 Egyptian J. Desert Res., **64**, 41-64 (2014)

RESPONSE OF POTATO (*SOLANUM TUBEROSUM*) PRODUCTIVITY TO SOIL AMENDEMENT AND WATER REQUIREMENTS

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An experiment was applied in DRC Experimental Station at East Elqantara in North Sinai to test the effect of water application rate of 40, 60, 80, 100 and 120% of ETc and bentonite as soil amendment at rate of 0, 2, 3, and 4 ton/fed on growth, yield, chemical composition, water use efficiency and investment ratio of potato plants. Result revealed that growth, tuber parameters and yield and its components were increased with increasing water and bentonite application. There were no significant differences between irrigation treatments of 100 and 120% of ETc or between 3 and 4 ton/fed bentonite in most studied parameters in both seasons. Also no significant effect was found on chemical components, except P, which was significantly increased with 100% of ETc in the second season. Moreover, the maximum WUE values were contributed to high bentonite treatments *i.e.*, 3 and 4 ton/fed combined with either 80 or 100% of Etc.

Significant positive correlations were found between total yield and either average tuber weight or number of tubers/plant. Also, between tuber number/plant and number of aerial stems/plant. Results of investment ratio and multiple regression of total yield on both amount of irrigation water and bentonite rate led to conclude that there were two options to get sufficient investment ratio.

Keywords: bentonite, irrigation, growth, yield, WUE, investment ratio

Population increase and water scarcity are the most important challenges for agricultural expansion in North Sinai, as most of these areas are sandy soil, which has low content of both clay and organic matter. This is responsible for low surface area and cations exchange capacity, which reduced its ability to retain water and nutrients as well.

Potato (*Solanum tuberosum* L.) is one of the *Solanaceae* species plants and considered as one of the most important vegetable crops in many regions of the world. Recent publications have shown the importance of potato as a global food crop. It is ranked as the fourth important crop after the three cereals including wheat, maize and rice. In Egypt, it is the second vegetable crop after tomato according to the cultivated area and one of the most important exported crops. Egypt is ranked as the 15^{th} one among the top potato producers and the 2^{nd} one among the African countries according to FAOSTAT (2012).

Water requirements for potato depend on several factors including; cultivar, plant population, water-holding capacity of the soil and climate. The measured values of crop-coefficient (Kc) for potato crop at four stages of growth, *i.e.*, initial, crop development, reproductive and maturity were 0.42, 0.85, 1.27 and 0.57, respectively (Doorenbos and Kassam, 1979). The Kc value at the maturity stage was found to be considerably higher than the recommended by FAO (Kashyap and Panda, 2001).

Onder et al. (2005) found that Water deficiency more than 33% of the irrigation requirement significantly affected the yield and yield parameters of early potato production. Potato is a shallow rooted, sensitive crop to water stress. Tuber quality parameters and irrigation requirement were based on soil water status or ETc., as water deficits reduced both tuber yield and quality, while excessive irrigation promoted potato diseases and reduced tuber yields and quality (Pereira and Shock, 2006).

Full irrigation requirements increased mean yield of fresh tubers from 11.8 to 24.7 t/ha in 1988 and from 13.6 to 49.8 t/ha in 1989 compared with dry treatments (Ferreira and Goncalves, 2007). Also, Ahmadi et al. (2012) showed that different soils affected irrigation water quantity, as loamy sand produced the highest yield under proper irrigation as compared with water-saved irrigations, which was not recommended due to considerable loss (28%) in yield. However, under restricted water resources, it was recommended to apply water-saving irrigation in sandy loam and coarse sand to achieve the highest yield productivity.

Karam et al. (2014) showed that potato plants subjected to irrigation deficit for two weeks at tuber bulking achieved marketable yield 12% lower than that obtained with well-irrigated control. Whereas, irrigation deficit at tuber ripening stage reduced tuber yield by 42% as compared with the control. However, yield reduction was compensated by an increase in tuber dry matter in the deficit-irrigated treatments.

Many soil conditioners such as polyvinyl polymer, bentonite, zeolite, perlite, vermiculite and wood coal can be used to improve soil proprieties (Brady, 1990). However, Bentonite application improved growth and yield of vegetable crops (Croker et al., 2004). Ding et al. (2009) reported that the special properties of bentonite were due to its ability to form thixotropic gels with water, which is the ability to absorb large quantities of water and negative charge on its surface, which led to a high cation exchange capacity.

Sittaphanit et al. (2010) found that variability in physical and chemical characteristics of the soil and morphological growth of the plant were due to bentonite amount mixed in the sandy soil. They reported, also, that bentonite was able to hold NH_4 in the soil solution of the top soil which, in turn, led to delaying NH_4 leaching to 15 day after fertilizer application in bentonite-amended sand soil. Similar trend was obtained by Reguieg et al. (2012) who indicated that NH_4 leaching was decreased by 38-43% with bentonite addition.

Jena and Kabi (2012) reported that it was possible to increase number and size of potato tubers by bentonite as a soil amendment throughout the growing period. They applied soil conditioners as zeolite and bentonite at the rate of 0, 1.5, 2.0 and 2.5 ton/fed. Their results revealed that soil chemical properties, i.e. EC, pH, soluble cations and anions and sodium adsorption ratio values were improved. Moreover, Hassan and Mahmoud (2013) showed that growth parameters of faba bean (*Vicia faba* L.) and corn (*Zea maize*) as well as their seed yields were increased with increasing the rate of applied conditioner. In the same respect, Shaheen et al. (2013) showed that application of bentonite as soil conditioner for sandy soil had a significant positive effect on all measured vegetative growth characteristics, tuber yield and chemical tuber quality of potato plants, except for protein and N contentes.

Therefore, it was suggested to study the response of potato growth and productivity to benonite as a soil amendment and the amount of irrigation water.

MATERIALS AND METHODS

Two field experiments were carried out at East El-Qantara Station of the Desert Research Center. It is located at altitude: 6 m, latitude: 30º 82` N and longitude: 32º 41` E at Ismailia Governorate during two consecutive seasons of 2012/2013 and 2013/2014. The experiments were conducted to study the response of potato plants cv. Sponta, grown in sandy soil, to benonite application and amount of irrigation water. Twenty treatments were used, which were the combination of five water quantities, *i.e.,* control

(100% Etc), 40, 60, 80 and 120% of Etc and four levels of bentonite as a soil conditioner, *i.e*. 0, 2, 3 and 4 ton/fed. The physical and chemical soil characteristics of the studied site recorded in table (1) were determined according to Page et al. (1982) and Klute (1986), respectively. The chemical analysis of irrigation water was carried out using the standard method of Page et al. (1982) and presented in table (2). In addition, bentonite mineral was supplied by Al Ahram company and its chemical analysis was given in table (3). Meteorological data of the studied area were collected for about 30 years from the Climatic Atlas of Egypt (1996) as shown in table (4). Experimental area is characterized by the Mediterranean climate, *i.e*., hot dry summer and relatively cold winter.

Organic manure was added at the rate of 30 m³/fed, while calcium super-phosphate (16% P_2O_5) at the rate of 400 kg/fed and assigned bentonite levels were added at the time of final land preparation. Nitrogen fertilizer was added as ammonium sulphate (20.5% N) at the rate of 300 kg/fed and potassium sulphate (48% K_2O) at the rate of 200 kg/fed. Nitrogen and potassium quantities were divided and applied all over the season within drip irrigation system starting after 30 days from planting.

Potato tubers of Sponta cultivar were sown 30 cm apart on one side of the ridge and irrigated with drip irrigation system. The ridges were 60 cm wide among drip irrigation lines. Each experimental plot consisted of 8 ridges with a net area of 15 m². Potato planting was carried out during the second week of October of both 2012/2013 and 2013/2014 seasons. All agricultural practices for potato crop production were followed according to the recommendation of Ministry of Agriculture.

As one of the main targets of this research was to detect the effect of water stress as applied for the upper part of pF curve, so the lower irrigation level was fixed at 30% of available soil moisture. Therefore, all plots were irrigated at 30% soil moisture depletion from available soil water. Soil moisture was measured with gravimetric method at depths of 0 -25, 25 - 50 and 50 - 75 cm. The values of soil moisture content were calculated. ETo was computed using Penman – Monteith equation (Allen et al.1998). Crop coefficients Kc of potato at different stages of growth recommended by Doorenbos and Pruitt (1977) were used to calculate ETc. The amounts of irrigation water (m³/fed) for both seasons were calculated using the equation of Doorenbos and Kassam (1979) as shown in table (5).

Table (1). Some physical and chemical properties of the experimental soil site.

Soil depth (cm)	Texture class	Bulk density (Mgm^{-3})	Moisture content (%)		Available soil water (%)	p		Soluble cations (me/l)			
			Field capacity	Wilting point		pH of soil paste	E.C. (dSm^{-1})	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
0 – 25	Sandy loam	1.40	11.79	2.08	9.71	8.01	3.31	6.00	11.40	14.80	0.90
25 – 50	Sandy loam	1.38	11.88	3.66	8.22	7.43	3.66	9.50	12.50	14.30	0.30
50 – 75	Sandy loam	1.42	11.75	3.62	8.13	7.60	3.54	6.50	14.50	14.10	0.30
Average	Sandy loam	1.42	11.81	3.12	8.69	7.68	3.50	7.33	12.80	14.40	0.50

pH: Acidity E.C.: Electrical conductivity me/l: milli equivalent per liter Mgm^{-3}: Mega gram per cubic meter

Table (2). Chemical analysis of the irrigation water.

Samples	pH	E.C. (dSm $^{-1}$)	S.A.R	Soluble cations (me/l)				Soluble anions (me/l)			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	$SO_4^{=}$	Cl^{-}
Initial	8.20	1.62	5.22	3.15	3.20	9.30	0.50	0.40	5.40	2.20	8.20
1st season	7.52	1.63	5.50	3.00	3.10	9.60	0.60	0.10	5.60	2.10	8.50
	8.26	1.58	5.20	3.10	3.15	9.20	0.30	0.30	3.50	3.00	9.00
2nd Season	8.10	1.65	5.52	3.25	3.05	9.80	0.40	0.50	3.81	3.69	8.50
	8.30	1.51	4.48	3.20	3.25	8.05	0.60	0.30	3.50	2.30	9.00
Average	8.08	1.60	5.18	3.14	3.15	9.19	0.48	0.32	4.36	2.66	8.64

pH: Acidity, E.C.: Electrical conductivity dSm-1: decimenz per meter S.A.R: Sodium adsorption ratio
me/l: mille equivalent per liter

Table (3). Chemical analysis of bentonite.

Item	SiO_2	TiO_2	Al_2O_2	Fe_2O_3	MgO	SO_2	MnO	P_2O_5	CaO	Na_2O	K_2O	L.O.I
%	52.46	1.39	20.93	7.70	1.14	0.27	0.10	0.23	2.81	0.08	1.65	11.05

Table (4). Meteorological data for about 30 years (1961-1990) of East El-Qantara region.

Elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Avg.
Max. Temperature (°C)	18.5	20.0	22.50	25.0	30.0	32.5	33.5	33.5	31.5	28.5	25.0	20.0	26.7
Min. Temperature (°C)	7.50	8.50	10.00	12.5	16.5	18.5	21.5	22.5	20.0	18.5	12.5	10.0	14.8
Relative Humidity (%)	70.0	67.0	65.00	60.0	60.0	60.0	70.0	70.0	65.0	65.0	65.0	68.0	65.4
Wind speed (km/hour)	13.9	13.1	18.54	16.0	14.6	14.9	8.05	8.11	7.82	8.76	11.9	15.0	12.5
Sunshine hours (hour)	7.52	8.32	8.87	9.69	11.18	12.22	12.41	11.64	10.6	9.53	8.24	7.62	9.83
Rainfall (mm)	10.00	10.00	7.50	5.00	1.00	0.00	0.00	0.00	0.00	2.00	7.50	10.00	53.0*
ETo (mm/day)	2.71	3.28	4.63	5.60	6.80	7.68	6.50	6.15	5.34	4.22	3.68	2.94	4.96

* Total
Avg.: Average
ETo = Potential evapotranspiration

Table (5). The amount of irrigation water (m^3/fed) for the growing seasons of 2012/2013 and 2013/2014.

Month	Amount of irrigation water (m^3/day)				
	Nov.	**Dec.**	**Jan.**	**Feb.**	**m^3/fed/season**
Q1 Control (100% Etc)	10.23	13.91	17.3	13.66	1656.82
Q2 (40 % ETc)	4.098	5.592	6.92	5.464	662.72
Q3 (60 % ETc)	6.14	8.35	10.38	8.20	994.09
Q4 (80 % ETc)	8.18	11.13	13.84	10.93	1325.46
Q5 (120%ETc)	12.28	16.69	20.76	16.39	1988.18

1. Sampling for Growth Parameters

After 60 days from full sprouting, three plants from each experimental unit were randomly taken for recording vegetative growth characteristics, *i.e.*, plant height, number of leaves/plant, number of aerial stems/plant, percentage of dry matter of the aerial vegetative parts.

2. Sampling for Tubers Parameters and Yield

At harvesting stage (110 days from planting date), a sample of 20 plant tubers were randomly taken from each experimental plot for recording tuber characteristics, *i.e.*, tubers number/plant, average of tuber volume and fresh weight and percentage of tuber dry matter. In addition, total tuber yield (ton/fed) and percentage of marketable tubers and yield were calculated.

3. Sampling for Tubers Chemical Component

Three samples of tubers from each experimental unit were taken and oven dried at 70ºC until stable weight, then ground to fine particles and used to determine chemical tuber quality, such as mineral contents; N, P and K. Phosphorus was determined using the colorimetric method for phosphorus content using spectrophotometer according to Cottenie et al. (1982). Total nitrogen was determined using the modified micro Kjeldah method. Potassium percentage was measured using flame photometer method as described by Brown and Lilliland (1964). Total carbohydrate contents were determined according to A.O.A.C. (1990).

4. Water Use Efficiency and Investment Ratio

Crop water use efficiency (WUE) was calculated by dividing the economic yield by the amount of seasonal evapotranspiration according to Molden (2003). Investment Ratio (IR) = (total revenue, LE / total cost, LE) following Rana et al. (1996).

Experimental Design and Statistical Analysis

The experimental treatments were arranged in a split plot design with three replicates. Main plots were assigned for irrigation treatments, whereas, bentonite rates were randomly arranged in the sub plots. Obtained data were subjected to statistical analysis at the level of 5% significance according to Sndecor and Cochran (1989).

RESULTS AND DISCUSSION

1. Plant Growth Parameters

Growth parameters, *i.e*., plant height, number of leaves and aerial stems/plant and shoot dry matter percent were presented in table (6). Obtained results indicated significant positive effect for increasing both irrigation water and bentonite on all investigated growth parameters except dry matter (%) of shoot. From the data the following remarks could be outlined:

a. The highest values in plant height, number of leaves and aerial stems/plant were recorded with 120% ETc in the first season, while 100% ETc gave the highest values in the second season. No significant differences were found between 100 and 120% of ETc. Also, shoot dry matter percent was decreased with increasing amount of irrigation water. Exceptional cases were noticed with 120% of Etc with all bentonite rates, which gave higher dry matter values than 100% Etc.
b. The highest values of plant height and number of leaves and aerial stems/plant were recorded with 4 ton bentonite /fed, followed by 3 ton/fed; no significant differences were found between 3 and 4 ton/fed. Also the highest values of shoot dry matter percent were recorded with control treatment in both seasons.
c. Obviously, the interaction of both combined treatments yielded greater values than individual could gave. Such result was clear with plant height and dry matter (%) in the first season and with number of leaves/plant in the second season.

Potato is relatively sensitive to soil water stress, therefore to optimize yield, the total available soil water should not be depleted more than 30 to 50% (Onder et al., 2005 and Pereira and Shock, 2006). It was achieved in the experiments by fixing the lower misuse level at 30% of available water. But, the irrigation treatments; i.e., 40, 60 and 80% of Etc didn’t reach to the maximum available range, so put plants under graded stress being 40, 60, 80% of Etc; obviously, the other two treatments; *i.e*., 100 and 120% of Etc reached the maximum available level in the first season and exceeded that in the second season being in surplus moisture.

Table (6). Effect of amount of irrigation water and bentonite rate on potato growth characters, plant height, number of leaves/plant, number of aerial stems/plant and shoot dry matter (%) during 2012/2013 and 2013/2014 growing seasons.

Plant character	Plant height (cm)					No. of leaves/plant					No. of aerial stems/plant					Shoot dry matter (%)				
Season	2102/2013																			
Bentonite (ton/fed) water amount (% of ETc)	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	26.4	28.6	32.2	33.5	30.18	15.6	16.1	19.3	21.2	18.0	5.2	6.7	6.6	7.5	6.5	17.7	15.2	15.7	14.7	15.8
60	32.6	33.9	36.4	35.9	34.71	23.0	25.7	22.7	23.3	23.7	10.0	10.3	9.7	10.0	10.0	12.5	12.8	12.3	12.5	12.5
80	33.4	39.9	41.8	42.4	39.36	24.0	27.3	24.7	29.7	26.4	10.7	12.3	12.0	13.3	12.1	11.6	11.0	11.6	11.2	11.3
100	41.4	42.2	40.7	46.0	42.58	28.3	32.8	33.9	35.5	32.6	12.0	13.3	14.3	13.3	13.3	10.7	9.9	10.4	10.0	10.3
120	42.0	44.4	45.5	46.8	44.68	36.7	36.9	39.7	39.7	38.2	14.3	15.6	15.2	17.5	15.6	11.3	11.0	10.4	10.1	10.7
X	35.15	37.79	39.31	40.94		25.5	27.8	28.0	29.9		10.43	11.67	11.55	12.33		12.7	12.0	12.1	11.7	
Season	2013/2014																			
	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	27.8	27.4	31.0	31.8	29.49	17.2	16.1	18.4	20.2	18.0	5.9	7.4	8.5	8.8	7.63	17.7	16.8	15.9	16.0	16.6
60	32.1	34.7	37.2	35.8	34.95	21.5	26.6	30.5	31.0	27.4	10.0	11.8	12.7	14.5	12.24	12.5	13.0	11.9	12.3	12.4
80	37.3	42.5	43.9	43.2	41.73	27.6	32.0	30.2	34.9	31.2	14.2	14.6	14.0	16.0	14.68	11.6	11.3	11.2	10.8	11.2
100	40.1	42.2	44.7	46.7	43.43	32.5	32.9	37.1	34.3	34.2	14.8	14.6	17.1	17.8	16.08	10.3	9.5	9.9	9.8	9.9
120	41.5	44.2	44.3	47.5	44.37	33.4	33.0	35.1	33.5	33.7	14.1	14.1	17.0	18.0	15.79	10.9	10.9	10.4	9.8	10.5
X	35.76	38.18	40.23	41.01		26.4	28.1	30.3	30.8		11.79	12.49	13.86	15.00		12.6	12.3	11.9	11.8	
LSD at 0.05		1st season		2nd season			1st season		2nd season			1st season		2st season			1st season		2nd season	
Water		2.961		1.986			3.034		3.234			0.767		1.58			0.899		0.673	
Bentonite		1.053		1.099			1.612		1.597			0.710		0.712			0.925		NS	
Wat. X Ben.		2.35		NS			NS		2.062			NS		NS			0.549		NS	

Bentonite, which is clay deposits, as a conditioner affect mainly the physical properties of sandy soil especially moisture storage. Increasing the amount of bentonite obviously increased water storage and declined water loss either, through evapotranspiration or deep percolation so maintained good soil moisture especially for such potato plant which is sensitive to water stress.

Potato is a shallow rooted, sensitive crop to water stress, so growth parameters were based on soil water status as water deficits reduce both growth and yield. Obtained results were in agreement with those obtained by Onder et al. (2005) and Pereira and Shock (2006). The important role of bentonite as soil conditioner was to improve water holding capacity and high cation exchange capacity, which could interpret its effect on improving growth parameters (Ding et al., 2009). In addition, the positive effect of bentonite on plant growth may be due to its positive effect on water holding capacity (Iskander et al. 2011), decreasing leaching of different nutrients through its higher colloid content (Sitthaphanit et al., 2010), stimulating the merestimatic activity for producing more tissues and organs (Marisa et al., 2009) and its vital contribution in several biochemical processes that are related to plant growth (Marschner, 1995).

2. Potato Tuber Traits

Table (7) displayed data of number of tubers/plant, average of tuber fresh weight, volume and tuber dry matter (%), which indicated, in general, increasing all tuber parameters as affected by the two investigated factors, *i.e*., amount of irrigation water and bentonite. However, from the data it could indicated that;

a. It was clear from the data that tubers number/plant, average tuber fresh weight and volume depended ultimately on both water support (indicated by amount of irrigation water and water storage indicated by rate of bentonite), both factors seemed to play equal roles in maintaining good conditions to produce healthy and heavy tubers of plants; both seasons showed the same results.

Table (7). Effect of amount of irrigation water and bentonite rate on number of potato tubers /plant, tuber volume and fresh weight and tuber dry matter per cent during 2012/2013 and 2013/2014 growing seasons.

Character	tubers number/plant					Tubers volume (cm³)					Tuber fresh weight (g)					Tuber dry matter(%)				
Season	2012/2013																			
Bentonite (ton/fed) Water (% ETc)	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	4.7	5.0	4.7	5.7	5.0	40.6	43.9	52.6	60.1	49.3	42.5	49.8	60.5	59.9	53.2	20.1	17.3	17.3	21.1	19.0
60	4.7	4.7	5.8	6.3	5.2	58.6	72.4	88.3	85.8	76.3	68.1	81.8	98.3	95.7	86.0	19.8	17.6	15.8	14.7	16.8
80	7.0	7.3	7.8	7.0	7.1	81.8	80.4	94.1	96.9	88.3	88.2	85.7	127.5	127.4	107.2	17.5	20.5	17.7	18.8	18.6
100	7.7	8.0	8.3	7.8	8.0	86.1	82.7	105.4	107.6	95.5	95.3	95.7	134.5	119.2	110.7	18.6	18.6	20.1	16.2	18.4
120	5.7	7.3	8.3	8.3	7.4	86.4	92.6	97.1	95.1	92.8	92.5	102.6	104.2	101.6	100.2	16.7	14.3	16.2	15.5	15.7
X	5.9	6.5	6.7	7.0		70.7	74.4	87.5	89.1		76.9	83.1	102.0	100.7		18.4	17.6	17.4	17.3	
	2013/2014																			
	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	4.3	4.7	4.3	5.7	4.8	41.8	39.2	48.6	47.0	44.2	46.4	43.8	53.2	51.6	48.8	20.9	19.2	18.9	18.0	19.3
60	4.3	5.0	5.8	5.0	4.8	60.1	72.9	70.2	74.5	69.4	68.0	80.8	78.1	82.4	77.3	20.8	19.3	18.7	18.9	19.5
80	4.3	5.3	6.3	7.0	5.8	90.4	106.4	100.3	101.4	99.6	96.0	112.0	121.5	121.4	112.7	19.0	19.3	17.1	18.8	18.5
100	6.0	5.7	6.7	7.7	6.5	75.2	96.8	115.6	110.2	99.4	89.7	116.0	136.3	117.1	114.8	18.1	18.5	17.5	17.4	17.9
120	7.0	5.7	7.7	7.3	6.9	86.3	90.6	92.9	88.7	89.6	95.0	97.3	99.6	95.4	96.3	15.4	16.4	15.6	16.0	15.9
X	5.2	5.3	6.0	6.5		70.7	81.2	85.5	94.4		78.6	90.0	97.7	93.6		18.8	18.6	17.6	17.8	
L.S.D at 0.05		1st season		2nd season			1st season		2nd season			1st season		2nd season			1st season			2nd season
Water		0.693		0.782			12.12		11.28			9.283		8.569			2.07			1.299
Bentonite		0.694		0.451			7.40		10.47			9.204		10.53			NS			NS
Wat. X Ben.		NS		0.582			NS		NS			NS		NS			2.95			NS

b. The above mentioned results were true up to 100% of Etc as above that level (120% of Etc), the tuber parameters values were declined indicating negative effect of excessive available moisture on tubers turgidity, such decrement of tuber parameters may be interpreted in the light of bad soil ventilation in case of high amount of applied water and decreasing depth of root penetration with frequently applied water (Bhella, 1985). Also Data displayed classic relation of moisture effect on diluting potato tuber sap, so the dry matter (%) values were decreased with increasing water application up to 100% of Etc then declined. This could be explained by sensitivity of tuber tissues to wetness. Such results were in the same line with those obtained by Ferreira and Goncalves (2007) and Pereira and Shock (2006) who indicated that excessive irrigation promoted potato diseases and reduced tuber yields and quality.
c. All tuber parameters significantly surpassed with increasing application of bentonite. But no significant differences were found between 3 and 4 ton/fed bentonite treatments. The positive effect of bentonite on tuber parameters may be due to its positive effect on water holding capacity (Iskander et al., 2011), decreasing leaching of different nutrients through its higher colloid content (Sitthaphanit et al., 2010). Those results were in agreement with those recorded by Shaheen et al. (2013). Also, bentonite had no different effect on dry matter (%) as it mainly played as physical conditioner not nutritional one according to Brady (1990).
d. The interaction between water depletion levels and bentonite rate, obtained results showed no significant effect in both seasons except application of either 4 ton bentonite/fed combined with 100% ETc or addition 3 ton bentonite/fed combined with 120% ETc, which showed the highest number of tubers/plant in the second season. Also treatment of 40% ETc combined either with 4 ton/fed or with control treatment (zero bentonite) showed the highest tuber dry matter percent in the first season.

3. Yield Quantity

Results concerned with total yield, marketable yield weight and percentage of marketable yield for all treatments were presented in table (8). From the data, the following could be concluded:

a. It was clear that total yield and marketable yield weight or its percentage were significantly increased with increasing water application up to 100% of ETc as above that level (120% of Etc) the yield parameters values declined indicating negative effect of excess

Table (8). Effect of amount of irrigation water and bentonite rate on weight of tubers/plant, tubers yield (ton/fed), marketable tubers (%) and marketable yield weight during 2012/2013 and 2013/2014 growing seasons.

Season	2012/2013																			
Characters	Tuber weight/plant (g)					Tubers yield ton/fed					Marketable tubers (%)					Marketable yield weight ton/fed				
Bentonite (ton/fed) Water (% of ETc)	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	199.4	241.4	278.8	342.0	265.4	2.39	2.91	3.46	4.29	3.26	36.7	46.7	41.7	34.3	39.8	0.85	1.36	1.41	1.52	1.28
60	321.0	379.3	487.0	607.5	448.7	4.02	4.83	6.31	8.00	5.79	43.3	50.0	43.9	52.2	47.4	1.71	2.38	2.88	4.17	2.78
80	622.2	629.9	899.3	891.5	760.7	8.08	8.26	11.76	12.01	10.03	72.4	63.1	62.1	71.4	67.3	5.72	5.29	7.32	8.29	6.65
100	710.7	770.5	1123.9	932.8	884.5	9.63	10.48	15.53	12.75	12.10	67.1	67.5	68.1	68.7	67.8	6.32	6.79	10.50	8.68	8.08
120	522.7	753.6	868.3	847.6	748.0	7.14	10.10	11.86	11.58	10.17	71.1	76.8	76.4	76.7	75.3	5.05	7.82	9.03	8.80	7.68
X	475.2	554.9	731.4	724.3		6.25	7.32	9.78	9.73		72.7	60.8	58.4	60.7		3.93	4.73	6.23	6.29	
Season	2013/2014																			
	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X	Cont.	2	3	4	X
40	199.4	204.4	228.2	295.0	231.7	2.37	2.48	2.87	3.66	2.84	38.3	35.0	30.0	35.6	34.7	0.94	0.89	0.86	1.28	0.99
60	297.4	401.8	392.1	412.0	375.8	3.86	5.25	5.16	5.47	4.94	38.3	46.7	55.0	53.3	48.3	1.49	2.45	2.75	2.87	2.39
80	417.2	591.6	774.3	858.3	660.4	5.58	8.01	10.58	11.70	8.97	55.0	62.2	63.5	66.9	61.9	2.93	4.98	6.64	7.75	5.57
100	537.8	664.7	900.5	906.8	752.5	7.35	9.16	12.34	12.52	10.34	67.1	82.2	75.4	82.7	76.9	4.91	7.56	9.34	10.30	8.03
120	644.4	549.5	764.2	699.5	664.4	8.63	7.51	10.31	9.50	8.99	67.7	82.2	83.1	73.2	76.5	5.74	6.18	8.52	6.91	6.84
X	419.3	482.4	611.9	634.3		5.56	6.48	8.25	8.57		53.3	61.7	61.4	62.3		3.20	4.41	5.62	5.82	
L.C.D at 0.05		1st season		2nd season			1st season		2nd season			1st season		2nd season			1st season		2nd season	
Water		112.9		96.39			1.506		1.325			12.69		7.98			1.145		0.851	
Bentonite		101.1		83.85			1.340		1.135			NS		NS			0.789		0.760	
Wat. X Ben.		NS		NS			NS		NS			NS		NS			NS		NS	

available moisture on yield and quality. Results were in the same line with those obtained by Pereira and Shock (2006).

b. Bentonite application up to 3 ton/fed improved the yield and marketable yield weight progressively with the same water application, which indicated better water use efficiency. However, bentonite at rate of 4 ton/fed declined yield as compared with 3 ton/fed in the first season probably due to more wetness or hardness of soil than that suitable for potato growth.

The question, that is of a great importance is how far the different investigated parameters are correlated with each other. It can be seen from Fig. (1) that number of tubers/plant was significantly correlated with number of aerial stems/plant. Correlation coefficients (r) were 0.803 and 0.767 in the first and second seasons, respectively. Corresponding coefficients of determination (r^2) were 0.644 and 0.588, indicating that 64.4 to 58.8% of the variation in number of tubers/plant was related to the number of aerial stems/plant. On the other hand, the regression coefficients (b) were 0.335 and 0.254 in the first and second seasons, respectively. This indicated that for each increase of one aerial stem/plant, number of tubers/plant correspondingly increased by 0.335 and 0.254 tuber. Similarly, highly significant positive correlations existed between total yield (ton/fed) and either average tuber weight or number of tubers/plant (Fig. 1). A linear regression showed that for each increase of one gram of tuber weight, total yield correspondingly increased by 0.137 and 0.115 ton/fed in the first and second seasons, respectively. Also, for each increase of one tuber per plant, total yield correspondingly increased by 2.491 and 2.464 ton/fed in the first and second seasons, respectively.

4. Chemical Composition

Data recorded in table (9) represented the studied chemical constituents of potato tubers. Results showed no significant effect of the studied factors, except phosphorus content, which was significantly increased with100% of ETc in the second season.

Also the interaction between the two studied factors showed that the highest values of K (%) was achieved by 100% of ETc combined with bentonite either at rate of 4 ton/fed or control treatment (zero bentonite). These results were in disagreement with those reported by Jena and Kabi (2012) who found that 60 kg bentonite/ha significantly increase uptake of N, P and K. Contradiction may be due to using different rates of bentonite.

5. Water Use Efficiency

Water use efficiency as the value of productive capacity of the unit of irrigation water amount could be expressed in two forms: either kg of economic yield/ unit of consumed water (m^3) or as amount of consumed water (m^3) /kg of economic yield; both are important. From previous work under similar location and conditions, Seidhom and Rizik (2006) studied the beneficial rate (BR) from application of irrigation water. Data presented in table 10 showed the actual consumption use for the applied water that meets in this experiment.

Table (11) gave the non marketable yields as ton/fed, so the WUE shown in the foot of the table as kg of gross yield (both marketable and non-marketable yields) per one m^3 of actual consumed water. From the table it can be concluded the following:

a. The maximum WUE values were contributed with high bentonite treatments; *i.e.*, 3 and 4 ton/fed combined with either 80 or 100% of Etc that means high revenue of yield can be got from unit of applied water.
b. Shortage in irrigation water from 100 to 80% of Etc could be compensated with increasing bentonite application from 3 to 4 ton/fed.
c. The surplus of irrigation water from 100 to 120% of Etc damped greatly the WUE values, which mean more water was used without sensible yield as gain.
d. For high rates of bentonite; *i.e.*, 3 and 4 ton/fed, WUE was improved by means of increasing the productivity of water unit from the crop yield.

6. Investment Ratio (IR)

The final goal of any agricultural application is to get profitable yield as gain from the invested cost. The agricultural process is mainly economic, so the net gain of each pound from the input is important to get the highest rate of revenue. Table (12 and 13) showed the calculation of input for all treatments, while table (14) gave the total output for all treatments. Also, in the same table the IR values ranged from 0.24 as minimum and 2.01 as maximum. The highest values were obtained with 100% of Etc combined with either 3 or 4 ton bentonite/fed and 120% of Etc combined with 3 ton bentonite/fed.

In this respect, multiple regression of potato yield (ton/fed) on the amount of irrigation water (m^3/fed) and rate of bentonite (ton/fed) revealed the following equations:

$\hat{Y} = -1.963 + 0.006\,X1 + 0.967\,X2$ in the first season

$\hat{Y} = -1.684 + 0.0053\,X1 + 0.8071\,X2$ in the second season

Where Y^ is the dependent estimated yield, which lie on the regression line and X1 and X2 are the independent variables, i.e., amount of irrigation water and rate of bentonite, respectively.

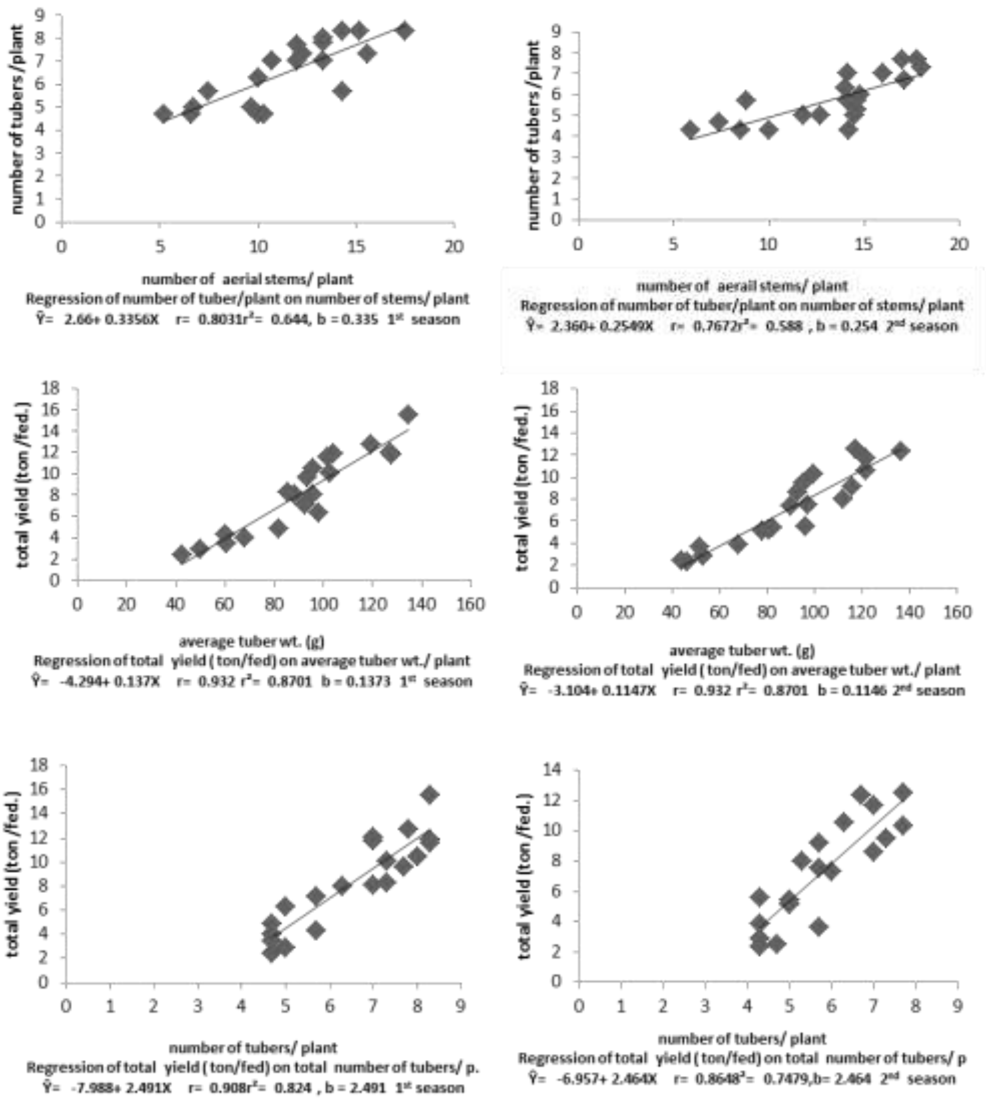

Fig. (1). Linear regression; correlation coefficients (r), coefficients of determination (r²) and regression coefficients (b) of total yield (ton/fed) on number and average weight of tuber (g)/plant, and regression of number of tubers/plant on numver of aerial stems/plant.

Table (9). Effect of amount of irrigation water and bentonite rate on K, P, N (%) and total carbohydrates (ppm) during 2012/2013 and 2013/2014 growing seasons.

Season	2012/2013																			
Characters	**K (%)**					**P (%)**					**N (%)**					**Total carbohydrates**				
Bentonite (ton/fed) Water (% ETc)	**Cont.**	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**
40	1.38	1.50	1.30	1.55	1.43	0.60	0.50	0.53	0.60	0.55	1.4	1.4	1.4	1.5	1.39	75.8	80.0	72.1	79.9	76.95
60	1.68	1.47	1.58	1.68	1.60	0.47	0.61	0.63	0.51	0.55	1.6	1.2	1.5	1.4	1.44	69.9	53.4	61.2	67.7	63.06
80	1.65	1.63	1.83	1.60	1.68	0.84	0.65	0.61	0.58	0.67	1.5	1.4	1.4	1.6	1.50	58.6	62.8	68.2	63.2	63.20
100	1.43	1.88	1.85	1.83	1.75	0.58	0.70	0.71	0.65	0.66	1.9	1.4	1.4	1.4	1.49	61.4	68.4	57.4	61.2	62.11
120	1.58	1.58	1.60	1.82	1.65	0.55	0.60	0.45	0.45	0.53	1.6	1.8	1.3	1.4	1.51	73.0	61.4	71.7	56.1	65.57
X	1.55	1.61	1.63	1.70		0.56	0.57	0.64	0.59		1.59	1.42	1.39	1.46		67.7	65.2	66.1	65.6	
Season	**2013/2014**																			
	Cont.	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**	**Cont.**	**2**	**3**	**4**	**X**
40	1.40	1.40	1.40	1.43	1.41	0.55	0.54	0.61	0.56	0.56	1.6	1.9	1.3	1.2	1.50	75.8	79.0	63.6	81.5	75.0
60	1.47	1.45	1.40	1.53	1.46	0.51	0.43	0.68	0.40	0.50	1.2	1.0	1.7	1.9	1.46	68.2	51.3	56.6	67.8	61.0
80	1.52	1.50	1.75	1.50	1.57	0.63	0.55	0.56	0.68	0.60	1.2	1.5	1.5	1.5	1.42	55.7	59.8	63.2	57.5	59.0
100	1.32	1.72	1.63	1.77	1.61	0.60	0.79	0.78	0.83	0.75	2.3	1.8	1.5	1.5	1.77	65.6	55.8	69.3	63.0	63.4
120	1.45	1.48	1.53	1.75	1.55	0.52	0.54	0.56	0.51	0.51	1.3	1.2	1.3	1.4	1.28	64.1	60.6	58.2	55.5	59.6
X	1.43	1.51	1.54	1.61		0.61	0.61	0.59	0.56		1.53	1.47	1.48	1.47		65.9	61.3	62.2	65.1	
L.C.D at 0.05	1st season			2nd season		1st season			2nd season		1st season			2nd season		1st season			2nd season	
Water	NS			NS		NS			0.14		NS			NS		NS			NS	
Bentonite	NS			NS		NS			NS		NS			NS		NS			NS	
Wat. X Ben.	NS			0.149		NS			NS		0.301			0.178		NS			NS	

Table (10). Calculated actual evapotranspiration for the applied treatments.

Moisture treatment (% of ETc)	**Applied irrigation M3/ fed/season**	**Beneficial rate %**	**Actual evapotranspiration m3/fed/season**
40	663	94	626
60	995	83	831
80	1326	72	954
100	1657	60	1004
120	1988	50	994

Table (11). Water use efficiency (WUE) as gross yield /one m³ water of Eta.

Season	**1st**				**2nd**			
	Non marketable yield (kg/fed.)							
Bentonite (ton/fed) Water (% ETc)	**Cont.**	**2**	**3**	**4**	**Cont.**	**2**	**3**	**4**
40	1543.1	1543.1	2052.0	2776.7	1425.1	1594.9	2005.5	2378.7
60	2316.5	2452.0	3432.4	3835.8	2367.4	2802.2	2409.6	2596.9
80	2355.3	2975.9	4438.0	3715.6	2655.8	3032.9	3942.2	3958.7
100	3307.6	3690.9	5030.7	4063.3	2439.9	1598.0	3004.4	2219.0
120	2087.9	2278.6	2838.5	2777.9	2881.1	1329.5	1796.3	2590.2

	Water use efficiency (kg tubers/m³)							
Bentonite (ton/fed) Water (% ETc)	**Cont.**	**2**	**3**	**4**	**Cont.**	**2**	**3**	**4**
40	3.61	4.39	5.22	6.48	3.58	3.74	4.32	5.52
60	4.05	4.86	6.35	8.05	3.88	5.29	5.19	5.50
80	6.09	6.23	8.87	9.06	4.21	6.04	7.98	8.83
100	5.81	6.33	9.37	7.69	4.44	5.53	7.45	7.56
120	3.59	5.08	5.97	5.83	4.34	3.78	5.19	4.78

Table (12). Fixed and variable input and output for potato production (LE/fed).

Items	Unit	Counts	Unit cost	Total LE
Fixed cost/fed				
Land preparation	hour	4	50	200
Organic fertilizer	M3	30	100	3000
Chemical fertilizer				1700
Tuber seeds	kg	750	3	2250
Labor cost	Worker/day			
1- Fertilizer add		5	60	300
2- Planting seeds		4	60	240
3- Seasonal labor		15	60	900
4- Harvest labor		4	60	240
Pesticides	Liter	7	100	700
Foliar fertilizer	Liter	3	100	300
Total				9830
Variable cost				
Bentonite cost/ ton	Ton	1	350	
Water cost/ m³	m³	1	0.5	
Output				
1- Marketable yield	kg	1	2	
2- Non marketable	kg	1	0.5	

Table (13). Gross input of potato (LE/fed).

Water application cost			**Bentonite application cost LE/fed**				
Water treatment (% ETc)	**Amount of added water**	**Cost LE/fed**	**0 ton**	**2 ton**	**3 ton**	**4 ton**	**Fixed cost LE/fed**
			0	**700**	**1050**	**1400**	
40	662.72	331.36	10161.4	10861.4	11211.4	11561.4	
60	994.09	497.045	10327.0	11027.0	11377.0	11727.0	
80	1325.46	662.73	10492.7	11192.7	11542.7	11892.7	9380
100	1656.82	828.41	10658.4	11358.4	11708.4	12058.4	
120	1988.18	994.09	10824.1	11524.1	11874.1	12224.1	

Table (14). Total output investment ratio (IR) for water and bentonite treatments.

Season	1st				2nd			
	Total output (LE/fed)							
Bentonite (ton/fed) Water (% ETc)	Cont.	2	3	4	Cont.	2	3	4
40	2464.5	3497.4	3838.4	4423.7	2602.4	2570.4	2722.4	3749.5
60	4569.1	5985.7	7477.4	10252.7	4168.1	6305.5	6706.6	7040.8
80	12617.8	12061.7	16860.6	18439.3	7184.8	11468.9	15247.8	17469.8
100	14302.3	15433.5	23515.0	19395.5	11038.0	15915.9	20178.9	21706.4
120	11151.6	16776.5	19470.3	18995.5	12928.5	13023.4	17932.8	15112.3
	Investment ratio (LE input/ LE output)							
	Cont.	2	3	4	Cont.	2	3	4
40	0.24	0.32	0.34	0.38	0.26	0.24	0.24	0.32
60	0.44	0.54	0.66	0.87	0.40	0.57	0.59	0.60
80	1.20	1.08	1.46	1.54	0.68	1.02	1.32	1.47
100	1.34	1.36	2.01	1.60	1.04	1.40	1.72	1.80
120	1.03	1.46	1.64	1.54	1.19	1.13	1.51	1.24

The meaning of this is the total yield of potato was increased by 0.006 and 0.0053 ton/fed for each one cubic meter water/fed in the first and second season, respectively, and by 0.967 and 0.807 ton/fed for each one ton bentonite/fed. If we took in consideration that the cost of one ton bentonite was equal to 700 m³ of water, increases in yield due to 700 m³ of water would be 4.2 and 3.71 ton/fed in the first and second seasons, respectively, which indicated that yield increased due to that the amount of water was higher than that due to bentonite at equal cost. Therefore, there are two options to get sufficient investment ratio:

a- When there is shortage in irrigation water, like 80% of ETc it can be recommended that it combined with high rates of benonite to enhance moisture storage in soil for the two seasons.

b- When there is a shortage in bentonite support, it is urgent to increase the water application up to even 120% of Etc.

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إستجابة إنتاجية البطاطس لمحسن التربة والإحتياجات المائية

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إجريت تجربة حقلية في محطة بحوث شرق القنطرة والتابعة لمركز بحوث الصحراء لإختبار تأثير إضافة معدلات مياة ري بنسبة ٤٠، ٦٠، ٨٠، ١٠٠ و١٢٠٪ من ETc ومعدلات البنتونيت بمعدل ٢ ، ٣ و ٤ طن/فدان بالإضافة الى معاملة الكنترول بدون إضافة على كل من النمو والمحصول والتركيب الكيميائي لنباتات البطاطس .

وأظهرت النتائج أن النمو الخضري والمحصول ومكوناته أظهرت زيادة مع زيادة كل من مياة الري ومعدلات البنتونيت المضافة. ولم يظهر إختلافات معنوية بين كلًا من معدلات المياه ١٠٠ أو ١٢٠٪ أو ٣ أو٤ طن بنتونيت /فدان فى كلا الموسمين. كذلك أظهرت النتائج عدم وجود فرق معنوي فى التركيب الكيميائي بإستثناء الفسفور الذى زاد معنويًا مع معدل مياة ١٠٠٪ في الموسم الثاني. بالإضافة إلى أن كفاءة إستخدام المياه حققت أعلى القيم في معاملات البنتونيت ٣ و٤ طن/فدان مع ٨٠ أو ١٠٠٪ من معدلات المياة. كما أظهرت النتائج وجود إرتباط معنوي بين المحصول الكلى وكلًا من متوسط وزن الدرنة أو عدد الدرنات على النبات، كذلك بين عدد الدرنات على النبات وعدد الأفرع على النبات. كما أظهرت النتائج لمعامل الإستثمار والإنحدار المتعدد بين كمية مياة الري المضافة ومعدلات البنتونيت أن هناك إختيارين لتحقيق معامل إستثمار مرضي.