WATER-YIELD RELATIONSHIPS OF POTATO UNDER DIFFERENT IRRIGATION METHODS AND REGIMENS

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ABSTRACT: Yield response to irrigation of different crops is of major importance in production planning where water resources are limited. This study aims to determine the effect of different irrigation methods and irrigation regimens on potato yield in the Trakya Region, Turkey, during 2003 and 2005. Potato was grown under furrow and drip irrigation methods and three regimens: irrigation applied when 30, 50, or 70% of the available water was consumed. The seasonal potato evapotranspiration ranged on 501 to 683 mm in 2003, and 464 to 647 mm in 2005. The furrow and drip irrigation methods had no significant effect on tuber yield for both years. Irrigation regimens influenced tuber yield ($P < 0.05$) in 2005, and the highest tuber yield was registered for 30% irrigation regimen, reaching 35.13 t ha^{-1} in 2003, and 44.56 t ha^{-1} in 2005. Water use efficiency values increased from 4.70 to 6.63 kg m^{-3} for furrow-irrigated treatments, and from 5.19 to 9.47 kg m^{-3} for drip-irrigated treatments.
Key words: furrow irrigation, drip irrigation, evapotranspiration, water use efficiency

RELAÇÃO ÁGUA-PRODUÇÃO NA CULTURA DA BATATA SOB DIFERENTES MÉTODOS E REGIMES DE IRRIGAÇÃO

RESUMO: Em casos de limitações de recursos hídricos, o planejamento da produção agrícola depende da resposta dos parâmetros de produção à prática da irrigação. Este estudo visa determinar o efeito de diferentes métodos e regimes de irrigação na produtividade da batata na região de Trakya, Turquia, durante os anos de 2003 e 2005. As batatas foram plantadas sob irrigação por sulcos e por gotejamento, em três regimes: prática de irrigação quando 30, 50 ou 70% da água disponível era consumida. A evapotranpisração sazonal da cultura variou entre 501 e 683 mm em 2003, e entre 464 e 647 mm em 2005. O método de irrigação não afetou significativamente a produção de tubérculos nos dois anos. Os regimes de irrigação influenciaram a produção de tubérculos ($P < 0,05$) em 2005, e as maiores produções foram registradas para o regime de irrigação 30%, 33,15 t ha^{-1} em 2003 e 44.56 t ha^{-1} em 2005. Os valores de eficiência do uso da água aumentaram de 4,70 para 6,63 nos tratamentos de irrigação por sulcos e de 5,19 para 9,47 kg m^{-3} nos tratamentos por gotejamento.
Palavras chave: irrigação por sulcos, gotejamento, evapotranspiração, eficiência hídrica

INTRODUCTION

Production of potato (*Solanum tuberosum* L.) takes a very important place in world agriculture, with a production potential of about 327 million t harvested and 18.6 million ha planted area (FAO, 2004). Potato is one of the main crops in Turkey where the production is about 4.80 million t harvested from 0.2 million ha (FAO, 2004). Early studies have shown that water is the most important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing season (Boujelben et al., 2001; Deblonde & Ledent, 2001; Faberio et al., 2001; Chowdhury et al., 2001; Panigrahi et al., 2001; Ferreira & Carr, 2002; Kashyap & Panda, 2003; Shock et al., 2003; Yuan et al., 2003; Onder et al., 2005).

The Trakya region, Turkey, lies within a semi-arid area with annual rainfall of about 575 mm. From April to October the rainfall reaches 175 mm, accounting for 30% of the annual precipitation. Water shortage in this season unfavors agricultural production, since the potato growing season goes from April to August. Therefore, because average rainfall and water resources are limited in this period, research on the relationships among yield, crop water consumption, and crop water stress is of great importance for developing water-sparing agricultural practices.

The aim of this research was determining the effects of furrow and drip irrigation methods under different irrigation regimens on potato yield and yield components for these conditions.

MATERIAL AND METHODS

Field experiments on potato were carried out in 2003 and 2005 during the growing season (April to August) in Tekirdag, Turkey (40°59' N, 27°29' E; altitude, 4 m), a semi-arid climatic region. Averages of annual temperature, relative humidity, wind speed, sunshine duration, and total annual precipitation are 13.8°C, 76%, 3.1 m s^{-1}, 6.5 h, and 575.4 mm, respectively (Orta et al., 2003). Climatic factors of the 2003 and 2005 growing seasons are listed in Table 1.

Chemical and physical properties of the experimental field soil related to irrigation are shown in Tables 2 and 3. The soil is generally deep, heavily textured, and well drained. The available water holding capacity within the 0.90 m soil profile is approximately 0.175 m. There are no salinity and alkalinity problems. Electrical conductivity (EC) of the irrigation water is 0.42 dS m^{-1} and the sodium absorption ratio (SAR) is 2.7, classified as C_2S_1 (Richards, 1954).

Selected, pre-sprouted potato tubers (*Solanum tuberosum* L. cv. Satina) were transplanted manually, at a depth of 10-12 cm on April 11, 2003, and April 15, 2005, and harvested respectively on August 8, 2003, and August 6, 2005. Fertilizer applications were based on soil test data (Table 2); a composed fertilizer including 60 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5 was utilized. Herbicides and insecticides were applied at ploughing to each plot when necessary. The preceding crop in both years was wheat.

The experiment was arranged in a split-plot design, with two irrigation methods as main plots and three irrigation regimens 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 0.6 m depth-rooting zone as follows:

(i) irrigation methods - furrow irrigation (F) and drip irrigation (D); (ii) irrigation regimens - irrigation when 30% of the available water was consumed (IR1), irrigation when 50% of the available water was consumed (IR2), and irrigation when 70% of the avail-

Table 1- Some climatic parameters of region for the experimental years.

Year	Month	Average relative humidity	Average relative humidity	Average wind speed	Average sunshine duration	Rainfall
		ºC	%	m s^{-1}	h	mm
2003	April	8.8	80	2.2	6.3	27.2
	May	17.9	76	2.0	9.5	5.0
	June	23.0	70	2.3	10.9	1.4
	July	24.8	70	2.6	10.7	15.8
	August	25.2	69	2.6	11.0	0.4
2005	April	12.2	76	2.5	7.4	12.7
	May	17.6	86	2.1	7.4	78.2
	June	20.5	77	2.2	11.1	13.0
	July	25.3	77	2.6	10.4	6.8
	August	26.2	80	2.5	9.9	-

Table 2 - Some chemical characteristics of the soil at the experimental site.

Soil depth	Total salt	pH	$CaCO_3$	P_2O_5	K_20	Organic matter
cm	%		%	------------ kg ha^{-1}	------------	%
0-20	0.071	7.8	2.82	64.9	820	1.87
20-40	0.077	7.8	3.35	47.4	515	1.24

Table 3 - Some physical characteristics of the soil at the experimental site.

Soil depth	Bulk density	Field capacity	Wilting point	Available water
cm	g cm^{-3}	--------- %	---------	mm/30 cm
0-30	1.46	28.69	15.90	56.0
30-60	1.53	28.88	15.63	60.8
60-90	1.58	26.97	14.74	58.0

able water was consumed (IR3). Level furrows were created between rows to ensure uniform water distribution in plots irrigated by furrow. 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 4 L h^{-1} flow in one lateral line per row; dripper and lateral spacings were 0.50 and 1.20 m, depending on soil characteristics. The percentage of wetted area (P) that relates dripper spacing to lateral spacing was determined as 71% (Keller & Bliesner, 1990).

Soil water was monitored in each plot using a neutron probe (CPN, 503 DR Hydroprobe) for each 0.30 m soil layer during the whole growing season. The soil moisture content of the top 0.30 m was measured by the gravimetric method (Evett et al., 1993). The amount of soil water in the 0.60 m top layer was used to initiate irrigation. The crop water use (evapotranspiration) for ten-day periods was calculated applying the water balance method to the upper 0.90 m soil layer. Evapotranspiration (ET) was calculated using the soil water balance method (Heerman, 1985);

$$ET = P + I - D \pm \Delta W$$

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.

Water use efficiency (WUE) for each treatment was calculated as tuber yield divided by seasonal evapotranspiration (ET). Irrigation water use efficiency (IWUE) was determined as (Zhang et al., 1999):

$$IWUE = \frac{(Y_1 - Y_{NI})}{I}$$

where, Y_1 is the tuber yield of irrigation treatments (t ha^{-1}); Y_{NI} is the tuber yield of non-irrigation treatment (t ha^{-1}); and I is the amount of irrigation water (mm).

Data on effects of treatments on the yield and yield components were submitted to analysis of variance (ANOVA). The Least Significant Difference Test (LSD) was used to compare and rank treatments (Gomez & Gomez, 1984).

RESULTS AND DISCUSSION

Seasonal ET

Data on the amounts of applied irrigation water and measured seasonal evapotranspiration for all treatments during the growing period are presented in Table 4. The number of irrigations events varied from 7 to 16 in 2003, and from 5 to 10 in 2005. The number of irrigations and the total applied irrigation water in 2005 growing season were smaller than in 2003 because of the higher rainfall. As expected, the drip-irrigated treatments required less water than the furrow-irrigated treatments, in both years. Among the irrigation regimens, the number of irrigations and the total applied irrigation water increased with irrigation when 30% of the available water was consumed, along with a decrease in the amount of water per irrigation event.

The seasonal (ET) is also shown in Table 4 and Figures 1 and 2. ET values for all treatments were close in both years, that of the first year being slightly higher. This may be attributed to differences in climatic conditions, planting date and total growing sea-

Table 4 - Amounts of irrigation water, rainfall and seasonal evapotranspiration.

Year	Irrigation method	Irrigation regimen	Number of irrigations	Soil water depletion	Rainfall	Irrigation water applied	Seasonal evapotranspiration
				----	----	mm	----
2003	Furrow	30%	14	57	50	576	683
		50%	9	69	50	554	673
		70%	7	57	50	537	644
	Drip	30%	16	64	50	469	583
		50%	10	57	50	417	524
		70%	7	56	50	395	501
2005	Furrow	30%	10	58	111	478	647
		50%	7	78	111	451	640
		70%	5	82	111	403	596
	Drip	30%	10	38	111	339	488
		50%	7	48	111	314	473
		70%	5	60	111	293	464

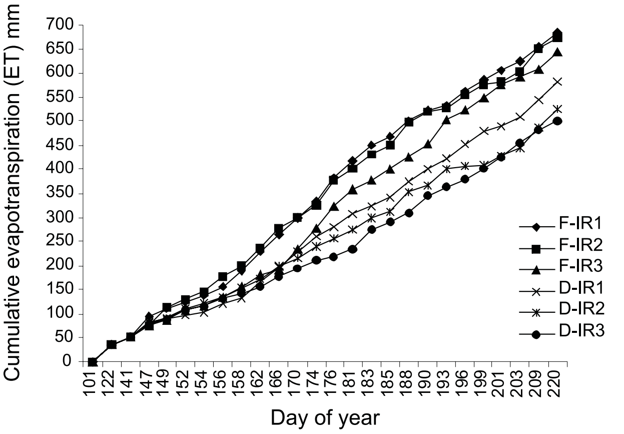

Figure 1 - Cumulative seasonal evapotranspiration in 2003.

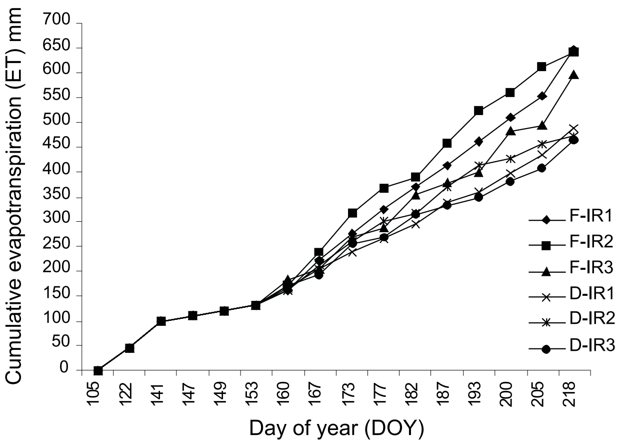

Figure 2 - Cumulative seasonal evapotranspiration in 2005.

son irrigation depth. Figures 1 and 2 show the cumulative seasonal evapotranspiration of potato for all treatments under the furrow irrigation method and 30% irrigation regimen. The furrow irrigation treatments consumed more water than drip irrigation treatments. The highest seasonal evapotranspiration was measured for the 30% irrigation regimen treatment (F-IR1 and D-IR2): 683 mm in 2003 and 647 mm in 2005 for the furrow irrigation. and 583 mm in 2003 and 488 mm in 2005 for drip irrigation. Early research reports that seasonal potato ET ranged from 350 to 800 mm for different climatic and environmental conditions (Doorenbos & Kassam, 1979; Fabeiro et al., 2001; Panigrahi et al., 2001; Ferreira & Carr, 2002; Shock et al., 2003; Onder et al., 2005).

Tuber yield and yield components

Tuber yield, plant height and yield components tuber size, tuber height, tuber weight, and tuber number per plant, monitored during both years for each treatment are listed in Tables 5 and 6. The furrow and drip irrigation methods had no effect ($P < 0.05$) on tuber yield for both years. Statistical analyses for irrigation regimens on tuber yield differed between years ($P < 0.05$). While no differences were registered in 2003 ($P > 0.05$) irrigation regimens affected tuber yield ($P < 0.05$) in 2005, and the highest tuber yield was obtained in the 30% irrigation regimen - 35.13 t ha^{-1} in 2003, and 44.56 t ha^{-1} in 2005. The highest tuber yield was registered for the drip-irrigated treatment, watered

Table 5 - Effects of irrigation methods and irrigation regimens on potato yield and yield components in 2003.

Treatments		Plant height	Tuber size	Tuber height	Tuber weight	Tuber number per plant	TuberYield
		----------------	cm	----------------	g		t ha^{-1}
				Irrigation method			
	Furrow	93.8	5.7	6.8	133.4	6.2	32.23
	Drip	93.4	5.7	6.8	134.1	5.8	30.60
	LSD (5%)	ns	ns	ns	ns	ns	ns
				Irrigation regimen			
	30%	94.6	5.5	7.1	135.5	6.8	35.13
	50%	90.0	5.8	6.5	127.7	5.6	29.39
	70%	96.2	5.9	6.9	138.2	5.8	29.75
	LSD (5%)	ns	ns	ns	ns	ns	ns
				Irrigation method × irrigation regimen interactions			
Furrow	30%	98.8	5.3	7.3	143.8	7.3	34.44
	50%	86.8	5.8	6.4	125.0	5.9	31.59
	70%	95.8	6.0	6.7	131.5	5.5	30.67
Drip	30%	90.4	5.6	6.8	127.1	6.2	35.81
	50%	93.2	5.8	6.6	130.3	5.2	27.18
	70%	96.5	5.7	7.0	144.9	6.0	28.82
	LSD (5%)	ns	ns	ns	ns	ns	ns

when 30% of the available water was consumed. The observed yield and water use relationship on potato was similar to that reported in previous investigations. Faberio et al. (2001), in Spain, found that 597 mm irrigation water was required to reach maximum tuber yield 45.18 t ha^{-1}; Onder et al. (2005) determined that surface drip irrigation and subsurface drip irrigation methods did not significantly affect tuber yield under Turkey soil/climate conditions. Other researchers have also reported increased tuber yield with irrigation applications (Shock et al., 1998; Ferreira & Carr, 2002; Kashyap & Panda, 2003; Yuan et al., 2003; Kang et al., 2004).

The yield characteristics were not affected by irrigation methods and irrigation regimens treatments ($P > 0.05$), although drip-irrigated treatments yielded generally higher values than furrow-irrigated treatments. The tuber number per plant increased from 5.5 to 7.3 in 2003, and from 5.6 to 6.5 in 2005. Similarity, Onder et al. (2005) reported that the number of tuber per plant was not significantly affected by irrigation methods. The highest values of tuber weight were recorded for the drip irrigation treatment.

Water use efficiency

Data on irrigation water use efficiency (IWUE) and water use efficiency (WUE) for both years are presented in Table 7. Although tuber yield was about the same, the furrow irrigation method used higher amounts of water than drip irrigation methods (Table 3). IWUE of drip-irrigated treatments were higher and differed from furrow-irrigated treatments in the second year ($P < 0.05$). However, the IWUE did not differ ($P > 0.05$) for irrigation regimen and irrigation method × irrigation regimen interactions. The drip-irrigated treatments produced higher WUE in comparison to furrow-irrigated treatments in 2005 ($P < 0.05$). WUE of potato was also found not to be significantly different for irrigation regimen and irrigation method × irrigation regimen interaction. Among the irrigation regimens, the highest WUE were generally obtained from application of irrigation when 30% of the available water was consumed. Kang et al. (2004) and Onder et al. (2005) also registered similar WUE values for potato.

The seasonal evapotranspiration presented peaks of 683 mm (2003) and 647 mm (2005) under furrow irrigation method, with irrigation when 30% of the available water was consumed. Irrigation regimens affected tuber yield ($P < 0.05$) in the second year, but tuber yield was not affected ($P < 0.05$) by the irrigation method. Different irrigation treatments did not result in significant difference on yield parameters. Drip irrigation method yielded higher values of IWUE and WUE, since drip irrigation consumed less water than furrow irrigation.

Table 6 - Effects of irrigation methods and irrigation regimens on potato yield and yield components in 2005.

	Treatments	Plant height	Tuber size	Tuber height	Tuber weight	Tuber number per plant	TuberYield
		----------------- cm		-----------------	g		t ha^{-1}
				Irrigation method			
	Furrow	94.4	6.2	7.4	159.0	6.0	38.30
	Drip	94.1	6.5	7.5	166.0	6.0	43.25
	LSD (5%)	ns	ns	ns	ns	ns	ns
				Irrigation regimen			
	30%	97.3	6.5	7.6	170.6	6.4	44.56 a
	50%	94.4	6.6	7.4	159.0	6.0	40.92 ab
	70%	91.2	5.9	7.4	158.0	5.8	36.85 abc
	LSD (5%)	ns	ns	ns	ns	ns	4.9
				Irrigation method x irrigation regimen interactions			
Furrow	30%	99.3	6.6	7.6	168.8	6.5	42.92
	50%	92.7	6.0	7.2	150.9	6.0	37.19
	70%	91.2	6.0	7.4	157.3	5.6	34.78
Drip	30%	95.3	6.4	7.5	172.3	6.2	46.20
	50%	96.0	7.2	7.5	167.0	5.9	44.65
	70%	91.1	5.8	7.4	158.6	5.9	38.91
	LSD (5%)	ns	ns	ns	ns	ns	ns

Table 7 - Irrigation water use efficiency (IWUE) and water use efficiency (WUE) for potato under different irrigation method and irrigation regime.

Treatments		IWUE 2003	IWUE 2005	WUE 2003	WUE 2005
		kg m^{-3}			
Irrigation method					
	Furrow	5.80	8.62 b	4.83	6.09 b
	Drip	7.15	13.71 a	5.69	9.10 a
	LSD (5%)	ns	4.37	ns	2.80
Irrigation regimen					
	30%	6.81	11.31	5.59	8.05
	50%	6.11	11.24	4.95	7.63
	70%	6.51	10.96	5.26	7.11
	LSD (5%)	ns	ns	ns	ns
Irrigation method x irrigation regimen interactions					
Furrow	30%	5.98	8.98	5.04	6.63
	50%	5.70	8.25	4.70	5.81
	70%	5.71	8.63	4.76	5.83
Drip	30%	7.64	13.63	6.14	9.47
	50%	6.52	14.22	5.19	9.44
	70%	7.30	13.28	5.75	8.39
	LSD (5%)	ns	ns	ns	ns

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