Effect of Pozzolan and Sulphur under Different Irrigation Water Salinity Levels on Growth Characteristics, Yield, and Water Use Efficiency of Squash

Wakid Mutowal*
MSc Student in Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdul-Aziz University, Jeddah, KSA

Samir Gamil Al-Solaimani
Professor in Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdul-Aziz University, Jeddah, KSA

Saleh Mahmoud Ismail
Professor in Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdul-Aziz University, Jeddah, KSA

Abstract

The main aim of this research is to improve the squash yield and quality using sulphur and pozzolan as soil conditioners in Saudi Arabia. This experiment conducted during winter and spring (2012 and 2013). A split split plot design with 3 irrigation water salinity levels (IWSL) (1200, 3000, and 6000 mg/l), 4 pozzolan placements (PP) (surface, 10 cm depth, 20 cm depth, and control), 3 sulphur doses (SD) (0, 4, 6 ton/ha), and 3 treatments was used. Applied PP in the soil surface and SD 6 ton/ha under IWSL 1200 mg/l increased plant height (77.57 and 72.80%) number of leaves/plant (38.21 and 31.45 leaves), fruit setting (42.54 and 40.24%), fruit yield (23.17 and 20.53 ton/ha), and water use efficiency (294.90 and 258.79 kg/mm/ha) respectively in the winter and spring compared with the control (no pozzolan, no sulphur and IWSL 6000 mg/l).

Key words: Salinity, Pozzolan, Sulphur, Squash Yield, Water Use Efficiency

Introduction

Squash (*Cucurbita pepo*) is a vegetable crop easy to grow, short season crop, adapted to temperate and subtropical climate and grown in many regions. It is one of the most widespread and important vegetable crops in Saudi Arabia. Squash production is economically important in Saudi Arabia, 13648 tons in 833 Ha of squash were produced in 2009. The average production per unit area was about 16 tons per hectare. Improvement of the squash production per unit area has been the objective of many recent studies. This could be achieved by using high yielding cultivars with good quality and the application of better cultural techniques [8].

The demand for water in agriculture is ever increasing. The water quality and quantity are the major limiting factors to the agricultural productivity, especially in regions characterized by adverse environmental conditions. Saudi Arabia is classified as an arid country, the irrigation water is medium saline to very saline water, and consist of calcareous saline sodic soil [2]. Many advanced methods of irrigation have been developed to maximize the water use efficiency. One of these methods is drip irrigation which all of other methods of irrigation and every drop of water is judiciously used in this system.

Sulphur is an essential nutrient for plants since it is involved in key steps of plant metabolism. During the last decades, sulphur deficiency in agricultural soils has become widespread in many countries. Sulphur is considered fourth in importance after nitrogen, phosphorus, and potassium. The fate of S in soil is important to S availability to plants and consequently, the crop growth and quality of the harvested products [9].

In the other side, maintaining soil physical condition in an adequate state contributes toward soil and water conservation. Numerous indicators such as aggregate stability, infiltration rate, soil erosion, etc can express the structural stability of soil quantitatively [1]. One of the best solutions for this problem is using pozzolan (a kind of porous rocks) as soil mulch for maintaining soil physical condition in an adequate state contributes toward soil and water conservation.

The present study was carried out to study the effects of pozzolan and sulphur under different irrigation water salinity levels on:

1. Improving the squash yield and quality.
2. Increasing water use efficiency and water saving.
3. Reducing salinity affect by using Sulphur soil amendment.

Materials and Methods

Experimental Location and Design

The present study conducted at the Agriculture Experimental Station belongs to King Abdulaziz University (KAU) located at Hada Alsham, 90 km northeast of Jeddah city. This experiment carried out during two successive seasons of winter and spring (2012 and 2013) to study the effect of using Sulphur and pozzolan as soil conditioner under different irrigation water salinity levels to improve squash yield and quality.

A split split plot design with three replications used on this experiment. This made a total of 108 plots corresponding to 3 irrigation water salinity levels (IWSL), 4 pozzolan placements (PP) and 3 Sulphur doses (SD). The main plot treatments are 1200, 3000 and 6000 mg/l IWSL, sub plot treatments are PP in the soil surface, 10 cm depth, 20 cm depth, and no pozzolan treatment, and sub-sub plot treatments are SD with 0, 4, and 6 ton/ha. The subplot size was be 2x3 m.

Environmental Conditions

Climatic condition data (maximum, minimum, and means) of air temperature, relative humidity and rainfall during the crop plantation for each season was collected from Faculty of Meteorology, Environment, and Arid land Agriculture meteorological station. The data of air temperature (°C), relative humidity (%) and rainfall (mm) was recorded and presented in Table (1).

Table 1. The climatic condition during experiment

No	Month	Temperature (°C)			Relative Humidity (%)			Rainfall (mm)		
		min	max	ave	min	max	ave	min	max	ave
Winter										
1	November	17.27	35.58	26.51	24.98	99.58	57.88	0	0	0
2	December	12.86	31.50	23.14	21.75	98.85	62.47	0	0	0
3	January	10.36	31.82	21.41	18.88	97.90	53.36	0	9.49	4.27
Spring										
4	February	12.14	34.21	23.20	12.46	98.15	50.21	0	2.17	1.02
5	March	12.78	39.07	26.14	9.52	99.35	48.08	0	0	0
6	April	14.47	41.93	29.59	12.67	97.18	42.89	0	0.035	0.035

Data Source: Meteorology Station, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz Univ. KSA

Cultural Practices

The experimental land for crop was tilled using moldboard plow at a depth of 25 to 30 cm. The land was harrowed with disk harrows, leveled, and then divided into 81 plots, at 2x3 m. Then, Sulphur as soil amendment applied with three doses (0, 4, and 6) ton/ha. After that, pozzolan placement conducted using dredger to put the pozzolan in the surface, 10 cm depth, and 20 cm depth of the soil. The physical and chemical characteristics of pozzolan presented in Table (2 and 3).

Fertilization applied using phosphorus fertilizer (P_2O_5: 100 Kg/Ha), potassium fertilizer (K_2O: 75 Kg/ha) and nitrogen fertilizer (N: 200 Kg/ha). Phosporus and pottasium fetilizer applied with the single dose before planting. Nitrogen fertilizers applied in 4 times (15, 30, 45 and 60 days after planting) with the same doses.

Table 2. Physical Properties of Pozzolan

Pozzolan Particle Size (mm)	Bulk Density (g/cm^3)	Particle Density (g/cm3)	Porosity (%)
Very Large Size(≥ 15)	0.64	2.89	80
Large Size (10.15)	0.82	2.84	72
Medium Size (5.10)**	0.78	2.87	63
Small≤ 5)	1.11	2.86	62

*** The experiment applied the medium size of pozzolan*

Table 3. Chemical Properties of Pozzolan

Component	Chemical formulae	Percentage (%)
Silica	SiO_2	70.55
Alumina	Al_2O_3	12.24
Ferric Oxide	Fe_2O_3	0.89
Lime	CaO	2.36
Magnesia	MgO	0.1
Sulphur Oxide	SO_3	0.03
Potassium Oxide	K_2O	4.21
Natrium Oxide	Na_2O	3.49
Loss on ingition	------	5.51
Undetermined	------	0.61
Total	------	100

Drip irrigation system was used under the current study. Three irrigation networks was installed, one for each water quality treatment. Each irrigation network contains storage tank with a capacity of 5000 L, disk filter, pump, controller, and solenoid valve to control the flow time. Daily irrigation interval practiced during the growing season for a period depend on the full water requirement of squash crop. The dripper lines was installed at 50 cm between two adjacent dripper lines. The distance between drippers is 45 cm. The type of the dripper lines used under the current study is RAIN BIRD LD-06 12-1000 Landscape drip 0.9 G/h @18'. The downstream end of each dripper connected to a manifold for convenient flushing. Inlet pressure on each tape supposes to be about 1.5 bars. The system used 125-micron disk filter. Water source was formed the installed containers. They always full of water via the transported saline water and the groundwater supplied from the main irrigation network of the farm. The groundwater and saline water mixed into volume by volume to give the required water salinity treatment based on EC measurements.

Statistical Analysis

The collected data in each experiment statistically analyzed using the analysis of variance procedures after applying the ANOVA assumptions then the treatment means separated and tested using Revised Least Significant Design (RLSD) test according to [4] using SAS program (2006).

Results

Growth Characteristics

Data in Table (4) illustrates the plant height of squash under the effects of interaction between salinity, pozzolan and sulphur during the two successive seasons of winter and spring (2012-2013). Interaction between salinity, pozzolan and sulphur treatments significantly affected to the squash plant height in both seasons. The best treatments occurre in the combination of 1200 mg/l IWSL, PP in the soil surface, and 6 ton/ha SD. In the opposite side, the bad treatments happened on the 6000 mg/l IWSL, no pozzolan treatment, and no sulphur doses.

The squash plant height under SD 0 ton/ha with PP in the soil surface higher than squash plant height under 6 ton/ha SD without pozzolan in all IWSL treatments. It indicates that pozzolan reduce the adverse effects of IWSL and reduce the using of sulphur.

Comparing with the control (1200 mg/l IWSL, no pozzolan, and no sulphur), applied the best treatments (1200 mg/l IWSL, PP in the soil surface, and 6 ton/ha SD) increased plant height 74.55% in the winter season and 64.28 in spring season. Increased squash plant height might be indicated the healthy condition of squash, and then squash could grow well.

Table (2) presents the number of leaves/plant means under the effects of salinity, pozzolan, and sulphur. Statistical comparisons in number of leaves/plant means under the combination of three treatments during two successive seasons using RLSD at $p \leq 0.05$ shows that as IWSL and SD increased, number of leaves/plant significantly decreased. In other side, PP in the soil surface resulted the highest number of leaves/plant, and then followed by pozzolan placement in the 10 cm soil depth, 20 cm soil depth, and the control (no pozzolan treatments).

Squash leaves number per plant increased 31.82 leaves/plant in winter season and 26.66 leaves/plant in spring season by applicated the best treatments (1200 mg/l of irrigation water salinity levels, pozzolan placement in the soil surface, and 6 ton/ha of sulphur dose) comparing with the control (1200 mg/l of irrigation water salinity levels, no pozzolan, and no sulphur). More leaves on the squash crop might be affected to the increasing the ability of squash to make photosynthesis. Photosynthesis is very important for plant growth and making sugar for developing squash crop cells.

Table 4. Means of squash plant height (cm) under the effect of interaction between salinity, pozzolan and sulphur

Salinity (mg/l)	Pozzolan Placements	Winter Season (2012)						Spring Season (2013)					
		Sulphur (ton/ha)						Sulphur (ton/ha)					
		0		4		6		0		4		6	
1200	No Pozzolan	30.75	pq	34.92	ijk	35.15	hij	25.83	opqr	26.89	mno	29.53	jk
	Surface	48.51	b	48.54	b	53.67	a	38.74	b	38.23	b	42.43	a
	10 cm Depth	37.66	g	41.03	def	41.72	de	31.50	gh	32.17	fgh	34.23	de
	20 cm Depth	32.50	mno	36.65	gh	39.42	f	27.16	mn	28.95	jkl	30.03	ij
3000	No Pozzolan	30.66	pq	31.17	op	33.57	klm	24.71	qr	26.18	nop	27.71	lm
	Surface	40.68	ef	44.35	c	47.33	b	32.58	fg	36.05	c	35.91	c
	10 cm Depth	35.40	hij	40.55	ef	42.39	d	29.21	jk	32.82	f	35.61	c
	20 cm Depth	31.23	op	33.56	klm	36.21	ghi	25.69	opqr	28.53	kl	30.16	ij
6000	No Pozzolan	30.22	pq	29.53	q	31.55	nop	24.56	r	24.81	qr	25.90	nopq
	Surface	39.55	f	39.90	f	44.03	c	30.98	hi	33.12	ef	35.20	cd
	10 cm Depth	34.35	jkl	35.49	hij	39.52	f	29.98	ij	31.26	hi	33.20	ef
	20 cm Depth	31.33	nop	32.83	lmn	33.27	lm	24.94	pqr	27.79	lm	25.56	pqr

** Means fallowed by the same letter of each trait under each factor are not significantly different according to LSD at P<0.05*

Table 5. Means of squash number leaves/plant under the interaction effect of salinity, pozzolan and sulphur

Salinity (mg/l)	Pozzolan Placements	Winter Season (2012)						Spring Season (2013)					
		Sulphur (ton/ha)						Sulphur (ton/ha)					
		0		4		6		0		4		6	
1200	No Pozzolan	8.49	mn	14.08	h	22.20	de	7.14	lmno	12.56	fgh	16.89	de
	Surface	13.51	h	22.95	d	40.32	a	11.83	ghi	20.44	c	33.80	a
	10 cm Depth	11.91	ij	20.68	f	37.14	b	11.07	ghij	16.83	de	32.68	a
	20 cm Depth	7.95	n	12.66	hi	26.17	c	9.16	ijklm	10.11	hijkl	23.62	b
3000	No Pozzolan	5.04	opq	10.15	kl	16.17	g	3.49	pqr	9.76	hijklm	11.36	ghi
	Surface	9.69	klm	13.42	h	26.02	c	8.31	jklmn	10.80	ghij	20.04	c
	10 cm Depth	9.33	klmn	13.58	h	25.17	c	7.26	lmno	10.99	ghij	18.24	cd
	20 cm Depth	6.17	op	10.07	kl	21.30	ef	4.96	opq	7.78	klmno	17.18	de
6000	No Pozzolan	2.11	r	5.57	opq	8.81	lmn	2.34	qr	7.48	lmno	7.45	lmno
	Surface	5.64	op	10.66	jk	22.71	de	6.80	mno	10.46	ghijk	20.72	c
	10 cm Depth	4.10	q	6.40	o	15.62	g	5.84	nop	5.61	nop	15.12	ef
	20 cm Depth	2.70	r	4.81	pq	13.63	h	1.88	r	5.11	opq	13.20	fg

** Means fallowed by the same letter of each trait under each factor are not significantly different according to LSD at P<0.05*

Table 6. Means of squash fruit setting (%) under the effect of interaction between salinity, pozzolan and sulphur

Salinity (mg/l)	Pozzolan Placements	Winter Season (2012)						Spring Season (2013)					
		Sulphur (ton/ha)						Sulphur (ton/ha)					
		0		4		6		0		4		6	
1200	No Pozzolan	76.08	p	80.61	ghijklmn	86.03	cdef	71.78	nop	81.02	efg	84.90	bcd
	Surface	81.76	ghijk	84.53	defg	92.44	a	75.49	jklm	82.50	def	89.70	a
	10 cm Depth	82.58	fghij	84.35	defg	88.16	bc	79.92	fgh	81.86	defg	87.06	abc
	20 cm Depth	81.56	ghijkl	83.53	efghi	87.23	bcd	76.10	ijkl	81.47	defg	84.45	bcd
3000	No Pozzolan	70.63	q	78.34	klmnop	84.28	defgh	69.51	p	75.80	ijklm	79.69	fgh
	Surface	79.89	ijklmno	83.88	defgh	89.05	abc	74.75	klmn	82.61	def	87.71	ab
	10 cm Depth	76.29	op	82.53	fghij	89.19	abc	72.52	mnop	79.09	ghi	86.53	abc
	20 cm Depth	77.55	mnop	79.18	jklmnop	88.40	bc	73.86	klmno	77.29	hijk	84.65	bcd
6000	No Pozzolan	64.85	r	76.92	nop	82.35	fghij	63.96	q	75.32	klm	75.51	jklm
	Surface	78.35	klmnop	80.80	ghijklm	89.99	ab	73.72	lmno	78.85	ghij	89.36	a
	10 cm Depth	77.61	mnop	77.81	mnop	86.69	bcde	74.78	klmn	75.27	klm	84.11	cde
	20 cm Depth	69.16	q	77.92	lmnop	86.41	bcde	71.00	op	77.01	hijkl	82.77	def

** Means fallowed by the same letter of each trait under each factor are not significantly different according to LSD at P<0.05*

Table 7. Means of squash fruit yield (ton/ha) under the interaction effect of salinity, pozzolan and sulphur

Salinity (mg/l)	Pozzolan Placements	Winter Season (2012)						Spring Season (2013)					
		Sulphur (ton/ha)						Sulphur (ton/ha)					
		0		4		6		0		4		6	
1200	No Pozzolan	10.47	mn	17.38	h	27.38	de	9.19	lmno	16.18	fgh	21.76	de
	Surface	16.67	h	28.32	d	49.74	a	15.24	ghi	26.33	c	43.55	a
	10 cm Depth	14.69	ij	25.52	f	45.82	b	14.26	ghij	21.68	de	42.10	a
	20 cm Depth	9.81	n	15.62	hi	32.28	c	11.80	ijklm	13.03	hijkl	30.44	b
3000	No Pozzolan	6.22	opq	12.52	kl	19.95	g	4.49	pqr	12.57	hijklm	14.64	ghi
	Surface	11.96	klm	16.56	h	32.10	c	10.72	jklm	13.92	ghij	25.82	c
	10 cm Depth	11.51	klmn	16.76	h	31.05	c	9.36	lmno	14.16	ghij	23.50	cd
	20 cm Depth	7.61	op	12.43	kl	26.27	ef	6.38	opq	10.03	klmno	22.13	de
6000	No Pozzolan	2.60	r	6.87	opq	10.87	lmn	3.02	qr	9.64	lmno	9.60	lmno
	Surface	6.95	op	13.15	jk	28.02	de	8.76	mno	13.48	ghijk	26.69	c
	10 cm Depth	5.06	q	7.89	o	19.27	g	7.53	nop	7.23	nop	19.48	ef
	20 cm Depth	3.32	r	5.94	pq	16.82	h	2.43	r	6.58	opq	17.01	fg

** Means fallowed by the same letter of each trait under each factor are not significantly different according to LSD at P<0.05*

Squash Fruit Yield

Based on the RLSD test at p<0.05 in the squash fruit setting, applied pozzolan in the soil surface with 6 ton/ha SD significantly increased fruit setting under 1200 mg/l IWSL (Table 6). Fruit yield of squash significantly increased with 21.51% in winter and 24.96% in spring. Increasing fruit setting means the amount of fruits that was formed from the flowers. Increasing fruit setting means increasing the amount of fruits/plant. The higher amount of fruits/plant increased squash yield.

The means of squash yield under the effect of interaction between salinity, pozzolan and sulphur presented in Table (7). The result of RLSD test at $p<0.05$ showed that the best combination of these three factors occurred on the 1200 mg/l IWSL, PP in the soil surface, and 6 ton/ha SD. This combination resulted the best fruit yield of squash. In the opposite side, the bad combination occurred on the highest IWSL, no pozzolan treatment, and the lowest SD.

No significant different occurred between no pozzolan treatment and pozzolan in 20 cm soil depth of the soil on 0 and 4 ton/ha SD and in all IWSL. It meant that pozzolan might be able to be useless if applied in 20 cm depth of the soil for producing squash fruit. Generally, placing pozzolan in the surface of the soil resulted the best pozzolan placement compared with the other pozzolan treatment.

Water Use Efficiency (WUE)

Effects of IWSL, PP, and SD treatments to WUE of squash crop presented in Table (5). The highest WUE resulted by the lowest IWSL combined with the PP in the soil surface and the highest SD in both winter and spring seasons. The opposite results occurred on the control treatment (1200 mg/l IWSL, no pozzolan treatment, and o ton/ha SD) which gave the lowest squash WUE in both season.

The best treatments of this experiment is (1200 mg/l IWSL, PP in the soil surface, and 6 ton/ha SD). This treatment increased WUE achieved 245.66 kg/mm/ha in winter and 219.36 kg/mm/ha in spring compared with the control. It meant that using these three treatments increased the WUE with a huge increasing. As we know that desert condition has not good environment to grow many crops, so these treatments might be solve many agricultural problems in the desert area.

Table 5. Means of squash WUE (kg/mm/ha) under the interaction effect of salinity, pozzolan and sulphur

Salinity (mg/l)	Pozzolan Placements	Winter Season (2012)						Spring Season (2013)					
		Sulphur (ton/ha)						Sulphur (ton/ha)					
		0		4		6		0		4		6	
1200	No Pozzolan	65.53	mn	108.72	h	171.31	de	58.70	lmno	103.33	fgh	138.94	de
	Surface	104.30	h	177.17	d	311.19	a	97.31	ghi	168.12	c	278.06	a
	10 cm Depth	91.89	ij	159.67	f	286.71	b	91.08	ghij	138.41	de	268.84	a
	20 cm Depth	61.40	n	97.73	hi	201.97	c	75.37	ijklm	83.18	hijkl	194.37	b
3000	No Pozzolan	38.90	opq	78.34	kl	124.82	g	28.69	pqr	80.28	hijklm	93.48	ghi
	Surface	74.83	klm	103.63	h	200.82	c	68.43	jklm	88.88	ghij	164.85	c
	10 cm Depth	72.00	klmn	104.86	h	194.30	c	59.74	lmno	90.39	ghij	150.05	cd
	20 cm Depth	47.61	op	77.75	kl	164.39	ef	40.76	opq	64.07	klmno	141.33	de
6000	No Pozzolan	16.29	r	43.01	opq	67.99	lmn	19.26	qr	61.55	lmno	61.28	lmno
	Surface	43.46	op	82.28	jk	175.32	de	55.91	mno	86.05	ghijk	170.44	c
	10 cm Depth	31.68	q	49.39	o	120.57	g	48.06	nop	46.14	nop	124.41	ef
	20 cm Depth	20.77	r	37.19	pq	105.26	h	15.49	r	42.02	opq	108.59	fg

** Means fallowed by the same letter of each trait under each factor are not significantly different according to LSD at P<0.05*

Discussion

The influence of salt stress caused the growth of many species of vegetables is decreased [7]. Using low IWSL automatically decreasing soil salinity if the salinity of the soil more than IWSL. Decreasing soil salinity is same with conducting a good condition for plant to get an adequate water and nutrient. Pozzolan placement treatment in the soil surface applied to increase the quality of the soil and providing an adequate water and nutrient for plant. In the other side, pozzolan as soil mulching also increased the ability of plant to uptake the nutrient and water [12]. In this good condition, sulphur added to regulate some useful enzyme for support plant growth [5]. Finally, the combination between these three treatments increasing the yield component of squash.

[10] explained that reducing IWSL increased the yield of some vegetable crops. Then applied pozzolan as soil mulch increased water holding capacity [6] and increasing soil moisture, then increased the yield of some vegetable crops [1].

Pozzolan as soil mulch or PP in the soil surface gave the higher squash WUE than the other pozzolan placements. It is caused by the PP in the soil surface played double functions as soil mulch and water holding capacity. Pozzolan as soil mulch played a role in decreasing the soil temperature [6]. Decreasing soil temperature might be influence many beneficial effects. In the low soil temperature, osmotic pressure of root zone decrease. Decreasing osmotic pressure in the root zone avoid the excess transpiration that caused by high soil temperature. Decreasing the rate of transpiration combined with increasing photosynthesis activity by sulphur treatment increased balancing activity. [3] and [11] explained that increasing balancing activity of the plant consequently increased the growth characteristics, yield, and WUE of vegetable crops.

Conclusion

Applied pozzolan in the soil surface and 6 ton/ha SD under 1200 mg/l IWSL increased plant height

(77.57 and 72.80%), number of leaves/plant (38.21 and 31.45 leaves), fruit setting (42.54 and 40.24%), fruit yield (23.17 and 20.53 ton/ha), and water use efficiency (294.90 and 258.79 kg/mm/ha) respectively in the winter and spring season compared with the control (no pozzolan, no sulphur and 6000 mg/l of irrigation water salinity levels.

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