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Potato (*Solanum tuberosum* L.) Response to Drip Irrigation Regimes and Plant Arrangements during Growth Periods

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Abstract: A field experiment comparing different drip irrigation regimes and plant arrangements on potato yield and its component, leaf, stem and total dry matters, harvest index and water-use efficiency was carried out in a clay soil. This study was carried out on the experimental Farm of Ardebil Agriculture Research Station in 2006. The experiment included three treatments for different drip irrigation regimes: I1 (full irrigation), I2 (80% of full irrigation), I3 (60% of full irrigation) and three treatments for plant arrangements: conventional cultivation (P1), two rows 35 (P2) and 45 (P3) cm apart on a wide bed 150 cm. Results indicate that both drip irrigation regimes and plant arrangements didn't influence the harvest index. In all varieties, I1, I2 and I3 produced the lowest amounts, respectively. Plant arrangement hadn't significant impress on tuber yield, numbers and average weight of tubers. P3 and P2 treatments produced maximum and minimum values in more characteristics. The yield of tuber, leaf, stem, total and harvest index indicated increasing trend during the harvest times and only the stem and leaf yield decreased at the two final harvests. In most variables interaction effect of the (I1×P3) generated. Accumulative amounts of reference and 100, 80 and 60% crop evapo-transpiration (EP) were 782.2, 627.6, 502.0 and 376.5, respectively. Water Use Efficiency (WUE) with increase water supply improved. Treatment of I1×P3 had the highest WUE. Its values during growth period increased and maximum WUE obtained at 109 Day after Planting (DAP).

Key words: Potato (*Solanum tuberosum* L.), wet tuber yield, tuber number, leaf dry weight, harvest index, WUE

INTRODUCTION

Potato (*Solanum tuberosum* L.) rate fourth among the world's various agricultural products in production volume, after wheat, rice and corn (Fabeiro *et al*., 2001). Production of potato (*Solanum tuberosum* L.) takes a very important place in world agriculture, with a production potential of about 327 million tons harvested and 18.6 million hectares planted area (FAO, 2006). It is a temperate crop (Onder *et al*., 2005) that grows and yields well in cool and humid climates or seasons, yet it is grown in climatic regions from the tropics to the sub-polar and comprises a major food crop in many countries. The ideal conditions for potato growth include high and nearly constant soil matric potential, high soil oxygen diffusion rate, adequate incoming radiation and optimal soil nutrients (Yuan *et al*., 2003). In natural environment plants are subjected to many stresses that can have negative effect on growth and yield. Biotic and abiotic factors affect the growth of higher plants. Among these, drought is a major abiotic factor that limits agricultural crop production (Reddy *et al*., 2004). Global warming, which causes fluctuations of precipitation distribution, could increase the risk of plants being exposed repeatedly to drought (Miyashita *et al*., 2005). The frequency of water limitation stress is likely to increase in the future, even outside today's arid/semi-arid regions (Chaves *et al*., 2002). Many irrigation experiments have shown that potato is relatively sensitive to moisture stress (Fabeiro *et al*., 2001; Yuan *et al*., 2003). But many other studies reported that potatoes are very sensitive to soil moisture stress (Kashyap and Panda, 2003; Onder *et al*., 2005) due to their sparse and shallow root system. 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

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irrigation programs throughout the growing season (Chowdhury *et al*., 2001; Panigrahi *et al*., 2001; Ferreira and Carr, 2002). Most researchers reporting on the influence of water stress on potato yield do so in terms of its effect on aerial parts (Jefferies and MacKerron, 1987; Deblonde *et al*., 1999; Lahlou *et al*., 2003). In recent years, cost of installation has relatively decreased with improving technology. Also, the use of drip irrigation has been increased in most crop commodities, mainly for vegetables and fruits, to improve water use efficiency and nutrition supply. Nowadays, surface drip irrigation is also under evaluation to improve water use efficiency since water is getting scarcer and more valuable year by year. Various techniques such as furrow irrigation, drip irrigation (Yuan *et al*., 2003) and macro-sprinklers were studied. Yield reduction was reported in these cases, as well as modest water saving. Water at 3-5 mm day^{-1} is necessary for Evapo-Transpiration (ET) and maintenance of optimal soil moisture tension (10-50 kPa) in growing potatoes (Marutani and Cruz, 1989). The maximum measured daily ET of potato crop was found to be 4.24 mm day^{-1} by a weighing type lysimeter in a sub-humid region in India (Kashyap and Panda, 2001). Under a hot and dry climate in northeastern Portugal, peak ET rates reached 12-13 mm day^{-1} on days immediately following irrigation, but then declined logarithmically by the time to about 3 mm per day within 5 days (Ferreira and Carr, 2002). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production. On the other hand, the intensity of the operation requires that the water supply be kept at the optimum level to maximum returns to the farmer. High-frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant and maintains a high soil matric potential in the rhizosphere to reduce plant water stress (Phene and Sanders, 1976). Effects of water stress on potato crop were studied by many researchers. But information about plant arrangement is very little.

The aims of this study were the effect of drip irrigation regimes, plant arrangements and special their interactions on yield, growth and water use efficiency of the potato (*Solanum tuberosum* L.) plant during growth periods.

MATERIALS AND METHODS

This study was carried out on the experimental Farm of Ardebil Agriculture Research Station (48°15' E and 38° 15' W) in 2006. The soil at the experimental area has clay texture. Feature of experimental field soil has shown in Table 1. Ardebil plain has a typical semi-arid climate conditions with good rainfall in earliest of springs, hot-dry summers and cold-snowy winters. The field experiment consisted of three drip irrigation regimes and three plant arrangements. In the experimental design, drip irrigation regimes were the main plots replicated 3 times and three plant arrangements were split plots within the main plots. Drip irrigation regimes were arranged in randomized complete block design and consisted of: full irrigation (I1), 80% of full irrigation (I2) and 60% of full irrigation (I3). Plant arrangements were: one row 75 cm apart on a 75 cm bed (Furrow to furrow or conventional) (P1), two rows 35 cm apart on a 150 cm wide bed (Furrow to furrow) (P2) and two rows 45 cm apart on a 150 cm wide bed (Furrow to furrow) (P3). Each plot consisted of 6 rows with 4.5 m width and 12 m long. Irrigation level treatments were based on the application of the amount of water at full irrigation treatment (I1). Plant population was 5.3 plants m^{-2}. The irrigation was started at the end of the rainfall period in spring and plots were irrigated at 3-4 days intervals. For surface drip irrigation T-Tape tubes with holes of 30 cm apart, 1.2 L ha^{-1} flow rate and 16 mm diameter was used. Tubers of Agria potato were hand planted at the depth of 10 cm (Jamaati-e-Somarin *et al*., 2009) with 25 cm apart in rows on May 20. In tow rows plots a single T-Tape tube was installed just at the middle of tow rows, but in one row plots tubes were installed on one side of each hill. Type and amounts of fertilizers used in this study were with regard to soil test from 0 to 30 cm depth. All of the other cultural practices that were used throughout the growing season were typical of those that were practiced by regular farmers. In order to calculate different variables, in each harvest, 53, 62, 73, 88, 98, 109 DAP, 5 plants with regard to border effect were harvested (Jamaati-e-Somarin *et al*., 2008). First and last samples harvested at development and late-season stages, respectively. The others harvested at mid-season stage. Then, wet and dry tuber yield, tuber numbers, tuber average weight, leaf and stem dry weight m^2 determined (Jamaati-e-Somarin *et al*., 2009) at Central Laboratory of

Table 1: Features of experimental field soil

Ece (dS m^{-1})	pH	sp	$CaCO_3$ (%)	N (%)	P	K	Clay	Silt	Sand	ZN	Fe	Mn	Cu
					----(ppm)-----		----------------(%)--------------			----------------(mg kg^{-1})---------------			
1.5	7.8	45	8.3	0.8	4.12	520	32	28	40	0.64	6.5	16.8	4.96

Mohaghegh Ardebili Agricultural College. Tubers weighted with weighting machine with precise of 0.01 g. Tubers with size of about larger than 1 cm counted (Onder *et al*., 2005). Tubers, stems and leaves separately dried within a period of 48 h at 75 centigrade degree in ovens to measurement of their dry weight (Jamaati-e-Somarin *et al*., 2009). Total dry weight consisted of sum leaves, stems and tubers dry weight (Shahnazari *et al*., 2007; Katerji *et al*., 2008).

$$\text{Harvest index (HI)} = \frac{(\text{Tuber dry weight})}{(\text{Tuber dry weight + Top dry weight})}$$

$$\text{WUE (kg mm}^{-1}) = \frac{\text{Fresh tuber yield}}{\text{Water consumption}}$$

All data were statistically analyzed and the means were compared using Software SAS and all tables were drawn using Software Microsoft Office, Excel. The means were compared by Duncan test at the level of 5%.

RESULTS

Analysis of variables, main effects, interaction of (I×P) have shown in Table 3-5, respectively.

Weather conditions and evapo-transpiration: Weather data were collected from a weather station located at approximately near the experimental field. Average rainfall for growth stages, initial, development, mid-season and late-season, were 2.35, 0.09, 0.77 and 0 mm, respectively. Mean air temperature for growth stages shown in Table 2. Its values were 13.8, 17.1, 18.5 and 17.6 celsius for initial, development, mid-season and late-season, respectively. Reference crop evapo-transpiration (ET_0) was calculated on average of 10 days basis by using Penman-Monteith's semi-empirical formula. Evapo-transpiration amounts were 156.6, 303.3, 186 and 135.3 for different growth stages. Potato is about 130 day's duration crop and may be divided into 4 stages namely:

- **Initial:** 1-25 days
- **Developmental:** 26-55 days
- **Mid-season:** 56-100 days
- **Tuber late-season:** 101-130 days

The actual evapo-transpiration was estimated by multiplying reference evapo-transpiration with crop coefficient ($ET = ET_0 \times K_C$) for different crop growth stages and weather data. The crop coefficient during the crop season was adopted as 0.45, 0.75, 1.15 and 0.85 at initial,developmental, mid-season and late-season stages, respectively. Crop evapo-transpiration for full irrigation (100%) were 70.5, 227.1, 215 and 115 at different growth stages. The 80 and 60% of crop evapo-transpiration were measured by multiplying 100% of crop evapo-transpiration with 0.8 and 0.6, respectively. The frequency of irrigation during this period was 3-4 days. Highest reference and crop evapo-transpiration obtained at crop development stage in which crops growth rapidly and occasionally named as rapid growth stage. For better use of water source it is essential that we must use the best approaches. Accumulative amounts of reference and 100, 80 and 60% crop evapo-transpiration were 782.2, 627.6, 502.0 and 376.5, respectively. So, use of K_C led to near 20% in saved water. In earlier initial stage amounts of

Table 2: Weather data and evapo-transpiration during potato growth stages

						Etc (%)		
Days after planting	Growth stages	Average rainfall	Average demperature	Kc	ETo	100	80	60
1-25	Initial	2.35	13.8	0.45	156.6	70.5	56.4	42.3
26-55	Development	0.09	17.1	0.75	303.4	227.1	181.6	136.2
56-100	Mid-season	0.77	18.5	1.15	186.0	215.0	172.0	129.0
101-130	Late-season	0.00	17.6	0.85	135.3	115.0	92.0	69.0

Table 3: Analysis of variables

Source of variation	Degree of freedom	Wet tuber yield	Dry tuber yield	Tuber No.	Average tuber weight	WUE	Leaf dry weight	Stem dry weight	Total dry weight	Harvest index
Replication	2	2.710	0.1300	2944.63	5286.16	0.0000740	0.01057	0.002849	0.2188	492.11
Irrigation (A)	2	9.810**	0.8230**	47.84	6936.55**	0.0000980**	0.01430**	0.003582**	1.1800**	263.86
Experimental error (1)	4	0.120	0.0280	90.53	456.54	0.0000020	0.00091	0.000172	0.0379	88.81
Cultivation pattern (B)	2	1.510	0.0530**	164.32	168.95	0.0000150**	0.00372**	0.002021**	0.1102**	46.31
A×B	4	0.600**	0.0250**	263.32**	980.62*	0.0000079*	0.00060*	0.000362**	0.0274**	210.98
Experimental error (2)	12	0.500	0.0170	129.76	165.16	0.0000043	0.00068	0.000280	0.0252	28.63
Sampling times (C)	5	51.620**	3.3590**	1003.52**	27576.61**	0.0001650**	0.01983**	0.003677**	3.6997**	7668.04**
A×C	10	1.220**	0.0770**	42.63	238.01*	0.0000067*	0.00131**	0.000259**	0.0983**	91.13
B×C	10	0.150	0.0045	42.25	254.77	0.0000099	0.00042	0.000061	0.0054	47.22
A×B×C	10	0.130	0.0043	46.03	300.30	0.0000017	0.00017	0.000071	0.0044	55.64
Experimental error (3)	90	0.107	0.0051	63.23	297.71	0.0000027	0.00042	0.000085	0.0067	67.73
Coefficient of variation (%)		14.650	14.3900	24.00	25.90	21.0000000	21.14000	21.210000	12.9000	11.61

*p = 0.01, **p = 0.05

Table 4: Effect of variants (irrigation amounts, plant arrangement and sampling times) on variables

Variables	Wet tuber yield	Dry tuber yield	Tuber No.	Average tuber weight	WUE	Leaf dry weight	Stem dry weight	Total dry weight	Harvest index
Irrigation amounts									
100%	2.69a	0.63a	33.89a	78.83a	0.00908a	0.1150a	0.052a	0.80a	71.69a
80%	2.19b	0.46b	33.39a	64.23b	0.00754b	0.0920b	0.040b	0.59b	68.77a
60%	1.84c	0.39b	32.07a	56.52b	0.00536c	0.0840b	0.037b	0.51b	67.36a
Plant arrangements									
75 (cm)	2.148a	0.48ab	32.20a	65.13a	0.00748ab	0.0960ab	0.044a	0.62ab	68.31a
35 (cm)	2.142a	0.47b	32.02a	65.93a	0.00725b	0.0900b	0.036b	0.60b	70.18a
45 (cm)	2.435a	0.53a	35.13a	68.52a	0.00827a	0.0106a	0.049a	0.68a	69.31a
Sampling times (DAP)									
53	0.51f	0.07f	23.69c	27.15d	0.00428e	0.0580e	0.023d	0.16f	45.47f
62	0.94e	0.16e	28.11b	35.87d	0.00528d	0.0920c	0.036c	0.29e	54.00e
73	1.83d	0.36d	35.16a	54.45c	0.00770c	0.1160b	0.049ab	0.53d	68.14d
88	2.74c	0.60c	35.16a	81.87b	0.00898b	0.1270a	0.054a	0.78c	76.35c
98	3.38b	0.79b	36.04a	97.98a	0.00963ab	0.0115b	0.052a	0.96b	82.66b
109	4.02a	0.96a	35.54a	101.82a	0.01016a	0.0074d	0.045b	1.08a	89.01a

Values with different letter(s) are significantly different

Table 5: Interaction effect of irrigation amounts with plant arrangement on variables

Treatments	Wet tuber yield	Dry tuber yield	Tuber No.	Average tuber weight	WUE	Leaf dry weight	Stem dry weight	Total dry weight	Harvest index
100%-75 cm	2.545ab	0.59abc	31.62bc	79.45ab	0.00879ab	0.118ab	0.057a	0.766ab	67.24a
100%-35 cm	2.50ab	0.61ab	36.97ab	69.23bc	0.00840cb	0.102bcd	0.040bc	0.762abc	75.14a
100%-45 cm	3.01a	0.68a	33.07abc	87.81a	0.01000a	0.127a	0.060a	0.877a	72.69a
80%-75 cm	1.96b	0.43bc	33.66bc	59.45cd	0.00678d	0.087de	0.040bc	0.561bcd	67.60a
80%-35 cm	2.14ab	0.44bc	29.30c	69.34bc	0.0730cd	0.058e	0.035c	0.562bcd	68.22a
80%-45 cm	2.46ab	0.51abc	39.22a	63.9cb	0.00853bc	0.104bc	0.045b	0.667abcd	70.49a
60%-75 cm	1.93b	0.42bc	33.30abc	56.49d	0.00688d	0.083de	0.036c	0.546bcd	70.15a
60%-35 cm	1.77b	0.36c	29.80c	59.22cd	0.00606d	0.082de	0.034c	0.477d	67.18a
60%-45 cm	1.82b	0.39bc	33.10abc	53.84d	0.00623d	0.088cde	0.041c	0.519cd	67.75a

Values with different letter(s) are significantly different

rainfall met the crop requirements for water. Thus, on many days irrigation wasn't necessity at this stage. Hence, 100, 80 and 60% crop evapo-transpiration in initial stage become 21.5, 17.2 and 12.9 mm. Therefore, consumption economy was approximately 30%. In late of late-season stage crops didn't irrigated to ensure that the potato tubers skin well-made. Thereupon, 100, 80 and 60% crop evapo-transpiration in late-season stage become 45, 36 and 27 mm, respectively. Amounts of saved water for late-season stage become about 39%.

Wet and dry tuber yield per one square meter: Tuber yields were significantly influenced by irrigation amounts, plant arrangements, their interactions, sampling times and interaction of irrigation amounts×plant arrangement (Table 3). Irrigation amounts extremely impressed wet tuber yield. Increase in irrigation amounts led to increase in wet tuber yield. 100, 80 and 60% of full irrigation produced 2.69, 2.19 and 1.84 kg m^{-2}, respectively. Dry tuber yield for full irrigation significantly was greater than other irrigation treatments. Dry tuber yield between 80 and 60% of full irrigation were insignificant. All 3 irrigation amounts had noticeable effect on wet tuber yield. Plant arrangement didn't have considerable effect on wet tuber yield. But its effect on dry tuber yield was significant. Plant arrangement of P3 produced highest tuber yield and P1 and P2 lain at subsequent places, respectively. At different harvest times wet and dry tuber yield were significant. Tuber yields extremely increased from first harvest to last harvest. Therefore, maximum and minimum yield obtained at first and late harvest, respectively. Trend of both wet and dry tuber yield during harvest times ware the same (Table 4). Interaction effects of plant arrangements and irrigation amounts have shown in Table 5. Highest wet tuber yield produced at interaction effect of (I1×P3) plant arrangement. Lowest wet tuber yield pertained to interaction effect of I3 with all plant arrangements and (I2×P1). Maximum and minimum dry tuber yield obtained at interaction effect of (I1×P3) and (I3×P2). Therefore, treatment with highest wet tuber yield, (I1×P3), produced greatest dry tuber yield. Plant arrangement of P3 was superior to the others at full irrigation and moderate deficit (I2) but at 60% deficit irrigation plant arrangement of P1 produced more yield. Irrigation amounts and harvest times interaction effects on wet and dry tuber yield were shown in Fig. 1 and 2, respectively. 100, 80 and 60% of full irrigation produced lowest wet and dry tuber yield during harvest times, respectively. The figures showed that wet and dry tuber yield linearly increased during growth period. Slope of linear regressions for 100, 80 and 60% full irrigation were 0.92, 0.72 and 0.55, respectively (Fig. 1). Dry tuber yield slope of linear regressions for 100, 80 and 60% of full irrigation were 0.23, 0.17 and 0.14, respectively (Fig. 2).

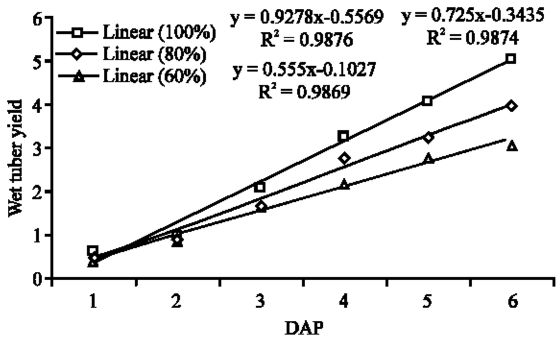

Fig. 1: Interaction effect of irrigation amounts with plant arrangement on wet tuber yield

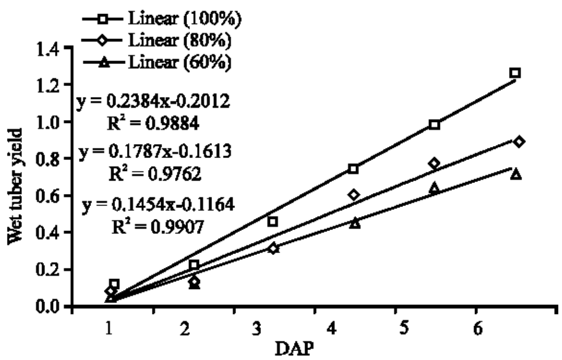

Fig. 2: Interaction effect of irrigation amounts with plant arrangement on dry tuber yield

Lower slope is indication of lower yield. Responses of wet and dry tuber yield were linear to full and deficit irrigation during growth stages.

Tuber number per one square meter: There were no statistically significant effect on irrigation amounts and plant arrangement treatments on tuber numbers. Tuber numbers significantly increased during harvest times (Table 4). Maximum tuber number belonged to 53 days after planting. Tuber numbers were significantly increased from 53 to 73 days after planting but there haven't important differences from 73 to 109 days after planting. Interaction effect of plant arrangement with irrigation treatments (Table 5) indicated that greatest tuber numbers gained at (I2×P3) treatment. Treatments of (I2×P2) and (I3×P2) produced the lowest tuber numbers. At 100, 80 and 60% of full irrigations, plant arrangements of P2, P3 and P1 produced more tuber number, respectively.

Average single tuber weight: Effects of water stress, irrigation amounts×plant arrangement interaction, I×sampling times interaction and sampling times were significant on average single tuber weight. Full irrigation

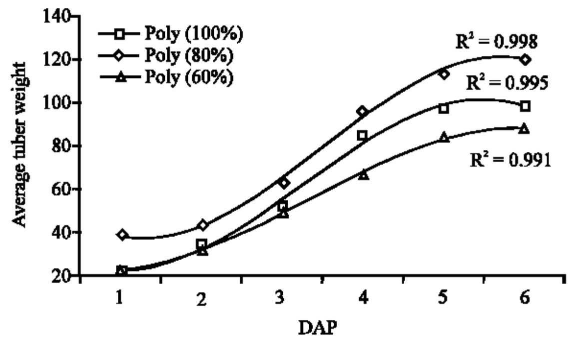

Fig. 3: Interaction effect of irrigation amounts with plant arrangement on average tuber weight

significantly had the highest mean tuber weight than others. The 80 and 60% of full irrigation couldn't affect mean weight of single tuber. Single tuber weight increased during growth period. The 98 and 109 days after planting achieved maximum single tuber weight and both 53 and 62 days after planting obtained lowest tuber weight. The period from 62 to 98 days after planting belonged to tuber bulking stage. Thereupon, the most increase in tuber weight occurred in this period. Interaction effect of (I×P) shown in Table 5. Highest mean tuber weight obtained at treatments of (I1×P3). Treatments of (I3×P1) and (I3×P3) produced lowest mean tuber weight. At full irrigation, 80 and 60% of full irrigation plant arrangements of P3, P2 and P2 yielded more tuber weight, respectively. Interaction effect of irrigation with plant arrangement was shown in Fig. 3. Changes of single tuber weight curve followed from polynomial function with 3 degrees. Maximum enlargement of tubers occurred in 62 to 98 days after planting. Decline of curves happened in last harvest for all three curves. Deficit irrigations hadn't difference at two first harvests but 80% of full irrigation was superior to 60% of full irrigation in the other harvests. Full irrigation in all harvests was of the highest rank than deficit irrigations.

Water use efficiency: Effects of irrigation amounts, plant arrangement, their interaction, sampling times and interaction effect of sampling times with irrigation amounts on water use efficiency were significant. In order to determine water use efficiency wet tuber yield per one square meter divided to amount of irrigation that applied to different plots during growth period. Trend of water use efficiency under irrigation amounts was the same as wet tuber yield. The level of irrigation amounts in which wet tuber yield was higher led to maximum water use efficiency. Irrigation amounts of 100, 80 and 60% gained 0.0098, 0.00754 and 0.00536 g wet tuber yield per one mm irrigation in one meter square, respectively. Plant arrangement of P3 and P2 obtained highest and lowest water use efficiency and treatment of P1 was mediocre. Effects of plant arrangement on water use efficiency were similar to dry tuber yield. Water use efficiency during growth period importantly increased. Lowest and highest water use efficiency gained at 53 and 109 days after planting, respectively. The 109 with 98 and 88 with 98 days after planting were in same groups. Therefore, increase in water use efficiency at the end of the mid-season and late-season was retarded. But WUE from 53 to 88 days after planting sharply enlarged. Interaction effect of (I×P) exhibited in Table 5. Treatment of (I1×P3) acquired peak WUE. Lowest degrees of WUE earned at (I2×P1) and interaction effect of I3 with all plant arrangements. This tendency is comparable with trend of wet tuber yield (Table 4). Interaction effect of (I×P) was exhibited in Fig. 4. Full irrigation was excellent to deficit irrigations. With increase in water stress water use efficiency decreased in all harvests. At full irrigation WUE up to 98 days after planting increased. Then decline of WUE occurred. For deficit irrigations of 80 and 60% increasing of WUE were seen up to 88 days after planting and afterwards decrease in WUE occurred but the slope of curve for 80% was more than 60% of full irrigation.

Leaf, stem, total dry weight and harvest index: The leaf, stem and total dry weight influenced by different drip irrigation regimes. Full irrigation meaningfully produced higher dry yield than deficit irrigation treatments in the three characteristic. Treatments of I2 and I3 placed in second rank and hadn't importance difference together (Table 4). Highest leaves dry weight obtained at plant arrangement of P3 and lowest amount gained at P2 plant arrangement. Conventional plant arrangement had mediocre leaf weight. The trend of total dry weight under different plant arrangements was similar to leaf dry weight. Plant arrangement of P1 and P3 importantly produced highest stem biomass than P2 treatment but difference between P1 and P3 wasn't significant. Influence of plant arrangement on tuber, leaf and total dry yield were similar. Leaf dry yield increased during growth periods up to 88 days after planting. Afterwards decreasing of its yield happened at 98 and 109 days after planting and reached to amount of leaf dry weight which belonged to 73 days after planting. Stem dry weight during harvest times from 53 to 88 days after planting increased then decline of its dry weight happened at 98 and 109 DAP. From 73 to 98 DAP stem dry yield hadn't much difference. So, maximum stem dry weights produced at 73 DAP and afterwards its biomass approximately was stable. Total biomasses during sampling times from 53 to 109 DAP extremely multiplied. Lowest and highest total biomass produced at 53 and 109 days after planting, respectively. This trend is similar to tuber yield. Interaction effect of irrigation amounts with plant arrangement was shown at Table 5. Maximum and minimum leaf dry weight gained at (I1×P3) and (I2×P2) treatments, respectively. Highest stem dry weight achieved at (I1×P1) plus (I1×P3) and interaction effect of I3 with all plant arrangements plus (I2×P2) produced lowest stem dry yield. The most total dry weight produced at (I1×P3) and treatment of (I3×P2) acquired least the yield. Growth trend of leaf dry weight and stem dry weight during growth period were shown in Fig. 5 and 6. During harvest times leaf dry weight increased at all three irrigation treatments and highest leaf dry weight obtained at 88 days after planting. During growth stages, from 53 to 88 days after planting, leaf biomass increased but then its biomass decreased. The decreases were result of leaves fall. Full irrigation had visible difference with deficit irrigations. At 80% full irrigation was superior to 60% full irrigation at two initial sampling times and at two late sampling times. Protection of leaves at 80% full irrigation than 60% full irrigation at the end of the season could be a sign of more tuber yield of 80% irrigation. Growth trend of stem biomass under irrigation amounts and during harvest times is similar to

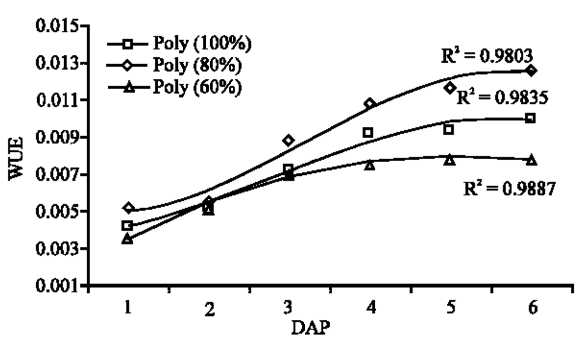

Fig. 4: Interaction effect of irrigation amounts with plant arrangement on WUE

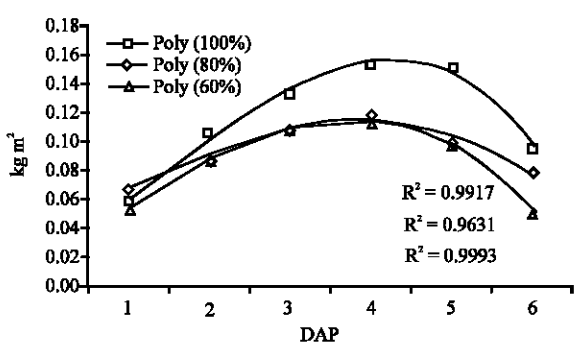

Fig. 5: Interaction effect of irrigation amounts with plant arrangement on leaf dry weight

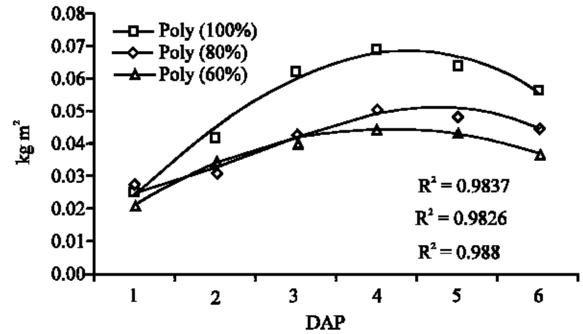

Fig. 6: Interaction effect of irrigation amounts with plant arrangement on stem dry weight

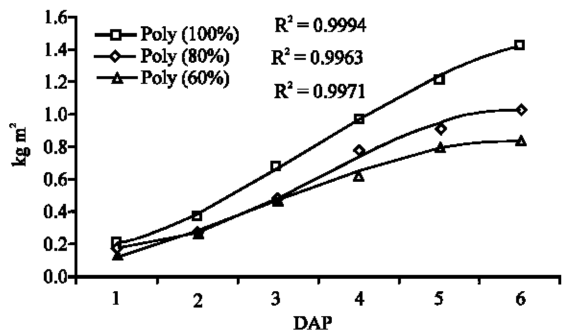

Fig. 7: Interaction effect of irrigation amounts with plant arrangement on total dry weight

leaf dry weight with this difference that violence of decrease in stem was lower than leaf biomass. Full irrigation produced the highest total biomass and it slowly decreased only at 109 DAP. Amount of decline for 80 and 60% full irrigation were the most, respectively (Fig. 7). This decline pertained to decrease in leaf and stem biomass plus decline of growth speed at the end of the harvest times. From 73 DAP up to last harvest slope of cure for 80% was greater than 60% full irrigation.

There wasn't a significant impress of irrigation amounts and plant arrangement on harvest index. Full irrigation had the highest HI, 71.69, than the others. Highest and lowest harvest index obtained at last and first harvests, respectively (Table 4). Amount of harvest index ranged from 45.47 at first sampling to 89.01 at last sampling.

DISCUSSION

Potato ET can be estimated using weather data and is the amount of water to be replenished during the growing season in order to assure potential tuber yields at a given site. In this study amounts of reference and crop evapo-transpiration for full irrigation were 781.3 and 627.6, respectively. Onder *et al.* (2005) reported that the highest evapo-transpiration were 473 and 391 mm at full irrigation in 2000 and 2002 years, respectively. Yuan *et al.* (2003) declared that during the experimental period, (total 110.5 mm before starting of irrigation applied for all treatments); the total amount of applied water and ET was 157.7, 205.0, 252.2, 299.3 and 346.6 mm for Ep0.25, Ep0.50, Ep0.75, Ep1.00 and Ep1.25, respectively. Erdem *et al.* (2005) reported that in the non-stressed treatments, the amount of total irrigation water applied and seasonal ET were 417 and 524 mm, respectively for drip irrigation. Early research reports that seasonal potato ET ranged from 350 to 800 mm for different climatic and environmental conditions (Fabeiro *et al.*, 2001; Panigrahi *et al.*, 2001; Ferreira and Carr, 2002; Onder *et al.*, 2005). Marketable tuber yield for 120% of full irrigation was significantly highest and for 60, 80 and 100% of full irrigation the yield hadn't considerable different. Tuber dry matter yield increased with increasing water supply from 60, 80 and 100% full irrigation, respectively and at 120% of full irrigation declined (Darwish *et al.*, 2006). Shahnazari *et al.* (2007) also reported that no significant differences were found among the full irrigation and partial root-zone drying in tuber yield. Onder *et al.* (2005) related that irrigation levels significantly affected all yield parameters in both years and yield for 66 and 100% irrigation was significantly superior to 33% and non-irrigated treatments. Also, Nagaz *et al.* (2007) said similar findings. Tuber fresh and dry weight from first harvest to three harvests full irrigation tended to be higher than partial root zone drying but at fourth harvest partial root zone drying had highest amounts (Shahnazari *et al.*, 2007). Potato yield increase as soil matric potential decreases to a threshold of -25 kPa and then declines. The linear decline in potato yield was higher significant, with a soil matric potential less than -25 KPa, dropping by 28.8% at -55 kPa (Kang *et al.*, 2004). Increase in tuber yield with increasing of water supply reported in other studies (Kashyap and Panda, 2003; Yuan *et al.*, 2003; Erdem *et al.*, 2006). The irrigation level of 66 and 33% significantly resulted in higher tuber number per plant in 2000, while the irrigation level of 66% resulted in highest number of tuber per plant in 2002. Both the un-irrigated (I0) and the full-irrigated (I100) potatoes produced lower number of tuber per plant (Onder *et al.*, 2005). Decrease in the number of tuber under un-irrigated conditions was reported by Walworth and Carling (2002). They recently demonstrated inconsistency between the previous findings and reported that the number of tubers per plant could be attributed to the cultivars differences as well as other environmental conditions such as soil type and temperature. Erdem *et al.* (2006) narrated that effect of irrigation regimes on tuber weight wasn't significant in both years but tuber yield only in 2005 significantly affected by irrigation regimes. Contradictory Darwish *et al.* (2006) stated deficit irrigation lowered both the tuber dry matter production and the average weight of the commercial tuber, leading to 21% loss in fresh yield. In addition, Onder *et al.* (2005) reported that treatment of 66 and 100% of full irrigation had the highest tuber mean weight and Between 66 and non-irrigated treatment, un- irrigated significantly had the lower tuber mean weight. Nagaz *et al.* (2007) related that the reduction in tuber yield was attributed to reduction in tubers number and weight as a consequence of water supply shortage during tubers initiation and development. The lowest water use efficiency belonged to 60% of full irrigation and 80, 100 and 120% irrigation obtained maximum water use efficiency, respectively (Darwish *et al*., 2006). Opposing, Kirda (2002) fund that in successful deficit irrigation of potato the relative water use efficiency in comparison with full water supply was 1.06 for drip irrigation. Onder *et al.* (2005) reported decreasing of WUE due to increase in water supply. Kashyap and Panda (2003) and Yuan *et al.* (2003) also reported similar findings for potato. Irrigation water use efficiency and water use efficiency didn't affected by drip irrigation treatments and the highest WUE were generally obtained from application of irrigation when 30% of the available water was consumed (Erdem *et al*., 2006). Increases in irrigation water use efficiency during sampling times reported by Shahnazari *et al.* (2007). Water use efficiency ranged no much among water stresses (Kashyap and Panda, 2003). Kang *et al.* (2004) and Onder *et al.* (2005) also registered similar WUE values for potato. Biomass production was significantly reduced in drought-treated plants (Bergaten *et al*., 2003). Similar result was related by Darwish *et al.* (2006). She reported that shoot dry matter yield increased during growth period and at full maturity decresed, too. Also, its yield at 120% of full irrigation declined. Plant yield for 66 and 100% full irrigation were highest and had significant different with other treatments, 33% and non-irrigated (Onder *et al*., 2005). Yuan *et al.* (2003) related that 0.25 and 0.50 evapo-transpiration significantly produced lower plant biomass than 0.75, 1.00 and 1.25 times of evapo-transpiration but differences within the two groups weren't significant. Plant and Total dry matter yield decreases with increase in water stress (Kashyap and Panda, 2003). Darwish *et al.* (2006) fund that harvest index increased with increase in water supply and highest amount was obtained at 100% of irrigation But weren't significant. Similar result was reported by Shahnazari *et al.* (2007). He also reported that HI increased at earlier growth period but from second harvest to fourth harvest didn't noticeably differ. Burdine *et al.* (2002) reported that row space caused a significant yield difference in U.S. No 1 and total marketable roots. Row space of 40 inches was superior to all other bed treatments in each yield grade except for jumbo where no differences were found. Shock *et al.* (2003) said there was no advantage to plant double rows of Umatilla Russet, increase the plant population, or offset the drip tape 7 inches from the plant row. But Shock *et al.* (2004) found that arrangement 3 at the high population (Arrangement 3 was 4 rows on a 72 inch bed with 16 inches between the pairs of rows and the paired rows 14 inches apart, with the drip tape centered between the pairs of rows) significantly produced higher total yield and the lowest yield of US No. 2 tubers was produced by the high population in two rows per bed with drip tape above the row (Arrangement 1) (Shock *et al*., 2005). Potatoes planted in flat beds with one drip tape above the rows were more productive and of better quality than drip-irrigated potatoes grown in conventional beds. It is notable that all these investigations on plant arrangement were with plant density or layout of irrigation tubes studied.

CONCLUSIONS

As a result of this study, it can be concluded that the full irrigation and P3 plant arrangement have significant advantage for both yield and WUE compared to deficit irrigation and other plant arrangements in potato production under semi-arid conditions with drip lines. Therefore, deficit irrigation would not be recommended due to its negative effects. Tuber yield for full irrigation was more because of higher average tuber weight and WUE. Also, full irrigation produced most top yield components. As a result of this research, full irrigation is recommended for irrigation of potato cultivation. Water deficiency more than 20% of the irrigation requirement could not be suggested. Effect of plant arrangement was significant on dry tuber yield not wet tuber yield. The P1 treatment had the most dry tuber yield, WUE, top yield components. Treatment of (I1×P3) produced maximum values for all variables except tuber number and HI. Perhaps, plant arrangements with two rows beds could produce more yields if plant population was higher than 5.3 plants m^{-1}. In other word, approach of two rows beds might produced more yield. The amounts of ETo and ETc for full irrigation were 782.2 and 627.6 mm, respectively. Its values depended on weather special sunshine intensity, humidity percent, wind speed and temperature. WUE increased with supply more water. Therefore, from deficit to full irrigation supply of one water unit affects tuber yield more than water consumption. Treatment of (I1×P3) has the most WUE. With drip irrigation cultivation of two rows on a wide bed recommended. Because, (1) pair rows with one drip lines between two rows used less drip lines (50%) than conventional cultivation. (2) Increasing of plant population may be cause to higher tuber yield. (3) Distances among pair rows didn't wet and so weeds growth limited. (4) Due to prepare of wide bed green tubers didn't show (data didn't reported).

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