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Effects of Water Stress on Water Demand, Growth and Tuber Grade of Potato (*Solanum tuberosum* L.) Crop

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Abstract: In order to study water demand, vegetative growth and tuber grade of potato crop under water stress and different cultivation patterns in different drip irrigation regimes, a split plot experiment based on the randomized complete block design with three replications carried out at the Allarog Research Station, Ardebil, Iran, in 2004. Estimation of crop evapotranspiration was conducted by CROPWAT computer program based on the relationship between crop coefficient (Kc) and crop evapotranspiration. Different drip irrigation levels were 100, 80 and 60% of potato crop evapotranspiration. Different levels of cultivation patterns were: 1 row 75 cm on bed 75 cm (furrow to furrow), 2 rows 35 cm on bed 150 cm (furrow to furrow) and 2 rows 45 cm on bed 150 cm and sampling times were the third factor with 6 levels. It was found that yield and growth of aerial parts was significantly affected by water stress and sampling times. Cultivation patterns had only significant effect on above ground biomass. The maximum and the minimum values of most traits studied were observed at 100 and 60% crop evapotranspiration levels, respectively. Number of tubers with 28-50 mm and larger than 50 mm diameter in size were higher at 80 and 100% of full irrigation, respectively. Estimating of amount of water irrigation during irrigation period for 100, 80 and 60% of water irrigation were 558.7, 445.96 and 335.22 mm, respectively.

Key words: Growth, potato, tuber grade, water requirement, water stress

INTRODUCTION

Potato (*Solanum tuberosum* L.) rate fourth among the world's various agricultural production volume, after wheat, rice and corn (Fabeiro *et al*., 2001). It is a temperate crop, 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 (Shalhevet *et al*., 1983). It is widely planted in the Ardabil Province in Iran under irrigated conditions. 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. Among the environmental factors, soil water is a major limiting factor in the production and growth of potatoes. Irrigation experiments have shown that potato is relatively sensitive to moisture stress (Fabeiro *et al*., 2001) because it has a sparse and weak root system and approximately 85% of the root length is concentrated in the upper 0.3 m of soil. Water

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stress decreased the yield through reducing the growth of crop canopy and biomass. Canopy has a major influence on the interaction of plants with their environment. Only little information is available on the importance of aboveground biomass for attaining high and stable tuber yields. Plant height, stems number and ground cover at tuber initiation have been proposed as criteria for indirect selection for tuber yield (Moll and Klemke, 1990). Potato is sensitive to water stress and even short periods of water stress can cause significant reduction in tuber yield (Haverkort *et al*., 1995). There are reports about the effect of water stress on potato yield resulting from its effect on aerial parts (Deblonde *et al*., 1999; Lahlou *et al*., 2003). Potato needs frequent irrigation for good growth and yield. The farmer applies water to the crop without regarding whether the plant actually needs water at that stage. In case of limitation in water supply, the irrigation demand of entire cropping pattern cannot be met fully. For example, in the Ardebil Province due to decreasing mud dam water farmers endure reduction of yield in crops such as potato, sugar beet and corn .On the other hand other crops such as wheat (*Triticum aestivum*) and barley (*Hordeum vulgar*) don't receive enough water too. Under this condition, deficit irrigation can play a major role. By deficit irrigation crops are purposefully irrigated during plant growth stages that are relatively sensitive to water stress as regard to quantity of the harvestable yield (Musick, 1994). Water stress at vegetative stage reduces growth, leaf area, development of above-ground and plant height. Therefore, crop canopy development is delayed (Ojala *et al*., 1990). Competition between the increasing demands of the domestic and industrial sectors and those of the agricultural sector to fresh-water resources is very challenging, mainly in populated arid and semi-arid regions. Deficit irrigation may be one approach to address this issue. It is a strategy which allows a crop to sustain some degree of water deficit in order to reduce irrigation costs and potentially increase revenues. Deficit irrigation can lead, in principle, to increased profits where water costs are high or where water supplies are limited. In these case studies, crop value was closely associated with yield and crop grade and marketability were not germane. Under these circumstances, deficit irrigation can be a practical choice for growers. Deficit irrigation has proved successful with a number of crops in various parts of the world. These crops are relatively resistant to water stress, or they can avoid stress by deep rooting, allowing access to soil moisture lower in the soil profile. However, deficit irrigation of potatoes may be difficult to manage, because reductions in tuber yield can result from even brief periods of water stress following tuber set (Lynch *et al*., 1995). However, in some circumstances, potatoes can tolerate limited deficit irrigation before tuber set without significant reductions in tuber quality (Shock *et al*., 1992). The advent of more efficient irrigation methods can make deficit irrigation of potatoes more manageable. Drip irrigation permits more precise control of the amount of water applied than does furrow irrigation, allowing accurate management of crop root zone soil moisture. Irrigation scheduling with estimated crop evapotranspiration (ETc) can provide the feedback for managing irrigations. Careful irrigation scheduling has resulted in optimum potato yield and quality. Water stress during tuber bulking, had been previously reduced Russet Burbank tuber grade (Eldredge *et al*., 1996). Studies on quite marked deviation from square plant arrangement have shown that the potato is remarkably tolerant to changes in its plant arrangement. However, choice of proper cultivation pattern may lead to reduction of water use and costs.

Aim of this research is to investigate the effects of water stress and different cultivation patterns in drip irrigation on water demands, growth and tuber grade of potato (*Solanum tuberosum* L.) crop.

MATERIALS AND METHODS

The study was conducted at the experimental farm of the Ardebil Agricultural Research Station during the growing season of 2004. The soil at the experimental area was medium texture with relatively deep profile. During the experiment the mean daily temperature was 17.18°C and the mean daily rainfall was 0.71 mm. Ardebil plain has a typical semi-arid climate with hot-dry summer and cold-snowy winter. The field experiment consisted of three irrigation levels (factor A), three different cultivation patterns (factor B) and six sampling dates (factor C). In the experimental design, irrigation treatments were the main plots replicated 3 times and three different cultivation patterns were split plots within the main plots. Irrigation treatments were arranged in a randomized complete block design and consisted of 3 treatments of full irrigation (A1), 80% of full irrigation (A2) and 60% of full irrigation (A3). Cultivation pattern were: 1 row 75 cm on bed 75 cm (Furrow to furrow) (B1), 2 rows 35 cm on bed 150 cm (Furrow to furrow) (B2) and 2 rows 45 cm on bed 150 cm (Furrow to furrow) (B3). Sampling started at 53 DAP with and ended at 107 DAP. 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. First irrigation water was applied to all treatments using drip irrigation system to bring the soil water content in (0-30 cm) soil depth up to level of field capacity. The irrigation was started at the end of rainfall season in spring and treatments were irrigated at 3-4 days intervals. For surface drip irrigation T-Tape tubes with holes of 30 cm apart, 1.2 L h^{-1} flow rate and 16 mm diameter was used. Tubers of Agria cultivar of potato crop were hand planted at the depth of 10 cm with 25 cm apart in rows. In two rows beds a single T-Tape tube was installed at the middle of two rows, but in one row beds a tube was installed at each hill so. In two rows beds a single T-Tape tube was installed at the middle of two rows, but in one row beds a tube was installed at each hill so. All of the other cultural practices that were used throughout the growing season were typical of those that were practiced by regular farmers but fertilizers were transported to crop root-zone by irrigation water based on soil test. To calculate crop water requirement the CROPWAT computer program was used. In this method the calculation of reference evapotranspiration (ET0) and crop coefficient (Kc) are required. ET0 was calculated using FAO Penman-Monteith method (Allen, 1998) by agrometeorological station. And crop water requirement (Etcrop) was calculated as: ETcrop = Kc×ET0. Amount of these factors was shown in Fig. 1. In order to grade of tubers, tubers of 10 randomly selected plants from the middle 2 rows of each plot were hand harvested at 128 DAP. Tubers were graded into three size categories (>50, 28-50 and <28 mm as unmarketable) and tuber number in each category counted and recorded.

Analysis of variance was used to evaluate the effect of treatments to determine the significant effect of main factors and interactions for the variables measured. Data were analyzed by using SAS software and Excel was used to drawn the figures with mean grouping.

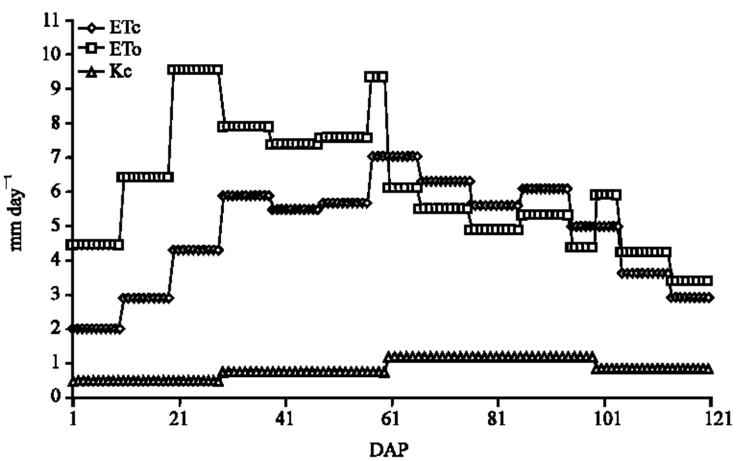

Fig. 1: Amounts of ETc, ETo and Kc for potato crop during growing season

RESULTS AND DISCUSSION

Water Requirement of Potato

Estimating of amount of irrigation water during irrigation period for 100, 80 and 60% of irrigation water were 558.7, 445.96 and 335.22 mm, respectively (Fig. 2). Since, the rainfall during 20 days after planting was equal to estimated amount of irrigation water, no irrigation was applied in this period and indeed the amount of applied irrigation during irrigation period became 509.7, 407.7 and 305.82, respectively.

With precise management of water supply and irrigation scheduling for 100, 80 and 60% of irrigation levels, saved water were 49, 39.2 and 29.4 mm, respectively. In other word, for different levels of drip irrigation the amount of saved water at vegetative stage was 8.77%. No irrigation was done for 23 days to the end of the growing season in order to prevent the second growth of tubers and quality loss. Thus, Potato ETc requirements are well-established and are based on weather data, the timing of the stages of plant development and crop coefficients during development (Jefferies and MacKerron, 1993). It ranged broadly from less than 300 to 700 mm, depending on the environment, the year and rate of crop growth. Using modern irrigation method and precise management of applied water can decrease water requirement of agricultural section.

Vegetative Growth Responses to Water Stress

Results of data analysis and comparison of means for yield and vegetative growth component are given in Table 1 and 2. Yield was not affected by different levels of cultivation pattern even at the probability level of 5%. Similar result was reported by Shock *et al.* (2003). It was found that fresh weight of tubers per plant was significantly affected by different levels of irrigation and the highest and lowest yield was on 100 and 60% of irrigation, respectively. Figure 3 also shows the result of changes of tuber yield over times. As shown, tuber yield differences at earlier sampling are low between different levels of water stress but this difference becomes much near the end of sampling. Therefore, full irrigation, 80 and 60% of irrigation water had maximum yield, respectively. In arid regions, other studies have shown that potato yield responds linearly to applied water where irrigation plus rainfall is less than or equal to ETc (Miller and Martin, 1983). Stems that had separate roots were considered as main stem. Main stem number was not affected by water stress but secondary stem number significantly affected by water stress. Full irrigation had most number and 80 and 60% of irrigation water didn't have significant difference from each other. Stems number during times were shown in

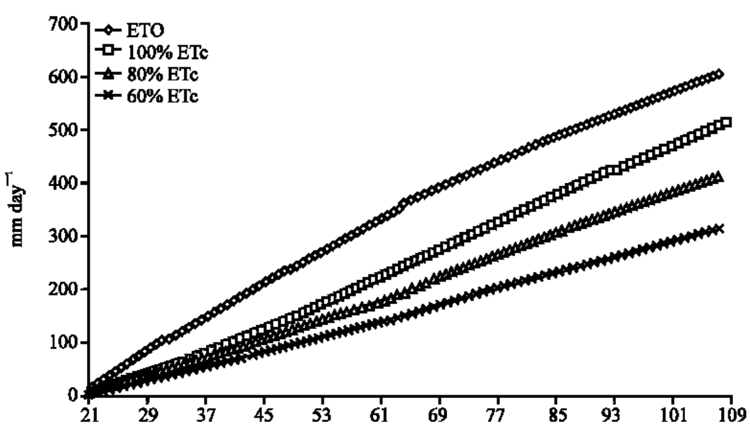

Fig. 2: Cumulative ETc and ETo for potatoes submitted to three irrigation treatments, 2004

Table 1: ANOVA water stress and cultivation patterns on vegetative growth

		MS					
SOV	df	Tuber yield (kg)	Main stem No.	Secondary stem No.	Stem height (cm)	Leaf No.	Above ground biomass (g)
Replication	2	95333.92	2.73	20.37	433.74	718.65	684.67
Irrigation (A)	2	345083.80**	1.90	44.92*	2333.64*	1700.66*	1130.94**
Error (1)	4	4231.20	1.74	5.40	158.46	9.58	52.63
Cultivation pattern (B)	2	53156.20	0.06	5.49	329.44	204.81	387.69**
Interaction of A*B	4	21333.20	1.24	2.97	87.64	105.48	387.69
Error (2)	12	17772.02	1.19	1.69	106.12	199.14	61.99
Sampling times ©	5	1815051.00**	1.14*	32.15**	1029.12**	3510.15**	50.48**
Interaction of A*C	10	42980.70**	0.39	1.59	101.56**	134.39	1342.38**
Interaction of B*C	10	5598.10	0.40	1.24	4.73	104.66	87.18
Interaction of A*B*C	10	4801.50	0.27	1.51	8.86	50.08	23.31
Error (3)	90	3793.04	0.48	2.05	15.44	123.40	12.25
CV (%)		14.65	19.61	37.75	8.31	23.33	24.63

**, *significant at $p<0.01$ and $p<0.05$, respectively. SOV: Source of variations, df: Degree of freedom, MS: Mean square, CV: Coefficient variation

Table 2: Mean comparison of growth parameters under water stress

Different levels of irrigation (%)	Tuber yield (kg)	Main stem No.	Secondary stem No.	Stem height (cm)	Leaf No.	Above ground biomass (g)
100	504.43a	3.76a	4.84a	54.71a	54.08a	31.64a
80	411.37b	3.39a	3.16b	44.88b	44.20b	24.91b
60	345.31c	3.50a	3.37b	42.23b	44.51b	22.91b

Values with same letter(s) in each column, have no significant differences to each other

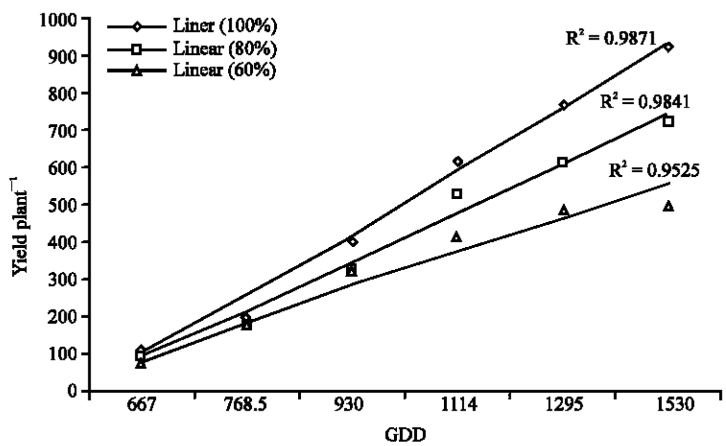

Fig. 3: Interaction of water stress and sampling times on tuber yield. GDD: Growth degree day

Fig. 4. Changes of main stem number during times were less but secondary stem number in earlier of sampling had lower number than the later. Drought stress reduced the total stem number in the field but when the main stem number not total stem number was considered, there was no effect of drought (Lahlou *et al*., 2003). Plant heights were determined by measuring the tallest portion of the haulm on each plant. Stem heights was affected by water stress and interaction of water stress and sampling times. Full irrigation had the greatest amount and difference among 80 and 60% full irrigation weren't significant and therefore were sit at the same group. Interaction of water stress-sampling times shows (Fig. 5) that stem height at full irrigation reached to maximum earlier than 80 and 60% of irrigation water and full irrigation had the most slopes. On the other word, in earlier of growing season full

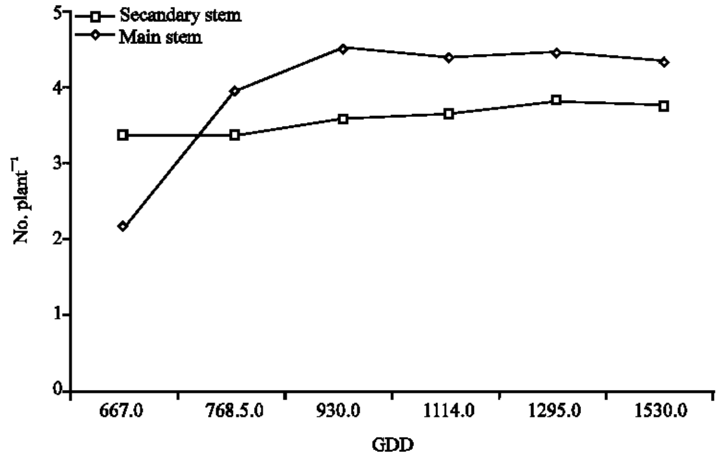

Fig. 4: Stem number of potato crop during the growth period. GDD: Growth degree day

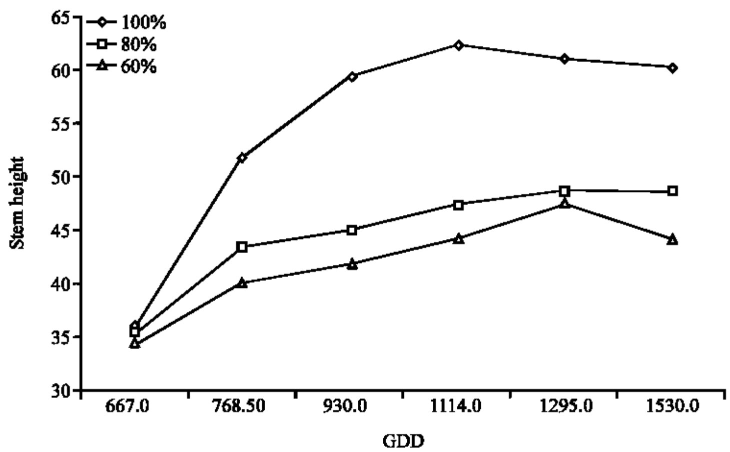

Fig. 5: Interaction of water stress and sampling times on plant height. GDD: Growth degree day

irrigation provided sufficient water to crops and thus enough turgor pressure to development and growth of stem. After third sampling stem height for full irrigation was almost similar. Stem height at 80% full irrigation was more than 60% full irrigation at all sampling times. Significant effects of irrigation water on potato height were reported by Yuan *et al*. (2003). Irrigation and sampling times had significant effect on leaf number. Leaf number at full irrigation was more than the other irrigation levels. This variety is the same as the varieties of secondary stem and plant height under water stress. Perhaps, because of increasing of secondary stem number and plant height full irrigation had earned more leaf number. Variety of leaf number per plant during growth period was shown in Fig. 6. Leaf number was increased at earlier of growth period then stabled for times and at long last decreased because tow final samples were picked up at the end of tuber bulking and tuber maturity stages, respectively. Variety of mean comparison of aboveground biomass is the same as leaf number, stem height and secondary stem number under water stress. Cultivation patterns influenced aerial biomass so that 2 rows 45 cm on one bed had greater biomass and 1 row 75 cm on one bed obtained lowest biomass (Fig. 7). Interaction of water stress and sampling times was shown in Fig. 8 at the same

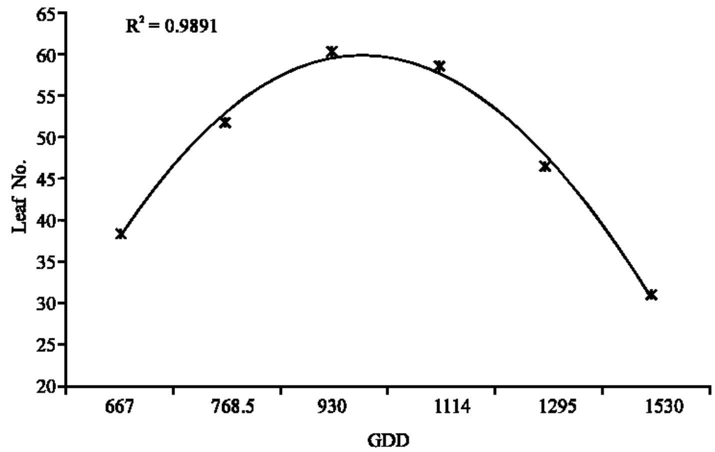

Fig. 6: Changes of leaf number during the growth period. GDD: Growth degree day

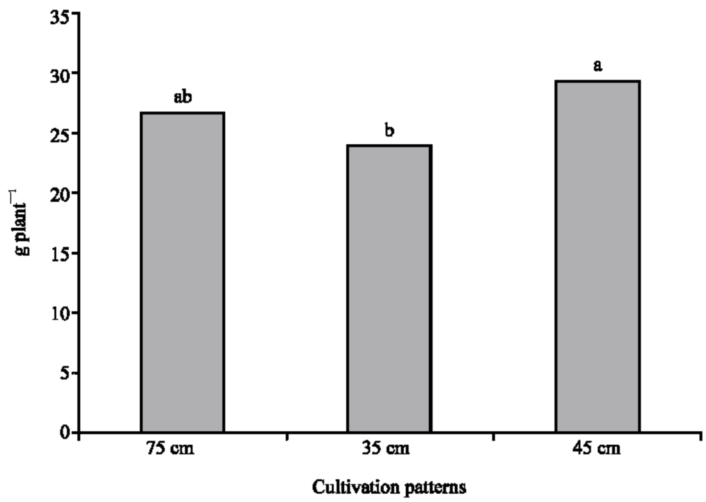

Fig. 7: Effect of cultivation patterns on aboveground biomass. GDD: Growth degree day. Value with the same letter(s) have no significant differences to each other

sampling times full irrigation had maximum biomass even at the end of sampling for full irrigation biomass was near to maximum biomass for the two other irrigation levels. Therefore, full irrigation contributed to better development of crop canopy and durability of biomass. Aboveground biomass for 80 and 60% full irrigation was equal by sampling four but then 80% irrigation had higher biomass than the 60%. This result shows that water stress causes to earlier falling of leaf and senescence. Water stress delays the growth rate, resulting in a smaller leaf canopy. According to Jefferies and MacKerron (1993), water stress usually causes early senescence of leaves thereby shortening the growing season, resulting in lower tuber yield.

Tuber Grade Responses to Irrigation Deficits

Before the tuber harvest, aerial parts cut and removed from field, then they harvested. Then tubers hand harvested. Different level of irrigation and cultivation pattern did not have significant effect

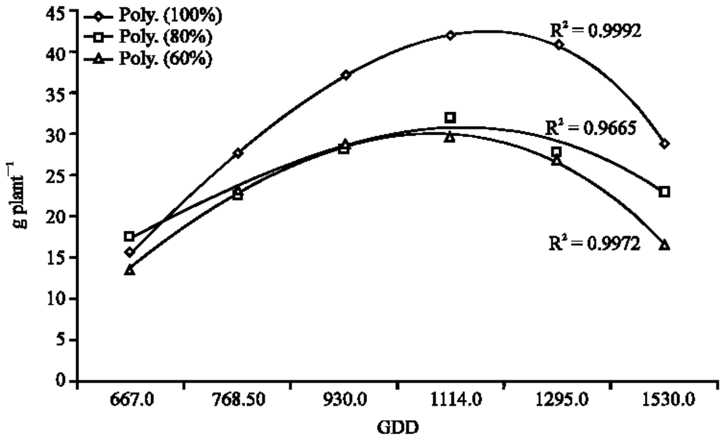

Fig. 8: Interaction of water stress and sampling times on aboveground biomass. GDD: Growth degree day

Table 3: ANOVA of water stress and cultivation pattern on tuber grade

		MS		
SOV	df	Tuber No. (<28 mm)	Tuber No. (28-50 mm)	Tuber No. (>50 mm)
Replication	2	0.01	20.96	8.03
Irrigation (A)	2	0.07	94.29*	235.70*
Error (1)	4	0.05	19.25	32.09
Cultivation pattern (B)	2	0.19	9.19	18.03
Interaction of A*B	4	0.01	21.03	13.25
Error (2)	12	0.10	3.20	26.74
CV (%)		10.61	11.37	24.71

**, *: Significant at $p<0.01$ and $p<0.05$, respectively. SOV: Source of variations, df: Degree of freedom, MS: Mean square, CV: Coefficient variation

Table 4: Mean comparison of tuber grade

Different levels of irrigation (%)	Tuber No. (>50 mm)	Tuber No. (28-50 mm)
100	5.16a	2.64b
80	4.25ab	3.24a
60	3.13b	2.73b

Values with same letter(s), in each column, have no significant differences to each other

on the numbers of small tubers (<28 mm) (Table 3). Number of large size tubers (>50 mm) was affected by different levels of irrigation and decreased with decreasing of amount of irrigation water (Table 4). Also, number of medium size tubers (28 to 50 mm) was significantly affected by irrigation treatments and its number at 80% of full irrigation was significantly greater than 100 and 60% of full irrigation. There was no difference between 80 and 60% irrigation in this respect (Table 2). Therefore, increased number of large tubers (>50 mm) and mean fresh weight of tuber led to increase yield with increasing of the amount of irrigation water. Losses in potato yield and grade in response to deficit irrigation were in agreement with previous observations (Eldredge *et al*., 1992; Stark and McCann, 1992).

CONCLUSION

Tuber yield and vegetative growth of potato significantly affected by different drip irrigation regimes. Tuber yield strongly decreased with decreasing of irrigation water. Therefore, in semi arid regions water stress at all recommended for potato crop production. Water stress diminished biomass of aerial parts, stem height and number and leaf number per plant as full irrigation could obtain greater rates. In contrast, water stress delayed the growth rate, resulting in a smaller leaf canopy. It caused early senescence of leaves thereby shortening the growing season, resulting in lower tuber yield. Cultivation pattern only affected biomass of aerial parts but this difference couldn't lead to significant increase in tuber yield. However, using pair rows on each bed probably will increase yield by exceeding plant density and decrease tuber production costs by reduction of tubes use.

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