	1st cut season 2012			2nd cut season 2012		
4 Day	125.42	17.58	3.97	111.82	13.95	3.30
8 Day	98.67	10.09	2.54	88.09	7.69	2.02
12 Day	78.45	5.21	1.38	65.93	4.57	1.32
LSD at 5%	0.27	0.12	0.03	0.52	0.13	0.08

Effect of soil treatments:

Table 3 reveals the effect of different soil additives on growth traits of pearl millet cultivars under saline conditions at Ras Sudr in 2012 season. All growth traits were significantly increased with all treatments as compared with the control during 2012 season. However, silicon treatment recorded the higher mean values for plant height, fresh and dry weights during 1st cut and 2nd cut in both growing season. Meanwhile, potassium humate and the mixture (silicon + potassium humate) recorded the 2nd and 3rd order, respectively.

Table 3. Effect of soil additives treatments on growth parameters of pearl millet cultivars grown under Ras Sudr conditions in 2012 season.

Soil additives treatments	Plant height (cm)	Forage yield (Ton/fed.)		Plant height (cm)	Forage yield (Ton/fed.)	
		Fresh	Dry		Fresh	Dry
	1st cut season 2012			2nd cut season 2012		
Control (H_2O)	91.93	8.57	2.13	79.62	7.25	1.86
Potassium humate	105.17	12.12	2.89	93.27	9.44	2.39
Silicon source	108.38	13.01	3.06	95.84	10.24	2.56
Mix PH+Si	97.91	10.15	2.44	85.72	8.01	2.03
LSD at 5%	0.42	0.14	0.04	0.36	0.07	0.04

Effect of cultivars performance:

The effect of cultivars performance on growth characters of pearl millet cultivars grown under Ras Sudr conditions at 2012 season showed in table 4. Pearl millet Sudan pop I cultivar exhibited the highest mean values of all growth traits, plant height, fresh weight and dry weight during 1st cut and 2nd cut in the growing season. These results indicate that Sudan pop I cultivar is more tolerant to drought than Shandawyl 1 cultivar.

Table 4. Effect of cultivars performance on growth characters of pearl millet cultivars grown under Ras Sudr conditions in 2012 season.

Cultivars	Plant height (cm)	Forage yield (Ton/fed.)		Plant height (cm)	Forage yield (Ton/fed.)	
		Fresh	Dry		Fresh	Dry
	1st cut season 2012			2nd cut season 2012		
Shandawyl 1	98.61	10.38	2.49	86.65	8.32	2.09
Sudan pop I	103.08	11.54	2.77	90.57	9.16	2.33
LSD at 5%	0.46	0.18	0.05	0.54	0.10	0.05

Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars on growth traits:

Data in table 5 show the Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars on growth traits under Ras Sudr conditions in 2012 season. The interaction between 4-day irrigation interval with silicon as a soil additive for Sudan pop1 cultivar gave the highest mean values of plant height, fresh and dry weights during 1st cut and 2nd cut in the growing season. Also, application of potassium humate as a soil additive with 4-day irrigation interval for Sudan pop1 cultivar recorded the 2nd order during 1st cut and 2nd cut in 2012 growing season. Generally, plant height, fresh and dry weights of pearl millet plant recorded the highest mean values during the 1st cut in 2012 season.

Table 5. Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars on growth traits under Ras Sudr conditions in 2012 season.

Treatments			Growth parameters					
Irrigation intervals	Soil additives	Cultivars	Plant height (cm)	Forage yield (ton/fed.)		Plant height (cm)	Forage yield (ton/fed.)	
			1st cut season 2012			2nd cut season 2012		
4 Day	Control (H_2O)	shwyl 1	111.73	13.42	3.25	101.00	11.45	2.73
		Sud.p 1	116.37	14.11	3.47	103.27	12.36	2.88
	Potassium humate	shwyl 1	127.93	18.26	3.96	115.57	14.22	3.24
		Sud.p 1	134.17	20.54	4.62	118.73	15.62	3.84
	silicon source	shwyl 1	132.07	19.85	4.22	117.03	14.92	3.57
		Sud.p 1	137.17	21.81	4.83	122.27	16.84	4.09
	Mix PH+Si	shwyl 1	120.47	15.50	3.64	106.00	12.84	2.97
		Sud.p 1	123.47	17.16	3.77	110.70	13.35	3.04
8 Day	Control (H_2O)	shwyl 1	93.07	7.90	2.00	78.63	6.12	1.64
		Sud.p 1	93.87	8.31	2.16	81.27	6.33	1.79
	Potassium humate	shwyl 1	98.40	10.25	2.59	89.00	7.31	1.91
		Sud.p 1	103.63	11.92	3.01	94.97	9.43	2.45
	silicon source	shwyl 1	101.27	10.91	2.73	92.70	8.62	2.13
		Sud.p 1	107.73	12.64	3.13	97.50	10.37	2.63
	Mix PH+Si	shwyl 1	94.63	9.05	2.28	84.00	6.50	1.75
		Sud.p 1	96.77	9.75	2.42	86.67	6.84	1.82
12 Day	Control (H_2O)	shwyl 1	64.73	3.55	0.89	55.03	3.41	0.95
		Sud.p 1	71.83	4.10	1.00	58.53	3.85	1.19
	Potassium humate	shwyl 1	81.00	5.58	1.45	68.87	4.90	1.44
		Sud.p 1	85.87	6.15	1.72	72.50	5.15	1.45
	silicon source	shwyl 1	83.23	5.85	1.60	70.63	5.03	1.43
		Sud.p 1	88.80	7.00	1.86	74.93	5.69	1.54
	Mix PH+Si	shwyl 1	74.80	4.40	1.23	61.37	4.46	1.37
		Sud.p 1	77.33	5.03	1.28	65.57	4.09	1.21
	LSD at 5%		1.58	0.61	0.17	1.86	0.35	0.19

Chemical composition:

Photosynthetic pigments content:

Effect of irrigation intervals:

The effect of different irrigation intervals on pigment contents of pearl millet cultivars under saline conditions at Ras Sudr is shown in table 6. Irrigation intervals treatment increased significantly pigment contents as compared with the control. Chlorophyll (a), chlorophyll (b), carotenoids, chlorophyll (a + b), and total pigments recorded the highest mean values in response to 4-day irrigation interval, whereas the lowest value of these parameters were recorded by increasing the irrigation interval to 12-days.

Table 6 Effect of irrigation intervals on pigment contents of pearl millet cultivars grown under Ras Sudr conditions.

Irrigation intervals treatment	Pigment contents (mg/g FW)				
	Chl. a	Chl. b	Cart.	Chl. a+b	Total pigments
4 Day	5.91	2.14	3.59	8.05	11.64
8 Day	4.98	1.55	2.94	6.53	9.47
12 Day	4.36	1.21	2.51	5.57	8.09
LSD at 5%	0.06	0.05	0.04	0.09	0.07

Effect of soil additives treatment:

Table 7 illustrates the effect of soil additive treatments on pigment contents of pearl millet cultivars under saline conditions at Ras Sudr. All soil additives increased significantly pigment contents as compared with the control. Potassium humate induced the highest mean values for chlorophyll (a), chlorophyll (a + b), carotenoids and total pigment contents. While, silicon recorded the highest mean values for chlorophyll (b) content as compared with other treatments.

Table 7. Effect of soil additives on pigment contents of pearl millet cultivars grown under Ras Sudr conditions.

Soil additives treatments	Pigment contents (mg/g FW)				
	Chl. a	Chl. b	Cart.	Chl. a+b	Total pigments
Control (H_2O)	4.22	1.32	2.85	5.54	8.40
Potassium humate	5.97	1.78	3.17	7.75	10.92
Silicon source	5.31	1.91	3.12	7.22	10.34
Mix PH + Si	4.82	1.54	2.93	6.36	9.29
LSD at 5%	0.03	0.03	0.02	0.04	0.05

Effect of cultivars performance:

Results in table 8 show the changes in photosynthetic pigments of two pearl millet cultivars in response to salinity conditions at Ras Sudr. It is clear from these results that Sudan pop I cultivar significantly exceeded Shandawyl 1 cultivar in chlorophyll (a), chlorophyll (b), chlorophyll (a + b), carotenoids and total pigments.

Table 8. Effect of cultivars performance on pigment contents of pearl millet cultivars grown under Ras Sudr conditions.

Cultivars	Pigment contents (mg/g FW)				
	Chl. a	Chl. b	Cart.	Chl. a+b	Total pigments
Shandawyl 1	4.24	1.52	2.91	5.76	8.67
Sudan pop I	5.92	1.76	3.12	7.68	10.80
LSD at 5%	0.03	0.03	0.03	0.04	0.05

Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars:

Data of pigment contents parameters of pearl millet plant as affected by the interaction between irrigation intervals, soil additives treatments and cultivars are presented in table 9. The results show that the interaction between 8-day irrigation interval with potassium humate as a soil additives for Sudan pop I cultivar gave the highest mean values of chlorophyll a, chlorophyll a + b and total pigments. Also, application of potassium humate as a soil additive with 4-day irrigation interval for Sudan pop1 cultivar recorded the highest mean values of chlorophyll b. However, the interaction between 4-day irrigation interval with the control for Sudan pop1 cultivar gave the highest mean values of carotenoids.

Table 9. Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars on pigment contents under Ras Sudr conditions.

Irrigation intervals	Soil additives	Cultivars	Chl. a	Chl. b	Cart.	Chl. a+b	Total pigments
4 Day	Control (H_2O)	shwyl 1	5.28	0.65	2.99	5.93	8.92
		Sud.p 1	4.79	1.59	4.99	6.39	11.38
	Potassium humate	shwyl 1	2.06	2.09	2.76	4.15	6.91
		Sud.p 1	4.62	3.42	4.78	8.04	12.81
	silicon source	shwyl 1	7.23	2.69	3.26	9.92	13.18
		Sud.p 1	8.53	3.09	3.52	11.62	15.15
	Mix PH + Si	shwyl 1	5.73	2.01	2.84	7.74	10.58
		Sud.p 1	9.04	1.61	3.58	10.64	14.22
8 Day	Control (H_2O)	shwyl 1	5.80	1.75	1.47	7.55	9.02
		Sud.p 1	3.19	2.21	3.38	5.40	8.78
	Potassium humate	shwyl 1	3.03	1.03	4.24	4.06	8.30
		Sud.p 1	14.82	2.04	1.58	16.86	18.45
	Silicon source	shwyl 1	3.42	0.80	2.01	4.22	6.23
		Sud.p 1	3.34	2.46	4.68	5.80	10.48
	Mix PH + Si	shwyl 1	3.89	1.43	3.38	5.31	8.69
		Sud.p 1	2.33	0.71	2.81	3.04	5.85
12 Day	Control (H_2O)	shwyl 1	4.24	1.02	2.63	5.26	7.89
		Sud.p 1	2.05	0.69	1.67	2.74	4.41
	Potassium humate	shwyl 1	5.13	1.27	3.46	6.41	9.86
		Sud.p 1	6.15	0.84	2.18	7.00	9.18
	Silicon source	shwyl 1	2.44	1.21	2.61	3.66	6.26
		Sud.p 1	6.92	1.18	2.62	8.10	10.72
	Mix PH + Si	shwyl 1	2.65	2.24	3.31	4.89	8.20
		Sud.p 1	5.30	1.22	1.65	6.52	8.17
	LSD at 5%		0.11	0.11	0.10	0.15	0.16

Mineral ions content:

Effect of irrigation intervals:

The effect of irrigation intervals on Mg, K, Ca, P, and Na ions content in dry shoots of two pearl millet cultivars growing under saline condition at Ras Sudr are presented in table 10. The data indicate that irrigation intervals had significant effect on mineral ions composition. It is clearly shown that 4-day irrigation interval produced the highest mean values for Mg, Ca, p and and K ions content. While, 12-days irrigation interval treatment marked the highest mean values for Na ion content.

Table 10. Effect of irrigation intervals on minerals composition of pearl millet cultivars grown under Ras Sudr conditions

Irrigation interval treatments	Mineral ions content (mg/g DW)				
	Na	K	P	Ca	Mg
4 Day	13.65	5.69	0.67	15.75	9.36
8 Day	15.72	4.06	0.59	10.55	7.43
12 Day	18.22	3.44	0.46	8.31	5.11
LSD at 5%	0.96	0.17	0.06	0.58	0.54

Effect of soil additives treatment:

Data concerning the effect of soil additives on Mg, K, Ca, P, and Na ions content in dry shoots of two pearl millet cultivars growing under saline condition at Ras Sudr are presented in table 11. It is evident from these results that Mg, K, Ca, and P contents were significantly increased with all soil additives as compared with the control values. On the contrary, Na content decreased with all soil additives. Soil additive with silicon produced the maximum values of K, Ca, P, and Mg contents as compared with the other treatments. On the other hand, control showed the highest mean value for Na content.

Table 11. Effect of soil additives on minerals composition of pearl millet cultivars grown under Ras Sudr conditions

Soil additives treatments	Mineral ions content (mg/g DW)				
	Na	K	P	Ca	Mg
Control (H_2O)	18.51	3.80	0.49	10.05	6.55
Potassium humate	14.77	4.75	0.60	12.02	7.59
Silicon source	13.52	4.96	0.64	12.96	7.88
Mix PH + Si	16.65	4.07	0.55	11.13	7.17
LSD at 5%	0.46	0.13	0.02	0.23	0.16

Effect of cultivars performance:

Table 12 shows the response of mineral ions content in shoots of two pearl millet cultivars to stress conditions at Ras Sudr. These results indicate that Sudan pop I cultivar produced the maximum value of Mg, Ca, K, and P ion contents. A reverse effect was observed for Na ion contents.

Table 12. Effect of cultivars performance minerals composition of pearl millet cultivars grown under Ras Sudr conditions

Cultivars	Minerals ion contents (mg/g DW)				
	Na	K	P	Ca	Mg
Shandawyl 1	16.28	4.21	0.55	11.22	7.14
Sudan pop 1	15.44	4.58	0.60	11.86	7.46
LSD at 5%	0.53	0.22	0.03	0.35	0.28

Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars on mineral ions content:

Data in table 13 show the effect of interaction between irrigation intervals, soil additives and cultivars on mineral ions content in shoots of two pearl millet cultivars growing under stress conditions at Rus Sadr. It is evident from these results that 12-days irrigation interval with control for Shandawyl 1 cultivar recorded the highest mean values of Na content. Meanwhile, 4-day irrigation interval treatment with potassium humate as soil additive for Sudan pop 1 cultivar recorded the highest mean value for K content. Also, 4-day irrigation interval treatment with silicon as soil additive for Sudan pop 1 cultivar recorded the highest mean value for Ca, P, and Mg ions content. The above results revealed that soil additives with potassium humate, silicon and mixture of potassium humate + silicon and their interaction with irrigation intervals treatments increased Mg, K, Ca, and P ions content, while, decreased Na level when compared with control. This response is much more pronounced in Sudan pop 1 cultivar indicating that Sudan pop 1 cultivar is more tolerant than Shandawyl 1 cultivar.

Table 13. Effect of interaction between Irrigation Intervals X soil additives X pearl millet cultivars on minerals composition under Ras Sudr conditions.

Treatments			**Minerals ion contents (mg/g DW)**				
Irrigation intervals	Soil additives	Cultivars	Na	K	P	Ca	Mg
4 Day	Control (H_2O)	Shwyl 1	15.39	4.66	0.57	13.09	8.65
		Sud.p 1	15.36	4.94	0.60	13.72	8.90
	Potassium humate	Shwyl 1	14.00	6.31	0.65	16.54	9.26
		Sud.p 1	12.48	7.11	0.73	17.08	9.57
	Silicon source	Shwyl 1	12.12	5.63	0.72	17.23	9.89
		Sud.p 1	11.28	6.27	0.78	18.80	10.19
	Mix PH + Si	Shwyl 1	14.86	5.16	0.62	14.31	9.10
		Sud.p 1	13.69	5.47	0.67	15.25	9.31
8 Day	Control (H_2O)	Shwyl 1	18.24	3.76	0.50	9.48	6.59
		Sud.p 1	18.02	3.89	0.55	10.05	6.74
	Potassium humate	Shwyl 1	14.75	3.58	0.58	10.27	7.64
		Sud.p 1	14.27	4.53	0.63	10.70	8.01
	Silicon source	Shwyl 1	13.94	4.39	0.61	11.51	7.74
		Sud.p 1	13.58	4.56	0.67	11.91	8.08
	Mix PH + Si	shwyl 1	17.02	3.43	0.56	9.97	7.21
		Sud.p 1	15.92	4.34	0.60	10.49	7.39
12 Day	Control (H_2O)	shwyl 1	22.49	2.77	0.33	6.85	4.13
		Sud.p 1	21.59	2.81	0.39	7.09	4.28
	Potassium humate	Shwyl 1	16.90	3.33	0.47	8.53	5.24
		Sud.p 1	16.20	3.62	0.54	8.97	5.83
	Silicon source	Shwyl 1	15.50	4.44	0.51	8.87	5.44
		Sud.p 1	14.69	4.49	0.57	9.41	5.94
	Mix PH + Si	Shwyl 1	20.16	3.12	0.42	7.96	4.79
		Sud.p 1	18.24	2.93	0.43	8.78	5.21
LSD at 5%			1.82	0.75	0.11	1.20	0.96

Proline, ascorbic acid, phenols and flavonoid contents:

Effect of irrigation intervals:

Data presented in table 14 show that drought affected positively proline, ascorbic acid, total phenols and flavonoid contents of the two pearl millet cultivars growing under saline condition at Ras Sudr. However, 12-day irrigation interval produced the highest mean values for proline, ascorbic acid, total phenols and flavonoid content, on the other hand, 4-day irrigation interval induced the lowest mean values of the same parameters.

Table 14. Effect of irrigation intervals on proline, ascorbic acid, total phenols and total flavonoids of pearl millet cultivars grown under Ras Sudr conditions

Irrigation intervals Treatments	Proline (μ mole/g)	Ascorbic acid (mg/g)	Phenols (mg/g)	Flavonoids (mg/g)
4 Day	3.06	0.77	1.95	0.37
8 Day	5.13	1.34	2.30	0.68
12 Day	7.15	2.48	2.75	1.05
LSD at 5%	0.15	0.08	0.04	0.05

Effect of soil additive treatments:

Data illustrated in table 15 reveal that the effect of soil additives treatments on proline, ascorbic acid, total phenol and flavonoid contents of two pearl millet cultivars growing under saline condition at Ras Sudr. It is evident from these results that proline, ascorbic acid, phenols and flavonoids contents were significantly increased with all soil additives as compared with that of the plants control. While, soil additives with silicon produced the maximum values as compared with those detected in other treatments.

Table 15. Effect of soil additives on proline, ascorbic acid, total phenols and total flavonoids of pearl millet cultivars grown under Ras Sudr conditions

soil additives Treatments	Proline (μ mole/g)	Ascorbic Acid (mg/g)	Phenols (mg/g)	Flavonoids (mg/g)
Control (H_2O)	4.34	1.19	2.13	0.55
Potassium humate	5.35	1.63	2.39	0.76
Silicon source	6.03	1.91	2.55	0.83
Mix PH + Si	4.74	1.39	2.26	0.65
LSD at 5%	0.08	0.03	0.04	0.04

Effect of cultivars performance:

Data in table 16 show the effect of cultivars performance on proline, ascorbic acid, and total phenol and flavonoid contents of two pearl millet cultivars grown under Ras Sudr conditions. Pearl millet Sudan pop I cultivar exhibited the highest mean values of proline, ascorbic, acid phenol and flavonoid contents.

Table 16. Effect of cultivars performance on proline, ascorbic acid, total phenols and total flavonoids of pearl millet cultivars grown under Ras Sudr conditions

Cultivars	Proline (μ mole/g)	Ascorbic Acid (mg/g)	Phenols (mg/g)	Flavonoids (mg/g)
shandawyl 1	5.00	1.49	2.30	0.67
sudan pop 1	5.23	1.57	2.36	0.73
LSD at 5%	0.10	0.04	0.05	0.03

Effect of interaction between irrigation intervals X soil additives X pearl millet cultivars:

Data in table 17 show the effect of interaction between irrigation intervals, soil additive treatments and cultivars performance on proline, ascorbic acid, total phenols and total flavonoid contents in shoots of two pearl millet cultivars growing under stress conditions at Rus Sadr. It is evident from these results that the interaction between 12-day irrigation interval treatment with silicon as a soil additive for Sudan pop 1 cultivar recorded the highest mean values of proline, ascorbic acid, total phenols and total flavonoid contents followed by the interaction between 12-day irrigation interval treatment with silicon as a soil additive treatment for Shandawyl 1 cultivar.

Table 17. Effect of interaction between Irrigation Intervals X soil additives X pearl millet cultivars on proline, ascorbic acid, total phenols and total flavonoids of pearl millet cultivars grown under Ras Sudr conditions

Treatments			Contents			
Irrigation intervals	**Soil additives**	**Cultivars**	**Proline (μ mole/g)**	**Ascorbic acid (mg/g)**	**Phenols (mg/g)**	**Flavonoids mg/g**
4 Day	Control (H_2O)	Shwyl 1	2.14	0.45	1.74	0.22
		Sud.p 1	2.38	0.57	1.83	0.26
	Potassium humate	Shwyl 1	3.24	0.83	1.97	0.40
		Sud.p 1	3.41	0.90	2.00	0.45
	Silicon source	Shwyl 1	3.75	0.98	2.06	0.49
		Sud.p 1	3.91	1.03	2.13	0.51
	Mix PH+Si	Shwyl 1	2.69	0.66	1.91	0.30
		Sud.p 1	2.99	0.71	1.95	0.35
8 Day	Control (H_2O)	Shwyl 1	4.15	1.15	2.16	0.54
		Sud.p 1	4.37	1.22	2.20	0.58
	Potassium humate	Shwyl 1	4.99	1.33	2.32	0.71
		Sud.p 1	5.56	1.39	2.35	0.74
	Silicon source	Shwyl 1	6.28	1.47	2.43	0.78
		Sud.p 1	6.35	1.57	2.47	0.80
	Mix PH + Si	Shwyl 1	4.56	1.26	2.22	0.64
		Sud.p 1	4.76	1.30	2.26	0.66
12 Day	Control (H_2O)	Shwyl 1	6.37	1.82	2.40	0.83
		Sud.p 1	6.61	1.89	2.42	0.89
	Potassium humate	Shwyl 1	7.33	2.56	2.79	1.07
		Sud.p 1	7.57	2.74	2.92	1.20
	Silicon source	Shwyl 1	7.83	3.17	3.07	1.15
		Sud.p 1	8.04	3.26	3.16	1.27
	Mix PH + Si	Shwyl 1	6.66	2.13	2.56	0.97
		Sud.p 1	6.80	2.25	2.65	1.00
	LSD at 5%		0.33	0.12	0.18	0.10

DISCUSSION:

Growth parameters:

In terms of our results concerning the effect of drought stress on growth characters of pearl millet plant, it could be concluded that delay of irrigation interval to 12-day (drought stress) had significantly depressed all the growth parameters; including plant height, fresh and dry weights of plant (Table 2). The increase in growth parameters was achieved with irrigation every 4-day compared to the other irrigation treatments. This may be due to high soil moisture content which reflected on the solubility and availability of soil nutrients, which increased nutrient absorption and thereby resulted in higher growth rate in terms of plant height, fresh and dry weights. These results agree with those obtained by Hussein and Ashok (2014) who showed that irrigation regime significantly decreased plant height, fresh and dry weights as compared with optimal irrigation in sorghum plants. Moreover, Almodares *et al.* (2013) showed that delay in irrigation intervals from 7 to 21 day significantly decreased stem height and biomass on two sweet sorghum cultivars.

Data present in table 3 indicated that application of potassium humate, silicon and mixture of both and their interaction (Table 5) had increased growth parameters of pearl millet plant, as compared to control. Our results are in agreement with those obtained by Eneji *et al*. (2008) who found that 1000 mg kg-1 potassium silicate (K_2SiO_3) application to the soil of four grass species under deficit irrigation (half of field capacity) “produced the greatest biomass yield responses across species,” as compared to calcium silicate ($CaSiO_3$) or silica gel. According to Gunes *et al*. (2008), sodium silicate applied to the soil mitigated the adverse dry mass reduction effects of drought in 6 of 12 sunflower cultivars. In this respects, Ihsanullah (2014) stated that humic acid (HA) significantly ($p < 0.05$) increased plant growth (i.e., plant height), green and dry matter yield on pearl millet. Moreover, Jahanzad *et al.* (2013) indicated that forage dry matter and forage quality parameters were significantly influenced by irrigation regimes and forage sorghum cultivars. Also, Shahryari *et al.* (2008) reported that potassium humate treatment increases the drought tolerance of wheat genotypes. Ghader and Hajiboland (2013) found that silicon treatment significantly increased plant dry weight and relative water content in pistachio plant under drought stress.

Many investigations declared the differences between cultivars in growth parameters. Abdullah *et al.* (2009), Cinisanim (2010) and Jamal and Meseka (2014) reported that pearl millet cultivars differ in drought and salt tolerance in terms of growth parameters.

Chemical composition:

Photosynthetic pigments content:

Drought stress caused significant decreases in chlorophyll a, chlorophyll b and carotenoids contents of pearl millet plants (Table 6). These results are in confirmation with those obtained by Manivannan *et al.* (2007) who reported that chlorophyll a, chlorophyll b and eventually the total chlorophyll contents decline under drought stress in *Helianthus annuus* plant. In addition, Najafinezhad *et al.* (2015) reported that chlorophyll a, total chlorophyll and carotenoid contents decreased significantly under drought stress on two plant species (corn and sorghum). Meanwhile, Mahalingam and Manivannan (2015) investigated that drought stress decreased pigment contents like chlorophyll and carotenoid when compared to control in maize plant.

Soil treatments with potassium humate, silicon and mixture of both and their interaction with irrigation intervals resulted in an increase in pigments content of pearl millet plants (Tables 7 & 9). These results are in agreements with that obtained by El-Bassiouny *et al.* (2014) who reported that humic acid increased significantly photosynthetic pigment (chlorophyll a, chlorophyll b, carotenoids and total pigments of wheat cultivars. In addition, El-Ghamry *et al.* (2009) found that application of humic acid increased pigment contents (chlorophyll a, b, total chlorophyll and caroteinoid) of faba bean plants. According, Lee *et al.* (2010) found that the addition of silicon to soybean plants increased chlorophyll content under salt stress conditions. In addition, Chen *et al.* (2011) found that applying silicon to drought-stressed rice increased chlorophyll concentration. Also, Shah *et al.* (2014) reported that Si application significantly increased the net photosynthesis in Kentucky bluegrass (*Poa pratensis* L.) plant after 20 days of drought stress.

The differences of photosynthetic pigments contents between cultivars (Table 8) were noticed by many authors (Manivannan *et al.,* 2007) on sunflower varieties, (Mafakheri *et al.,* 2010) in three chickpea cultivars.

Mineral ions content:

Drought stress had markedly decreased potassium, calcium, phosphorus and magnesium contents of pearl millet plants (Table 10). In this respect, Ibrahim (2005) found that leaf content of phosphorus and potassium increased by increasing water supply in *Simmondsia chinensis*. In the same direction, Mazhar *et al.* (2007) investigated that irrigation intervals treatments have a depressing effect on P and K uptake on *Bauhinia variegata*. However, Mazhar *et al.* (2010) investigated that P and K content increased as water level decreased in *Jatropha curca*.

Potassium humate, silicon and mixture of both and their interactions (Tables 11 & 13) are resulted in an increase in potassium, calcium, phosphorus and magnesium ions content of pearl millet plants compared to control. These results agree with those obtained by Siminis *et al*. (1998) on tomato (cv. Alexandros) plants. They found that K and Ca contents were higher in leaf petioles of plants treated with humic substances than in those of untreated plants. Also, El-Ghamry *et al*. (2009) investigated that macronutrients content (N, P, and K in seeds and straw) of faba bean increased by the application of humic acid. In addition, Gunes *et al.* (2008) found that application of silicon under drought stress significantly improved K and Mg uptake on sunflower cultivars.

Concerning the effect of cultivars performance on mineral ions content (Table 12), Küçükyumuk *et al.* (2015) showed that drought stress reduced N, P, K, Ca, and Mg contents on sweet cherry leaves. Also, Hussein and El-Dewiny (2011) found differences in mineral contents between fenugreek varieties in drought and salt areas.

Proline, ascorbic acid, phenols and flavonoids contents:

Proline, an amino acid, is well known to accumulate in a wide variety of organisms ranging from bacteria to higher plants on exposure to abiotic stress (Ahmad and Jhon, 2005; Ahmad *et al.,* 2006; Ahmad *et al.,* 2008). Proline being a cytosolic osmoticum and a scavenger of hydroxyl radicals can stabilize the structure and function of macromolecules such as DNA, protein, and of the membranes (Kishor *et al.,* 2005). Proline, sharing this property with other compounds collectively referred to as compatible solutes, are accumulated by a wide range of organisms to adjust cellular osmolarity (Yancey, 2005). The increase in proline content can be helpful in maintaining osmoticum under various environmental stresses.

Flavonoids are probably the most important natural phenols. These compounds possess a broad spectrum of chemical and biological activities including free scavenging properties (Khatiwora *et al.,* 2010). They also protect plants against infection by microbes and insects (Kähkönen *et al.,* 1999).

The present results (Table 14) were in complete harmony with that obtained by Hussein and Khursheed (2014) who found that proline content increased significantly with increasing drought stress while total protein was decreased. Also, Mahalingam and Manivannan (2015) investigated that drought stress increased proline content when compared to control in maize plant. Several studies showed that plant resistance to both biotic and abiotic stresses is related to phenolic compounds (Parr and Bolwell, 2000; Dicko *et al.,* 2005). However, Shehab *et al.* (2010) showed that AsA and total phenols increased by increasing drought conditions in rice Plants.

Proline, ascorbic acid, total phenols and total flavonoids contents in shoots of pearl millet cultivars were increased in response to soil treatments with Potassium humate, silicon and mixture of both and their interaction (Tables 15 & 17). The previous results were in agreement with those obtained by Ahmad and haddad (2011) who reported that silicon partially offset the negative impacts of drought stress increasing the tolerance of wheat by rising proline accumulation. However, Jafari *et al.* (2015) found that silicon increased total phenolic compounds and flavonoids under osmotic stress in cucumber.

Many investigations declared the differences between cultivars in proline, ascorbic acid, total phenols and total flavonoids contents (Table 16). In this respect, Shashi and Godara (2011) reported that proline accumulation increased with increasing soil moisture stress in *Ziziphus mauritiana* cultivars. In addition, Ashraf and Ibram (2005) concluded that under water stress in leguminous species, proline contents were increased. Salama *et al.* (2015) reported that sweet fennel cultivars were significantly differences in total phenolics (TPC), total flavonoids (TFC) and vitamin C content. Also, Chakraborty and Pradhan (2012) found that the accumulation of proline, phenol and ascorbate differ in susceptible varieties and tolerant varieties of wheat plant.

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تحسين الاجهاد الجفافي للأداء الفسيولوجي لنبات الدخن النامي تحت الظروف الملحية باستخدام هيومات البوتاسيوم ومصدر للسليكون

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أجريت تجربة حقلية خلال موسم (٢٠١٢ م) في محطة بحوث رأس سدر التابعة لمركز بحوث الصحراء بمحافظة جنوب سيناء - مصر، لدراسة استجابة صنفين من الدخن (شندويل 1 وسودن بوب I) لثلاث فترات ري (٤أيام، ٨ أيام و١٢ يوما)، وكذلك أربع إضافات أرضية باستخدام (هيومات البوتاسيوم، السيليكون، مخلوط من هيومات البوتاسيوم ومصدر للسليكون والنباتات الضابطة) تحت ظروف الملوحة وذلك لدراسة تأثيرها على دالات النمو والمحصول وبعض المكونات البيوكيميائية. أظهرت النتائج أن زيادة فترات الري لها تأثير سلبي على دالات النمو مما أدى الى انخفاض محتوى الاصباغ النباتية وبعض العناصر المعدنية (البوتاسيوم، الكالسيوم، والمغنيسيوم والفوسفور) بالإضافة الى زيادة محتوى الصوديوم، محتوى البرولين، ومحتوى حمض الأسكوربيك محتوى الفينولات ومحتوى الفلافونيدات في نباتات الدخن قيد الدراسة. كما أوضحت النتائج ان استخدام الاضافات الارضية أدى الى زيادة معنوية في المعايير سالفة الذكر. كما أشارت النتائج المتحصل عليها الى ان السلالة سودن بوب I أكثر تحملا للإجهاد الجفافى مقارنة بالصنف شندويل 1 حيث حققت سلالة الدخن سودن بوب I اعلى قيم لدالات النمو، محتوى الاصباغ النباتية والعناصر المعدنية، محتوى البرولين، ومحتوى حمض الأسكوربيك، محتوى الفينولات ومحتوى الفلافونيدات. كما أوضحت النتائج ان الافضل من حيث التأثير على الملوحة والجفاف هو استخدام السيلكون يليه هيومات البوتاسيوم ثم يأتي بعد ذلك استخدامها كمخلوط وبناء على ذلك من خلال هذه الدراسة يمكن الاستفادة من تقليل التأثير الضار للجفاف على نبات الدخن باستخدام السيليكون أو هيومات البوتاسيوم والتي تلعب دورا هاما في دفع النباتات لمقاومة الإجهاد الجفافى.