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Design and Management of a Drip Irrigation System for an Optimum Potato Yield

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ABSTRACT

This study was conducted to determine the effects of different lateral spacings and wetting factors on the yield and yield components of drip-irrigated potato under the Middle Anatolian climatic conditions in Konya, Turkey. The experiments were carried out during the growth seasons of 2008 and 2009. The Russet Burbank potato variety was used as a plant material in this study. The irrigation design treatments consisted of two different lateral spacings (A_1= 0.7 m and A_2= 1.4 m) and three different wetting factors (P_1= 1.0, P_2= 0.5, and P_3: A variable percentage of the wetted area depending on the lateral spacing). The results showed that the total amounts of applied irrigation water ranged from 297 to 625 mm and from 288 to 598 mm in 2008 and 2009, respectively. Considering the average yields for the two years, the highest tuber yield (50.87 t ha^{-1}) was obtained from the A_1P_1 treatment, and the lowest tuber yield (27.37 t ha^{-1}) was obtained from the A_2P_3 treatment. It was found that the different lateral spacings and wetting factors statistically affected the mean tuber weight, the number of tubers per plant, the tuber diameter, the tuber size, and the marketable tuber yield ($P<$ 0.01). The highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE) calculated were 7.78 and 9.40 kg m^{-3}, respectively, in the A_1P_3 treatment. A single lateral design for two crop rows resulted in less income than one lateral design for each crop row for drip-irrigated marketable potatoes.

Keywords: Konya Plain, Lateral spacing, Percentage of wetted area, Water use efficiency.

INTRODUCTION

Potato (*Solanum tuberosum* L.) ranks fourth behind wheat, rice, and corn in the volume of production among the worldwide agricultural products (FAO, 2012). Although it is a temperate crop, it is grown in different climates, from the tropics to sub-polar zones, and is a major food crop in many countries (Wright and Stark, 1990). Potato production takes a very important place in the worldwide agriculture, with about 365 million tons harvested and 19.2 million hectares planted (FAO, 2012). Potato is a very important crop in the Mediterranean Basin, occupying an overall area of about one million ha and producing 18 million tons of tubers in several countries, including Tunisia, Egypt, Cyprus, Israel, Lebanon, Italy and Turkey (Lerna *et al*., 2011).

Potato is one of the main crops in Turkey where its production reaches about 4.80 million tons (FAO, 2012). The Konya Plain, where water resources are limited and the climate is arid, has 10% of arable lands in Turkey. Irrigation is very important for crop production in the Konya Plain, and potato needs irrigation in the Konya Plain as well as everywhere in Turkey.

In arid and semi-arid climates, potato is one of the major crops on irrigated land. Many irrigation experiments have shown that potato is relatively sensitive to moisture stress (Wright and Stark, 1990; Foti *et al*., 1995; Fabeiro *et al*., 2001; Onder *et al*., 2005; Erdem *et al*., 2006; Ünlü *et al*., 2006;

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Shahbazi *et al*., 2010; Yavuz *et al*., 2012) because it has a sparse root system and approximately 85% of the root length is concentrated in the upper 0.3 m soil layer (Opena and Porter, 1999). Therefore, potatoes need frequent irrigations for optimum growth and a good tuber yield (Ahmadi *et al*., 2014). Ferreira and Carr (2002) investigated responses of potato to different water supplies and concluded that actual evapotranspiration of potato crops varied from 150 to 320 mm, depending on the treatments in the first year, and from 190 to 550 mm in the second year. Research conducted by Shock *et al*. (2003) to determine tuber yield and quality responses to limited irrigation showed that the yield and quality decreased under reduced irrigation.

Irrigation requirements differ with locations, soil types, and agricultural practices. Under the condition of limited water supply, higher benefits may be achieved by adopting suitable irrigation and planting techniques (Sharma *et al*., 1993). Furrow and sprinkler irrigation methods are widely used in potato production in Turkey. Because of its higher costs, drip irrigation has not been widely used in potato production in this region. However, in recent years, drip irrigation costs have relatively decreased due to technology improvements.

In drip irrigation, water is applied close to plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. This is one of the major advantages of drip irrigation over other methods. Indeed, irrigation is scheduled based on the soil volume in the root zone, which is only partially wetted. Soil moisture depletion is controlled to keep available moisture in the wetted area. The Percentage wetted area (Pw) is the average horizontal area wetted within the top 30 cm of the crop root-zone depth relative to the total crop area. The proper minimum value for *Pw* has not been established. A reasonable approach is to wet at least one-third of the potential root volume of soil for widely spaced crops, i.e., 33%< *Pw*< 67% (Keller and Bliesner, 1990). It is important to determine and use an appropriate percentage of the wetted area for both the system design and water use efficiency.

Design of drip irrigation systems is very important for improving the irrigation application efficiency and economic return in the production process (Pannunzio *et al.*, 2004). Regarding drip systems, an analysis has been made to determine the optimum lateral spacing for drip-irrigated corn in Turkey (Bozkurt *et al.*, 2006). Lateral spacings of 0.7, 1.4, and 2.1 m were compared, leading to a conclusion that the optimum lateral spacing for corn was 1.4 m (one drip lateral per two crop rows).

The objective of this work was to study the effects of different lateral spacings and wetting factors on yield and yield components of drip-irrigated potato by studying the effects of one lateral for each plant row versus one lateral for every two plant rows on water use, yields, and quality parameters of potato.

MATERIALS AND METHODS

The study was conducted on the experimental field of Konya Sugar, Inc. in Konya, Turkey, during the 2008 and 2009 growing seasons. The experimental field was located at 37°48′ N latitude, 32°25′ E longitude, and altitude of 1,020 m. According to the long-term meteorological data, the climate in this region is semi-arid with the total annual precipitation of 312 mm. The climatologic data for the experimental seasons (in 2008 and 2009) are given in Table 1. The total rainfall from April to September was 142.1 mm, corresponding to 43% of the annual rainfall, and 159.8 mm, corresponding to 45% of the annual rainfall, in 2008 and 2009, respectively.

The soil in this area is of alluvial origin, with no salinity and drainage problems; the water table and terrain are almost flat. The bulk density ranges from 1.30 to 1.37 g cm^{-3}

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in the soil profile. The available water holding capacity of the soil is 85.2 mm 60 cm^{-1}. Selected soil properties of the experimental site are given in Table 2. Evaporation data were recorded daily using a standard Class A pan in the experimental area. The water quality classification was determined as C_2S_1 according to the USA Salinity Laboratory Graph System (EC= 0.625 dS m^{-1}, SAR= 0.61).

The drip irrigation system consisted of a control unit and distribution lines. The control unit contained a hydrocyclone, a fertilizer tank, a disk filter, control valves, and pressure gauges. The drip irrigation system was designed and installed to meet the objectives of the study. In the distribution system, PolyEthylene (PE) pipes of 90 and 63 mm in diameter were used for the main and sub-main lines, respectively. The PE lateral lines had in-line compensating emitters, and the discharge rates of the emitters were 4 L h^{-1} at the pressure of 100 kPa. Each plot was connected with a flow meter in order to deliver the desired amount of water. Irrigation water was taken by a submersible pump, powered by a 10 HP engine, from a deep well close to the experimental site, during both years.

The Russet Burbank potato variety was planted with a two-row planting machine at a 0.7 m row spacing on April 22, 2008 and on April 28, 2009. The experimental site was fertilized with 200 kg of N, 75 kg of P_2O_5, and 75 kg of K_2O per ha before planting, and 40 kg of N ha^{-1} was applied at the beginning of tuber bulking. After emergence, the plots were irrigated by the sprinkler irrigation method, with a watering volume of 45 and 40 mm, respectively, in 2008 and 2009, as pre-treatment irrigation.

Table 1. Variations of meteorological parameters of the study region during experimental years.

Year	Month	Average temperature (^{0}C)	Relative humidity (%)	Precipitation (mm)	Average wind speed (m s^{-1})	Evaporation (mm)
2008	April	14.1	51.4	20.5	1.7	102.3
	May	15.6	51.4	28.2	1.4	152.2
	June	21.6	42.6	5.2	1.3	235.1
	July	23.3	39.1	14.8	1.2	279.2
	August	23.9	41.7	0	1.0	261.1
	September	18.8	54.1	73.4	0.7	156.7
Average/Total		19.6	46.7	142.1	1.2	1186.6
2009	April	10.1	66.4	57.8	1.0	104.1
	May	14.6	59.4	47.2	0.9	149.8
	June	20.4	46.8	11.8	1.1	236.1
	July	22.6	49.1	17.4	1.2	245.5
	August	21.2	41.5	0	0.9	223.1
	September	16.8	55.9	25.6	0.6	134.1
Average/Total		17.6	53.2	159.8	0.9	1092.7

Table 2. Physical and chemical properties of the experimental site soil.

Soil depth (cm)	pH	Organic materials (%)	Texture class	Bulk density (g cm^{-3})	Field Capacity (FC)		Wilting Point (WP)		Available soil water content	
					%vol	mm	%vol	mm	%vol	mm
0-30	7.74	1.94	CL[a]	1.30	29.8	89.4	15.7	47.1	14.1	42.3
30-60	7.76	1.27	CL	1.34	35.3	105.9	21.0	63.0	14.3	42.9
60-90	7.70	0.52	CL	1.33	37.1	111.3	20.3	60.9	16.8	50.4
90-120	7.84	-	CL	1.37	41.2	123.6	25.8	77.4	15.4	46.2
			Total (0-60 cm)			195.3		110.1		85.2

[a] Clay Loam.

Herbicides and insecticides were applied to each plot when necessary. The preceding crop in both years was wheat.

The experiment was laid out in a randomized block factorial design consisting of combinations of two lateral spacings (A) and three wetting factors (P). The lateral spacings were 0.7 m (A_1) and 1.4 m (A_2). The wetting factors were 1.0 (P_1), 0.5 (P_2) and a variable percentage of the wetted area (P_3), depending on the lateral spacing. Thus, the six treatments were designated as A_1P_1, A_1P_2, A_1P_3, A_2P_1, A_2P_2 and A_2P_3 (Table 3).

In order to determine the emitter spacing and the percentage of the wetted area, some tests were carried out in the experimental field by using a single drip tubing (14 mm inner diameter, the dripper delivering 4 L h^{-1} at the operating pressure of 100 kPa). The wetted diameter of soil at a depth of 0.30 m from the surface under the dripper was calculated to be 0.52 m in the tests conducted. The emitter spacing was accepted as nearly 66% (0.33 m) of the measured wet diameter (Yildirim, 2003). The percentages of the wetted area were calculated by dividing the wet diameter (0.52 m) by the lateral spacing (0.7 or 1.4 m) (Keller and Bliesner, 1990; Cetin and Uygan, 2008). Thus, the percentages of the wetted area measured in the experimental site were 75 and 37.5% for the lateral spacings of 0.7 and 1.4 m, respectively.

For the plots having one lateral for each crop row, the width and length of each plot were planned as 2.8 and 40 m, respectively, with 4 crop rows. Each plot designed with one lateral for two crop rows had 6 plant rows. Therefore, the width and length of each of these plots were designed as 4.2 and 40 m, respectively (Ünlü *et al*., 2006). On the other hand, the lateral line spacing was either 0.7 or 1.4 m, depending on the treatment. For 0.7 m lateral spacing (A_1), a lateral line was placed for each plant row, while for the 1.4 m lateral spacing (A_2), a lateral line was placed for two plant rows (Figure 1).

Taking the features of the soil into consideration, the experimental tests were carried out in the experimental field using a single lateral and 4 L h^{-1} discharge emitters at an operating pressure of 1 atm to determine the emitter spacing and the percentage of the area planned to be wetted. The percentage of the wetted area in treatment A_1P_3 was calculated to be 75% for the lateral spacing of 0.7 m, while in treatment A_2P_3 it was calculated to be 37.5% for the lateral spacing of 1.4 m. Consequently, each lateral design resulted in different percentages of the wetted area in terms of the drip line spacing.

The amounts of water applied in the irrigation treatments were determined using Class A pan evaporation and the following equation (Doorenbos and Kassam, 1979):

$$I = A \times Ep \times Kcp \times P \quad (1)$$

Where, *A* is the plot area (m^2), *Ep* is the cumulative pan evaporation measured during an irrigation period of 7 days using a standard Class A pan (mm), *Kcp* is the coefficient of crop-pan evaporation, and *P* is the wetting factor. The *Kcp* applied was 1.2 as recommended for potato by Ünlü *et al*. (2006) for the Middle Anatolian conditions.

Table 3. The treatments in the experiment.

Lateral spacings	Wetting factors
A_1: 0.7 m lateral spacing	P_1: Wetting factor was set to a value of 1.0 P_2: Wetting factor was set to a value of 0.5 P_3: Wetting factor was determined as a value of 0.75 according to the percentage of wetted area measured in the experimental site
A_2: 1.4 m lateral spacing	P_1: Wetting factor was set to a value of 1.0 P_2: Wetting factor was set to a value of 0.5 P_3: Wetting factor was determined as a value of 0.375 according to the percentage of wetted area measured in the experimental site

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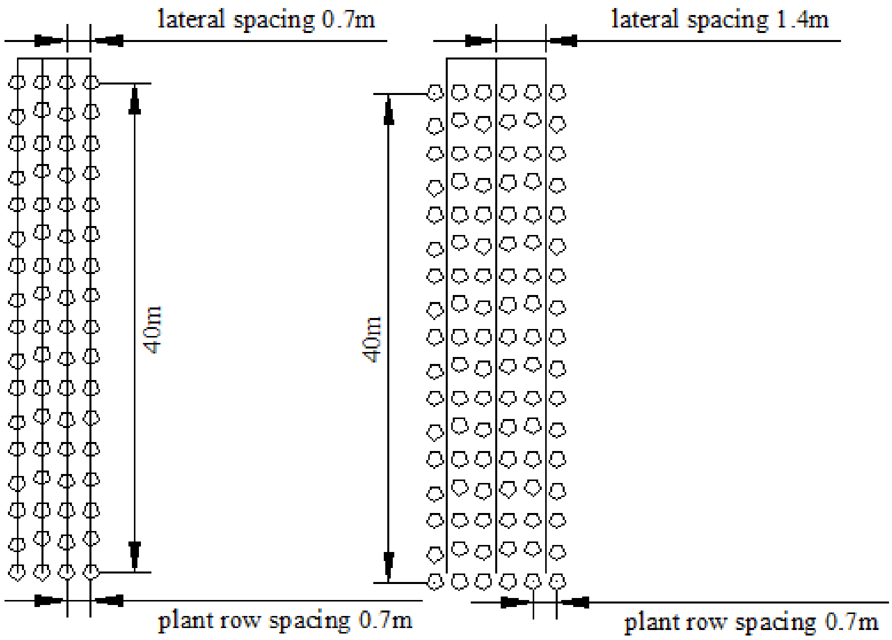

(a) (b)

Figure 1. Design of lateral pipe for each crop row (a) and each two crop rows (b).

Class A pans were placed inside the experimental plots on both sides and covered with mesh to prevent animals from drinking the water. Pan evaporation was carefully measured every day, and the pans were frequently cleaned and filled with fresh water. Tubers were harvested by a potato harvester when plants reached physiological maturity, on September 15, 2008 and September 23, 2009. The harvest areas in each plot were 28.0 m^2 for the treatments where the lateral spacing was 0.7 m (2 rows, each 20 m long) and 56 m^2 for the treatments where the lateral spacing was 1.4 m (4 rows, each 20 m long).

The irrigation was started when 50-55% of the available water content was consumed. The irrigation treatments were started 64 days after planting, on June 25, 2008, and 63 days after planting, on July 1, 2009. Subsequent irrigations were applied at 7-day intervals according to the treatments. The last irrigation was applied on August 27, 2008 and September 2, 2009. The number of tubers per plant, the mean tuber weight, the tuber diameter, the tuber size, and the marketable tuber yield were determined for 10 randomly selected plants in each sub-plot prior to harvest. It is accepted that a marketable tuber should be larger than 40 mm in diameter (Yilmaz, 1993).

The crop water use (ET) was estimated based on a one-dimensional water balance equation (Eq. 2) using soil water measured by gravimetric sampling methods:

$$ET = I + R - D_P \pm \Delta S \quad (2)$$

Where, *ET* is the evapotranspiration value (mm), *I* is the amount of irrigation water (mm) calculated in Equation (1) for each treatment, *R* is the amount of precipitation (mm), *Dp* is the water loss by deep percolation (mm), and *ΔS* is the change in soil water stored in the plant rooting zone (mm). Precipitation was measured daily at a nearby weather station. To calculate *ΔS*, soil water contents in the soil profile were determined by gravimetric measurements immediately before planting and harvesting. *Dp* is water that drained below the rooting zone. Thus, the 60 cm layer was considered to be the depth at which water flows into or out of the root zone. Soil samples for water content measurements were obtained at distances

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equal to 0, 35, and 70 cm from drip emitters at depth intervals of 60-80, 80-100 and 100-120 cm. The water content was measured by the gravimetric method and converted to the volumetric water content using the bulk densities, and *Dp* was calculated according to Kang *et al*. (2004).

The Water Use Efficiency (WUE) was computed by dividing the marketable potato yield by crop water use. The Irrigation Water Use Efficiency (IWUE) was considered to be the ratio between the marketable yield and the total irrigation water applied to a particular treatment because the non-irrigated yield was zero in this experiment (Howell *et al*., 1990).

The net income for each treatment was computed by subtracting all the production costs from gross incomes. All calculations were done based on a unit area of 1 ha (Cetin and Uygan, 2008). The potato production costs and the sale prices were obtained from the Seydibey Potato Factory of Konya Sugar, Inc. Potato production costs include fertilizer, seeds, soil cultivation, and hoeing and harvesting expenditures. For the calculation of the total cost of potato production for one year, the sum of the crop production costs, the annual cost of the irrigation system, and the irrigation cost are taken into account.

Analysis Of Variance (ANOVA) was conducted to evaluate the effects of the treatments on the yield and quality parameters. Duncan's multiple range tests were used to compare and rank the treatment mean values. The differences were considered significant at $P< 0.05$ or $P< 0.01$. The variance analyses were conducted by using the SPSS 16.0 computer program.

RESULTS AND DISCUSSION

Irrigation Water and Evapotranspiration

The total effective rainfall during the growing seasons was 63 and 105 mm in 2008 and 2009, respectively. The total amount of water applied to the plots varied according to the lateral spacing and the wetting factors. The total irrigation water applied ranged from 297 to 625 mm in 2008 and from 288 to 598 in 2009 (Table 4). The highest total irrigation water amount was applied to the A_1P_1 and A_2P_1 plots where the wetting factor was 1.00 in both experimental years.

The highest deep percolation (138 and 145 mm in 2008 and 2009, respectively) occurred in the A_2P_1 treatment in which the lateral spacing was 1.4 m and the wetting factor was 1.00. The seasonal water use (ET)

Table 4. Net and total irrigation water amount applied to the treatments and Evapotranspiration (ET).

Years	Treatments	Number of irrigation	Total irrigation water (mm)	Net Irrigation Water (mm)	Deep percolation (mm)	Effective rainfall	ΔS (mm)	*ET* (mm)
2008	A_1P_1	10	625	571	54	63	2	636
	A_1P_2	10	362	362	0	63	32	457
	A_1P_3	10	494	476	18	63	15	554
	A_2P_1	10	625	487	138	63	8	558
	A_2P_2	10	362	338	24	63	34	435
	A_2P_3	10	297	297	0	63	38	398
2009	A_1P_1	10	598	538	60	105	5	648
	A_1P_2	10	350	350	0	105	35	490
	A_1P_3	10	474	460	14	105	13	578
	A_2P_1	10	598	453	145	105	10	568
	A_2P_2	10	350	328	22	105	37	470
	A_2P_3	10	288	288	0	105	41	434

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varied between 398 and 636 mm in 2008 and between 434 and 648 mm in 2009. The highest ET values calculated were 636 and 648 mm in 2008 and 2009, respectively, in the A_1P_1 treatment i.e. one lateral for each crop row and the wetting factor of 1.00 (Table 4).

In previous studies, it has been observed that seasonal evapotranspiration of potato ranged from 350 to 800 mm depending on the climate and growing conditions (Doorenbos and Kassam, 1979; Fabeiro *et al.*, 2001; Panigrahi *et al.*, 2001; Ferreira and Carr, 2002; Shock *et al.*, 2003; Erdem *et al.*, 2006). Ünlü *et al.* (2006) found that seasonal water use for drip-irrigated potato varied between 565 and 830 mm, depending on the irrigation regime, in Middle Anatolian (Niğde-Nevşehir District) conditions. Seasonal evapotranspiration of drip-irrigated potato obtained by Yavuz (2011) was 572 mm for a full irrigation treatment in Konya conditions. Ayas and Korukcu (2010) indicated that seasonal water use for potato ranged from 655 (fully irrigated) to 370 mm (deficit-irrigated) in Bursa conditions.

Yield and Yield Components

The results of the variance analyses (ANOVA) for the tuber yield and quality parameters such as the marketable tuber yield, mean weight, diameter, and size are presented in Table 5. The results for the total tuber yield and the marketable yield are given in Table 6. Additional data are presented in Table 7 to analyze the effects of the lateral spacing and the wetting factors on the yield and quality parameters separately.

The lateral spacing and the wetting factor had significant effects on the tuber yield and the quality parameters in both years (P< 0.01). The lateral spacing and wetting factor interactions also significantly affected the yield and yield parameters (P< 0.01) (Table 5).

In 2008, the tuber yields varied from 27.61 to 51.61 t ha^{-1} depending on the treatments (Table 6). The different lateral spacings and wetting factors had significant (P< 0.01) combined effects on the tuber yield, i.e., there was significant interaction between the two variables. At the same time, each of the lateral spacing and the wetting factor had a

Table 5. Mean squares from the variance analyses of the yield and yield components.

Source of variation	*df*	Tuber yield (t ha^{-1})	Marketable tuber yield (t ha^{-1})	Tuber number per plant (number plant^{-1}	Mean tuber weight (g)	Tuber diameter (mm)	Tuber size (mm)
2008 Year							
replications	2	0.471ns	0.082ns	0.044ns	9.591ns	16.952ns	7.109ns
Lateral spacing	1	732.81*	1816.036*	13.347*	29290.067*	1084.227*	5463.609*
(A)	2	203.16*	415.891*	1.721*	6603.11*	217.252*	1048.696*
Wetting factor	2	115.51*	194.552*	2.351*	3898.95*	148.767*	658.176*
(P)	10	1.14	2.923	0.093	69.481	11.096	49.128
A×P							
Error							
2009 Year							
replications	2	0.56ns	0.035ns	0.224ns	5.229ns	22.832ns	57.95ns
Lateral spacing	1	705.38*	1725.19*	14.58*	28480.889*	898.880*	5318.242*
(A)	2	174.63*	434.344*	2.967*	7325.107*	224.282*	1662.177*
Wetting factor	2	102.98*	202.207*	5.852*	5539.344*	179.295*	1069.161*
(P)	10	1.002	2.515	0.047	48.516	6.252	45.137
A×P							
Error							

ns: Letters indicates statistically insignificant according to *P*< 0.01 and *P*< 0.05. *: Letters indicate statistically significant according to *P*< 0.01

Table 6. The tuber yield and marketable yield according to years (2008 and 2009).

Treatments	Tuber yield (t ha^{-1})				Marketable tuber yield (t ha^{-1})			
	2008	2009	Mean	Relative tuber yield (%)	2008	2009	Mean	Relative mark. tuber yield (%)
A_1P_1	51.61a	50.12a	50.87	100.0	48.38a	46.45a	47.42	100.0
A_1P_2	40.47c	39.57b	40.02	78.7	27.63b	26.52b	27.08	57.1
A_1P_3	50.51a	49.22a	49.87	98.0	43.98a	44.02a	44.00	92.8
A_2P_1	43.83b	42.12b	42.98	84.5	29.85b	30.23b	30.04	63.4
A_2P_2	32.86d	32.08c	32.47	63.8	18.07c	16.50c	17.29	36.5
A_2P_3	27.61e	27.13d	27.37	53.8	11.81d	11.52d	11.67	24.6

Table 7. Yield and quality parameters according to the lateral spacing and wetting factor.

Treatments		Tuber yield t ha^{-1}	Marketable yield t ha^{-1}	Number of tuber for each Plant	Tuber diameter (mm)	Tuber size (mm)	Mean tuber weight (g)
2008 year							
Lateral spacing	A_1(0.7m)	47.53a	40.00a	6.3b	64.61a	106.9a	187.6a
	A_2(1.4m)	34.77b	19.91b	8.1a	49.09b	72.0b	107.0b
Wetting factor	P_1	47.72a	39.11a	6.6b	63.41a	103.2a	182.6a
	P_2	36.66c	22.85c	7.6a	51.60b	76.8b	116.8c
	P_3	39.06b	27.89b	7.4a	55.53b	88.3b	142.5b
2009 year							
Lateral spacing	A_1(0.7m)	46.30a	39.00a	6.21b	63.83a	105.11a	187.03a
	A_2(1.4m)	33.78b	19.42b	8.01a	49.70b	70.73b	107.48b
Wetted area percentage	P_1	46.12a	38.34a	6.30b	63.65a	103.90a	184.18a
	P_2	35.83c	21.51c	7.48a	51.97b	70.68c	114.72c
	P_3	38.18b	27.77b	7.55a	54.68b	89.18b	142.87b

[a and b]: Letters indicates significantly different according to $P< 0.01$

significant effect on the yield. The maximum tuber yield was obtained for treatment A_1P_1 in which the lateral spacing was 0.7 m and the wetting factor was 1.00. Treatment A_1P_3 produced a smaller yield of 50.51 t ha^{-1}, but was in the same statistical group (Duncan's multiple range test). It is notable that the total irrigation water amount applied to A_1P_1 (625 mm) was more than 26% higher than that applied to A_1P_3 (494 mm) (Table 4). In 2009, the obtained tuber yields ranged from 27.13 to 50.12 t ha^{-1}, depending on the treatments.

These results were similar to the findings obtained in 2008. Faberio *et al.* (2001) determined that 597 mm of irrigation water was required for a maximum tuber yield of 45.18 t ha^{-1} using drip irrigation in Albacete, Spain. Ünlü *et al*. (2006) reported that under drip irrigation tuber yields ranged from 40.9 to 46.0 t ha^{-1} in one of the two-year study in Middle Anatolia. Stylianou and Orphanos (1981) found detrimental effects of continuous wet conditions during growing period on the tuber yield and quality of early potato under similar environments in Cyprus. There were some inconsistencies, though, in regards to the effects of irrigation levels on potato yields under Mediterranean-type environments. Lerna *et al.* (2011) reported that tuber yields varied between 34.80 and 56.64 t ha^{-1}, depending on the irrigation regime, in Italy.

It is accepted that a marketable potato tuber should be larger than 40 mm in diameter (Yilmaz, 1993). Based on the average values for the two years, the highest marketable tuber yield obtained was 47.42 t

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ha^{-1} in the A_1P_1 treatment, where the lateral spacing was 0.7 m and the wetting factor was 1.00. The marketable tuber yields decreased for A_1P_2, A_1P_3, A_2P_1, A_2P_2 and A_2P_3 by 42.9, 7.2, 36.6, 63.5, and 75.4%, respectively, compared to A_1P_1 (Table 6).

Although equal amounts of irrigation water were applied in the A_1P_1 and A_2P_1 treatments in both years, the marketable tuber yield decreased by 36.6% for A_2P_1 where the lateral spacing was 1.4 m compared to the A_1P_1 treatment where the lateral spacing was 0.7 m. Yavuz (2011) also reported similar findings in Konya conditions. The treatments where the lateral spacing was 1.4 m produced lower marketable tuber yields compared to the treatments where the lateral spacing was 0.7 m (Figure 2).

The number of tubers per plant was significantly affected by the lateral spacing, the wetting factor and the interactions of the lateral spacing and the wetting factor in both years (Table 5). In 2008 and 2009, the highest tuber numbers per plant were 8.1 and 8.0, respectively, and those were obtained for A_2 treatments in which the lateral spacing was 1.4 m. Similarly, Yavuz

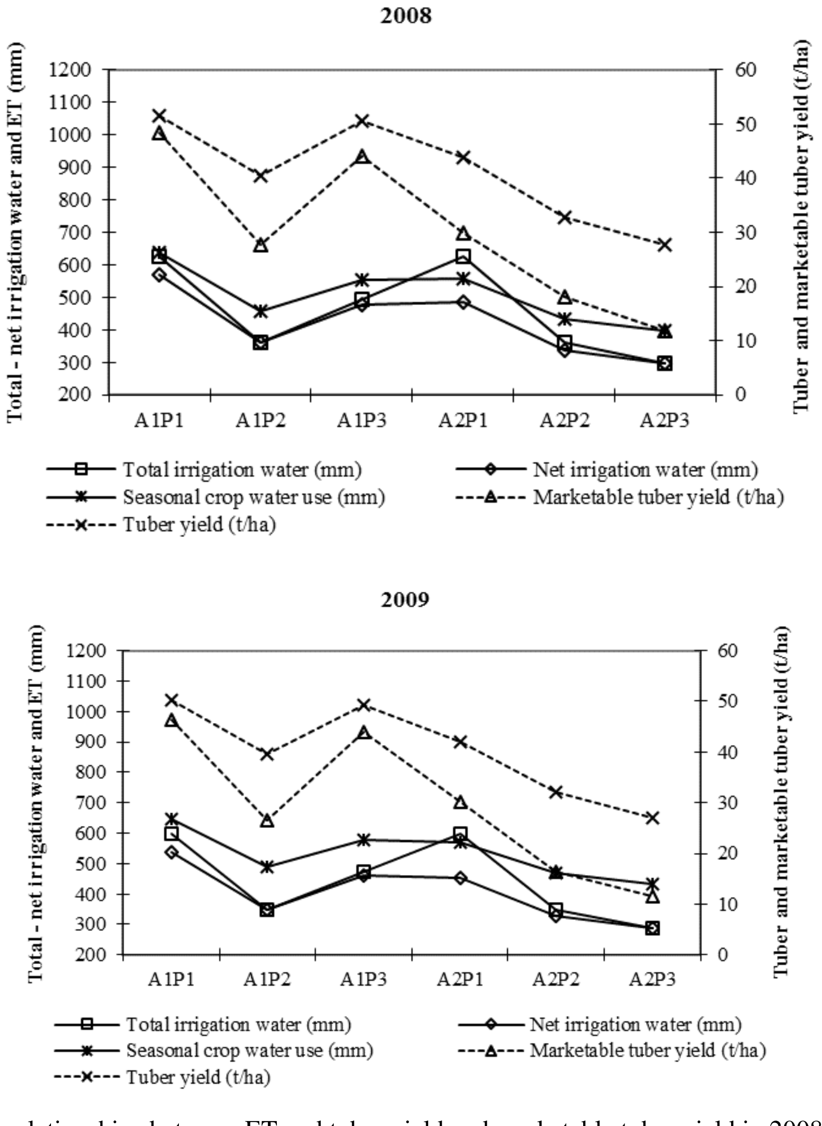

Figure 2. The relationships between ET and tuber yield and marketable tuber yield in 2008 and 2009.

(2011) obtained the highest number of tuber per plant at 1.4 m lateral spacing in Middle Anatolia. Walworth and Carling (2002) suggested that the differences in the numbers of tubers per plant could be attributed to the cultivar differences as well as to the environmental conditions such as soil and climate conditions.

As can be seen from Table 7, in 2008, the tuber yields fell into two different groups, consistent with the lateral spacing. While the plots in the first group (a), with the 0.7 m lateral spacing (A_1), produced an average yield of 47.53 t ha^{-1}, the plots in the second group (b), with the 1.4 m lateral spacing (A_2), produced an average yield of 34.77 t ha^{-1}, a decrease of 27.4%. When the data were arranged by the wetting factors, 1.00 wetting factor (P_1) treatments were in the first group (a) with an average yield of 47.72 t ha^{-1}, and the percentage of wetting area (P_3) treatments were in the second group (b) with an average yield of 39.06 t ha^{-1}. In 2009, two different groups were also formed based on the lateral spacing. While the plots with the 0.7 m lateral spacing were in the first group (a) and produced on average 46.30 t ha^{-1}, the 1.4 m lateral-spaced experimental plots were in the second group (b) with an average yield of 33.78 t ha^{-1}. Similar results were also obtained for the marketable yield values. Thus, it is obvious that the lateral spacing and wetting factor applications had important effects on potato grown under drip irrigation.

Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE)

Based on the average values for the two years, the highest *WUE* and *IWUE* calculated were 7.78 and 9.40 kg m^{-3}, respectively, in the A_1P_3 treatment in which the lateral spacing was 0.7 m and the wetting factor was 0.75. The lowest average *WUE* and *IWUE* obtained were 2.81 and 3.99 kg m^{-3}, respectively, in the A_2P_3 treatment in which the lateral spacing was 1.4 m. Generally, the *WUE* and *IWUE* values of the A_1 treatments were higher than those of the A_2 treatments (Figure 3). The *IWUE* values were higher than the *WUE* values. The differences can be attributed to the water used from soil storage, deep percolation, and rainfall received during the growing seasons.

Doorenbos and Kassam (1979) reported that the *WUE* values for irrigated potato crops in humid and semi-tropical areas were 4–7 kg m^{-3}. Wright and Stark (1990) noticed that *WUE* of potato crops varied between 5.4 and 12.0 kg m^{-3}, depending on the region, irrigation program, amount of fertilizers, and production techniques. Fabeiro *et al*. (2001) reported *WUE* values between 6.3 and 8.6

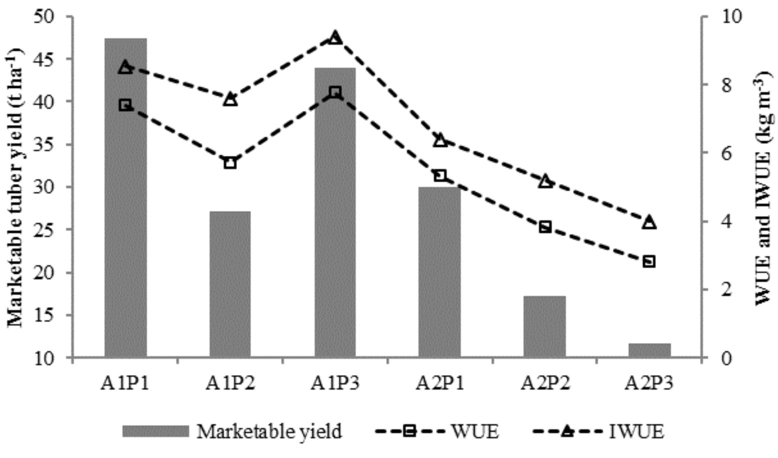

Figure 3. Variations of marketable tuber yield, *WUE* and *IWUE* according to the treatments (average across years).

kg m^{-3} for trickle-irrigated potato crops in Spain. Yuan *et al*. (2003) obtained *WUE* of 3.15–3.73 kg m^{-3} for high-frequency drip-irrigated potato crops, and Panigrahi *et al*. (2001) found *WUE* of potato crops irrigated by a furrow method with double planting to be 4.54 and 4.66 kg m^{-3}. Yavuz *et al*. (2012) reported *WUE* and *IWUE* values of 7.51 and 8.32 kg m^{-3}, respectively, for drip-irrigated potato crops in Middle Anatolia.

Economic Analysis and Evaluation

According to the economic calculation and evaluation, the highest net income, equivalent to \$ 4,041 ha^{-1}, was obtained for the treatment in which the lateral spacing was 0.7 m and the wetting factor was 1.00 (A_1P_1). Similarly, Onder *et al.* (2005) found that the maximum net income for drip-irrigated potato was \$3,506 ha^{-1}, depending on the irrigation treatments. The treatment in which the lateral spacing was 0.7 m and the wetting factor was based on soil properties (A_1P_3) resulted in a net income of \$3,464 ha^{-1} and was ranked second among the treatments. It is noted that there was a significant difference in terms of the net income between these two treatments (A_1P_1 and A_1P_3) and the rest, which resulted in significantly less income (Figure 4).

The annual costs of the drip systems were calculated to be \$607 and \$388 ha^{-1} for lateral spacings of 0.7 and 1.4 m, respectively. Compared to the treatments in which the lateral spacing was 0.7 m, the annual costs of the irrigation systems for those in which the lateral spacing was 1.4 m were 36% lower. However, the net income for the treatments in which the lateral spacing was 0.7 m was considerably higher because the latter treatments produced higher marketable tuber yields. These results revealed that one lateral for two crop rows resulted in less income than one lateral for each crop row of drip-irrigated marketable potatoes.

As a result, placing one lateral for a pair of rows to save on costs of the drip irrigation system resulted in less net productivity or net income per year. On the other hand, per ha expenditures are high for drip irrigation systems. However, initial investment costs can be amortized over an expected lifetime of the drip systems.

CONCLUSIONS

In this study, one lateral for each plant row and one lateral for two plant rows were used for drip irrigation, and the effects of these applications on the water use, yield, and quality parameters of potato were investigated to determine whether it was necessary to increase the lateral spacing for potato cultivation.

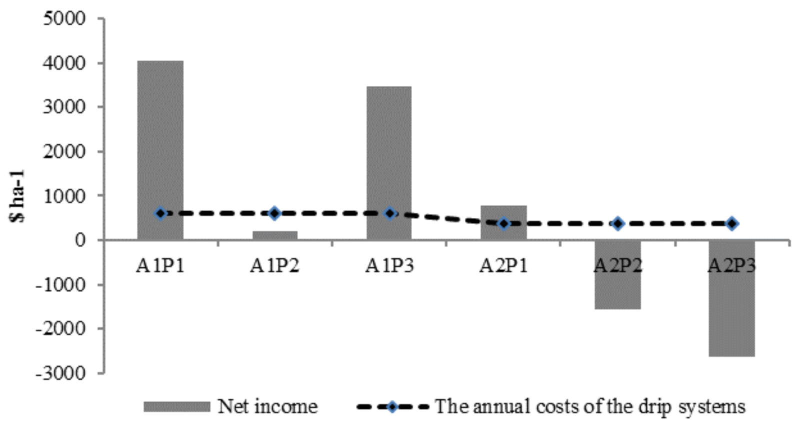

Figure 4. The economic analysis of the treatments (average of 2008 and 2009).

One of the most significant aspects of the drip irrigation method is high water application efficiency. When one lateral was used for two crop rows, the water application efficiency was reduced due to high deep percolation. The highest *WUE* and *IWUE* calculated were 7.78 and 9.40 kg m^{-3}, respectively, in the A_1P_3 treatment in which the lateral spacing was 0.7 m and the wetting factor was 0.75 as determined in accordance with the lateral spacing and soil properties. These values could be used as a good basis for irrigation strategy development for semi-arid regions where irrigation water supplies are limited. The investment costs for the design of one lateral for two crop rows were 36% lower because the lengths of the laterals were shorter compared to the design of one lateral for each crop row. The yield obtained was, however, also lower in the former case compared to the latter.

As a result of this two-year field study, it can be concluded that one lateral design for each two crop rows is not beneficial in terms of both marketable yield and *WUE* compared to one lateral design for each crop row in potato production under Middle Anatolian conditions. Also, a wetting factor should be determined based on soil and irrigation system properties to obtain irrigation water savings.

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طراحی و مدیریت سامانه آبیاری قطره ای برای عملکرد بهینه سیب زمینی

د. یاووز، ن. یاووز و س. سوهری

چکیده

هدف این پژوهش تعیین اثر فاصله لوله های فرعی (لترال) و ضریب سطح خیسی روی عملکرد و اجزای عملکرد سیب زمینی زیر آبیاری قطره ای در شرایط آب وهوایی آناتولی وسطا در ناحیه Konya در ترکیه بود. پژوهش در فصل زراعی سال های ۲۰۰۸ و ۲۰۰۹ انجام شد و در آن از سیب زمینی رقم Russet Burbankاستفاده شد. تیمارهای طراحی آبیاری شامل بود بر دو فاصله لوله های

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فرعی (A_1=0.7 mو A_2=1.4 m) و سه ضریب سطح خیسی (P_1=1، P_2 =۰/۵، و P_3که در صد متغییری بود از سطح خیس شده بر حسب فاصله لوله های فرعی). نتایج نشان داد که حجم کل آب آبیاری بین ۲۹۷ و ۶۲۵ میلی متر در سال ۲۰۰۸ و بین ۲۸۸ و ۵۹۸ میلی متردر سال ۲۰۰۹ بود. با در نظر گرفتن میانگین عملکرد ها در دو سال، بیشترین عملکرد غده (۵۰/۸۷ تن در هکتار) از تیمار A_1P_1 و کمترین عملکرد (۲۷/۳۷ تن در هکتار) در تیمار A_2P_3 به دست آمد. نتیجه گیری شد که فواصل مختلف لوله های فرعی و ضرایب سطح خیسی از نظر آماری ($P<0.01$)روی میانگین وزن غده، تعداد غده در بوته، قطر غده، اندازه بوته، و عملکرد بازارپسند غده تاثیر گذار بود. همچنین، بالاترین راندمان کاربرد آب (WUE) و راندمان کاربرد آب آبیاری (IWUE) به ترتیب برابر ۷/۷۸ و ۹/۴۰ کیلوگرم بر متر مکعب برای تیمار A_1P_3محاسبه شد. نیز، در سیب زمینی آبیاری شده با روش قطره ای، طراحی یک خط لوله فرعی برای دو ردیف کاشت درمقایسه با یک خط لوله برای هر ردیف کاشت منجر به درآمد کمتری شد.

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