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Original Article

Water use efficiency of potato (*Solanum tuberosum* L.) under different irrigation methods and potassium fertilizer rates

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Abstract This study was conducted to determine the effect of different irrigation methods and potassium fertilizers on potato yield in the Abu–Graib–Baghdad, Iraq Region, during season 2011–2012. Potato was grown under furrow and drip irrigation methods and three potassium fertilizers rates applied with 0.0, 300 and 600 kg K_2SO_4 ha^{-1}. The obtained results indicated that, actual potato evapotranspiration ranged from 357.3 to 511.4 mm in the growth season for all treatments. Furrow and drip irrigation methods had no significant effect on tuber yield under the experiential conditions. Potassium fertilizer influenced the tuber yield ($P < 0.05$), and the highest tuber yield was registered for 600 kg K_2SO_4 ha^{-1}, reaching 35.23 T ha^{-1}and 36.65 T ha^{-1}for furrow and drip irrigation, respectively. Water use efficiency increased from 5.129 to 7.379 kg m^{-3} for furrow-irrigated treatments, and from 6.907 to 10.257 kg m^{-3} for drip-irrigated treatments using the above mentioned rate of K-fertilizer.

Introduction

Water is the most important compounds in an active plant and constitutes more than 80% of the growing tissue. Because it is essential for most plant functions, the amount of water applied during irrigation, the time and method of water application, the quality of the irrigation water, and prevailing micro-meteorological conditions are important in plant health and yield. In Asia, yields from most crops have increased 100–400% after irrigation (FAO, 1996). Irrigation allows farmers to apply water at the most beneficial times for the crop, instead of being subject to the erratic timing of rainfall. Water for irrigation is becoming both scarce and expensive and necessitates to be utilized in a scientific manner. Drip irrigation has proved to be a success in terms of water and increased yield in a wide range of crops (Bhardwaj, 2001). Based on that, water resources are limited for irrigation worldwide; therefore there is a need for water-saving irrigation practices to be explored. Water saving may be achieved with drip irrigation, and even improved results seem to be possible (Shahnazari et al., 2007) with partial root-zone drying, which is a new water-saving irrigation strategy being tested in many crop species.

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Early studies have shown that water is a very important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing period (Panigrahi et al., 2001; Ferreira and Carr, 2002; Kashyap and Panda, 2003).

Moreover, fertilization especially potassium is considered one of the most important factors affecting the growth and yield of potato. Many researchers recorded an increase of potato tubers yield as a result of increasing the levels of potassium (K) fertilization (El-Gamal, 1985; Humadi, 1986). Such increases in the yield of potato tubers was either due to the formation of large sized tubers or increasing of the number of tubers per plant or both (El-Gamal, 1985). Potassium also plays a key role in increasing crop yield and improving the quality of produce (Tisdale et al., 1985).

Production of potato (*Solanum tuberosum* L.) takes a very important place in world agriculture, with a production potential of about 327 million ton harvested and 18.6 million ha planted area. Potato is a water-stress-sensitive crop. Potato plants are more productive and produce higher quality tubers when watered precisely using soil water tension (SWT) than if they are under- or over irrigated.

The aim of this research was to determine the effects of furrow and drip irrigation methods under different levels of potassium fertilizer on potato yield, water use efficiency, and irrigation water use efficiency.

Materials and methods

Field experiments were carried out during autumn season of 2011–2012 at the Experimental Farm, Department of Field Horticultural Science, College of Agriculture of Abu–Graib–Baghdad–Iraq (33°20′N, 44°12′E; elev. 34.1 m). Climatic factors of the 2011 growing seasons are listed in Table 1. Some soil physical and chemical properties are shown in Table 2.

The experiment was arranged in a split-plot design with two irrigation methods as the main plots and three level potassium fertilizers as subplots. Experimental plots measured 10.50 m^2 (3.50×3.00 m) and contained 50 plants spaced 0.70×0.30 m. Plots were separated 3 m from each other. Irrigation treatments were established to refill a 0.45 m depth-rooting zone as follows:

(i) Irrigation methods – furrow irrigation (*F*) and drip irrigation (*D*).
(ii) Potassium fertilizer rates.
  a. 0 kg K_2SO_4 ha^{-1} (K_0).
  b. 300 kg K_2SO_4 ha^{-1} (K_1).
  c. 600 kg K2SO4 ha^{-1} (K_2).

Level furrows were created between rows to ensure uniform water distribution in plots irrigated by furrows. Furrows were closed at the end to prevent runoff and a flow meter was used to measure the amounts of applied water. Drip irrigation was performed through pressure-compensating drippers, with 3.5 L h^{-1} flows in one lateral line per row. Irrigation was done when 50% of the available water was consumed.

Selected, potato tubers *Solanum tuberosum* L. (Bowren variety) were transplanted manually, at a depth of 10–12 cm on September 15, 2011, and harvested on January 2, 2012. All plots received basic application of 300 kg N and 250 kg P_2O_5 ha^{-1}. Herbicides and insecticides were applied at ploughing to each plot when necessary.

Some soil characteristics were determined as follows: soil particle size distribution by pipette method (Day, 1965), a soil bulk density was determined by the core method, (Blacke, 1965). Soil reaction (pH) and electrical conductivity (EC) were determined at the same soil water suspension 1:1 (*W*:*V*) by pH – meter and electrical conductivity – bridge, respectively (U.S.D.A., 1954). Organic matter was determined by the method of Walkly and Black (Jackson, 1958). Soil water content by weight at the field capacity (under 0.3 bar) and wilting point (under 15 bar) was measured (Klute, 1986). Available water (AW = FC − WP) was calculated.

Evapotranspiration (ET_a) was calculated using the soil water balance method:

$$ET = P + I - D \pm \Delta W \qquad (1)$$

where P is the rainfall (mm); I is the irrigation applied to individual plots (mm); D is the deep percolation; and ΔW is the change in water storage of the soil profile (mm). Since the amount of irrigation water was only sufficient to bring the water deficit to field capacity, deep percolation was ignored.

Reference evapotranspiration ET_0 was calculated using Penman–Montieth modified equation (Allen et al., 1998). Crop coefficient was calculated as the ratio between ET_a and ET_0 (Doorenbos and Pruitt, 1977). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated as follows:

$$WUE = \frac{\text{Yield (kg)}}{ET_a\ (m^3)} \qquad (2)$$

$$IWUE = \frac{\text{Yield (kg)}}{\text{Total water applied}\ (m^3)} \qquad (3)$$

Analysis of variance (ANOVA) was conducted to evaluate the effects of the treatments on the yield and water use efficiency. Least significant differences method (LSD) was used to differentiate means at the 0.05 level (SAS, 2002).

Table 1 Some climatic parameters of the experimental region.

Month	Average wind speed ($m\ s^{-1)}$)	Average sunshine ($mJ\ m^{-2}$)	Rainfall (mm)
September	2.78	39.13	0.0
October	1.78	18.71	0.0
November	1.52	11.67	0.9
December	1.34	9.52	6.5

Results and discussion

Yield and its components

Tuber yield, yield components tuber size, tuber weight, and tuber number per plant, monitored during season growth for each treatment are listed in Table 3. The furrow and drip irrigation methods had no effect ($P < 0.05$) on tuber yield for the growth season. Statistical analyses for potassium fertilizer on tuber yield and yield components differed ($P < 0.05$).

The yield characteristics were not affected by irrigation methods but affected by potassium fertilizer treatments ($P > 0.05$), although drip-irrigated treatments yielded generally higher

Table 2 Physico–chemical properties of the soil.

Soil depth (cm)	BD (g cm^{-3})	FC (%)	WP (%)	AW (%)	Particle size distribution (%)				EC (dS m^{-1})	pH	OM (%)
					Clay	Silt	Sand	Texture			
0–20	1.36	30.2	15.4	14.8	320	560	130	SiCL	2.85	7.6	1.72
20–45	1.40	30.5	14.1	16.4	420	500	80	SiC	2.72	7.7	1.22

Table 3 Effects of irrigation methods and potassium fertilizer rate on potato yield and yield components.

Treatment	Tuber size (cm^3)	Tuber weight *G*	Tuber number per plant	Tuber yield (T ha^{-1})
Irrigation method				
Furrow	115	188.9	6.4	34.23
Drip	118	200.5	6.8	36.56
LSD	ns	ns	ns	ns
Potassium fertilizer rates				
0 kg K_2SO_4 ha^{-1} (K_0)	107	165.7	5.6	26.71
300 kg K_2SO_4 ha^{-1} (K_1)	118	190.6	6.8	34.67
600 kg K_2SO_4 ha^{-1} (K_2)	121	196.8	7.4	37.78
LSD	2.4	3.2	0.9	2.34
Irrigation method × potassium fertilizer rates				
Furrow				
(K_0)	110	161.2	5.3	26.23
(K_1)	117	181.3	5.9	32.76
(K_2)	120	188.6	6.2	35.23
Drip				
(K_0)	112	170.2	5.8	27.45
(K_1)	119	188.8	6.2	33.87
(K_2)	123	197.2	6.3	36.65
LSD	ns	ns	ns	ns

values than furrow-irrigated treatments. The tuber size, tuber weight and number per plant increased with increase potassium rate and recorded 107, 118, 121 cm^3, 165.75, 190.6, 196.8 g and 5.6, 6.8 and 7.4 for 0.0, 300 and 600 kg K_2SO_4 ha^{-1}, respectively.

The highest significant values were obtained when plants treated with 600 kg K_2SO_4 ha^{-1} were compared to other treatments of K fertilizers, while, the lowest one was recorded in the control (without addition of K fertilizers). This trend obtained by Asmaa and Magda (2010) found that the total tuber yield was gradually and significantly increased with increasing the level of potassium application as shown in both growing seasons. Also, they concluded that the nutritive values of potato tubers were significantly affected by potassium application from. The highest tuber yield was obtained in the 600 kg K_2SO_4 ha^{-1} 36.65 T ha^{-1} for drip irrigation and 35.23 T ha^{-1} for furrow irrigation.

Actual evapotranspiration (ET)

Data on the amounts of applied irrigation water and measured actual evapotranspiration for all treatments during the growing period are presented in Table 4. The number of irrigations events varied from 9 to 10 for furrow and drip irrigation, respectively. As expected, the drip-irrigated treatments required less water than the furrow-irrigated treatments, recorded 300–338 mm and 415–447 mm, respectively. Among the potassium fertilizer rate, the total applied irrigation water decreased with increasing potassium level.

The actual ET_a under different irrigation methods are also presented in Table 4. The mean ET_a measured during the season was 375.7 mm for drip irrigation and 495.4 mm for furrow irrigation. The highest actual evapotranspiration was measured for the K_0 fertilizer + furrow irrigation treatment (511.4 mm), while the lowest value recorded 357.3 for K_2 + drip irrigation. Early research reports that seasonal potato ET ranged from 350 to 800 mm for different climatic and environmental conditions (Panigrahi et al., 2001; Ferreira and Carr, 2002; Shock et al., 2003; Onder et al., 2005; Ati et al., 2010).

Water use efficiency

Data on irrigation water use efficiency (IWUE) and water use efficiency (WUE) for all treatments are presented in Table 5. The furrow irrigation method used the higher amounts of water than drip irrigation methods (Table 4). IWUE of drip-irrigated treatments were higher and differed from furrow-irrigated treatments in the growth season ($P < 0.05$). However, the IWUE did differ ($P > 0.05$) for irrigation method and potassium fertilizers interactions. The drip-irrigated treatments produced higher WUE in comparison to furrow-irrigated in all treatments in the growth season ($P < 0.05$). The water use efficiency of all the treatment ranges from 5.129 to 10.257 kg m^{-3}

Table 4 Amounts of irrigation water, rainfall and actual evapotranspiration.

Treatment	Number of irrigation	Soil water depletion (mm)	Rainfall (mm)	Irrigation water applied (mm)	Actual evapotranspiration (mm)
Furrow					
(K_0)	9	57	7.4	447	511.4
(K_1)	9	55	7.4	435	497.4
(K_2)	9	55	7.4	415	477.4
Mean	9	55.67	7.4	432	495.4
Drip					
(K_0)	10	52	7.4	338	397.4
(K_1)	10	50	7.4	315	372.4
(K_2)	10	50	7.4	300	357.3
Mean	10	50.67	7.4	317	375.7

Table 5 Effects of irrigation methods and potassium fertilizers in water use efficiency (WUE) and irrigation water use efficiency (IWUE) in season growth.

Treatment	IWUE (kg m^{-3})	WUE (kg m^{-3})	Kc
Irrigation method			
Furrow	7.923	6.909	0.75
Drip	11.533	9.731	0.57
LSD	2.875	2.112	0.21
Irrigation method × potassium fertilizer rates			
Furrow			
(K_0)	5.868	5.129	0.78
(K_1)	7.531	6.586	0.76
(K_2)	8.489	7.379	0.73
Drip			
(K_0)	8.121	6.907	0.61
(K_1)	10.752	9.095	0.57
(K_2)	12.216	10.257	0.54
LSD	1.545	1.297	0.14

while the irrigation water uses efficiency ranges from 5.868 to 12.216 kg m^{-3}. It can also be deduced from the results of the percentage difference in water use efficiency compared between irrigation methods. Also for the potassium fertilizers, an increase in IWUE was seen and WUE records an increase from 5.868 to 8.489; 5.129 to 7.379 with furrow irrigation while an increase from 8.121 to 12.212 and 6.907 to 10.257 with drip irrigation was seen. Drip irrigation method yielded higher values of IWUE and WUE, since drip irrigation consumed less water than furrow irrigation. Crop coefficients (Kc) for potato calculated as the ratio of ET_a/ET_0 were for all treatments (Table 5). The maximum value of Kc was 0.78 for furrow irrigation + K_0 and the lowest value 0.54 for drip irrigation + K_2. Cumulative ET_0 calculated from Penman–Monteith modified equation totaled 657.29 mm which is close to the ET_a (495.4, 375.7 mm) proved the validity of this equation for estimating the water requirements of potato within the context of the region.

Conclusion

Irrigation management is a key to obtaining profitable growth in the absence of wasting water. Irrigation led to higher soil water content favoring crop evapotranspiration. The application of the effective use of water will go a long way in addressing the global water crisis in future, thereby reducing wastage. Potassium is the nutrient taken up by potato in the greatest quantity; it also takes up much nitrogen and appreciable amounts of phosphorus, calcium, magnesium and sulfur. Therefore, based on water use efficiency values, it is recommended that potato (Bowren variety) should be fertilized within 600 kg K_2SO_4 ha^{-1} with furrow and drip irrigation to achieve the optimum quantity and quality of tuber yield and water use efficiency.

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